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Re-Evaluation of F2 and F3 Petroleum Hydrocarbon Management Limits – Phase 2

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1.0 INTRODUCTION

Management limits for petroleum hydrocarbon (PHC) fractions were developed to indicate concentrations where factors other than toxicity, such as aesthetics, mobile free-phase formation and explosion hazard 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, 2019) is applicable to all land uses, and one set is specific to remote parts of the Green Area of Alberta (ESRD, 2014). These two sets of management limits each consider a range of factors and base the overall management limit for each fraction on the lowest value suggested by any of the factors considered. This project examines the scientific basis for the two existing sets of management limits for F2 and F3, assesses the validity of each of the factors that went into the management limits and undertakes laboratory research to develop new management limits for specific factors as required.

This is a multi-phase project. Phase 1 was completed in 2019. The scope for Phase 1 is summarized in Section 1.1 and a summary of the Phase 1 findings is provided in Section 2. The current phase of the project is Phase 2. The scope of Phase 2 is summarized in Section 1.1 and the results of Phase 2 are summarized in Sections 3 and 4. Recommendations for a proposed third phase are provided in Section 5.2.

1.1 Project Objective and Scope of Work

The overall objective of this project is to conduct a thorough review of the scientific basis for existing management limits for petroleum hydrocarbon fractions F2 and F3 and undertake any research necessary to develop management limits with a more robust scientific basis as appropriate.

The scope of work for Phase 1 and 2 of the project are summarized below.

Phase 1

- Review the background and context for PHC management limits.
- Review the basis for the PHC management limits in the Canada-Wide Standard for PHCs.
- Review the basis for the PHC management limits in the Alberta Green Area PHC subsoil guidelines.
- Re-evaluate the relevant factors to include in calculating PHC management limits in various land uses in Alberta.
- Evaluate the scientific defensibility of the various components of the current PHC management limits.
- Make any appropriate recommendations for updated PHC management limits based on currently available data.
- Make recommendations for additional research to fill any identified data gaps.

Phase 2

- Conduct a literature review to determine whether any new modelling approaches have been developed for vapour migration into trenches since 2008 and evaluate applicability.
- If required, investigate the underlying science relating to this issue and evaluate the feasibility of developing an approach from first principles that better reflects the realities of the situation under consideration.
- Develop an experimental design and conduct appropriate experiments to measure the equilibrium concentrations of PHC sub-fractions in an airspace that is at equilibrium with F2 fraction PHC as a pure phase liquid and homogenized into soil at appropriate concentration(s). These experiments will define the input concentrations for the air mixing models within the air space of a utility trench.
- Put the above information together to calculate revised threshold values for the Exposure of Workers in Trenches to PHC Vapours (The "Worker Trench Scenario"), if appropriate.
- Effects on Buried Infrastructure. This factor was researched extensively in a 2003 contract report, and existing published data were found to be inadequate to develop a quantitative threshold. Two tasks are proposed to investigate this issue further:
  - Update the literature review to see whether further relevant information has become available since 2003.
  - Develop an experimental design and conduct appropriate experiments to determine conservative thresholds for F2 and F3 concentrations in soil that are protective of buried drinking water supply pipe. Of the various types of buried infrastructure, this is perceived as being of greatest concern.

1.2 Funding Acknowledgements

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1.3 Key Source Documents

Six key documents are referenced extensively in this report. 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 the CCME in 2008. The original 2001 version of this document was also consulted for historical details.

2. 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 research findings upon which the following document (ESRD, 2014) was based.
3. 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.
4. Alberta Environment and Parks (AEP), 2019. Alberta Tier 1 *Soil and Groundwater Remediation Guidelines*. Land Policy Branch, Policy and Planning Division. 198 pp. This document indicates the currently applicable management limits for F2 and F3 in Alberta sites outside the Green Area.
5. PTAC (Petroleum Technology Alliance Canada), 2019. Re-Evaluation of F2 and F3 Petroleum Hydrocarbon Management Limits. January 2019. PTAC File #18-RRRC-08. This document reports on Phase 1 of this project.
6. InnoTech (InnoTech Alberta Inc.), 2020. Petroleum Hydrocarbon Fractions 2 and 3: Evaluation of Management Limits. Report dated May 1, 2020. This document reports on the research carried out to support the current Phase of work and is included in Appendix A.

2.0 PHASE 1 – SUMMARY OF FINDINGS

Full details of Phase 1 are provided in PTAC (2019). A summary of the main points relevant to Phase 2 is provided below. The detailed scope for Phase 1 is provided in Section 1.1 of this report. Overall, Phase 1 was focussed on conducting a critical review of each of the factors considered in the two existing sets of management limits for PHC F2 and F3. Phase 1 made recommendations on which factors should be retained for consideration going forward, which factors had an existing satisfactory scientific basis, and which factors had a scientific basis that would benefit form additional research.

2.1 Background to Management Limit "Factors"

The Alberta Tier 1 guideline framework (AEP, 2019) 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 also some non-toxicological "factors" relevant to setting soil remediation guidelines. Within the Tier 1 soil guideline framework, these non-toxicological factors 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" (subsequently adopted by AEP, 2019) and the ESRD (2014) document

"Subsoil Petroleum Hydrocarbon Guidelines for Remoted Forested Sites in the Green Area". These two documents considered different but overlapping sets of factors as discussed in the following Section.

2.2 Factors Considered

The management limits for petroleum hydrocarbon fractions currently used in the AEP (2019) 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.

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:

- the site is within the Green Area;
- the site is in a forested area and reclaimed to a forested ecosystem;
- the site is remote from existing residences and roads;
- there is no dugout on site and future construction of a dugout is unlikely; and
- 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) gave consideration to 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 hydrocarbon;
2. Fire and explosion hazard;
3. Hydrophobicity; and
4. Upwards migration of hydrocarbons into the root zone.

Existing sources of PHC management limits therefore 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.

Phase 1 evaluated these 8 factors. No other relevant factors were identified in Phase 1, and the above list was considered to be complete. Note that issues related to toxicity are evaluated elsewhere in the Tier 1 guideline framework.

2.3 Assessment of Factors

The eight factors identified above were considered in Phase 1. The evaluation for each is summarized below.

2.3.1 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) experimental data with a high degree of relevance to the question at hand, and has a high degree of scientific defensibility for the following reasons:

- The experiments were conducted with F2 and F3 hydrocarbon fractions generated by distilling crude oil sourced from Alberta.
- The coarse and fine soils used in the experiments were field-collected soils from Alberta.
- Adequate replication was conducted.
- 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.

No further research is recommended in relation to this issue, since the existing (PTAC, 2013) data appear to be of high quality and developed specifically to set thresholds for F2 and F3 mobile free phase formation.

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. Going forward, it is recommended that the ESRD (2014) data be used for setting mobile free phase thresholds when developing new management limits. These thresholds are relevant and applicable in all soil types and land uses.

2.3.2 Exposure of Workers in Trenches to PHC Vapours

The CCME (2008) limits for this factor were established based on a trench vapour model published by VDEQ (2020). However, various scenarios were run, and the results varied widely depending on input assumptions about trench geometry (width *vs* depth) and proximity of trench face to affected soil. It is unclear exactly how the F2 management limit of 1,000 mg/kg was derived from the various scenarios run. The model and key default inputs, including trench air exchange rate, were not validated against real-world measurements.

A preliminary review was conducted for subsequent development of trench vapour modelling.

An evaluation of available trench models was conducted for the CCME (Meridian, 2010). The review recommended use of an analytical solution of the Jury model used by US EPA (1996, 2002) and the Ontario Ministry of the Environment (OMOE) Model for vapour migration into trenches, and a simple box model for mixing of vapours in trench air. An internet search in 2018 did not yield any indication that the OMOE model was ever officially released.

The CCME (2014) soil vapour protocol indicated the pathway may need to be considered on a site-specific basis but did not recommend a model for the derivation of generic soil vapour guidelines.

VDEQ (2020) continue to apply their model with no significant modification since 2005.

Overall, the management limits for vapour intrusion into trenches are not based on either experimental data or validated modelling, and there is no currently available alternative. Therefore, this limit represents a gap where further research may improve the values. This data gap was a primary driver for conducting experimental validation of selected model input parameters in Phase 2 (See Section 3).

2.3.3 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.

2.3.4 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.

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. That approach is reasonable; however, this is an area where additional research may be helpful.

This need for additional research was addressed in Phase 2 (see Section 4).

2.3.5 Aesthetic Considerations

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 outdoor 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 most appropriately 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 it is recommended to retain this approach.

Further research to identify odour and/or visual impact thresholds for residual hydrocarbons in soil is not recommended as it is unclear how such thresholds could be incorporated in a meaningful management limit value given the above discussion.

2.3.6 Technological Factors

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, it is recommended that “Technological Factors” be dropped from the list of valid factors for calculating management limits for petroleum hydrocarbons.

Accordingly, "Technological Factors" are not retained in this review.

2.3.7 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:

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

No further research is recommended in relation to this issue, since the existing data appear to be of high quality and were developed specifically to set hydrophobicity thresholds for F2 and F3.

Going forward, it is recommended that the PTAC (2013) data be used for setting hydrophobicity thresholds when developing new management limits. These thresholds are relevant and applicable in all soil types and land uses.

2.3.8 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:

- 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.

- 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.
- 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.
- Adequate replication was conducted.

Give the above, this issue is considered to have been addressed adequately, and further research is neither needed nor recommended.

2.4 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 2.3.6 above).

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:

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.

2.5 Phase 1 Recommendations for Management Limit Components

Phase 1 recommended management limit components are summarized in Table 1.

Table 1 Phase 1 - 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				
Trench worker scenario	P2	P2	NGR	NGR
Aesthetic considerations	SSB	SSB	SSB	SSB
Effects on buried infrastructure	P2	P2	P2	P2

Notes:
P2 = identified for further research in Phase 2
NGR = no guideline required
SSB = any issues should be managed on a site-specific basis

2.6 Recommendations for Further Research

Based on the discussion in Section 2.3, further research is not required or recommended in relation to:

- mobile free phase formation;
- fire and explosion hazards;
- aesthetic considerations;
- technological factors;
- hydrophobicity; or
- upwards migration of hydrocarbons into the root zone.

A need for further research was identified and undertaken in Phase 2 (“P2” in Table 1 above) to refine and validate the model predictions for vapour intrusion into trenches. This research involved:

- review of appropriate models;
- review and refinement of model input parameters based on new experimental and other data; and
- recalculation of F2 management limits based on the above.

A need for further research was identified and undertaken in Phase 2 (“P2” in Table 1 above) to collect data with the aim of developing quantitative thresholds or confirming the lack of need for thresholds for the protection of buried infrastructure. This research involved:

- overview of currently available data;
- additional research to identify the various classes of buried infrastructure common in Alberta and the materials involved;
- experimental work to determine soil concentration thresholds to protect drinking water quality in water supply pipes and prevent damage to other types of buried infrastructure; and
- calculation of a quantitative management limit threshold for this issue, or confirmation that a quantitative limit is not required.

3.0 PHASE 2 – WORKER EXPOSURE TO PHC VAPOURS IN TRENCHES

3.1 Approach

At the conclusion of Phase 1 of this project, the limiting consideration for setting management limits for F2 was the Trench Worker Scenario. However, the existing management limit calculations for this scenario included a number of conservative assumptions for parameter values where empirical values were not available at the time.

The overall approach taken in Phase 2 of this project in relation to the Trench Worker Scenario was to review the various modelling approaches available for estimating the relationship between soil concentrations and trench vapour concentrations and refining the previous model calculations by developing or adopting empirical data for:

- vapour concentrations of F2 sub-fractions in equilibrium with F2 spiked soil; and
- trench air exchange rates.

3.2 Summary of Modelling Approaches

Meridian (2010) conducted a detailed review of modelling approaches used to predict vapour concentrations of volatile compounds in trench air. No additional relevant information was identified since the date of the Meridian report. This section is a summary of the Meridian (2010) work highlighting elements relevant to the current project. Meridian (2010) identified four basic processes that the various models considered:

1. volatilization of soil and/or groundwater contaminants;
2. migration of vapours into the trench;
3. mixing of contaminant vapours in the trench; and
4. removal of vapours from the trench *via* air exchange with outdoor air.

The models considered in the Meridian (2010) review were the following:

- Virginia Trench (VDEQ, 2020) Model;
- US EPA (1996, 2002) Trench Volatilization Model;
- American Society for Testing and Materials (ASTM, 2004) Model;
- Jury Model (Jury *et al*., 1983, 1990);
- Ontario Ministry of the Environment (OMOE) Model; and
- Modified Hwang & Falco (1986) Model.

All of the models had some elements in common:

- All models calculated or assumed a flux rate at the trench face (mass of contaminant entering trench air per unit area of trench face per unit time).
- All models used a simple box mixing model to calculate trench vapour concentration from flux rate.
- All models used either an assumed air exchange rate for the trench (number of times the air in the trench exchanges with the atmosphere per hour) or calculated an air exchange rate from assumed wind speed.

The differences between the models mostly related to the assumptions made about the location and type of source material, whether the source was adjacent to or distanced from the trench wall/floor and whether an equilibrium or a transient approach was used. Some models allow for more than one type/location of source.

The source, location and time dependence assumptions that the models made are summarized in Table 2 below.

Table 2 Model Assumptions – Source, Location and Time Dependence

Model	Groundwater Pooling in Excavation	Soil Source Adjacent to Trench Wall/Base	Soil or Groundwater Source at a Distance from Trench Wall/Base
VDEQ	Steady State	-	Steady State
US EPA	Steady State	-	-
ASTM	Steady State	Steady State	Steady State
Jury	-	Transient	-
OMOE	-	Transient	-
Hwang & Falco	-	Transient	-

The "groundwater pooling in trench" scenario is not directly relevant to setting management limits and is not discussed in detail here.

The other two approaches summarized in Table 2 both have potential relevance to setting management limits but there are significant differences to the two approaches that are relevant for the current project.

The "soil source at a distance from trench wall/base" scenario assumes a soil source distant from the trench. The adjacent soil vapour concentration is then calculated from the soil (or groundwater) concentration using standard equilibrium partitioning equations, and the vapour flux at the trench wall/base is calculated using standard equations for diffusion through a porous medium. The equations for both the equilibrium partitioning process and the diffusion through a porous medium are the same as used in equivalent parts of the AEP (2019) equations for calculating soil guidelines protective of indoor vapour inhalation. The relevance of this scenario to the current project is that it readily lends itself to using the measured equilibrium vapour concentrations for F2 sub-fractions determined experimentally in this phase of the project (Section 3.4).

The "soil source adjacent to trench wall/base" scenario assumes that the trench is excavated right through the soil source. The flux rate of contaminant mass entering the trench at the trench face is then estimated using steady state or transient model assumptions. The relevance of this scenario for the current project is that these models could be readily adapted to use experimentally determined values for surface flux rates for F2 sub-fractions. Determining these flux rates is proposed for Phase 3 of the current project (Section 5.2).

3.3 Appropriate Value for Air Exchange Rates in Trenches

All of the models in Table 2 use an assumed value for the trench air exchange rate or calculate a value from wind speed. However, at the time these models were developed, data supporting selection of an appropriate value for trench air exchange rate were limited. For instance, the VDEQ model uses an air exchange rate of 2/hour for any trench that is deeper than it is wide. This value is based on air exchange rates for buildings (VDEQ, 2020) and is likely to be conservative for actual air exchange rates in trenches. For trenches that are wider than they are deep, an air exchange rate of 360/hr is used based on the ratio of trench depth to average wind speed (Meridian, 2010). The OMOE model also uses an air exchange rate of 2/hour.

More recently, Thompson *et al*. (2017) have conducted empirical studies to help resolve some of the uncertainty associated with the appropriate air exchange rate to use for trenches. These authors performed a field study to measure the air exchange rate within a series of trenches to provide more representative default air exchange rates. Trenches were installed over an LNAPL source at a former refinery. Wind direction and speed were continuously monitored throughout the study to understand the relationship of ACH with meteorological factors. They determined that the default ACH value of 2/hour was overly conservative, and measured air exchange rates between 34/hour and 79/hour, with an average of 46/hour when wind speeds were relatively low (between 3.5 and 7 mph). The air exchange rates determined in this study are based on experimental measurements and are therefore preferred over the default air exchange rates assumed in the studies. The Thompson *et al.* (2017) average trench air exchange rate of 46/hour is adopted in the current study.

