ntepa Northern Territory Environment Protection Authority

NOTICE TO CARRY OUT ENVIRONMENTAL AUDIT PROGRAM

(Issued pursuant to Section 48(1) of the *Waste Management and Pollution Control Act 1998*)

ISSUED TO:	One Rail Australia Pty Ltd ACN 079 444 296
OF:	Level 3, 33 Richmond Road KESWICK SA 5035

WHEREAS the Northern Territory Environment Protection Authority ("NT EPA") is satisfied for the reasons stated in **Attachment "A"** to this notice that you are a person required to carry out an Environmental Audit Program in relation to the Berrimah Rail Terminal, located at Section 5411 and Section 5641, Hundred of Bagot, as delineated in **blue** in **Attachment "C"** ("the premises") to evaluate:

(i) **the types, amount, distribution and mobility of contaminants and wastes present in the environment resulting from "the incident" as defined in Reason 4 of Attachment "A"; and**

(ii) **the extent to which actions are required to be taken, or results required to be achieved, for waste management or the prevention, reduction, control, rectification or clean-up of pollution or environmental harm resulting from pollution have been taken or achieved as a result of the incident.**

NOW TAKE NOTICE that you are required to comply with each of the requirements specified in **Attachment "B"** to this notice on and from the date of issue of this notice.

ISSUE DATE: 07/07/2021

[signature]

AMY DENNISON
EXECUTIVE DIRECTOR
ENVIRONMENTAL REGULATION
DELEGATE OF THE NT EPA

Important Notice

Failure to comply with this notice is an offence under Section 52 of the *Waste Management and Pollution Control Act 1998* and may incur significant penalties and/or other statutory action.

This notice takes effect on the date on which it is served upon you. Pursuant to Section 108 of the *Waste Management and Pollution Control Act 1998*, **you have the right to apply for a review of the decision to issue you with this Notice to carry out an Environmental Audit. If you intend to apply for a review, YOU MUST MAKE AN APPLICATION NOT LATER THAN 28 DAYS after the day on which this Notice of the decision was given.** For information on how to lodge an application for review, contact the Northern Territory Environment Protection Authority, telephone 8924 4041.

Pursuant to Section 112 of the *Waste Management and Pollution Control Act 1998* the person issued with this notice must fulfil certain obligations before selling, leasing, sub-leasing, giving or exchanging land, premises, a vehicle or business which is the subject of this Notice.

ATTACHMENT "A"

REASONS FOR ISSUING THIS NOTICE

1. One Rail Australia Pty Ltd (One Rail) occupies and controls Section 5411 and Section 5461, Hundred of Bagot, also known as the Berrimah Rail Terminal, and located off Export Drive, Berrimah as delineated in blue in **Attachment "C"** ("the premises");

2. One Rail provides a rail service to the freight forwarding and transportation industry and transports containers that may contain listed waste via rail, between terminals in South Australia and the Northern Territory;

3. One Rail holds Environmental Protection Licence (EPL222) for the transport of listed wastes on a commercial or fee for service basis;

4. On 30 May 2020 at 9:30am, approximately 20,000 litres of diesel was released to the environment during the fuelling of a locomotive at the premises ("the incident");

5. The approximate location of the incident referred to in 4 above is designated by the green highlighted area in **Attachment "D"**;

6. On 12 June 2020, One Rail submitted a report to the NT EPA titled *Berrimah Fuel Spill May 2020*, which detailed the actions taken in response to the incident and states:

   (a) Upon discovery of the spill, immediate spill control measures were implemented including excavation of makeshift bunds and installation of shallow sumps to collect free product under the supervision of environmental consultants "Greencap";

   (b) Approximately 4,500 litres of diesel was recovered during the immediate spill response;

   (c) Following the spill response an Interim Remedial Action Plan (RAP) was prepared to guide impact delineation works;

   (d) Approximately 400 tonnes of diesel impacted soils were excavated and stockpiled at the premises for future management;

   (e) Daily monitoring of the mangroves offsite was undertaken to determine the extent of any impacts; and

   (f) Any residual impacts were to be managed via the implementation of an updated RAP;

7. On 28 May 2021, One Rail submitted a report to the NT EPA titled *Detailed Site Investigation Report Final April 2021* ("The DSI Report") which details the investigation and remedial works undertaken by Greencap in response to the incident, including:

   (a) Excavation and stockpiling of an additional 345 m^3 of diesel impacted soils at the premises;

   (b) A soil investigation to delineate the extent and mobility of in situ diesel impacted soils;

(c) Validation sampling to determine whether all of the diesel impacted soil from the incident has been removed;

(d) Installation and sampling of 11 groundwater monitoring wells; and

(e) Mass balance calculations to determine the extent of diesel impacts in the remaining in situ soils;

8. The DSI Report estimated approximately 18,000 litres of diesel had been recovered during remedial works (as either free phase product or as impacted soils), resulting in approximately 2,000 litres of diesel remaining in situ at the premises;

9. The DSI Report identified Light Non-Aqueous Phase Liquid (LNAPL) impacts within one groundwater monitoring well adjacent the incident location;

10. On 4 February 2021, NT EPA officers attended the premises ("the inspection") and observed:

    a. An area of new ballast placed across the incident location, understood to have been a result of remedial works referred to in **8** above.

    b. A stockpile of soil (excavated as part of the incident response and remediation) that was uncovered, unsecured and positioned approximately 10 metres south of an earthen stormwater drain, that flows beyond the boundary of the premises into the surrounding mangroves, as shown in **Attachment "D"**;

    c. A hydrocarbon-like sheen seeping from the stockpile into adjacent soils and stagnant surface water (photos are provided in **Attachment "E"**); and

    d. A hydrocarbon-like sheen within the adjacent earthen stormwater drain (photos are provided in **Attachment "E")**;

11. During the investigation, NT EPA officers obtained a copy of the stormwater drainage plan for the premises, provided in **Attachment "F"**;

12. The stormwater drainage plan for the premises, referred to in **11** above, indicates that the earthen stormwater drain collects surface water before discharging into the mangrove community beyond the northern boundary of the premises;

13. During the inspection NT EPA officers collected soil samples from the stockpile and adjacent ground surfaces, and a surface water sample from the stagnant surface water pools down gradient of the stockpile;

14. The location of collected samples, referred to in **13** above, are shown in **pink** in **Attachment "G"** and laboratory analytical results, provided in **Attachment "H"** show that:

    a. The soil sample collected from the stockpiled soil associated with the incident contained very high levels of diesel;

    b. The soil sample collected from the ground surface adjacent to the stockpile contained high levels of diesel; and

    c. The surface water sample collected from the stagnant surface water pools down gradient of the stockpile, and adjacent the earthen stormwater drain contained diesel;

15. Diesel is categorised as a heavy end hydrocarbon and typically contains saturated hydrocarbons (e.g. paraffin) and aromatic hydrocarbons (e.g. naphthalene);

16. Diesel and diesel contaminated soil resulting from the pollution incident, that occurred at the premises on 30 May 2020, is defined as a contaminant and as a waste pursuant to section 4 the *Waste Management and Pollution Control Act 1998* (the Act);

17. Hydrocarbons have the potential to kill or inhibit microbial species and reduce water/nutrient uptake by plants which can result in toxicity to some plant species and impaired ecosystem functioning[1];

18. Human health may also be impacted as a result of hydrocarbon contamination whereby impacts migrate into surface/groundwater used for consumption[2];

19. The incident has impacted soil and has potentially impacted nearby water environments;

20. An evaluation of the suitability of the management of the contaminated soil stockpile at the premises is required to ensure that it is not causing pollution and environmental harm; and

21. An evaluation of the effectiveness of prevention, reduction, control, rectification or clean up measures implemented following the incident, which resulted in pollution and environmental harm, is required to inform any additional actions to prevent further pollution or environmental harm.

[1] Truskewycz A, Gundry TD, Khudur LS, et al. *Petroleum Hydrocarbon Contamination in Terrestrial Ecosystems-Fate and Microbial Responses* in Molecules. (2019), accessed via: Petroleum Hydrocarbon Contamination in Terrestrial Ecosystems—Fate and Microbial Responses (nih.gov)

[2] Kuppusamy S., Maddela N.R., Megharaj M., Venkateswarlu K. (2020) I*mpact of Total Petroleum Hydrocarbons on Human Health* in Total Petroleum Hydrocarbons pp 139-165, Springer, Cham. Accessed via Petroleum Hydrocarbon Contamination in Terrestrial Ecosystems—Fate and Microbial Responses (nih.gov).

ATTACHMENT "B"

NOTICE REQUIREMENTS

1. The environmental audit program (the program) must be performed by *a* person registered under section 68 of the *Waste Management and Pollution Control Act 1998* (the Act), in this case an environmental auditor specifically accredited under the New South Wales or Victorian auditor accreditation schemes;

2. Within one month from the date of issue of this notice you must engage the environmental auditor referred to in requirement 1 above;

3. Within two months from the date of issue of this notice you must submit a scope of works for the program to the NT EPA for consideration;

4. Within six months from the date of issue of this notice you must submit an **Environmental Audit Report** prepared by the person referred to in requirement 1 above;

5. The **Environmental Audit Report** referred to in requirement 4 above must relate to the risk of any possible harm or detriment to the land, surface water and groundwater environments caused by the incident at the premises, as determined by:

   (a) review of any monitoring programs, data, records, reports or other information relevant to the scope of the audit; and

   (b) collection and/or modelling of any data as the auditor sees fit;

9. The **Environmental Audit Report** referred to in requirement 4 must:

   (a) indicate if the incident which occurred at the premises has caused a risk of any possible harm or detriment to the land, surface water and groundwater environments;

   (b) where a risk of any possible harm or detriment to a segment of the environment has been determined in 9(a) recommend any measures necessary to reduce the risk to an acceptable level; and

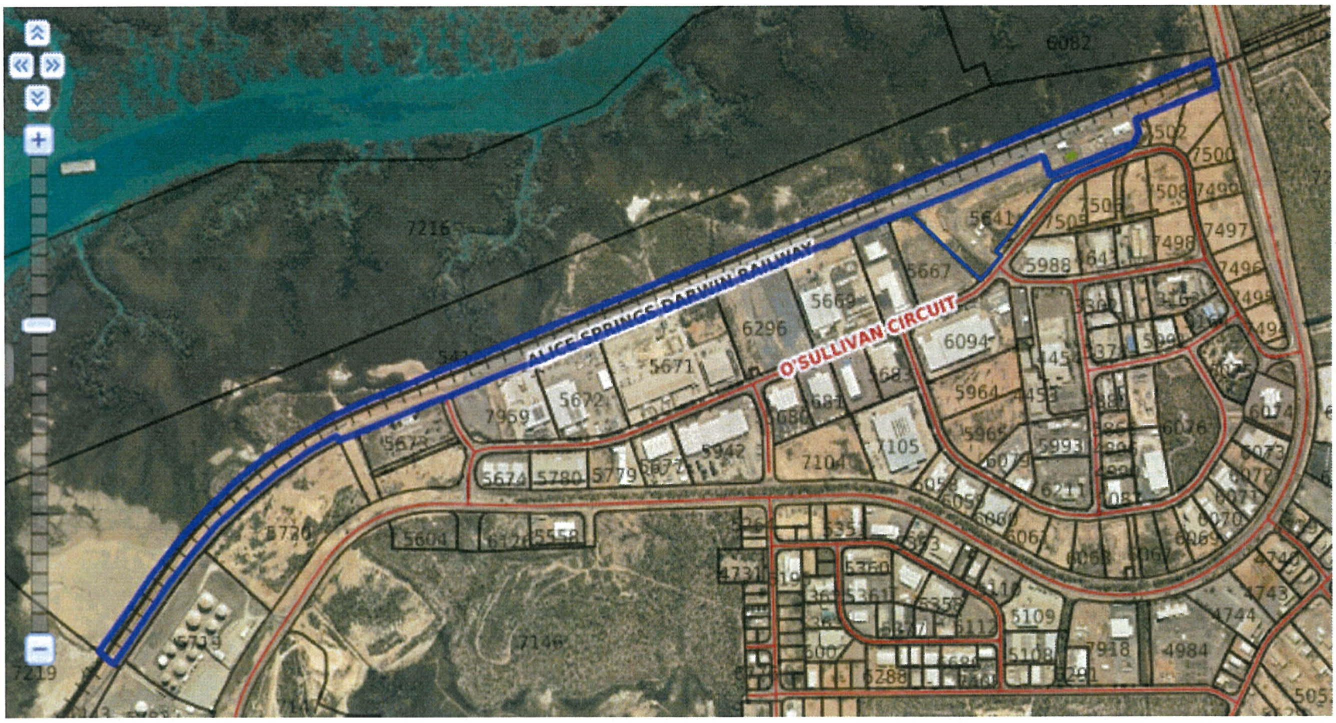
   (c) include an indicative implementation timetable for any recommended clean-up and/or management works referred to in requirement 9(b); and

10. The program must relate to the activities, processes and operations associated with the incident undertaken by or for One Rail at the premises.

ATTACHMENT "C"

"THE PREMISES"

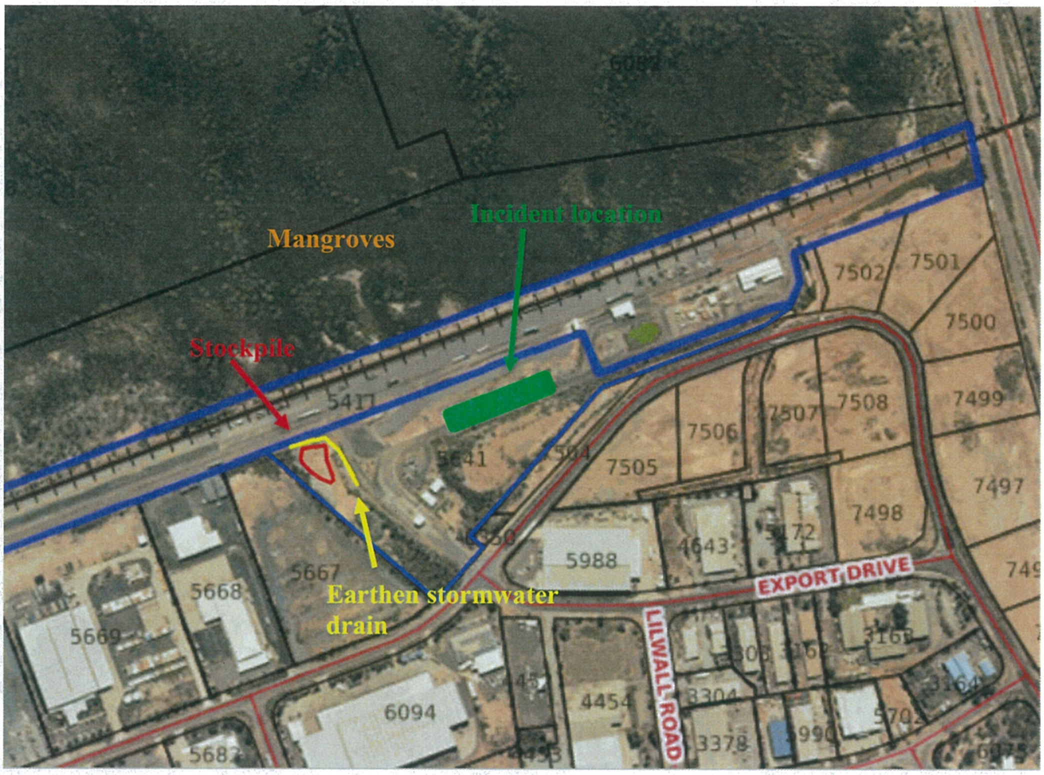
SITE LOCATION AND PROPERTY BOUNDARY (DELINEATED IN BLUE)