3.4 Equilibrium Vapour Concentrations of F2 Sub-Fractions

One of the primary goals of Phase 2 of this project was to conduct an experimental determination of the equilibrium vapour concentrations of the F2 sub-fractions in contact with soil spiked with F2. This work was completed by InnoTech Alberta Inc. and the report, InnoTech (2020) is included as Appendix A.

Full details are available in Appendix A and InnoTech (2020). Key points are summarized below.

InnoTech (2020) characterized a previously-distilled sample of F2 using gas chromatography – flame ionization detection (GC-FID) and determined that 93.3% of the sample mass was in the F2 range. From previous studies, this is typical for carefully distilled F2 samples.

The experimental setup for vapour measurements in equilibrium with F2 distillate involved placing the distillate in a petri dish inside a Tedlar bag. The bag was evacuated, and laboratory grade air was added. The lid was removed form the petri dish at time 0. After equilibrium was achieved, a sample of the vapour in the bag was analyzed for F2 sub-fraction concentrations. Full details of the steps taken to ensure that equilibrium had been achieved, that the results were reproducible, and that equilibrium concentrations were not limited by the availability of distillate in the bag are provided in Appendix A.

A second task in the InnoTech (2020) work was to determine the vapour concentrations of F2 sub-fractions in equilibrium with coarse- and fine-grained soil spiked with F2 at approximately 10,000 mg/kg. There was assumed to be a linear relationship between the vapour concentrations and the spiked soil concentration and therefore the exact concentration in spiked soil was not critical so long as it was known. The experimental setup for this task was similar to the setup for F2 distillate described above except that the petri dish was filled with coarse- or fine-grained soil spiked with F2 and compacted to approximate the default AEP (2019) bulk density for coarse- or fine-grained soil (1.7 kg/L or 1.4 kg/L, respectively).

Measured coarse and fine soil concentrations and associated equilibrium headspace concentrations for F2 sub-fractions from the InnoTech (2020) work are summarized in Table 3.

Table 3 Measured Equilibrium Headspace Concentrations for F2 Sub-Fractions

Parameter	Unit	Coarse Soil	Fine Soil
Soil Concentrations			
Total F2	mg/kg	9,393	13,167
Vapour Concentrations			
Total F2	mg/m^3	1023	930
Aliphatic $C_{10} – C_{12}$	mg/m^3	599	520
Aromatic $C_{10} – C_{12}$	mg/m^3	314	291
Aliphatic $C_{12} – C_{16}$	mg/m^3	55	61
Aromatic $C_{12} – C_{16}$	mg/m^3	55	58

Notes:
Data from InnoTech (2020)
All values in this table represent the average of 3 measured values.
Average soil moisture content: coarse soil 1.43%, fine soil 14.23%

3.5 Phase 2 Trench Vapour Management Limit Value for F2

The existing (AEP, 2019) F2 management limit protective of workers in trenches was based on default assumptions in the VDEQ (2020) model. Two elements in Phase 2 of this project allow refinements to the existing calculations:

1. Using the measured headspace concentrations of F2 sub-fractions in Table 3 relative to the measured F2 soil concentration to reduce the uncertainty involved in using default partitioning assumptions and parameters.
2. Using the average measured trench air exchange rate of 46/hour from the Thompson *et al*. (2017) study rather than assumed values (Section 3.3).

The VDEQ (2020) model was re-run using the two refinements noted above to calculate the maximum F2 soil concentration where none of the trench vapour concentrations for F2 sub-fractions exceed applicable thresholds. Full details of these calculations are provided in Appendix B and the results are summarized below.

The VDEQ model used is based on diffusion through a separation layer of soil between contamination and trench. The thickness of the separation layer can be adjusted, but the model breaks down if the separation is set to zero. Two scenarios were run (Appendix B). The first scenario was to set the thickness of the separation unit to be 30 cm and calculate the resulting management limit for F2. The value of 30 cm was selected as being the same as the assumed thickness between contamination and floor slab in the AEP (2019) indoor vapour model.

Using the assumed 30 cm (lateral or vertical) separation between the trench and the soil contamination and a trench air exchange rate of 46/hour, the calculated F2 trench worker management limits (rounded to 2 significant figures) are:

- Coarse soil: 50,000 mg/kg
- Fine soil: 40,000 mg/kg

Full details of these calculations and the associated assumptions are provided in Appendix B. Comparison with the F2 management limit components from Phase 1 of this project summarized in Table 1 indicate that these values are much larger than the limiting values for other considerations (10,000 mg/kg for fine soil and 9,000 mg/kg for coarse soil).

Since the model depends strongly on the distance between soil source and trench wall/base, and the value of 30 cm is somewhat arbitrary, it may be more appropriate to ask the question: “with this model and assumptions, how small can the separation be between soil contamination and trench wall before the Trench Worker Scenario becomes limiting”. Or to rephrase this question: “what are the separation distances that result in the F2 management limit being 10,000 mg/kg for fine soil and 9,000 mg/kg for coarse soil". The details of these calculations are also provided in Appendix B, and the results are summarized below.

The Trench Worker Scenario is not a limiting consideration in setting management limits for F2 so long as the separation distance between soil source and trench wall is at least:

- Coarse soil: 6 cm
- Fine soil: 8 cm

Uncertainties and conservative model assumptions are discussed in Section 3.6 below. Proposed additional experimental work to reduce the uncertainties in this conclusion even further is summarized in Section 5.2.

3.6 Uncertainties and Conservative Model Assumptions

The VDEQ model considers the four basic processes indicated in Section 3.2:

1. volatilization of soil and/or groundwater contaminants;
2. migration of vapours into the trench;
3. mixing of contaminant vapours in the trench; and
4. removal of vapours from the trench *via* air exchange with outdoor air.

The uncertainty in Process 1 has been largely removed in this project by measuring the vapour concentrations of F2 sub-fractions in equilibrium with soils spiked with F2.

The diffusion of vapours between contaminated soil and the trench face (Process 2) uses well-accepted standard models and assumptions. The separation distance between contaminated soil and the trench face can be reduced to a small value, but the model breaks down when the separation distance becomes zero. There is therefore uncertainty as to whether the conclusions reached in Section 3.5 for small separation distances (6 and 8 cm) will also be valid for the situation where a trench intersects a contaminated area.

The VDEQ model assumes complete mixing of soil vapours in trench air (Process 3) which seems reasonable.

The uncertainty in Process 4 has been significantly reduced in this project by using an air exchange rate that is based on an empirical study rather than an assumed value.

The modelling process incorporates a number of conservative features which may help to mitigate some of the uncertainties discussed above. Two specific conservative model elements are summarized below.

- The model assumes that the full extent of trench base and walls are impacted by F2. In many real situations, only part of a trench may intersect the area of contaminated soil.
- The model uses chronic inhalation thresholds for F2 sub-fractions (adjusted for occupational exposure and other sources of exposure, see Appendix B). These are conservative thresholds considered acceptable for a worker spending every working day continuously in a contaminated trench. In reality, workers would only be exposed to this hazard on an occasional basis, and a less conservative sub-chronic or acute exposure threshold might be more appropriate. However, only chronic inhalation thresholds are available for F2 sub-fractions and therefore this element builds significant conservatism into the conclusions reached in Section 3.5.

Based on these updated calculations, it seems highly unlikely that the Trench Worker Scenario will be a limiting consideration in setting management limits for F2.

4.0 PHASE 2 – EFFECTS ON BURIED INFRASTRUCTURE

4.1 Approach

Concerns about possible adverse effects of petroleum hydrocarbons in soil on buried infrastructure is one of the considerations cited by CCME (2008). CCME (2008) indicates that the potential for PHC to enter water distribution systems is of particular concern, though impacts on other utilities are undesirable as well. AEP (2019) has adopted PHC management limits from CCME (2008) and lists concrete foundations, metal pilings or pipelines, fibre-optic communication cables, power cables, polymer piping and joints as possible concerns.

CCME (2008) reviewed available information on the possible effects of PHCs on buried infrastructure and concluded that the available data were not adequate to derive meaningful thresholds for the PHC fractions on a generic basis and 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 soils. CCME (2008) did not, therefore, include a quantitative value for this consideration when setting management limits.

In Phase 2 of this project, additional data was 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 indicated by CCME (2008). Of the other types of buried infrastructure listed by AEP (2019), 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. 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 is not directly exposed to PHCs in sub-surface soil.

For the reasons indicated above, experimental work in the InnoTech (2020) study focused on the possible intrusion of PHCs into 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 PVC, HDPE, and fibre-reinforced plastic (FRP), with PVC being the commonest. Sections 4.2 and 4.3 below summarize the work that was done in this phase of the project to improve the understanding of these concerns.

4.2 Incubation of Pipe Coupons

Possible physical deterioration of drinking water pipe was investigated in the InnoTech (2020) report (Appendix B) by incubating 4 cm x 4 cm “coupons” of PVC, HDPE, and FRP pipe material in pure F2 or F3 for 80 days. Three replicates of each material were tested, as well as appropriate controls. After incubation, the coupons were cleaned and tested for visual changes or changes in physical properties (thickness, weight, hardness).

No visible changes were evident to any of the coupons tested. No statistically significant changes were evident for any of the physical properties for any of the three materials exposed to F2 or F3 with a few minor exceptions (slight increase in weight for HDPE exposed to F2; slight decrease in hardness for PVC exposed to F2 and to F3).

Bear in mind that these coupon incubation tests exposed these polymers to pure F2 or F3. However, a management limit of 10,000 mg/kg (for example) is equivalent to 1% (by weight) of F2 or F3 in soil and therefore the slight changes in physical properties resulting from incubation in pure F2 or F3 distillates would be much smaller or non-existent for exposure to 10,000 mg/kg of F2 or F3 in soil.

4.3 Infiltration into a Water Pipe

An experiment was set up to determine 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, 2019).

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 (3 reps) was surrounded by cotton batting soaked in F2, and then covered with neoprene rubber. One control was also set up that was similar but without the F2. The pipes were incubated for 80 days and then water samples were collected and analyzed.

The results (Table 4 in Appendix A) indicate apparent detectable F2 in 2 out of the 3 reps and the control. However, chromatograms of the corresponding analyses (Appendix D in InnoTech, 2020) show a tight doublet of peaks corresponding to two single compounds (or two isomers of a single compound). These chromatograms are not consistent with F2, which would show a complex spectrum, and may be related to the caulking used to seal the pipe segments.

4.4 Recommended Management Limit Values

Overall, 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.

Overall, therefore, the management limit component protective of buried utilities for PHC F2 and F3 is assessed as NGR or "no guideline required".

5.0 PHASE 2 – SUMMARY AND RECOMMENDATIONS

5.1 Updated Management Limits Based on Phase 2

Table 1 indicated the recommended management limit components that were developed in Phase 1 of this project. The Trench Worker Scenario and effects on buried infrastructure were identified for further investigation in the current phase of the project (Phase 2).

Based on the discussion in Sections 3.5 and 3.6 of this report, the management limit component for the Trench Worker Scenario is assessed as "NL" or not limiting, in relation to mobile free phase formation (10,000 mg/kg and 9,000 mg/kg for fine and coarse soil respectively).

Based on the discussion in Section 4.4 of this report, the management limit component protective of buried utilities for PHC F2 and F3 is assessed as NGR or "no guideline required".

Table 4 presents the recommendations for management limit components developed in Phase 1 and Phase 2 of this project.

Table 4 Phase 2 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				
Trench worker scenario	NL	NL	NGR	NGR
Aesthetic considerations	SSB	SSB	SSB	SSB
Effects on buried infrastructure	NGR	NGR	NGR	NGR

Notes:
NL – not a limiting consideration (see text)
NGR = no guideline required (see text)
SSB = any issues should be managed on a site-specific basis (see text)

Table 5 presents the overall management limits recommended for PHC F2 and F3 based on Phase 1 and Phase 2 of this project. These management limits are recommended for all land uses.

Table 5 Phase 2 Recommended Overall Management Limits (mg/kg)

Land use	F2		F3	
	Fine Soil	Coarse Soil	Fine Soil	Coarse Soil
All Land Uses and Areas	10,000	9,000	14,000	4,000

5.2 Recommended Additional Work

Based on the findings of Phase 1 and Phase 2 of this project, sufficient data are now available to assess six out of the seven management limit components listed in Table 4 with a high degree of confidence.

Phase 2 work conducted in 2019 and 2020 has provided a reasonably high level of confidence that the Trench Worker Scenario is not a limiting consideration for F2 in relation to other components that have been quantified. Using empirical data for the vapour concentrations of F2 sub-fractions in equilibrium with F2-impacted soil and using empirical data for air exchange rates in trenches has enabled the modelling to be refined for this scenario. Phase 2 data has shown that diffusing through as little as 6 to 8 cm of soil is sufficient to make this consideration not limiting. However, the scientific rationale for this decision could be strengthened even further by directly measuring flux rates of F2 sub-fractions from the surface of soil samples. Empirical flux rates could be combined with empirical trench air exchange rates in a very simple box model that would allow the appropriate management limit component for this consideration to be calculated with a high degree of confidence.

For this reason, a third, and final phase of this project is recommended to build on the existing experimental work and develop an experimental procedure to measure F2 flux rates from the surface of fine and coarse soils. The empirical flux rates would be used together with empirical trench air exchange rates do develop definitive values for the Trench Worker Scenario and therefore for overall F2 and F3 management limits.

6.0 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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Yours truly,

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7.0 REFERENCES

Alberta Environment and Parks (AEP), 2019. Alberta Tier 1 *Soil and Groundwater Remediation Guidelines*. Land Policy Branch, Policy and Planning Division. 198 pp.

Alberta Environment and Sustainable Resource Development (ESRD), 2014. Subsoil petroleum hydrocarbon guidelines for remote forested sites in the Green Area. ESRD, Reclamation and Remediation, 2014, No. 4. September 12, 2014.

American Society for the Testing of Materials (ASTM), 2004. Standard Guide for Risk-Based Corrective Action. ASTM E 2081-00 (Reapproved 2004).

Canadian Council of Ministers of the Environment (CCME), 2008. Canada-Wide Standard for Petroleum Hydrocarbons (PHCs) in Soil: Scientific Rationale. Supporting Technical Document, January 2008.

Canadian Council of Ministers of the Environment (CCME), 2014. A Protocol for the Derivation of Soil Vapour Quality Guidelines for Protection of Human Exposures *via* Inhalation of Vapours.

Hwang, S. T., and J. W. Falco. 1986. Estimation of Multimedia Exposure Related to Hazardous Waste Facilities. Y. Cohen, Ed. Plenum Publishing.

InnoTech Alberta Inc. (InnoTech), 2020. Petroleum Hydrocarbon Fractions 2 and 3: Evaluation of Management Limits. Report dated May 1, 2020.

Jury, W.A., D. Russo, G. Streile, and H.E. Abd. 1990. Evaluation of volatilization by organic chemicals residing below the soil surface. Water Resources Research 26(1):13-20.

Jury, W.A., W.F. Spencer, and W.J. Farmer. 1983. Behavior assessment model for trace organics in soil: I. Model description. J. Environ. Qual. 12(4):558-564.

Meridian Environmental Inc. (Meridian), 2010. Review of Approaches for Modelling Vapour Migration into Trenches and Excavations. Report prepared for the Canadian Council of Ministers of the Environment (CCME). CCME Contract #485-2010. Dated November 24, 2010.

Petroleum Technology Alliance Canada (PTAC), 2013. Proposed management limits for F2 and F3 Petroleum Hydrocarbons at Remote Alberta Green Zone Sites. PTAC Project #GL09-9178-50.

Petroleum Technology Alliance Canada (PTAC), 2019. Re-Evaluation of F2 and F3 Petroleum Hydrocarbon Management Limits. January 2019. PTAC File #18-RRRC-08.

Stantec Consulting Ltd. (Stantec), 2003. Research for utility criteria development. Contractor report prepared for Alberta Environment.

Startsev, A. 2009. Validation of critical F2 and F3 subsoil concentrations on perennial deeply rooted crop (alfalfa) grown in greenhouse. Unpublished report prepared by Andrei Startsev, Alberta Research Council for Alberta Environment.

Thompson, S, Michalski, P., and Pruis, J., 2017. Empirical Study to Estimate the Air Exchange Rate Within a Trench for Modeling Inhalation Risks. Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies. Battelle Memorial Institute, Columbus, OH.

US EPA (United States Environmental Protection Agency). 1996. Soil Screening Guidance: Technical Background Document – Second Edition. Office of Solid Waste and Emergency Response. EPA/540/R95/128, Publication 9355.4-17A.