ATTACHMENT “D”

INSPECTION AREA

SITE EXTENT WITH APPROXIMATE LOCATION OF THE INCIDENT AND ASSOCIATED STOCKPILE AND EARTHEN STORMWATER CHANNEL



ATTACHMENT "E"

PHOTOGRAPHS

Photograph 1: *Stockpiled material facing east. Stockpile is uncovered with no erosion or sediment controls in place.*

Photograph 2: *Stockpiled material facing west. Earthen stormwater drain visible on far right of image, flowing west.*

Photograph 3: *Stockpiled material facing south. Visible hydrocarbon-like sheen leaching out of stockpile and pooling in surface water adjacent the stockpile.*

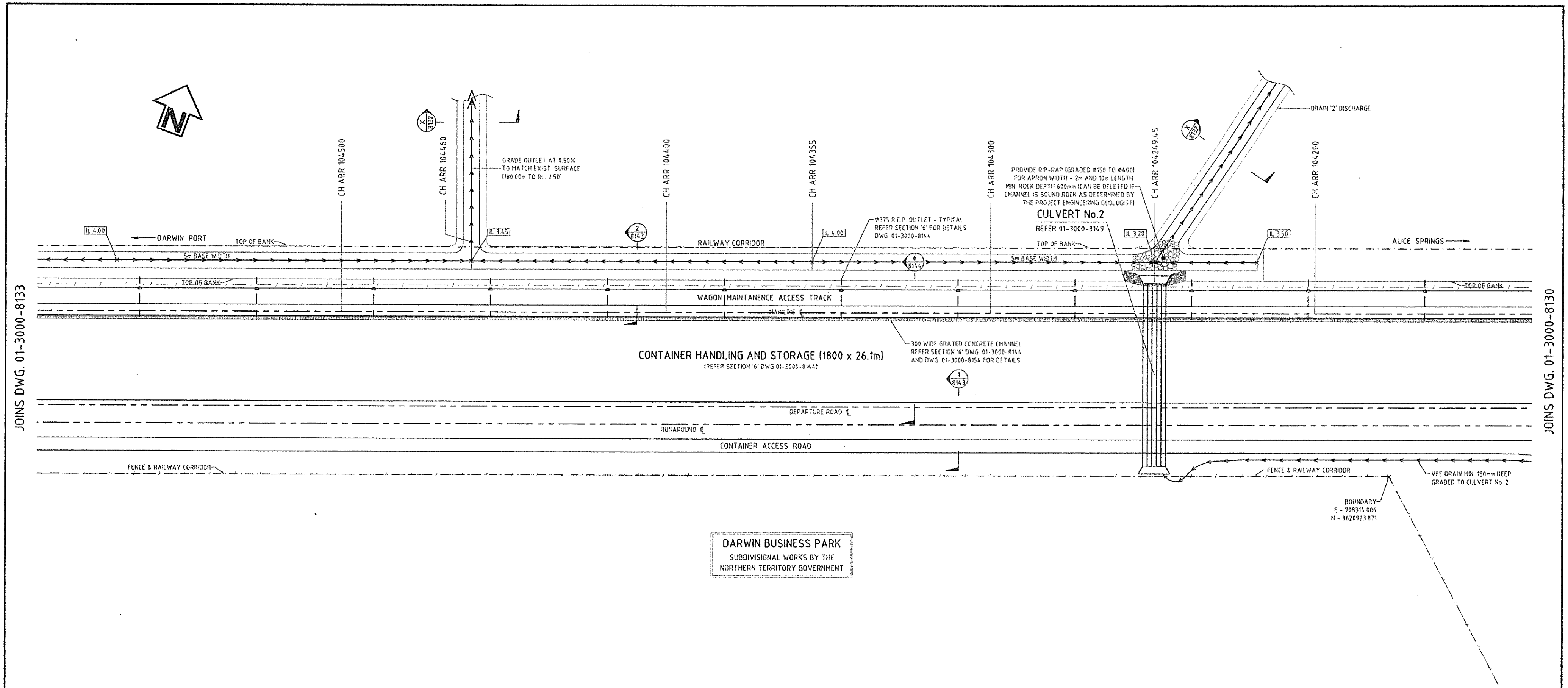
Photograph 4: *Visible hydrocarbon-like sheen atop ground surfaces and pooling in surface water adjacent stockpile.*

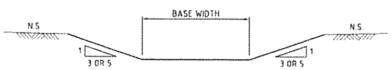
Photograph 5: *Earthen stormwater drain located north of the stockpile. Visible hydrocarbon-like sheen visible in water and on surrounding ground surfaces.*

Photograph 6: *Earthen stormwater drain located north of the stockpile. Visible hydrocarbon-like sheen visible in water and on surrounding ground surfaces.*

ATTACHMENT "F"

FACILITY DRAINAGE MAP





SECTION X-X

N.T.S

NOTE

GRADE BASE AT 1:200 TO DAYLIGHT BY SHORTEST ROUTE
SIDE SLOPES = 1:3 WHERE N.S. RL > 3.00m
SIDE SLOPES = 1:5 WHERE N.S. RL < 3.00m
BASE WIDTH = 5.0M AT CHN 104460.00
BASE WIDTH = 10.0M AT CHN 104249.45

LEGEND

- RAILWAY CORRIDOR BOUNDARY
- CHAIN MESH FENCE
- RAILWAY TRACK CENTRELINE
- OPEN DRAIN CENTRELINE
- U.G. DRAINAGE PIPE

NOTES

1. ALL VEE DRAINS TO BE CUT TO 1 ON 4 BATTERS
2. REFER DWG Nos. 01-3000-8143, 8145 & 8156 FOR TYPICAL SECTIONS
3. CULVERT SETOUT COORDINATES SHOWN ARE TO THE FACE OF THE HEADWALL UNITS AND CENTRELINE ON THE CULVERT STRUCTURE
4. CULVERT SETOUT CHAINAGES SHOWN ARE TO THE CENTRELINE OF THE CULVERT STRUCTURE AND RELEVANT OFFSETS ARE FROM THE MAINLINE CENTRELINE TO THE FACE OF THE CULVERT HEADWALL UNITS
5. ALL REINFORCED CONCRETE PIPES SHALL BE 375mm DIA U.N.O., CLASS 4 WITH HS3 SUPPORT CONDITIONS TO AS 3725
6. REFER TO DWG Nos. 01-3000-8149, 8152 & 8153 FOR REINFORCED BOX CULVERT ARRANGEMENT DETAILS/WINGWALL DETAILS
7. REFER DWG No. 01-3000-8144 FOR GRATED INLET & FIELD INLET DETAILS
8. COORDINATES TO MGA94 ZONE 52