US EPA (United States Environmental Protection Agency). 2002. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Office of Solid Waste and Emergency Response. OSWER 9355.4-24.

Virginia Department of Environmental Quality (VDEQ), 2020. Virginia Unified Risk Assessment Model – VURAM User Guide. Updated March 2020.

APPENDIX A: INNOTECH ALBERTA 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.

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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_{10-12} and C_{12-16}) 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.

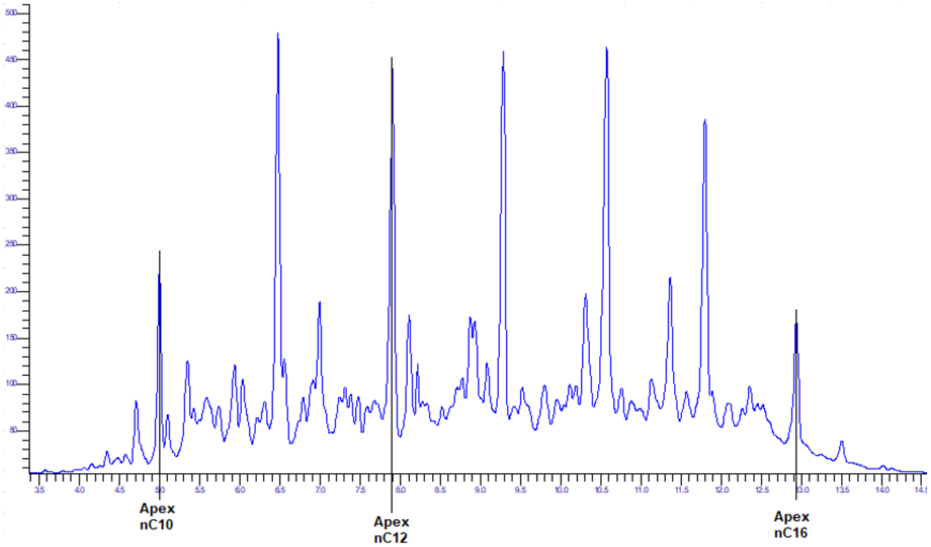


Figure 1. Analysis of PHC F2 distillate and indication of peak apex categories.

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.

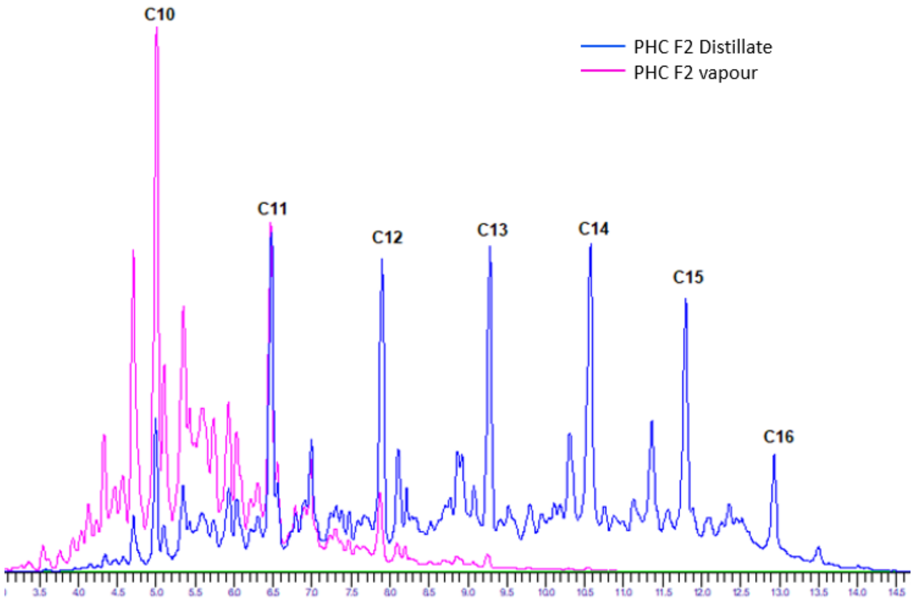


Figure 2. PHC F2 headspace vapour distribution.
PHC F2 distillate placed in petri dish within Tedlar® bag. Bag evacuated and lab-grade air injected. 100 mL headspace at steady state as assessed by PID.

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.

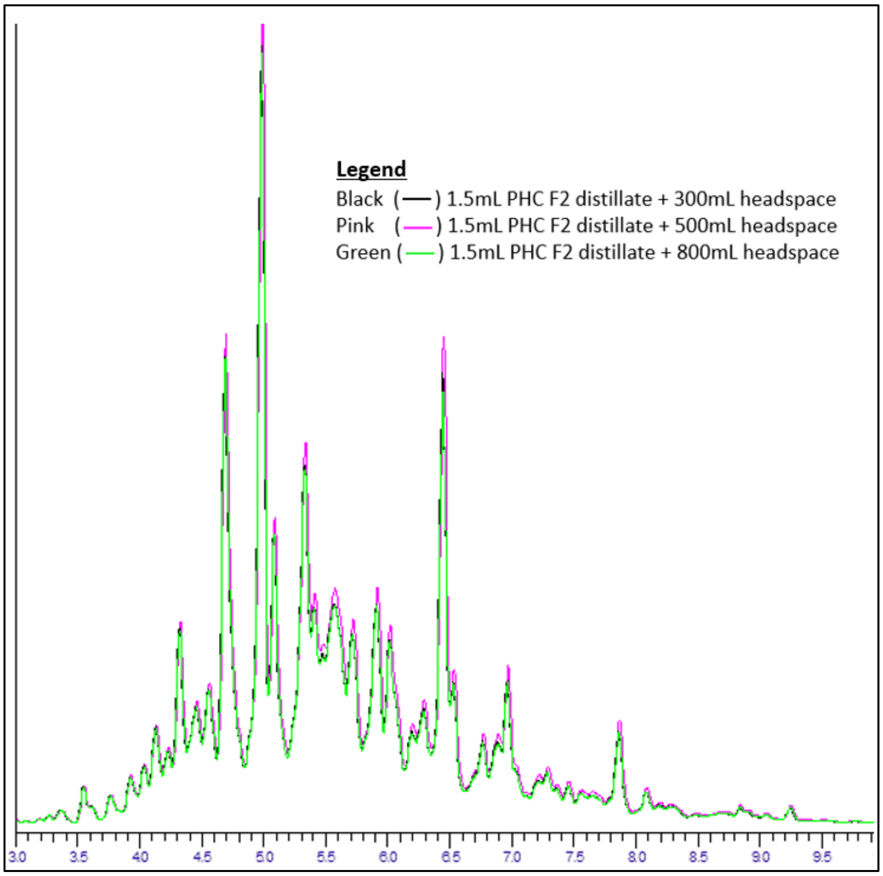


Figure 3. Overlain chromatograms of PHC F2 distillate in petri dishes within Tedlar® bags with differing volumes of injected headspace after complete evacuation.

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.

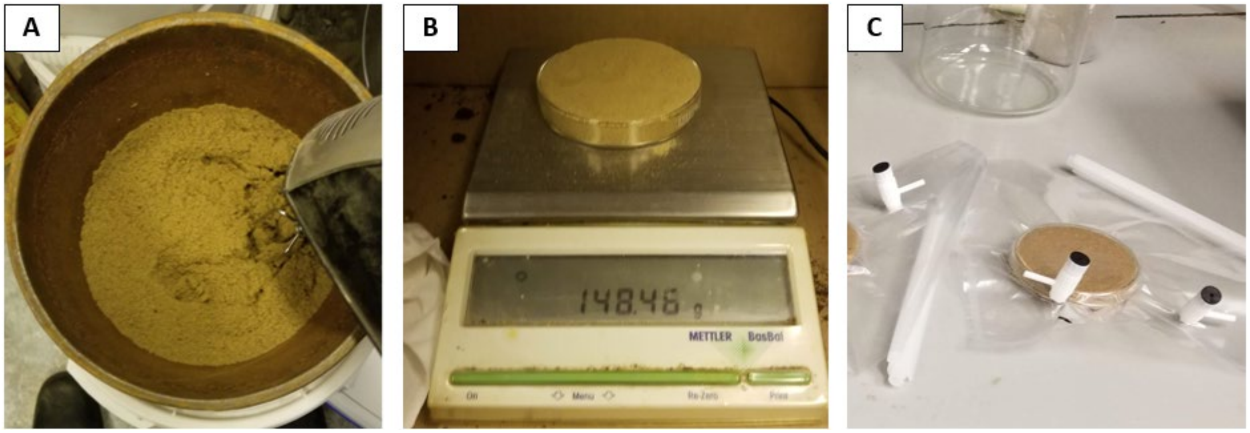


Figure 4. Experimental setup for spiked soils including mixing distillate into soil, weighing once in petri dish for density calculation, placement into Tedlar® bag, and evacuation.

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.

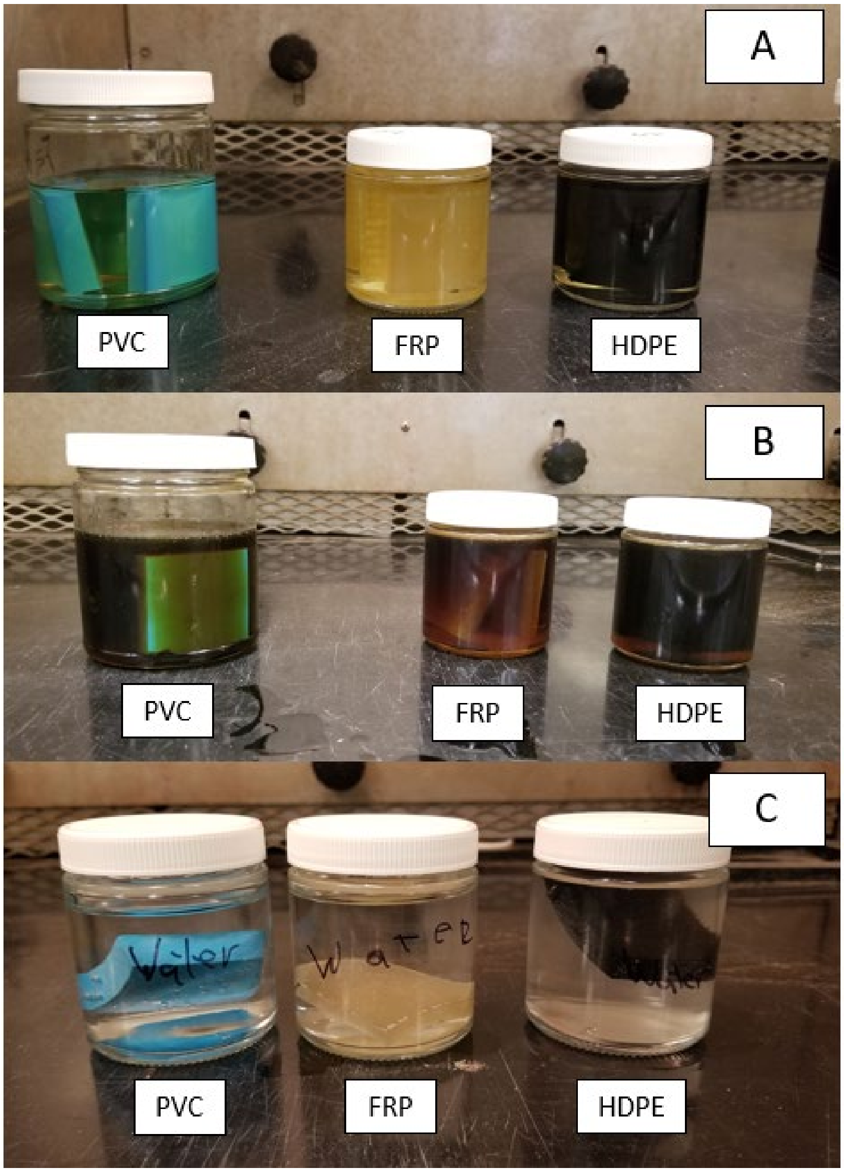


Figure 6. Polyvinyl chloride (PVC), fibre-reinforced plastic (FRP) and high density polyethylene (HDPE) coupons (5 x 5 cm) incubated in (A) PHC F2 distillate; (B) PHC F3 distillate; (C) water.

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).

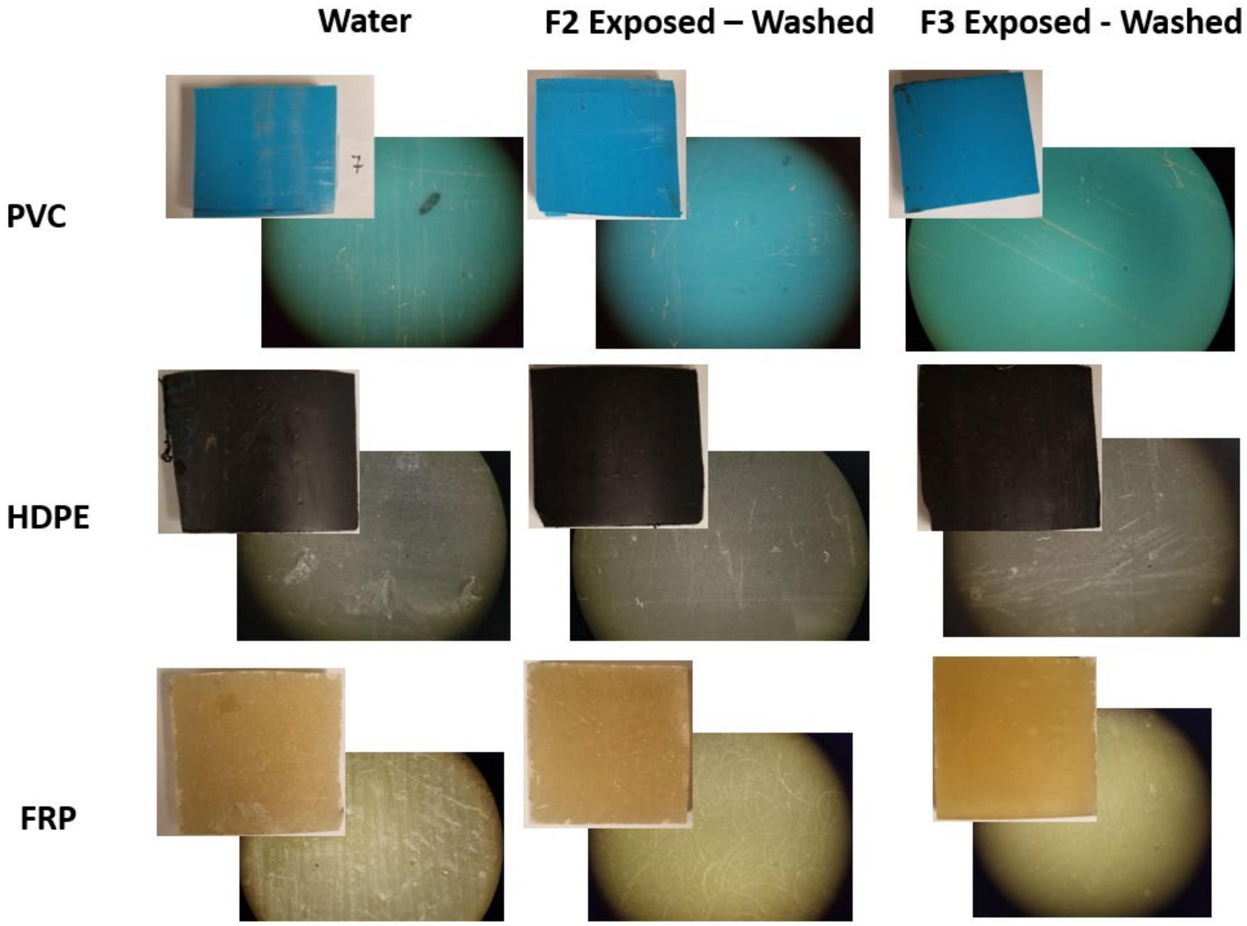


Figure 7. Photographs of one representative coupon of each polymer type post-incubation in water, PHC F2 or PHC F3 distillate. Photos of coupons (top right) overlain on magnified image of same coupon.

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.

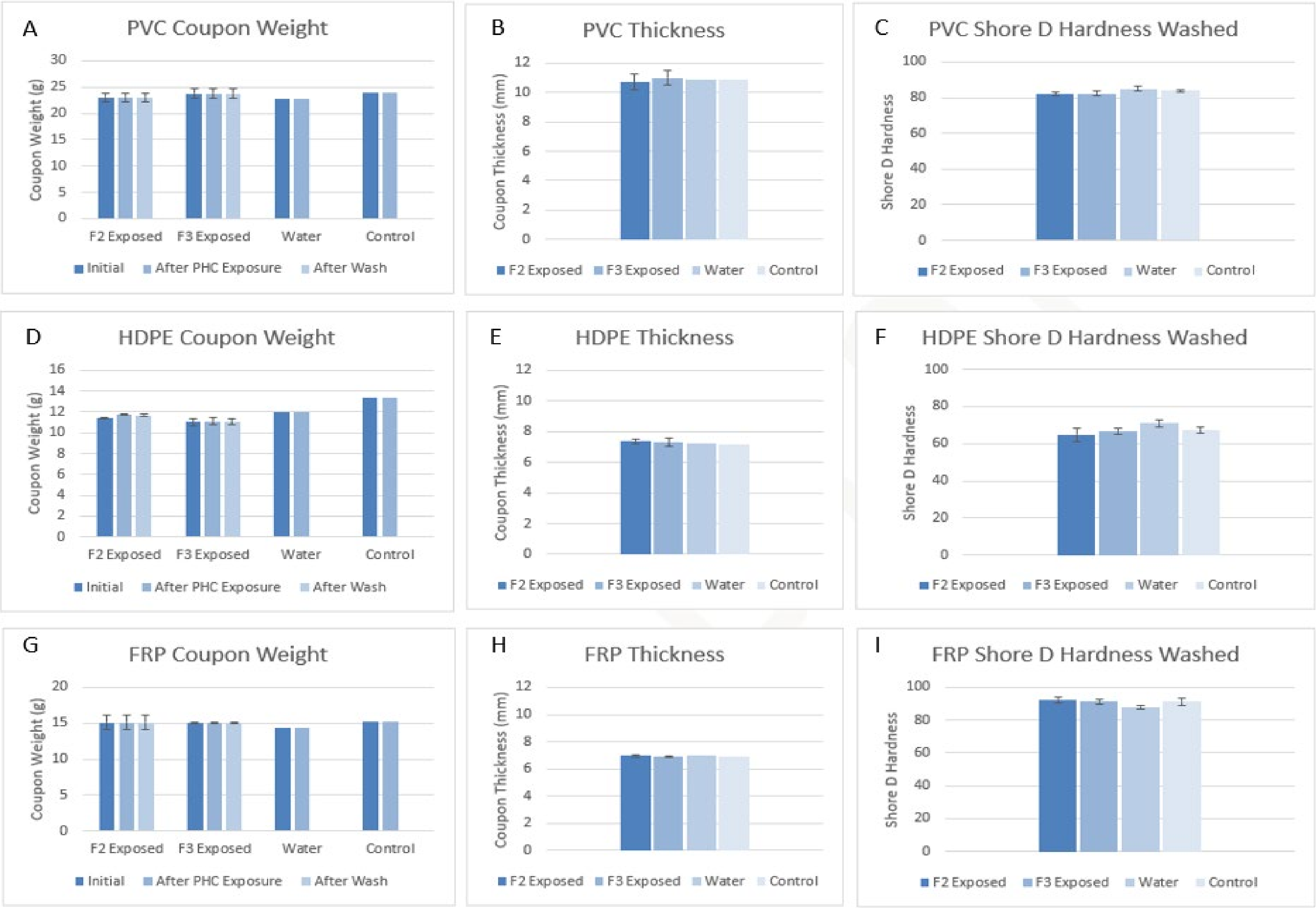


Figure 8. Graphs of average ± standard deviation (n = 3) for PVC (A-C), HDPE (D-F) and FRP (G-I) coupons incubated in PHC F2 and F3 distillates, water, and non-incubated (control).

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.

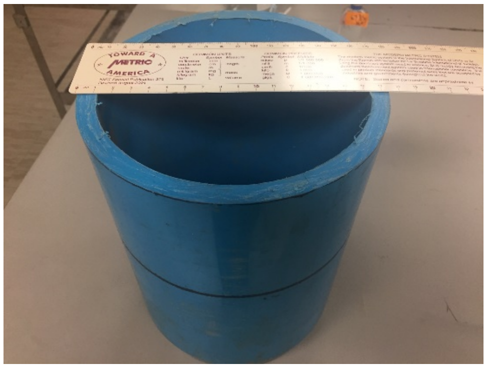


Figure 9. Cross section of PVC piping with ruler, showing piping diameter and thickness.

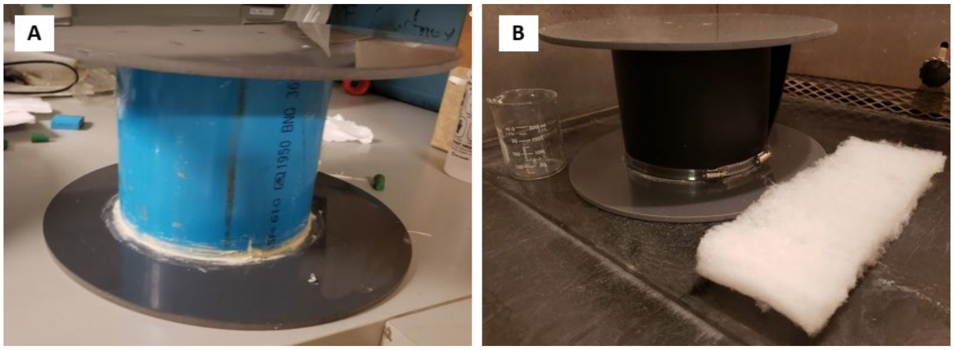


Figure 10. (A) Assembled piping incubation setup prior to installation of distillate-soaked batting and enclosure; (B) final setup including batting and closure.

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

Alberta Environment and Parks (AEP). 2019. Alberta Tier 1 *Soil and Groundwater Remediation Guidelines*. Land Policy Branch, Policy and Planning Division. 198 pp. Available online: https://open.alberta.ca/dataset/842becf6-dc0c-4cc7-8b29-e3f383133ddc/resource/a5cd84a6-5675-4e5b-94b8-0a36887c588b/download/albertatier1guidelines-jan10-2019.pdf

Alberta Environment and Sustainable Resource Development (AESRD), 2014. Subsoil Petroleum Hydrocarbon Guidelines for Remote Forested Sites in the Green Area. 6 pp. Available online: https://open.alberta.ca/dataset/5d16a851-0794-49c8-8265-80b271ecd003/resource/ec2c57bd-db6c-4572-b385-dcb0ddf631d0/download/subsoilpetroleumhydrocarbon-sep12-2014.pdf

American Society for Testing Materials (ASTM), 2019. ASTM D2887: Standard Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography. ASTM International, West Conshohocken, PA, 2016, www.astm.org

Millennium EMS Solutions Ltd., 2019. DRAFT Re-Evaluation of F2 and F3 Petroleum Hydrocarbon Management Limits. Prepared for the Petroleum Technology Alliance Canada (PTAC). Calgary, Alberta. January 2019, 25 pp.

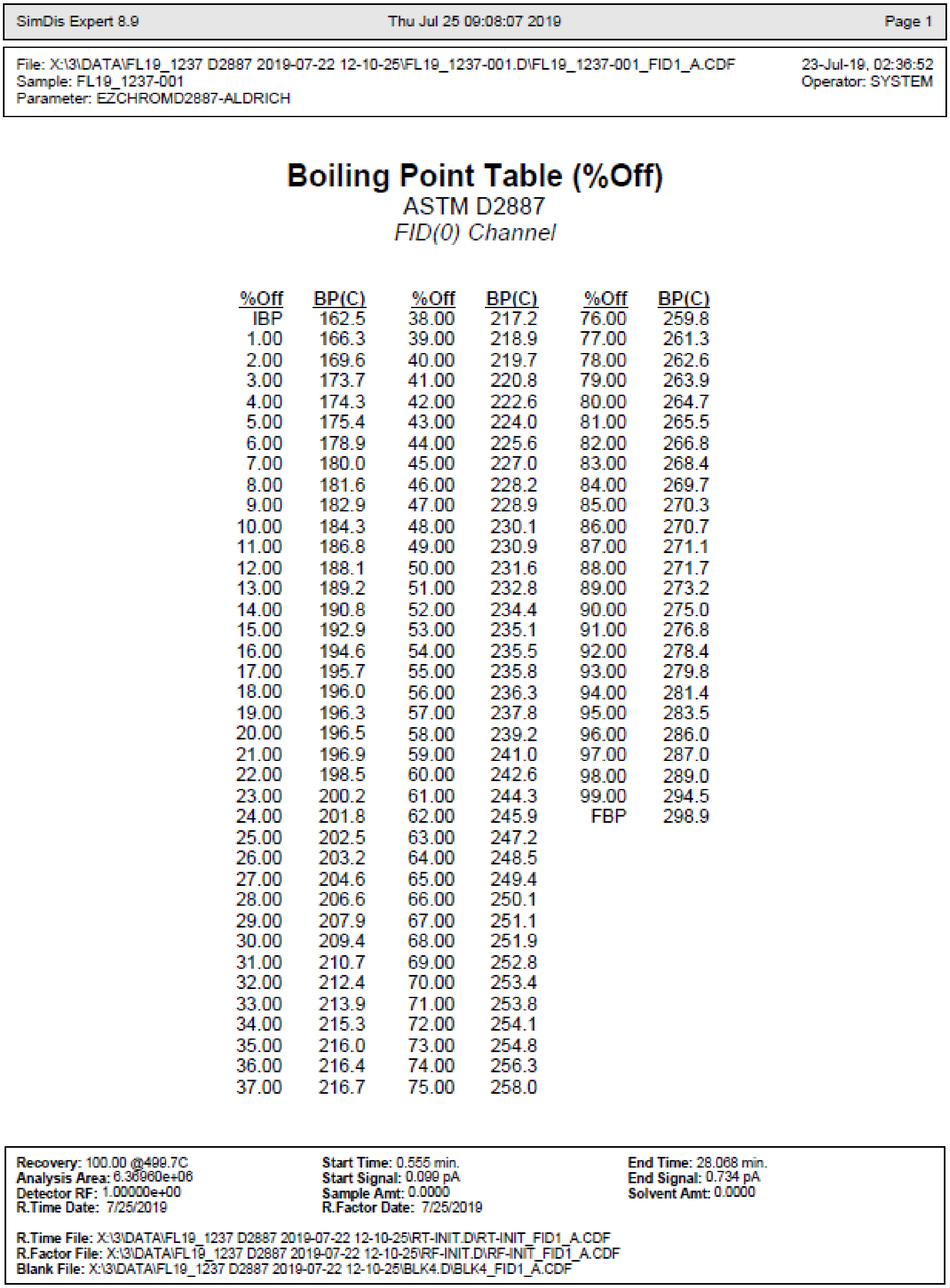
Robinson, C.J., 1971. Low-resolution mass spectrometric determination of aromatics and saturates in petroleum fractions, Analytical Chemistry Vol. 43, No. 11: 1425-1434.

Stantec Consulting Ltd., 2003. Draft Research for Utility Criteria Development. 42 pp.

United States Environmental Protection Agency (US EPA), 2002. Permeation and Leaching. Office of Water (4601M). Office of Ground Water and Drinking Water. Distribution System Issue Paper. Available online: https://www.epa.gov/sites/production/files/2015-09/documents/permeationandleaching.pdf

Virginia Department of Environmental Quality (VDEQ), 2005. Voluntary Remediation Program – Risk Assessment Guidance. Available online: https://www.deq.virginia.gov/Programs/LandProtectionRevitalization/RemediationProgram/VoluntaryRemediationProgram/VRP-RiskAssessmentGuidance/Guidance.aspx

APPENDIX A: PHC F2 AND F3 DISTILLATE CHARACTERIZATION



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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

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: 6.36960e+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
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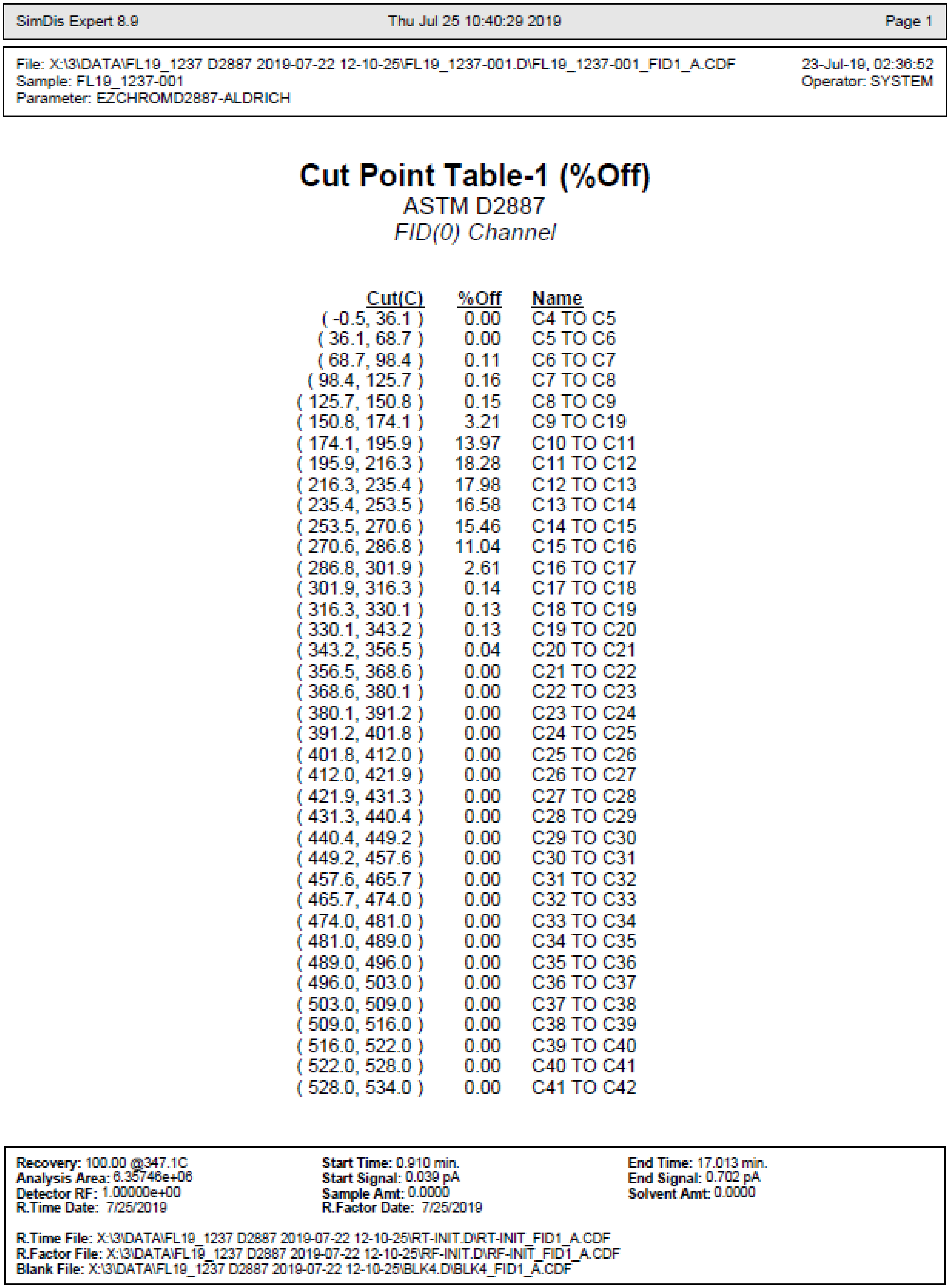


SimDis Expert 8.9 Thu Jul 25 10:40:29 2019 Page 1

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

Cut Point Table-1 (%Off)