NOTE: FOR COMPLETE INFORMATION THIS DRAWING SHOULD BE READ IN CONJUNCTION WITH PROJECT QUALITY ASSURANCE AND CONSTRUCTION RECORDS (AB)

0 10 20 30 40 50
SCALE 1:500

FINAL DESIGN DOCUMENTATION

B1	
CAD FILE	01-3000-8132.dwg
REFERENCE FILES	see above
PLOT SCALE	1:1
SCALES USED	1:500

DRAWING INDEX

100 MILLIMETRES ON ORIGINAL DRAWING

REVISIONS AND ISSUES

CODE	DATE	DESCRIPTION	DA	PA
AB	08.09.03	FINAL DESIGN DOCUMENTATION	CWD	CWD
6	31.07.03	5m WIDE OPEN DRAIN (STH) DELETED, VEE DRAIN ADDED AND FENCE MOVED TO BOUNDARY	CWD	CWD
5	23.04.03	CONTAINER PAVEM'T PIPE SIZE CHANGED TO 375mm AND NOTES ADDED/AMENDED	CWD	CWD
4	08.02.03	NORTHERN FENCE AMENDED. CONTAINER PAVEMENT DETAILS AMENDED. DRAINAGE DETAIL DELETED	CWD	CWD

REVISIONS AND ISSUES

CODE	DATE	DESCRIPTION	DA	PA
3	23.01.03	APPROVED FOR CONSTRUCTION	CWD	CWD
2	13.12.02	TOP OF BANK/DRAIN MOVED NTH 18m, PRECAST RCP OUTLETS DELETED. RIP-RAP, ROCK PROTECT. ADDED RIP-RAP, EDGE STRIP ADDED, INV. LEVELS CHANGED, PIPE END DETAIL 'A' ADDED	C.W.D.	C.W.D.
1	12.11.02	ISSUED FOR AUTHORITY APPROVAL ROADWORKS DETAILS REMOVED. VARIOUS DRAINAGE DETAILS AMENDED	C.W.D.	C.W.D.
0	13.06.02	ADRAIL APPROVED FOR SUBMISSION TO PRINCIPAL	C.W.D.	C.W.D.

		DATE
DESIGNER	T.C.	13.06.02
DRAFTER	M.L.	13.06.02
DESIGN CHECKER	D.B.	13.06.02
DRAFTING CHECKER	G.S.C.	13.06.02
DESIGN APPROVAL	C.W.D.	13.06.02
QUALITY CHECK	G.J.H.	13.06.02
PROJECT APPROVAL	C.W.D.	13.06.02
PRINCIPAL APPROVAL	A.P.T.C.	15.01.03

ADrail

- Brown & Root Construction Pty Ltd ABN 84 094 542 533
- Barclay Mowlem Construction Limited ABN 36 009 830 460
- Macmahon Contractors Pty Ltd ABN 37 007 611 485
- John Holland Pty Ltd ABN 11 004 282 268

ALICE SPRINGS - DARWIN RAILWAY PROJECT

BERRIMAH FREIGHT TERMINAL DRAINAGE SHEET 4 OF 7

DRAWING NUMBER: 01-3000-8132

REVISION CODE: AB

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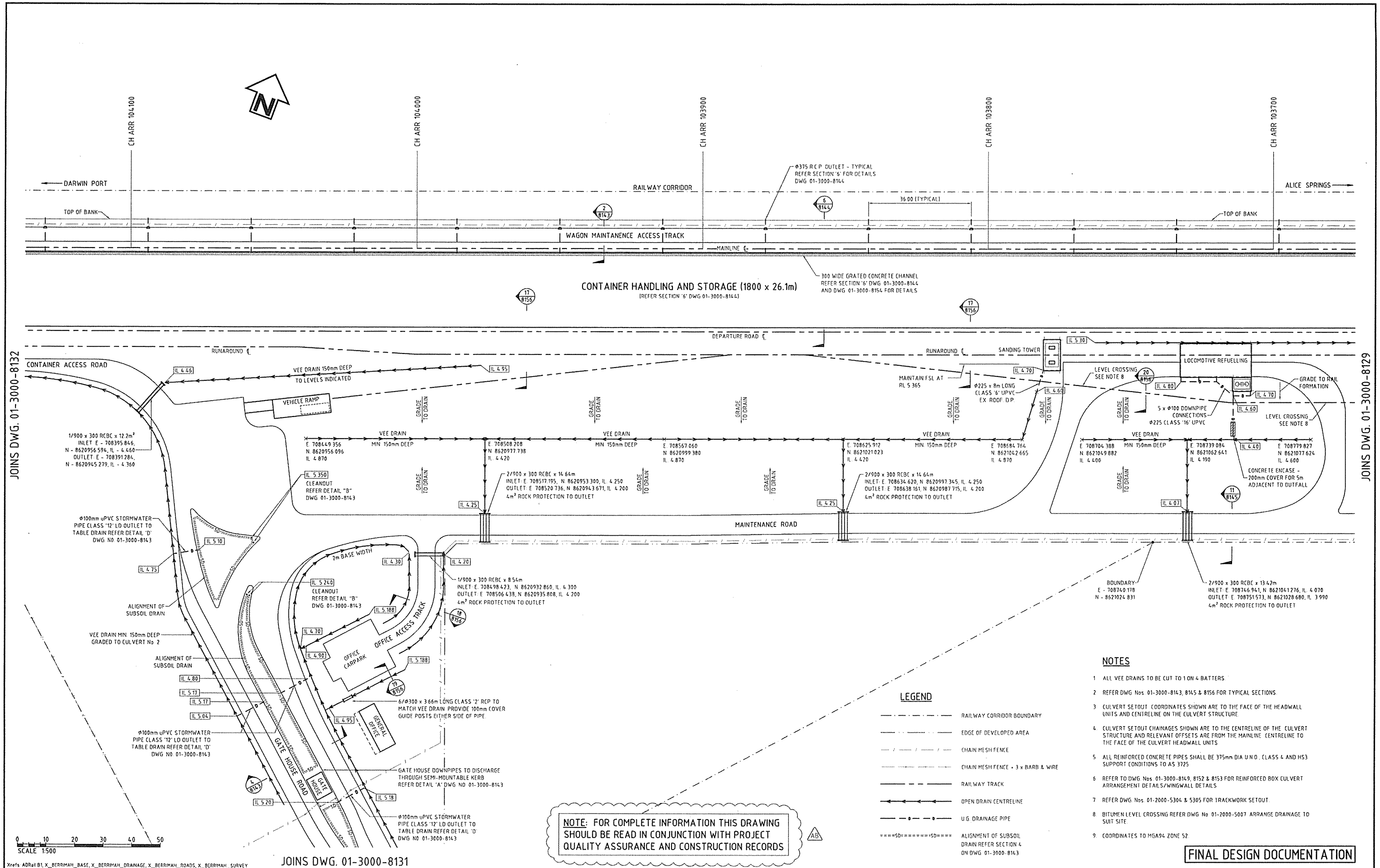

NOTE: FOR COMPLETE INFORMATION THIS DRAWING SHOULD BE READ IN CONJUNCTION WITH PROJECT QUALITY ASSURANCE AND CONSTRUCTION RECORDS

LEGEND

- RAILWAY CORRIDOR BOUNDARY
- EDGE OF DEVELOPED AREA
- CHAIN MESH FENCE
- CHAIN MESH FENCE + 3 x BARB & WIRE
- RAILWAY TRACK
- OPEN DRAIN CENTRELINE
- U.G. DRAINAGE PIPE
- ALIGNMENT OF SUBSOIL DRAIN REFER SECTION 4 ON DWG 01-3000-8143

NOTES

1. ALL VEE DRAINS TO BE CUT TO 1 ON 4 BATTERS.
2. REFER DWG Nos. 01-3000-8143, 8145 & 8156 FOR TYPICAL SECTIONS.
3. CULVERT SETOUT COORDINATES SHOWN ARE TO THE FACE OF THE HEADWALL UNITS AND CENTRELINE ON THE CULVERT STRUCTURE.
4. CULVERT SETOUT CHAINAGES SHOWN ARE TO THE CENTRELINE OF THE CULVERT STRUCTURE AND RELEVANT OFFSETS ARE FROM THE MAINLINE CENTRELINE TO THE FACE OF THE CULVERT HEADWALL UNITS.
5. ALL REINFORCED CONCRETE PIPES SHALL BE 375mm DIA U.N.O., CLASS 4 AND HS3 SUPPORT CONDITIONS TO AS 3725.
6. REFER TO DWG Nos. 01-3000-8149, 8152 & 8153 FOR REINFORCED BOX CULVERT ARRANGEMENT DETAILS/WINGWALL DETAILS.
7. REFER DWG Nos. 01-2000-5304 & 5305 FOR TRACKWORK SETOUT.
8. BITUMEN LEVEL CROSSING REFER DWG No. 01-2000-5007. ARRANGE DRAINAGE TO SUIT SITE.
9. COORDINATES TO MGA94 ZONE 52.

Xrefs: ADRail B1, X_BERRIMAH_BASE, X_BERRIMAH_DRAINAGE, X_BERRIMAH_ROADS, X_BERRIMAH_SURVEY

100 MILLIMETRES ON ORIGINAL DRAWING

B1	
CAD FILE	01-3000-8131.dwg
REFERENCE FILES	see above
PLOT SCALE	1:1
SCALES USED	1:500

DRAWING INDEX

CODE	DATE	DESCRIPTION	DA	PA
AB	08.09.03	FINAL DESIGN DOCUMENTATION	CWD	CWD
6	31.07.03	5m WIDE OPEN DRAIN DELETED, VEE DRAIN ADDED	CWD	CWD
5	23.04.03	CONTAINER PAVEMENT PIPE SIZE CHANGED TO 375mm AND NOTES AMENDED	CWD	CWD

REVISIONS AND ISSUES

CODE	DATE	DESCRIPTION	DA	PA
4	08.02.03	CONTAINER PAVEMENT & NORTHERN FENCE AMENDED, SOUTHERN BDY COORD'S CORRECTED NOTES AMENDED	CWD	CWD
3	23.01.03	APPROVED FOR CONSTRUCTION. TOP OF BANK MOVED NORTH 18m, PRECAST RCP OUTLETS DELETED, ROCK PROT. INCREASED TO 4m	CWD	CWD
2	13.12.02	DRAIN, GRADING NOTES & CONC EDGE STRIP ADDED	CWD	CWD
1	12.11.02	ISSUED FOR AUTHORITY APPROVAL. ROADWORKS DETAILS REMOVED. VARIOUS DRAINAGE DETAILS AMENDED	CWD	CWD
0	13.06.02	ADRAIL APPROVED FOR SUBMISSION TO PRINCIPAL	CWD	CWD

REVISIONS AND ISSUES

		DATE
DESIGNER	T.C.	13.06.02
DRAFTER	M.L.	13.06.02
DESIGN CHECKER	D.B.	13.06.02
DRAFTING CHECKER	G.S.C.	13.06.02
DESIGN APPROVAL	C.W.D.	13.06.02
QUALITY CHECK	G.J.H.	13.06.02
PROJECT APPROVAL	C.W.D.	13.06.02
PRINCIPAL APPROVAL	A.P.T.C.	15.01.03

ADrail

- Brown & Root Construction Pty Ltd ABN 84 094 542 533
- Barclay Mowlem Construction Limited ABN 36 009 830 460
- Macmahon Contractors Pty Ltd ABN 37 007 611 485
- John Holland Pty Ltd ABN 11 004 282 268

FINAL DESIGN DOCUMENTATION

ALICE SPRINGS - DARWIN RAILWAY PROJECT

BERRIMAH FREIGHT TERMINAL
DRAINAGE
SHEET 2 OF 7

DRAWING NUMBER: 01-3000-8130

REVISION CODE: AB

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ATTACHMENT "G"

INVESTIGATION AREA
APPROXIMATE LOCATION OF STOCKPILE, EARTHEN STORMWATER DRAIN AND COLLECTED SAMPLE LOCATIONS

ATTACHMENT "H"

LABORATORY ANALYTICAL RESULTS

Client Project: Berrimah Rail Terminal – PRL9059
Client Ref: NTEPA2020/0007-193
Ref: 20S3454
Contact: Leif Cooper
Phone: +61 (0)8 9422 9933

Claudia Bennett
Department of Environment and Natural Resources
Level 1, Arnhemica House, 16 Parap Road
Parap, NT 0820

REPORT ON THE ANALYSIS OF SPILLED HYDROCARBONS

5-May-2021

INTRODUCTION

ChemCentre received six samples from the Department of Environment and Natural Resources on 18 February 2021. The Chain-of-Custody document accompanying the samples provided details of the six samples (see Appendix 1).

Photographs of all the samples were taken and are included in Appendix 2.

NT EPA requested ChemCentre analyse the samples together with a diesel reference sample (previously supplied on 31 July 2020) to determine if the hydrocarbon content of the samples was related.

SUMMARY

The samples were compared to each other using the method CEN/TR 15522-2, with analysis conducted by gas chromatography–flame ionisation detector (GC-FID) and gas chromatography–mass spectrometer (GC-MS).

Two of the samples contained soil with significant amounts of diesel fuel. One sample contained mainly water with a trace amount of diesel. The remaining samples (two waters, one soil) did not contain significant amounts of any hydrocarbon.

Percent weathering plots of the three samples containing diesel (comparing them to each other) showed that the samples have different degrees of weathering, with the two soil samples showing evaporation, and the water sample also showing significant evaporation and water-washing effects.

The diagnostic ratios of the two soil samples show they come from the same source as the reference diesel, where differences in the chromatographic patterns and/or diagnostic ratios of samples are lower than the variability of the method or can be explained as being the result of expected weathering processes. The degradation of hydrocarbons in the water sample meant that any match with the other samples was inconclusive.

CONTENTS

SAMPLE IDENTIFICATION

The samples were assigned a unique laboratory identification number (see Table 1). Note: Sample 20S3454/002 (BRT-01) was described as having the following containers "1 x Jar, 2 x bottles, 2 x vials" of "Soil and Liquid". Only one jar of soil was received by ChemCentre personnel for this sample, as annotated on the Chain of custody (no bottles/liquid).

A reference diesel was also analysed. This reference diesel was previously provided by NT EPA (from the same sample location) and was initially analysed in report 20S0458_R0.