ASTM D2887

FID(0) Channel

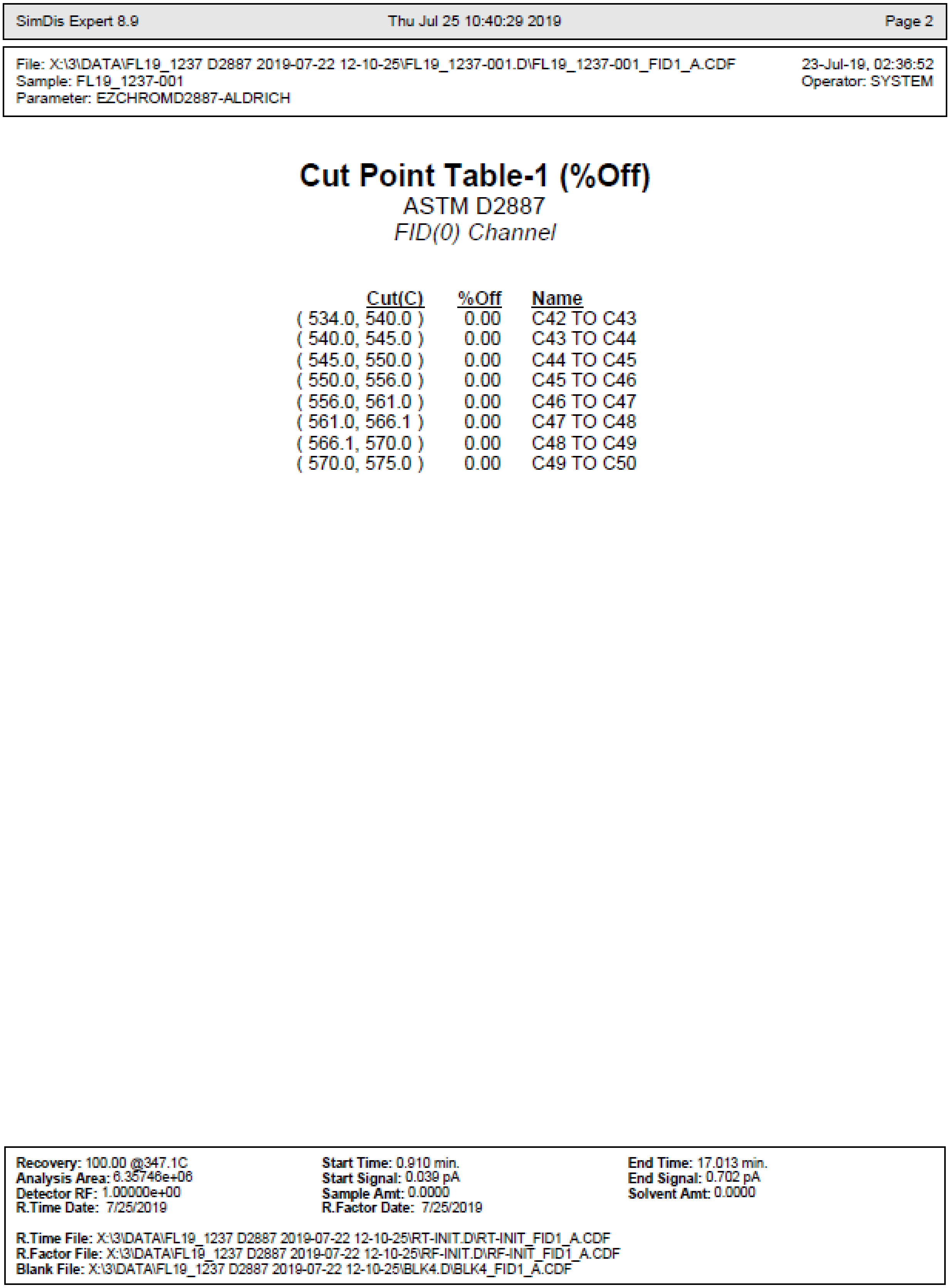
Cut(C)	%Off	Name
(-0.5, 36.1)	0.00	C4 TO C5
(36.1, 68.7)	0.00	C5 TO C6
(68.7, 98.4)	0.11	C6 TO C7
(98.4, 125.7)	0.16	C7 TO C8
(125.7, 150.8)	0.15	C8 TO C9
(150.8, 174.1)	3.21	C9 TO C19
(174.1, 195.9)	13.97	C10 TO C11
(195.9, 216.3)	18.28	C11 TO C12
(216.3, 235.4)	17.98	C12 TO C13
(235.4, 253.5)	16.58	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
Sample: FL19_1237-001
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
(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

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

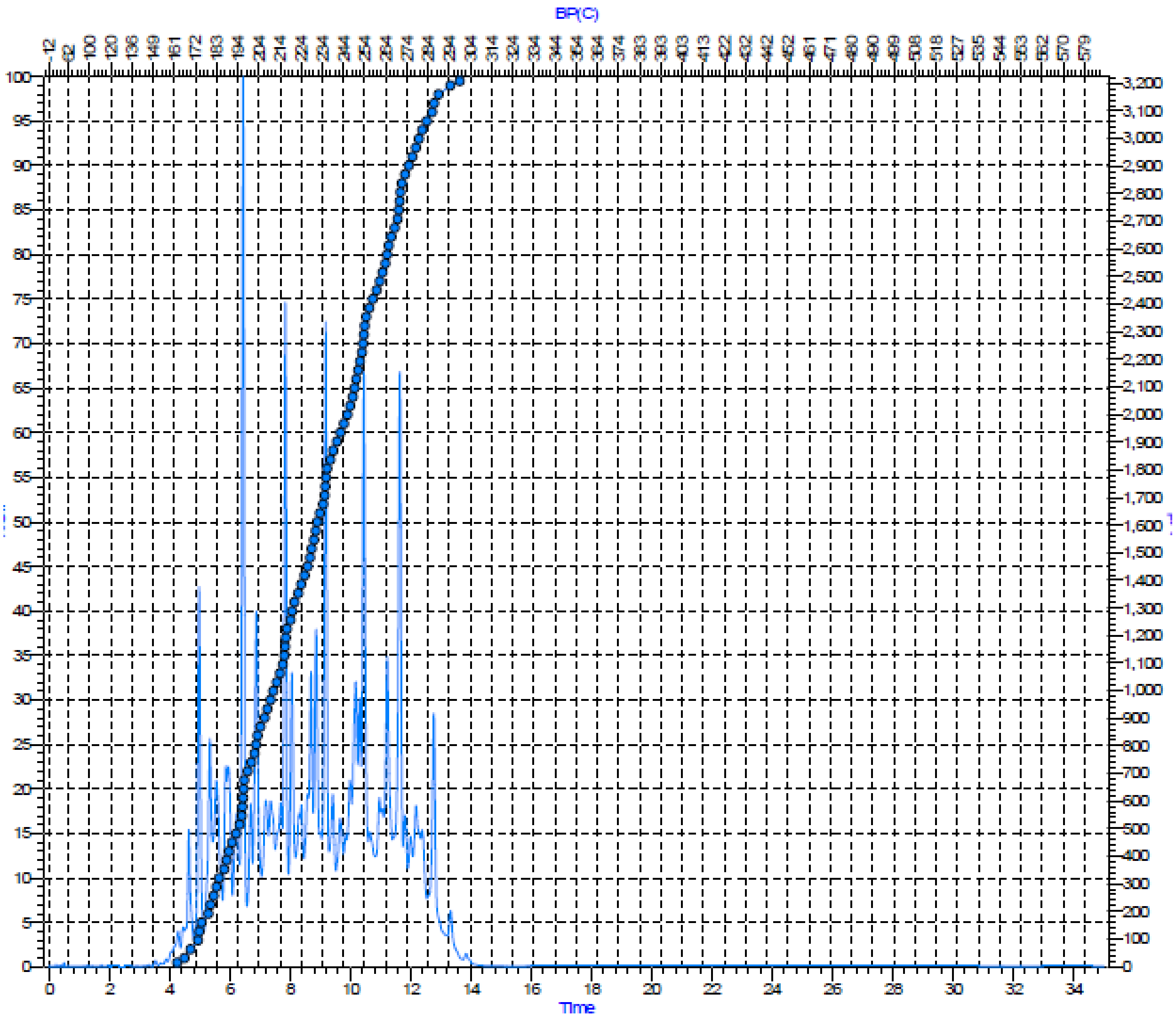
File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\FL19_1237-001.D\FL19_1237-001_FID1_A.CDF
Sample: FL19_1237-001
Parameter: EZCHROMD2887-ALDRICH

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

Distillation Chart

ASTM D2887

FID(0) Channel



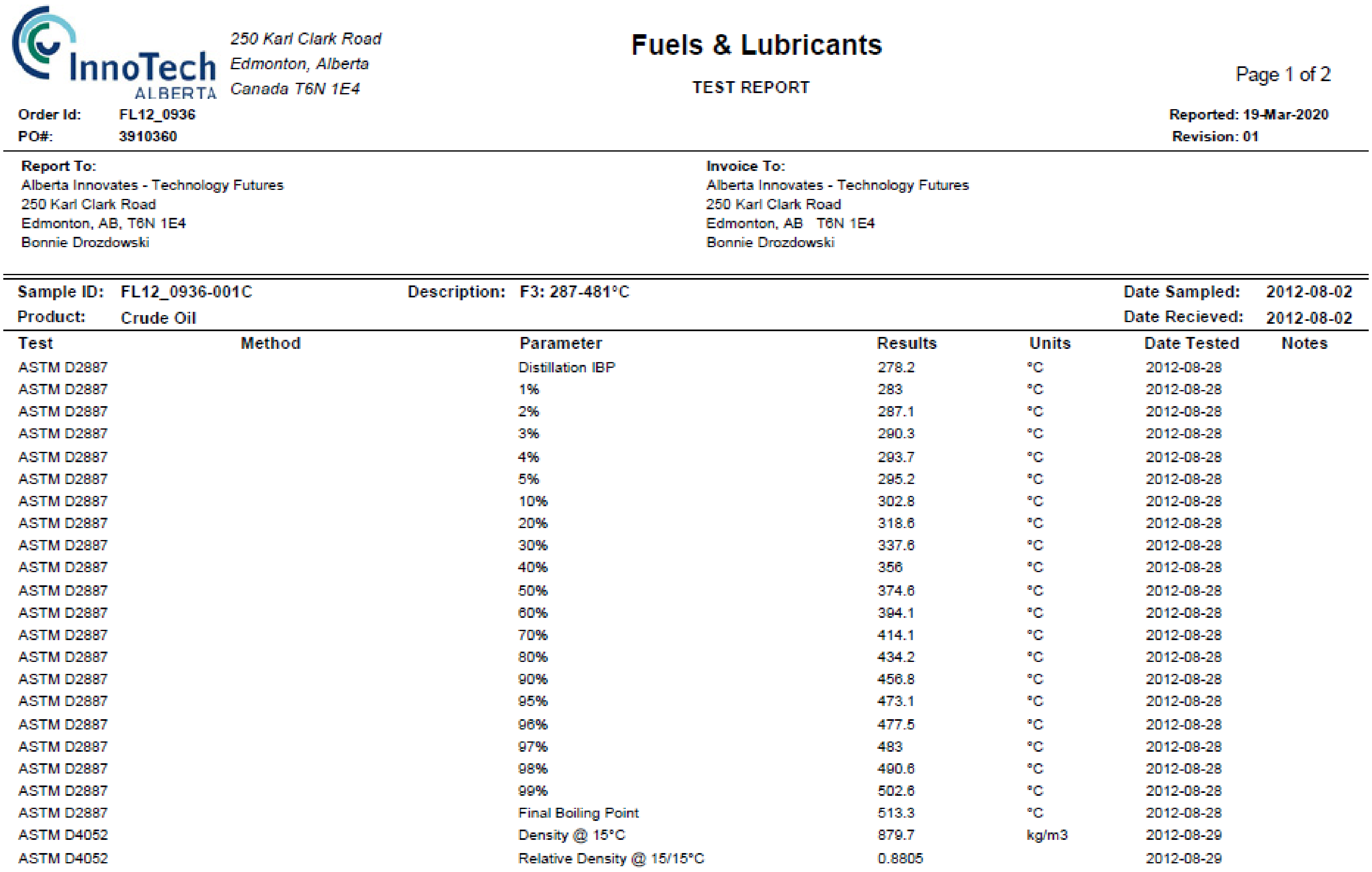
Recovery: 100.00 @499.7C
Analysis Area: 6.36960e+06
Detector RF: 1.00000e+00
R.Time Date: 7/25/2019

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

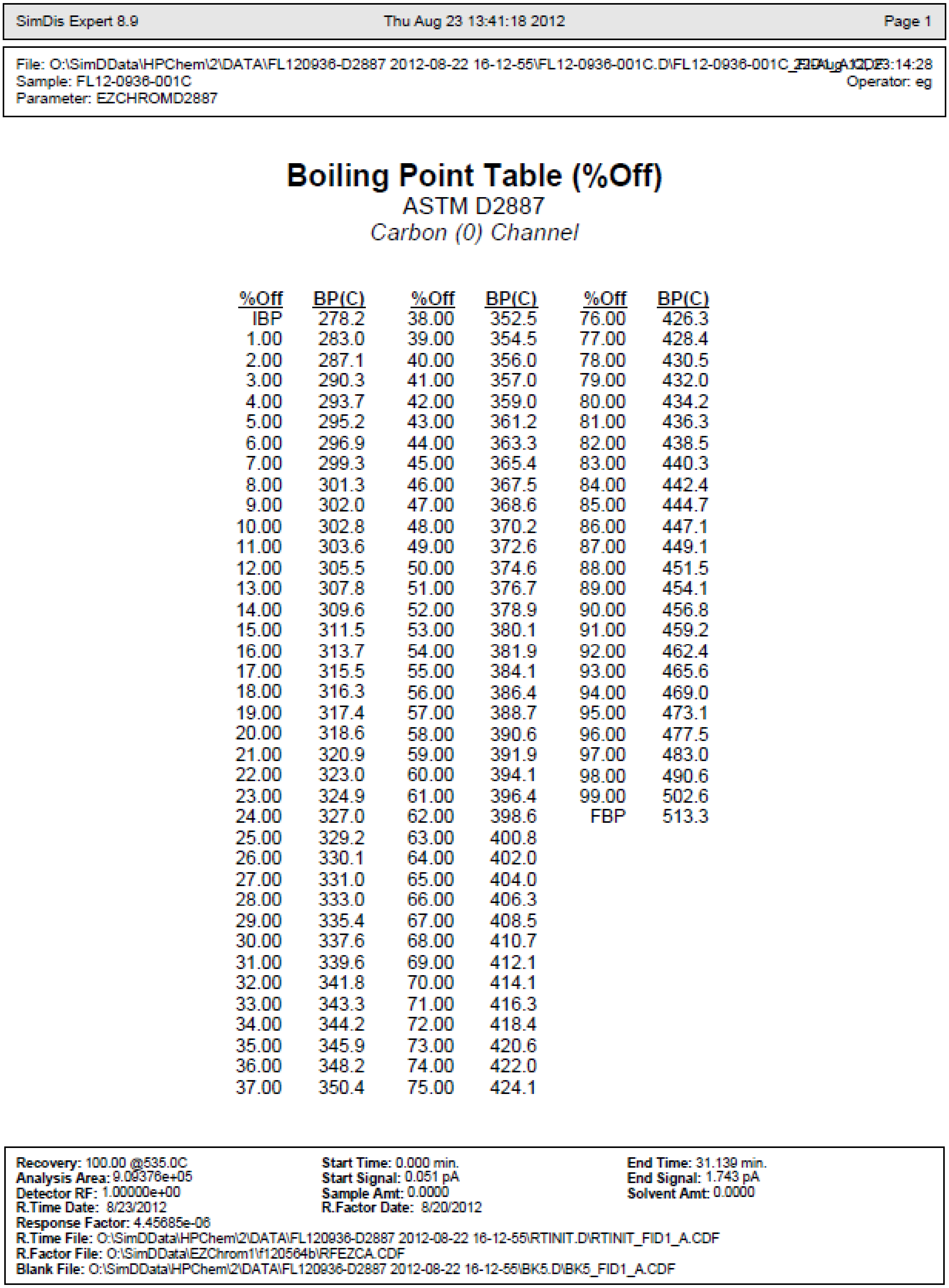
Reported: 19-Mar-2020
Revision: 01

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 12 13:14:28
Sample: FL12-0936-001C
Operator: eg
Parameter: EZCHROMD2887