Table 1

ChemCentre Lab No	Client Sample ID	Description	Date sampled	Date received
20S3454/001	BRT-SP01	Soil (one jar)	4/02/2021	18/02/2021
20S3454/002	BRT-01	Soil (one jar)	4/02/2021	18/02/2021
20S3454/003	BRT-03	Liquid (two bottles and two vials)	4/02/2021	18/02/2021
20S3454/004	BRT-08	Liquid (two bottles and two vials)	4/02/2021	18/02/2021
20S3454/005	BRT-09	Soil (one jar)	4/02/2021	18/02/2021
20S3454/006	BRT-09	Liquid (two bottles and two vials)	4/02/2021	18/02/2021
20S0458/001	BTY 5	Vial of diesel (reference)	30/05/2020	31/07/2020

ANALYSIS

Each of the soil samples, 20S3454/001, 002, and 005, were extracted by sub-sampling 10 g into a vial, adding 20 mL of dichloromethane (DCM) : acetone (1:1) along with the addition of sodium sulfate. The samples were then sonicated for 30 minutes, and a portion of this extract was subsampled for analysis.

Samples 20S3454/003, 004, and 006 were primarily water. These samples were extracted with DCM and the extract dried with sodium sulfate and placed into vials for analysis.

The diesel reference sample 20S0458/001 was diluted in DCM and vialled for analysis.

The water and soil extracts were analysed by GC-FID and the total hydrocarbon content was calculated.

Selected extracts were then further analysed along with the diesel reference sample, using GC-MS to identify individual compounds in the sample.

WEATHERING

When oil is spilled and exposed to the environment, the chemical properties of the oil begin to change. Several factors such as evaporation, water washing, photo-oxidation and microbial degradation alter the oil's chemical characteristics. These processes are termed "weathering" and can confound oil spill identification if not properly understood, as they create differences between an oil spill sample and a suspected source sample. Generally, the most important effect on an oil spill is evaporation, as significant losses of the more volatile components of an oil (less than C_{14}) occur within hours of exposure to the environment. Other processes may take place over months or years. Annex G of CEN/TR 15522-2 summarises the weathering processes and their effects on an oil's composition, including evaporation, dissolution, re-distribution, biodegradation, and photooxidation.

FINGERPRINTING

The basis of oil spill identification is the detection of the oil's "fingerprint". This fingerprint is made up of several compounds, predominantly polycyclic aromatic hydrocarbons (PAHs) and biomarkers, whose relative concentrations to each other can be calculated and compared to positively match one oil sample to another. The CEN/TR 15522:2 method outlines several PAHs and biomarkers, in the following classes:

- n-alkanes
- branched alkanes, including isoprenoids (e.g. pristane and phytane)
- PAHs
- alkylated-PAHs
- bicyclic sesquiterpanes
- alkylbenzenes/toluenes
- adamantanes/diamantanes
- tricyclic diterpanes
- hopanes
- steranes and diasteranes
- triaromatic steroids

These compounds have low volatility and are water-insoluble, making them highly resistant to biodegradation and weathering. Many studies have shown that diagnostic ratios of compounds within these classes are stable, sometimes over long periods of time (Philp 1985, Leeder et al 1992, Douglas et al 1996).

METHOD CEN/TR 15522-2

The CEN/TR 15522-2 method builds on the earlier NordTest methodology (Daling et al, 2002), and uses Gas Chromatography (GC) to separate and identify the distribution of compounds that make up an oil. GC analysis is coupled with either a Flame Ionisation Detector (GC-FID), or with a Mass Spectrometer (GC-MS).

Gas Chromatography – Flame Ionisation Detection (GC-FID)

A tiered approach is taken to oil spill fingerprinting. The first tier is to screen each sample using GC-FID, which gives a chromatogram of the whole oil. This chromatogram will (usually) display a series of peaks representing the n-alkanes, which shows the boiling range of the oil, as well as the isoprenoid compounds pristane and phytane. At this stage, the chromatograms of the spill samples and the potential source samples are compared, and any obviously non-matching samples can be ruled out of further tiers of analysis. This comparison should consider the boiling range of the samples, and a weathering check of the compounds. It is important not to rule out a potential source based only on a difference in boiling ranges, without first considering if that difference could have been caused by evaporation of the lighter components of the spill sample. As well as the boiling range and weathering check, some biodegradation ratios can also be calculated (as ratios of n-alkanes and isoprenoids). These n-alkanes and isoprenoids can also be used to compare spill samples with potential source samples, particularly if the spill was relatively fresh and no significant biodegradation is expected.

Gas Chromatography – Mass Spectrometer (GC-MS)

The second tier of the CEN/TR 15522-2 method is analysis of the spill samples and the potential source samples by GC-MS. The mass spectrometer has the capability to scan the components coming out of the chromatograph at all ion ratios, which generates a total ion chromatograph (TIC). Alternatively, the spectrometer can operate in selected ion monitoring (SIM) mode. This will enhance the detection of the chosen fragmentation ions by detecting those ions for longer times. This capability allows the oil spill analyst to look specifically for those compounds that will yield the diagnostic ratios required to characterise an oil's "fingerprint". There are over 130 compounds recommended by the CEN/TR 15522-2 methodology that comprise a basic fingerprint, listed in Appendix 5.

Percent Weathering (PW) Plots and Diagnostic Ratios

The use of PW plots and diagnostic ratios for comparison of oil samples is based on both the GC-FID data of n-alkanes and isoprenoids and on GC-MS data of a suite of alkylated PAHs and petroleum biomarkers. Collectively, these targeted compounds provide a range of markers capable of monitoring different types of weathering and revealing "genetic" differences between oil from different origins and between different product (fuel) types. PW plots are generated by comparing a peak size in a suspected source oil's chromatogram to the size of the same peak in the chromatogram from a sample of spilled oil. To eliminate differences caused by the concentration of the oil in the solvent, the peak sizes are normalised, usually to the hopane concentration of each sample, but to other weathering-resistant compounds when hopanes are absent.

Conclusions

Once all the analysis has been completed, conclusions can be drawn by comparing results from all sources, including samplers' information, GC-FID chromatograms, GC-MS chromatograms, PW plots, and diagnostic ratios. The methodology suggests some criteria for the classification of spill samples from the correlations, outlined in Table 2.

Table 2

Classification	Definition
Positive match	Differences in the chromatographic patterns and diagnostic ratios of samples submitted for comparison are lower than the variability of the method, or can be explained unequivocally, for example by weathering
Probable match	Differences in chromatographic patterns and diagnostic ratios do not permit an unequivocal positive match, but they can be explained reasonably by external factors, for example weathering in combination with mixing or by non-representative or heterogeneous properties of the available samples
Inconclusive	Differences in the chromatographic patterns and diagnostic ratios of the samples submitted for comparison do not permit a probable or non-match conclusion; for example, in case the concentration of the contaminant in a sample is too low
Non-match	Differences in the chromatographic patterns and diagnostic ratios of the samples submitted for comparison are pronounced and are larger than the variability of the method, and such differences cannot be explained by any external factors such as weathering, contamination, or heterogeneity

GC-FID RESULTS

The sample **20S3454/001 (BRT-SP01)** was a 250 mL jar full of soil. A portion of the soil was placed in a vial with some sodium sulfate and a 1:1 mix of dichloromethane and acetone. This vial was sonicated for 30 minutes to extract any hydrocarbons into the solvent mix, and the resulting extract was analysed in duplicate by GC-FID. The chromatographic profiles are shown in Figure 1 and Figure 2.

The chromatogram indicates that the sample contains diesel.

Figure 1: 20S3454/001 (BRT-SP01), GC-FID chromatogram

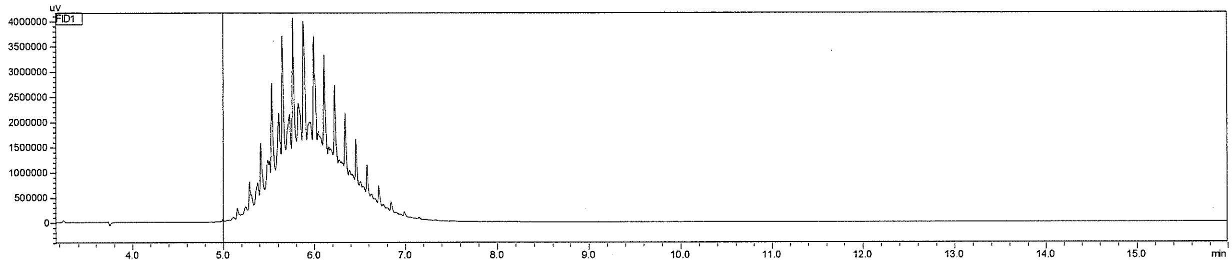
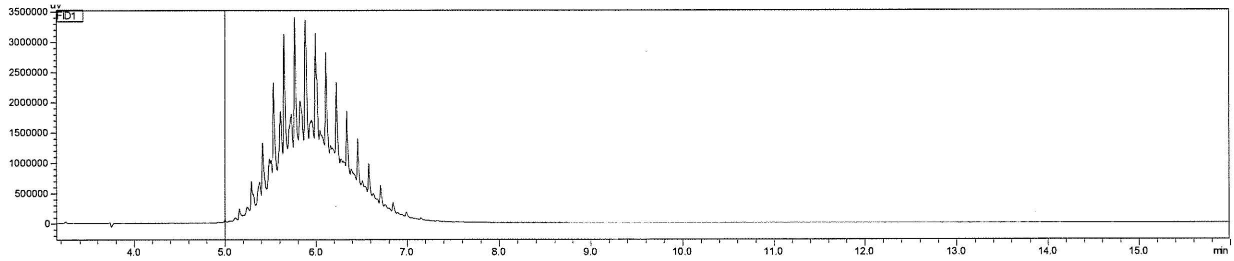


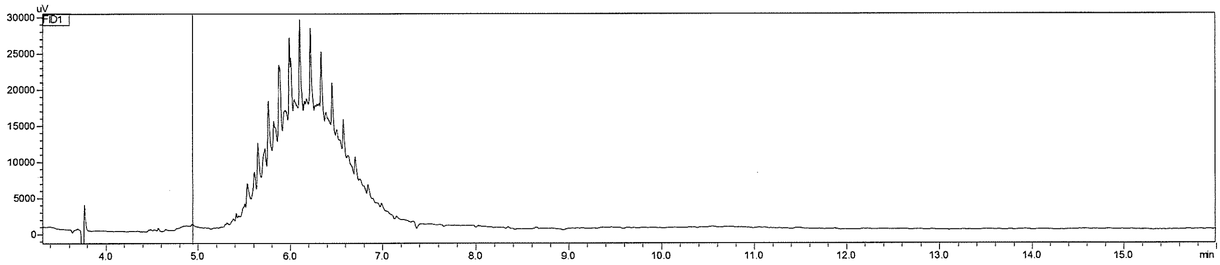
Figure 2: 20S3454/001 (BRT-SP01) duplicate, GC-FID chromatogram



The sample **20S3454/002 (BRT-01)** was a 250 mL jar full of soil. A portion of the soil was placed in a vial with some sodium sulfate and a 1:1 mix of dichloromethane and acetone. This vial was sonicated for 30 minutes to extract any hydrocarbons into the solvent mix, and the resulting extract was analysed by GC-FID. The chromatographic profile is shown in Figure 3.

The chromatograms indicate that the sample contains diesel.

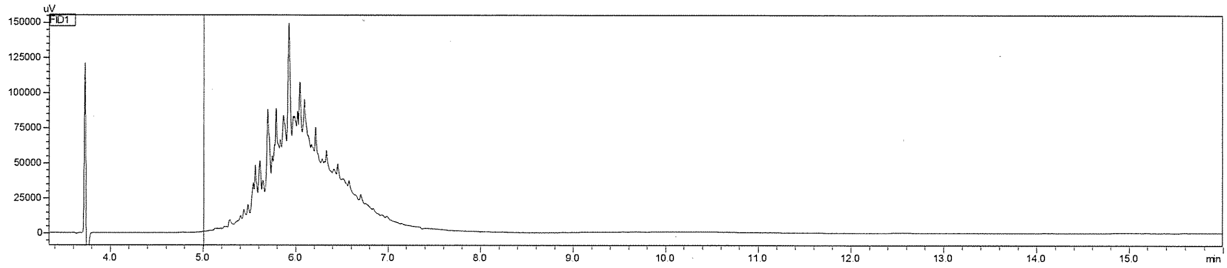
Figure 3: 20S3454/002 (BRT-01), GC-FID chromatogram



The sample **20S3454/003 (BRT-03)** was two 40 mL vials and two 100 mL bottles containing primarily water. This was extracted with a small portion of dichloromethane and the resulting extract was analysed by GC-FID. The chromatographic profile is shown in Figure 4.

The chromatogram indicates that the sample contains a small amount of degraded diesel.

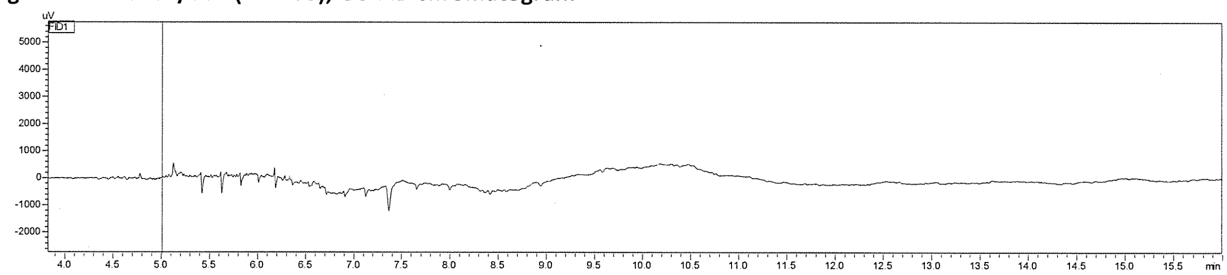
Figure 4: 20S3454/003 (SP1), GC-FID chromatogram



The sample **20S3454/004 (BRT-08)** was two 40 mL vials and two 100 mL bottles containing primarily water. This was extracted with a small portion of dichloromethane and the resulting extract was analysed by GC-FID. The chromatographic profile is shown in Figure 5.

The chromatogram indicates that the sample contains no significant levels of hydrocarbon.

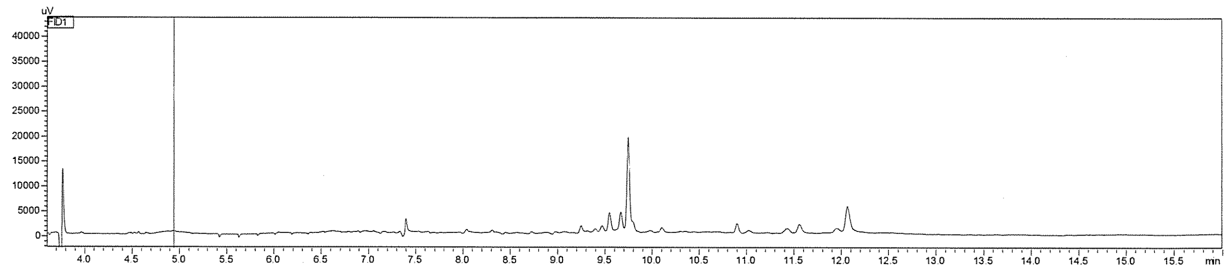
Figure 5: 20S3454/004 (BRT-08), GC-FID chromatogram



The sample **20S3454/005 (BRT-09, soil)** was a 250 mL jar full of soil. A portion of the soil was placed in a vial with some sodium sulfate and a 1:1 mix of dichloromethane and acetone. This vial was sonicated for 30 minutes to extract any hydrocarbons into the solvent mix, and the resulting extract was analysed by GC-FID. The chromatographic profile is shown in Figure 6.