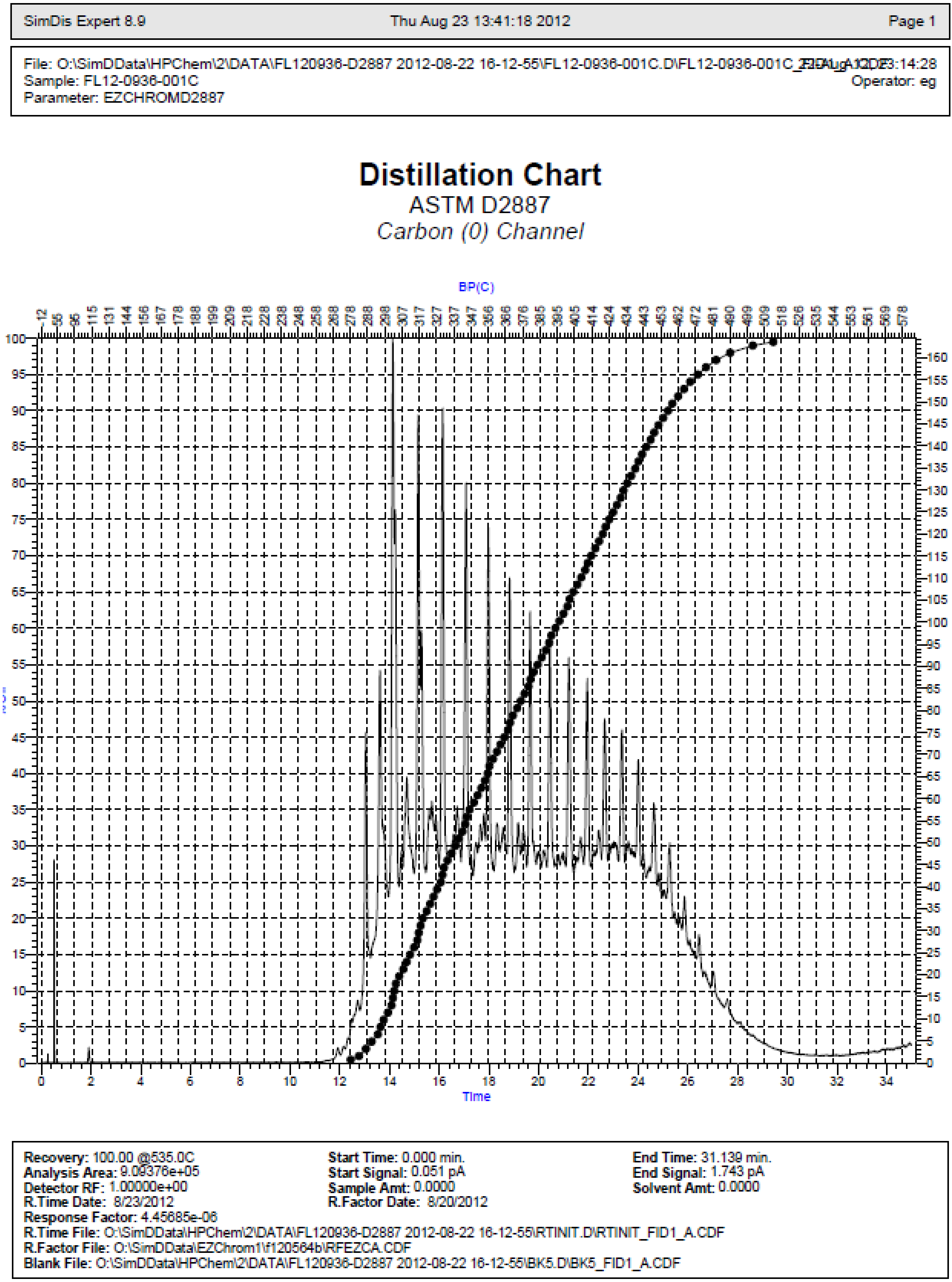
Boiling Point Table (%Off)

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

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

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
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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	3
			26 – 65	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	0
			21 – 57	0
			57 – 65	0
	Cyclohexane	C_6H_{12}	21 – 65	5
	Hexane	C_6H_{14}	21 – 65	0
	Trimethylpropane	C_6H_{14}	21 – 26	3
			26 – 65	0
	Toluene	C_7H_8	21 – 51	0
			51 – 65	0
	Heptane	C_7H_{16}	21 – 26	5
			26 – 37	0
			37 – 65	0
	Xylene	C_8H_{10}	23 – 60	0
	Gasoline	N/A	21 – 26	3
			26 – 57	0
			57 – 65	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.

1. Government of Alberta (2012a). Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems, Part 1: Standards for Municipal Waterworks.
2. Government of Alberta (2012b). Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems, Part 2: Guidelines for Municipal Waterworks.
3. EPCOR (2017). Design and Construction Standards, Volume 4: Water. https://www.edmonton.ca/city_government/documents/Design_and_Construction_Standards_Volume_4_Water.pdf
4. City of Calgary (2018). Standard Specifications Waterworks Construction.
5. IPEX Inc. TerraBrute Pipe Brochure. http://www.ipexna.com/media/8907/brochure_usen_terrabrutecr.pdf
6. IPEX Inc. Centurion Pipe Brochure. http://www.ipexna.com/media/9039/prods_caen_centruion.pdf
7. Brunet/Next Polymers. Aqualoc Municipal PVC Pressure Pipe Data Sheet. http://www.brunet.cc/Document/EnAqualocdatasheet.pdf
8. NAPCO Pipe. CIOD PVC Pressure Pipe. https://napcopipe.com/sites/default/files/media/MU-BR-022-CA-EN-0919.1_CIOD-PVC-Pressure-Pipe.pdf
9. NAPCO Pipe. Cobralock Technical Specification. https://napcopipe.com/sites/default/files/media/Cobralock_2019.pdf
10. Northern Pipe Products. C-900 Pipe Specifications. http://www.northernpipe.com/downloads/C-900.pdf
11. IPEX Inc. Municipal Technical Manual Series, Volume 1: Pressure Piping Systems Design. http://www.ipexna.com/media/9141/tm_caen_pressurepiping.pdf
12. Performance Pipe. Driscoplex 4000/4100 Pipe. http://www.performancepipe.com/en-us/Documents/PP%20501%20Driscoplex%204000-4100%20Water%20Pipe%20Brochure.pdf
13. Uponor Infra. Sclairpipe Versatile High Density Polyethylene Pipe. https://hdpe.ca/wp-content/uploads/2016/03/sclairpipe-general-info.pdf
14. Collings & Wyse. Literature Review of Research on the Potential for Petroleum Hydrocarbons to Degrade or Permeate Buried Plastic Utility Lines.
15. NACE International, The Corrosion Society (2002). Corrosion Survey Database (COR•SUR). https://app.knovel.com/hotlink/toc/id:kpCSDCORSE/corrosion-survey-database/corrosion-survey-database
16. IPEX Inc. PVC Chemical Resistance Guide. http://www.ipexna.com/media/2086/pvc-chemical-resistance-guide.pdf
17. Vinidex. PVC Properties. https://www.vinidex.com.au/technical-resources/material-properties/pvc-properties/
18. INEOS (2012). HDPE Chemical Resistance Guide. https://www.ineos.com/globalassets/ineos-group/businesses/ineos-olefins-and-polymers-usa/products/technical-information--patents/ineos-hdpe-chemical-resistance-guide.pdf
19. Polymer Database. HDPE. https://polymerdatabase.com/Commercial%20Polymers/HDPE.html
20. Vinidex. Polyethylene Properties. https://www.vinidex.com.au/technical-resources/material-properties/polyethylene-properties/

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

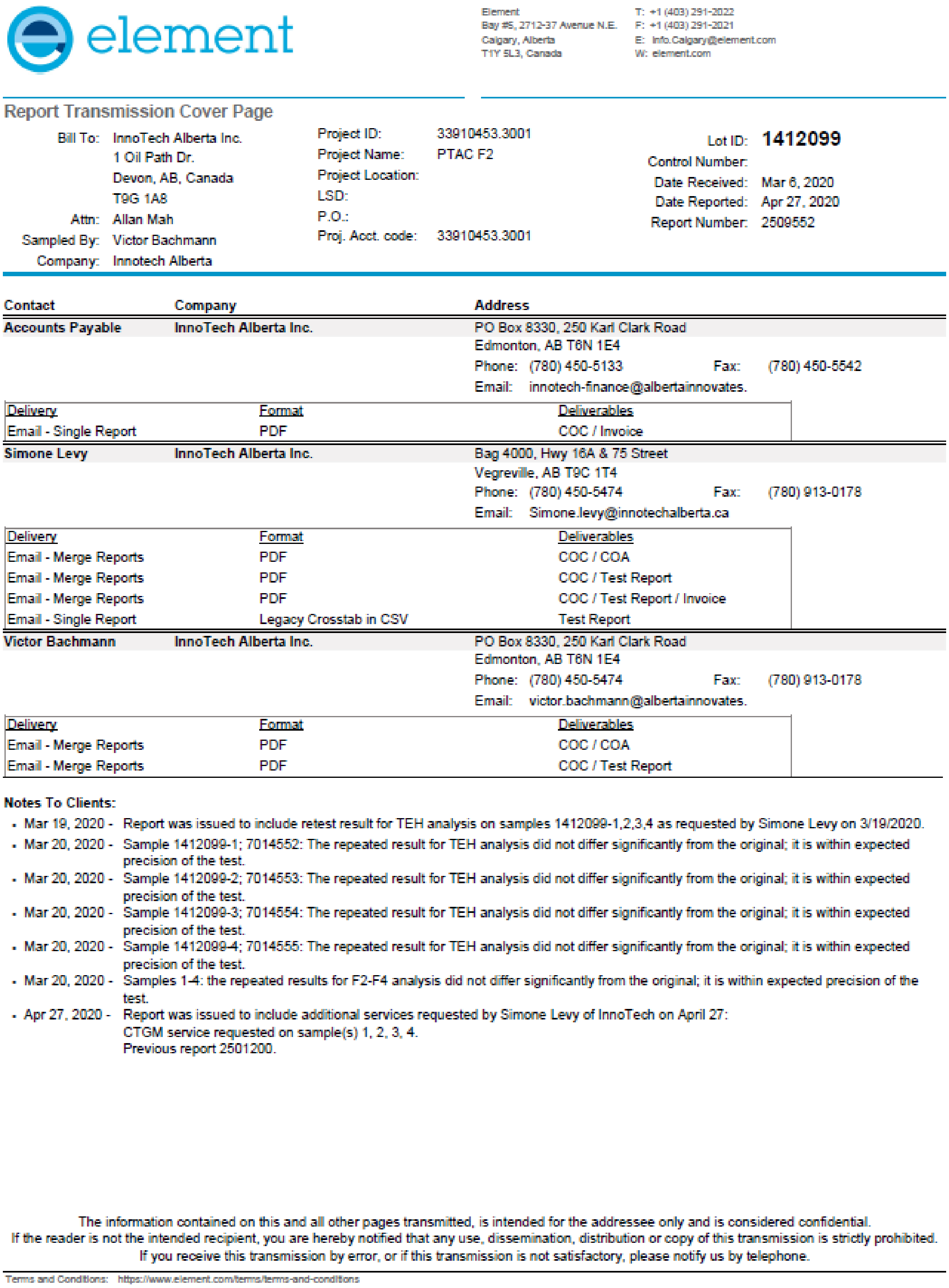
3.0 VC, FRP AND HDPE Coupon Shore D Hardness

		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	Project ID:	33910453.3001	Lot ID:	**1412099**
		Project Name:	PTAC F2	Control Number:	
		Project Location:		Date Received:	Mar 6, 2020
		LSD:		Date Reported:	Apr 27, 2020
Attn:	Allan Mah	P.O.:		Report Number:	2509552
Sampled By:	Victor Bachmann	Proj. Acct. code:	33910453.3001		
Company:	Innotech Alberta				

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.

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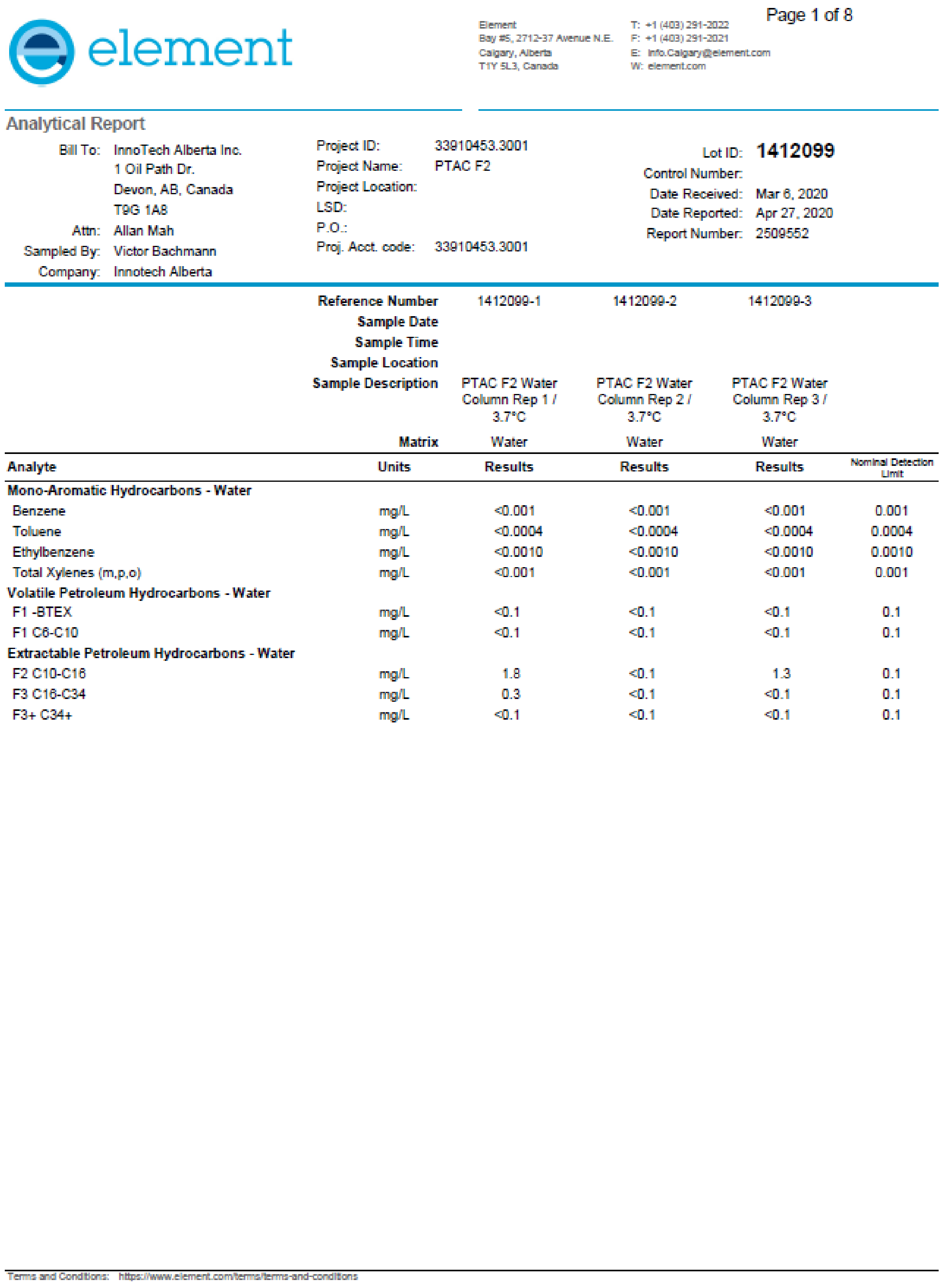

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Analytical Report

Bill To:	InnoTech Alberta Inc. 1 Oil Path Dr. Devon, AB, Canada T9G 1A8	Project ID:	33910453.3001	Lot ID:	**1412099**
Attn:	Allan Mah	Project Name:	PTAC F2	Control Number:	
Sampled By:	Victor Bachmann	Project Location:		Date Received:	Mar 6, 2020
Company:	Innotech Alberta	LSD:		Date Reported:	Apr 27, 2020
		P.O.:		Report Number:	2509552
		Proj. Acct. code:	33910453.3001		

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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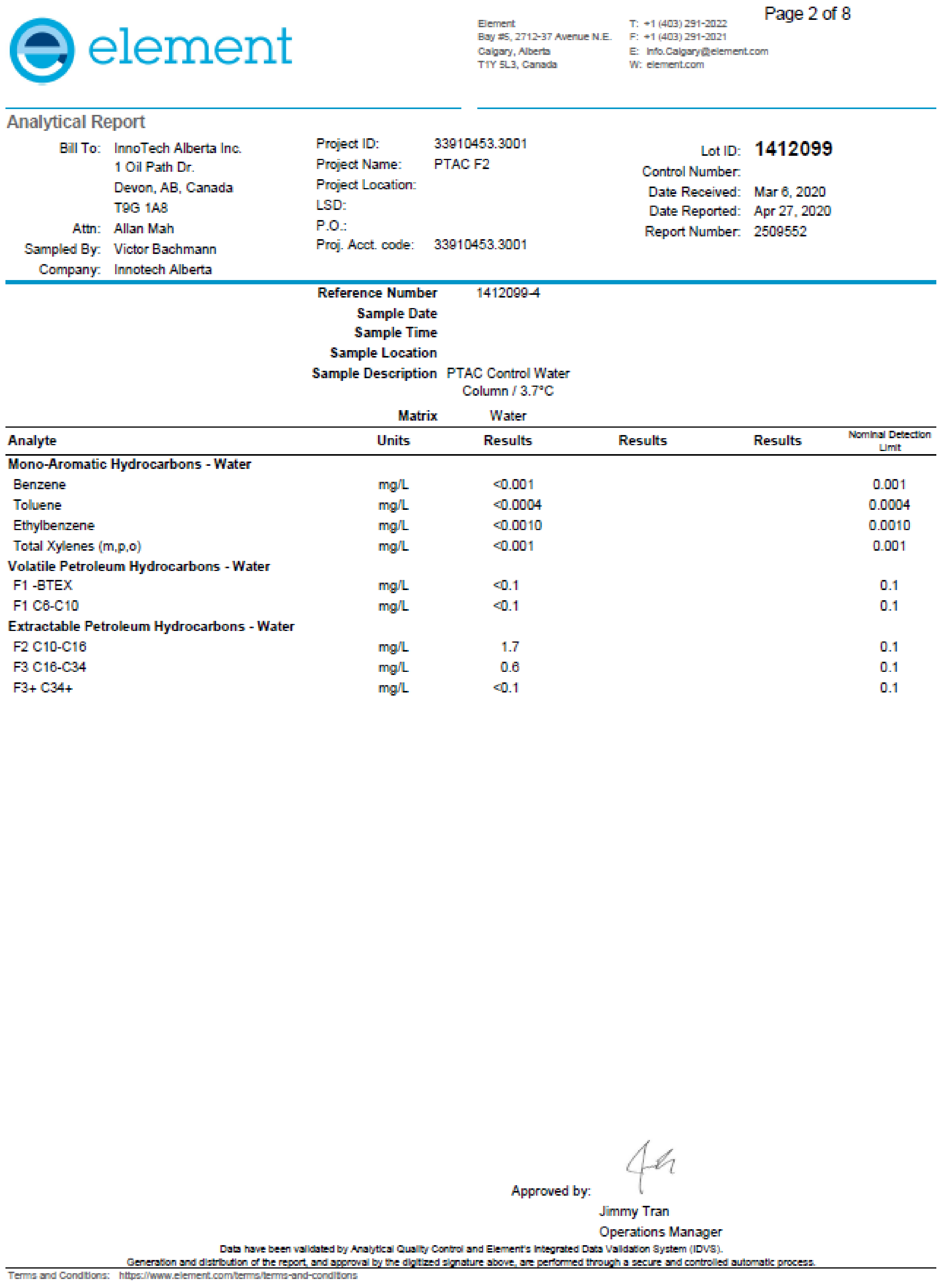

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Analytical Report

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 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.

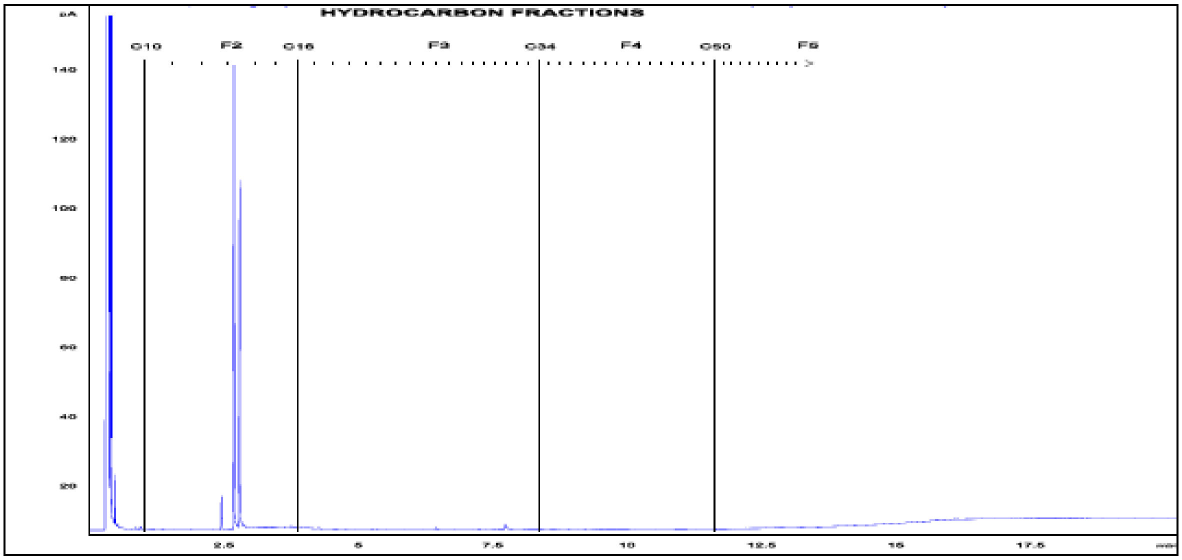
Chromatograms Results

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

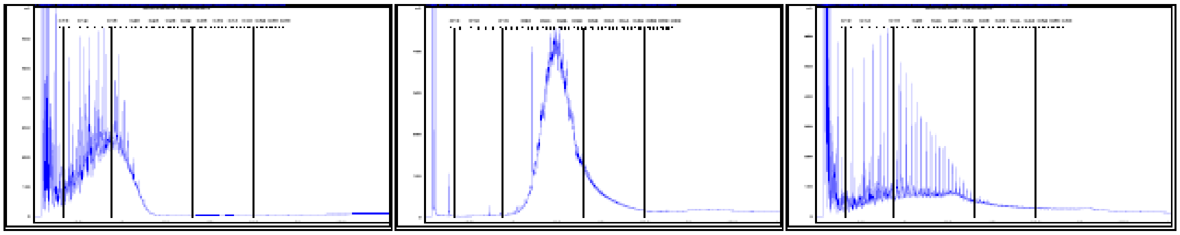
Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

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+

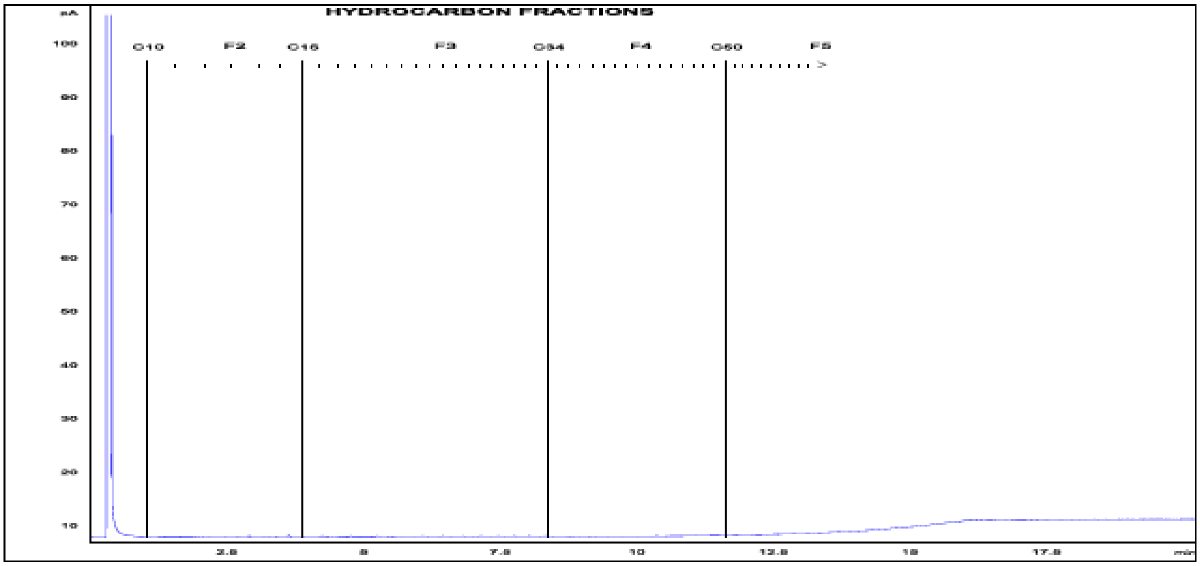
Chromatograms Results

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



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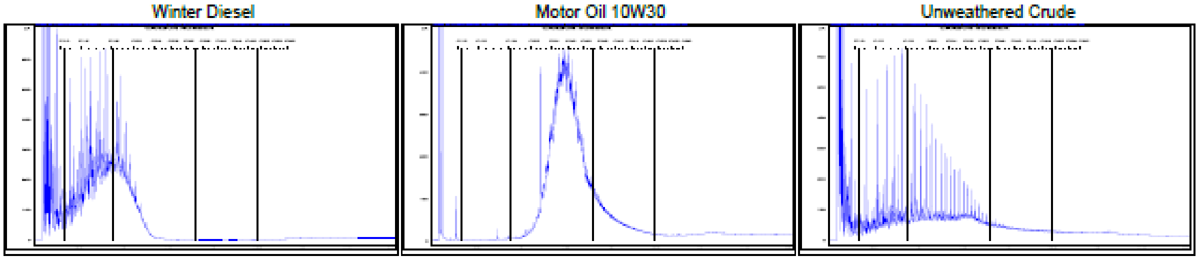
Winter Diesel
Motor Oil 10W30
Unweathered Crude

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

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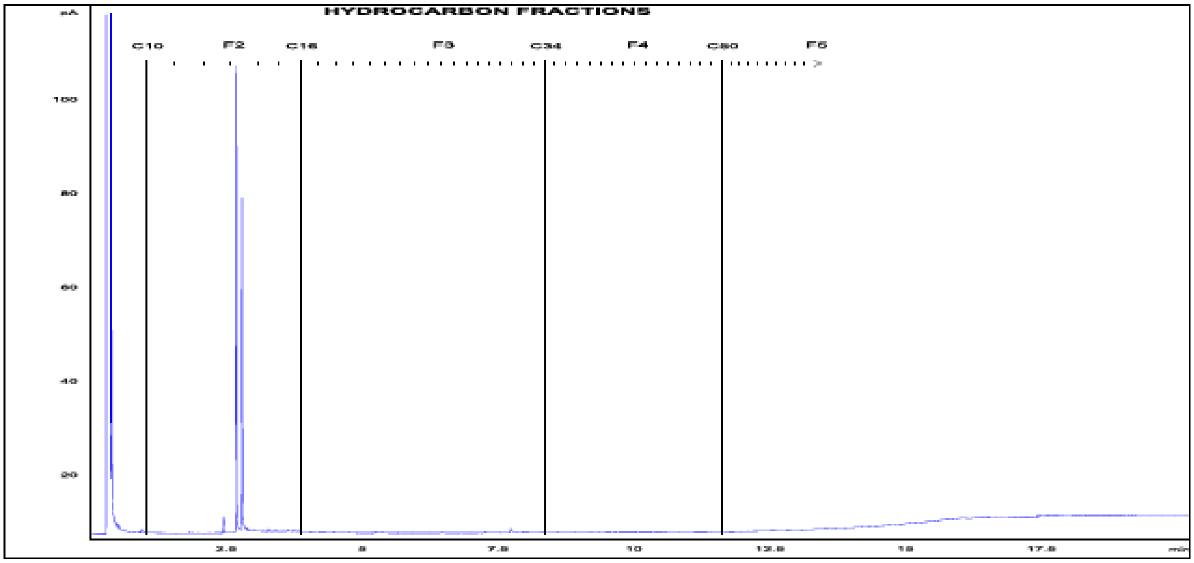
Chromatograms Results

Bill To:	InnoTech Alberta Inc. 1 Oil Path Dr. Devon, AB, Canada T9G 1A8	Project ID:	33910453.3001	Lot ID:	**1412099**
		Project Name:	PTAC F2	Control Number:	
		Project Location:		Date Received:	Mar 6, 2020
		LSD:		Date Reported:	Apr 27, 2020
Attn:	Allan Mah	P.O.:		Report Number:	2509552
Sampled By:	Victor Bachmann	Proj. Acct. code:	33910453.3001		
Company:	Innotech Alberta				

Reference Number: 1412099-3
Sample Date:

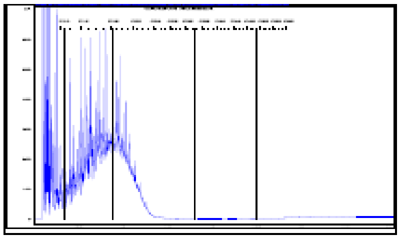
Sample Description: PTAC F2 Water Column Rep 3 / 3.7°C
Location:

Matrix: Water

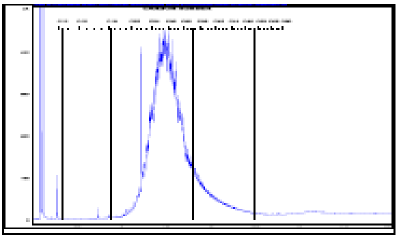


TYPICAL PRODUCT CHROMATOGRAMS

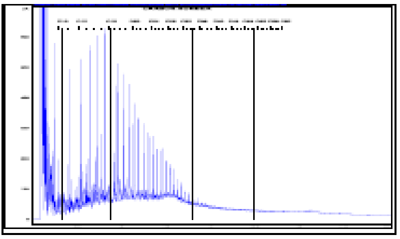
Winter Diesel



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+

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Chromatograms Results

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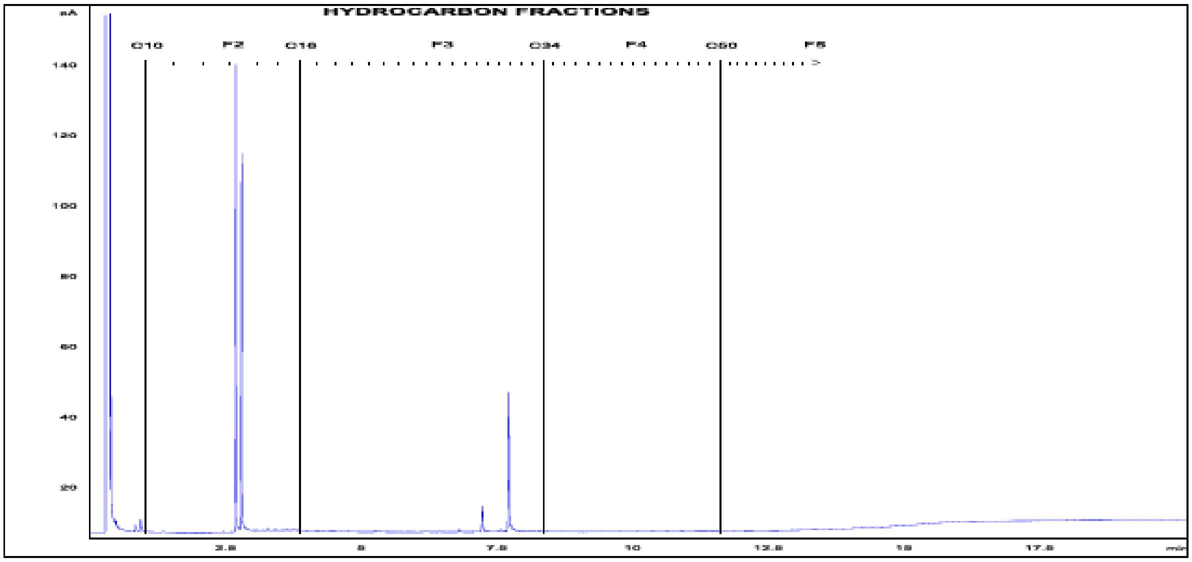
Devon, AB, Canada
T9G 1A8
Attn: Allan Mah
Sampled By: Victor Bachmann
Company: Innotech Alberta

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

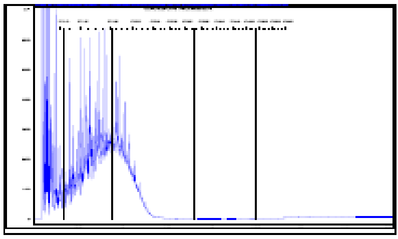
Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

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

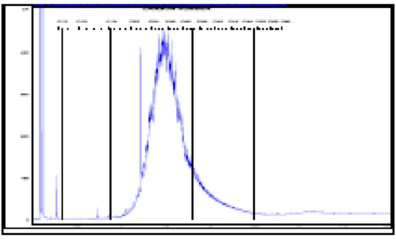


TYPICAL PRODUCT CHROMATOGRAMS

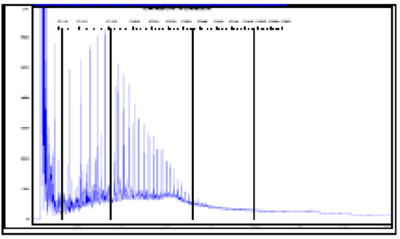
Winter Diesel



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+

Quality Control

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

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

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Methodology and Notes

Bill To:	InnoTech Alberta Inc. 1 Oil Path Dr. Devon, AB, Canada T9G 1A8	Project ID:	33910453.3001	Lot ID:	**1412099**
		Project Name:	PTAC F2	Control Number:	
		Project Location:		Date Received:	Mar 6, 2020
		LSD:		Date Reported:	Apr 27, 2020
Attn:	Allan Mah	P.O.:		Report Number:	2509552
Sampled By:	Victor Bachmann	Proj. Acct. code:	33910453.3001		
Company:	Innotech Alberta				

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

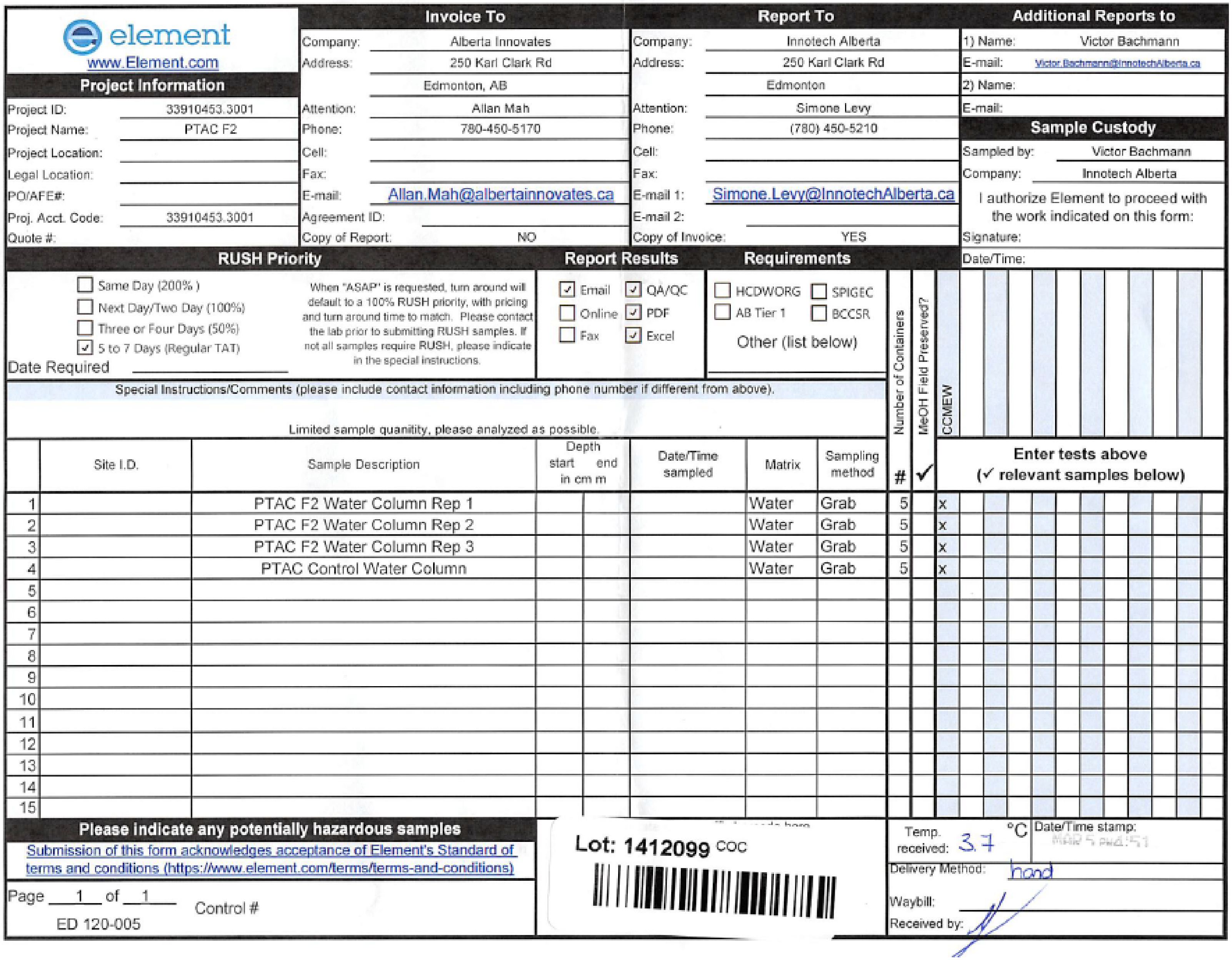
** Reference Method Modified*

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.



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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
Address: 250 Karl Clark Rd
Edmonton, AB
Attention: Allan Mah
Phone: 780-450-5170
Cell:
Fax:
E-mail: Allan.Mah@albertainnovates.ca
Agreement ID:
Copy of Report: NO

Report To

Company: Innotech Alberta
Address: 250 Karl Clark Rd
Edmonton
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: 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 in cm m	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: F2 MANAGEMENT LIMITS FOR TRENCH WORKER SCENARIO CALCULATION

Appendix B – F2 Management Limits for Trench Worker Scenario Calculation

Table of Contents

Page

List of Tables

1.0 PURPOSE

This Appendix provides the details of the calculations for the PHC F2 management limit component for the Trench Worker Scenario.

2.0 SCOPE OF CALCULATIONS

The scope of the calculations in this Appendix is to answer the two questions posed in Section 3.5 of the main text:

- What F2 management limit would prevent trench vapour concentrations of any F2 sub-fraction exceeding appropriate inhalation thresholds when the separation distance between impacted soil and trench is 30 cm?
- What minimum separation distance is required such that calculated F2 management limits are not limited by the Trench Worker Scenario?

3.0 CALCULATIONS

3.1 The VDEQ Model

The calculations in this Appendix use the equations from the Virginia Department of Environmental Quality (VDEQ, 2020) model. This is the same model used in the original calculations for the Trench Worker Scenario in CCME (2008). The VDEQ model for the Trench Worker Scenario is substantially unchanged since the 2005 version that was used by CCME (2008).

The VDEQ model is found in Appendix A2 of VDEQ (2020). Two versions of the model are available. Version 1 considers a shallow groundwater table intersecting the trench where contaminants volatilize directly from groundwater pooling in the base of the trench. Version 2 considers groundwater that is below the base of the trench, and contaminant vapour diffuse from the groundwater surface to the trench. Version 2 is used in this Appendix. The model is generated for a contaminated groundwater source, but it can easily be adapted to account for a soil or soil vapour source. The model works equally well for a lateral or vertical separation between source and trench.

3.2 Model Equations

The VDEQ model is written in terms of a "volatilization factor" VF. The volatilization factor is the ratio between source concentration and trench concentration and as such is equivalent to the (inverse of the) DF1 to DF4 "dilution factors" in the Tier 1 groundwater models (AEP, 2019).

The equations for the VDEQ model are presented below. Some parameter names and units have been adjusted for consistency with the terminology and units used in the Tier 1 guidelines (AEP, 2019), and the equations have been adjusted for a soil vapour, rather than groundwater source.

$$C_{trench} = C_{sv} \times VF$$

Where:

C_{trench} = vapour concentration of contaminant in trench (mg/m^3)

C_{sv} = soil vapour concentration of contaminant at source (mg/m^3)

VF = volatilization factor (-)

$$VF = \frac{D_a \times \theta_a^{3.33} \times A \times F \times 3{,}600}{\theta_t^2 \times L_d \times ACH \times V}$$

Where:

D_a = diffusion coefficient in air for contaminant (cm^2/s)

θ_a = soil vapour-filled porosity (-)

A = surface area of trench (cm^2)

F = fraction of trench surface area through which contaminant can enter (-)

3,600 = conversion factor (seconds/hour)

θ_t = soil total porosity (-)

L_d = vertical or lateral distance between trench and contaminant (cm)

ACH = trench air exchange rate (exch/hour)

V = trench volume (cm^3)

3.3 Equilibrium F2 Sub-Fraction Vapour Concentrations

The management limits for the Trench Worker Scenario in the original CCME (2008) document were calculated by assuming standard equilibrium partitioning to calculate soil vapour concentrations from soil concentrations. The current project was able to remove some uncertainty from this process by measuring the equilibrium vapour concentrations of F2 sub-fractions in equilibrium with F2 spiked into coarse and fine soil at approximately 10,000 mg/kg. Complete data are available in Appendix A, and the measured values for soil and vapour concentrations (average of 3 replicates) are summarized in Table B-1.

Table B-1 Measured Equilibrium Headspace Concentrations for F2 Sub-Fractions

Parameter	Unit	Coarse Soil	Fine Soil
Soil Concentrations			
Total F2	mg/kg	9,393	13,167
Vapour Concentrations			
Total F2	mg/m^3	1023	930
Aliphatic $C_{10} – C_{12}$	mg/m^3	599	520
Aromatic $C_{10} – C_{12}$	mg/m^3	314	291
Aliphatic $C_{12} – C_{16}$	mg/m^3	55	61
Aromatic $C_{12} – C_{16}$	mg/m^3	55	58

Notes:
Data from InnoTech (2020)
All values in this table represent the average of 3 measured values.
Average soil moisture content: coarse soil 1.43%, fine soil 14.23%

The relationship between soil and vapour concentrations is assumed to be linear, so for example if the total F2 soil concentrations in Table B-1 were doubled, it is assumed that the corresponding F2 sub-fraction vapour concentrations would also be doubled.

3.4 Model Parameter Values

The non-chemical specific parameters used in the model are summarized in Table B-2 and discussed below.

Table B-2 Model Parameter Values

Parameter	Symbol	Unit	Coarse Soil	Fine Soil	Rationale
Air diffusion coefficient	D_a	cm^2/s	0.05	0.05	AEP (2019) default
Soil vapour-filled porosity	θ_a	-	0.241	0.302	AEP (2019) default
Soil total porosity	θ_t	-	0.36	0.47	AEP (2019) default
Contaminant-trench distance	L_d	cm	30	30	VDEP (2020) default
Trench depth	D	cm	457	457	VDEP (2020) default
Trench width	W	cm	91	91	VDEP (2020) default
Trench length	L	cm	244	244	VDEP (2020) default

Table B-2 Model Parameter Values

Parameter	Symbol	Unit	Coarse Soil	Fine Soil	Rationale
Fraction of trench surface area	F	-	1	1	VDEP (2020) default
Trench surface area	A	cm^2	245,220	245,220	calculated
Trench volume	V	cm^3	10,147,228	10,147,228	calculated
Trench air exchange rate	ACH	exch/hr	46	46	See Section 3.3 in main text

Air diffusion coefficient is a chemical-specific parameter, however, the Alberta Tier 1 (AEP 2019) default value is the same for all F2 sub-fractions (0.05 cm^2/s).

Soil porosity values are adopted without change from the Alberta Tier 1 default values (AEP 2019).

Trench dimensions are VDEP default values for the scenario where the source is separated from the trench. Note that the trench length is arbitrary in that it has no affect on the calculations. The trench surface area is assumed to be the total area of trench base plus side walls.

The trench air exchange rate was adopted from the Thompson *et al*. (2017) empirical study on trench air exchange rates as discussed in Section 3.3 of the main text.

3.5 Trench Air Target Values

The Alberta Tier 1 guidelines document (AEP, 2019) provides inhalation tolerable concentrations (TCs) for each of the PHC F2 sub-fractions. These are concentrations considered acceptable for continuous 24/7 exposure over an entire lifetime. Consistent with the approach taken in the Tier 1 guideline calculation for indoor vapour inhalation, these tolerable concentrations are adjusted as follows to calculate a Trench Air Target. The tolerable concentration values are:

- multiplied by the soil allocation factor (SAF; 0.5 for all F2 sub-fractions; AEP, 2019) to allow for exposure *via* other contaminated media; and
- divided by the commercial/industrial exposure term (ET; 0.2747; AEP, 2019) to adjust for occupational exposure (8 hours/day, 6 days/week, 50 weeks/year).

The AEP (2019) TC values for each of the F2 sub-fractions and the calculated Trench Air Target values are summarized in Table B-3.

Table B-3 Tolerable Concentrations and Adjusted Inhalation Thresholds

		Aliphatic		Aromatic	
Parameter	**Unit**	**C_{10}-C_{12}**	**C_{12}-C_{16}**	**C_{10}-C_{12}**	**C_{12}-C_{16}**
Tolerable concentration (TC)	mg/m^3	1.0	1.0	0.2	0.2
Soil allocation factor (SAF)	-	0.5	0.5	0.5	0.5
Exposure term (ET)	-	0.2747	0.2747	0.2747	0.2747
Trench Air Target (TAT)	mg/m^3	1.82	1.82	0.36	0.36

3.6 Management Limit Values

Management limit values were calculated as follows:

- The starting point of the calculation is an assumed input F2 concentration in soil ($F2_{assumed}$).
- The soil vapour concentrations of F2 sub-fractions corresponding to this (C_{sv}) were calculated by multiplying the appropriate measured sub-fraction vapour concentrations in Table B-1 by $F2_{assumed}$/ $F2_{measured}$ where $F2_{measured}$ is the measured F2 soil concentration for the appropriate soil texture in Table B-1.
- The corresponding trench concentration for each F2 sub-fraction is calculated using the model equation in Section 3.2 and the parameter values in Table B-2.
- The assumed input soil concentration of F2 is then adjusted to estimate the highest F2 soil concentration that does not result in the trench vapour concentration for any of the F2 sub-fractions exceeding the corresponding Trench Air Target in Table B-3. That value of F2 is then the calculated management limit for the scenario considered.

3.6.1 Management Limits for 30 cm Separation

In this scenario, the contaminant-trench distance, L_d is set at 30 cm, and the input value of $F2_{assumed}$ is adjusted to estimate the greatest F2 soil concentration that doesn't result in any of the predicted subfraction trench vapour concentrations exceeding their respective Trench Air Targets. The results of this scenario are provided below.

F2 Management Limits for 30 cm Separation between Source and Trench:

- Coarse soil management limit: 50,000 mg/kg
- Fine soil management limit: 40,000 mg/kg

3.6.2 Minimum Separation such that Trench Worker Scenario is not Limiting

The VDEQ model depends strongly on L_d, the distance between soil source and trench wall/base, and the value of 30 cm is somewhat arbitrary. It may therefore be more appropriate to ask the question: "with this model and assumptions, how small can the separation be between soil contamination and trench wall without the Trench Worker Scenario becoming limiting". Or to rephrase this question: "what is the separation distance that results in the F2 management limit being 10,000 mg/kg for fine soil and 9,000 mg/kg for coarse soil". These values, 10,000 mg/kg for fine soil and 9,000 mg/kg for coarse soil are the lowest of the management limits for other considerations (Table 1 in main text).

The results of this scenario are provided below.

Minimum Separation between Source and Trench such that Trench Worker Scenario is not Limiting:

- Coarse soil: minimum separation = 6 cm
- Fine soil: minimum separation = 8 cm

4.0 REFERENCES

Alberta Environment and Parks (AEP), 2019. Alberta Tier 1 *Soil and Groundwater Remediation Guidelines*. Land Policy Branch, Policy and Planning Division. 198 pp.

Canadian Council of Ministers of the Environment (CCME), 2008. Canada-Wide Standard for Petroleum Hydrocarbons (PHCs) in Soil: Scientific Rationale. Supporting Technical Document, January 2008.

InnoTech Alberta Inc. (InnoTech), 2020. Petroleum Hydrocarbon Fractions 2 and 3: Evaluation of Management Limits. Report dated May 1, 2020.

Thompson, S, Michalski, P., and Pruis, J., 2017. Empirical Study to Estimate the Air Exchange Rate Within a Trench for Modeling Inhalation Risks. Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies. Battelle Memorial Institute, Columbus, OH.

Virginia Department of Environmental Quality (VDEQ), 2020. Virginia Unified Risk Assessment Model – VURAM User Guide. Updated March 2020.