The chromatogram indicates that the sample contains no significant levels of hydrocarbon.

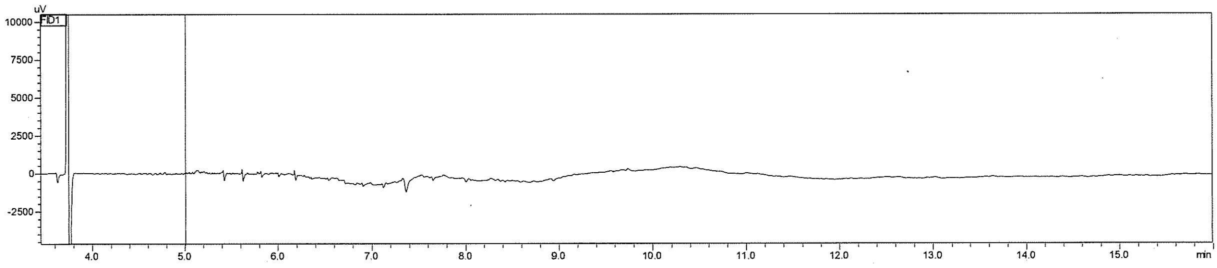
Figure 6: 20S3454/005 (BRT-09, soil), GC-FID chromatogram



The sample **20S3454/006 (BRT-09, liquid)** was two 40 mL vials and two 100 mL bottles containing primarily water. This was extracted with a small portion of dichloromethane and the resulting extract was analysed by GC-FID. The chromatographic profile is shown in Figure 7.

The chromatogram indicates that the sample contains no significant levels of hydrocarbon.

Figure 7: 20S3454/006 (BRT-09, liquid), GC-FID chromatogram



The amount of Total Recoverable Hydrocarbon (TRH) in each sample was calculated by comparing the area under the chromatogram to the area of alkane standards (see Table 3).

Table 3

Sample	Total Recoverable Hydrocarbons
203454/001	36,000 mg/kg
203454/001 duplicate	29,000 mg/kg
203454/002	320 mg/kg
203454/003	49 mg/L
203454/004	< 2.5 mg/L
203454/005	< 100 mg/kg
203454/006	< 2.5 mg/L

Visual comparison of chromatograms

The chromatograms shows that the three samples containing diesel have similar boiling ranges, with some degradation of n-alkanes evident in sample 3.

Percent Weathering plots (PW plots) were calculated from the GC chromatograms of samples 1, 2, and 3 by normalising the heights of the alkane peaks to the average height of the C20 to C24 alkanes and comparing each sample's alkane profile to the least weathered sample (20S3454/001). The duplicate samples were also compared to each other.

The plots appear in Appendix 3 and show the following:

- All plots show a normal weathering pattern and differences between the samples could be caused by evaporation and biodegradation.
- Sample 3 shows less biodegradation, with pristane and phytane apparently lower than the surrounding n-alkanes in this sample.

These findings are supported by the calculation of the acyclic isoprenoid ratios (see Table 4). The ratios are similar for all samples, indicating that the samples are potentially from the same source.

Table 4: Acyclic isoprenoid ratios

Sample	C17/Pr	C18/Ph	Pr/Ph
20S3454/001	1.73	2.63	1.41
20S3454/001r	1.73	2.65	1.42
20S3454/002	1.88	2.73	1.10
20S3454/003	2.19	3.81	1.15

GC-MS RESULTS

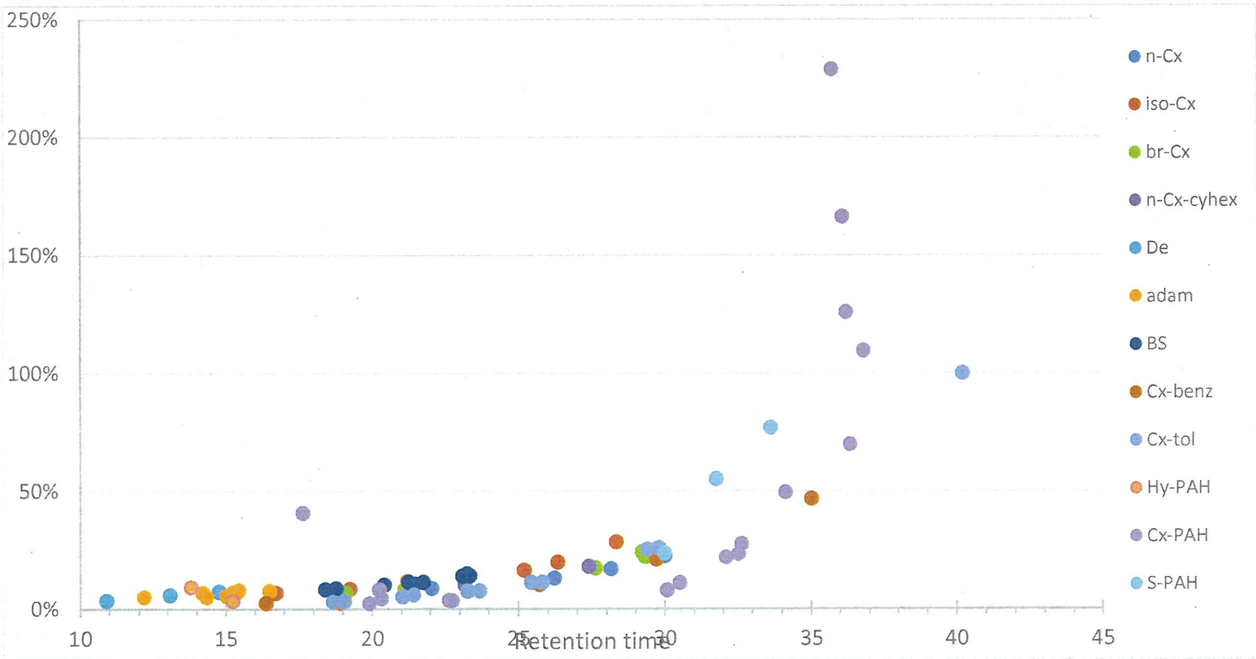
Based on the GC-FID chromatograms, samples 1, 2, and 3 (and sample 1 duplicate) were further analysed by GC-MS. The remaining samples did not contain significant hydrocarbons and were excluded from further analysis. A well-characterised reference oil (the AGSO standard) and the reference diesel sample from the same location (20S0458/001 – BTY 5) were also analysed for comparison.

The GC-MS analysis was conducted in selected ion monitoring (SIM). Analysing in selected ion monitoring (SIM) mode increased the sensitivity of the m to the compounds required for Percent Weathering (PW) plots, here normalised to the peak height of phytanyltoluene (or C23 terpane if present). The diagnostic ratios of PAHs and biomarkers were then calculated. A list of the compounds of interest used in PW plots and the diagnostic ratios derived from them appear in Appendix 5.

Samples 2 and 3 are each compared to sample 1 in the PW plots below (Figure 8 and Figure 9). All three samples are compared to the reference diesel in Figure 10 to Figure 12.

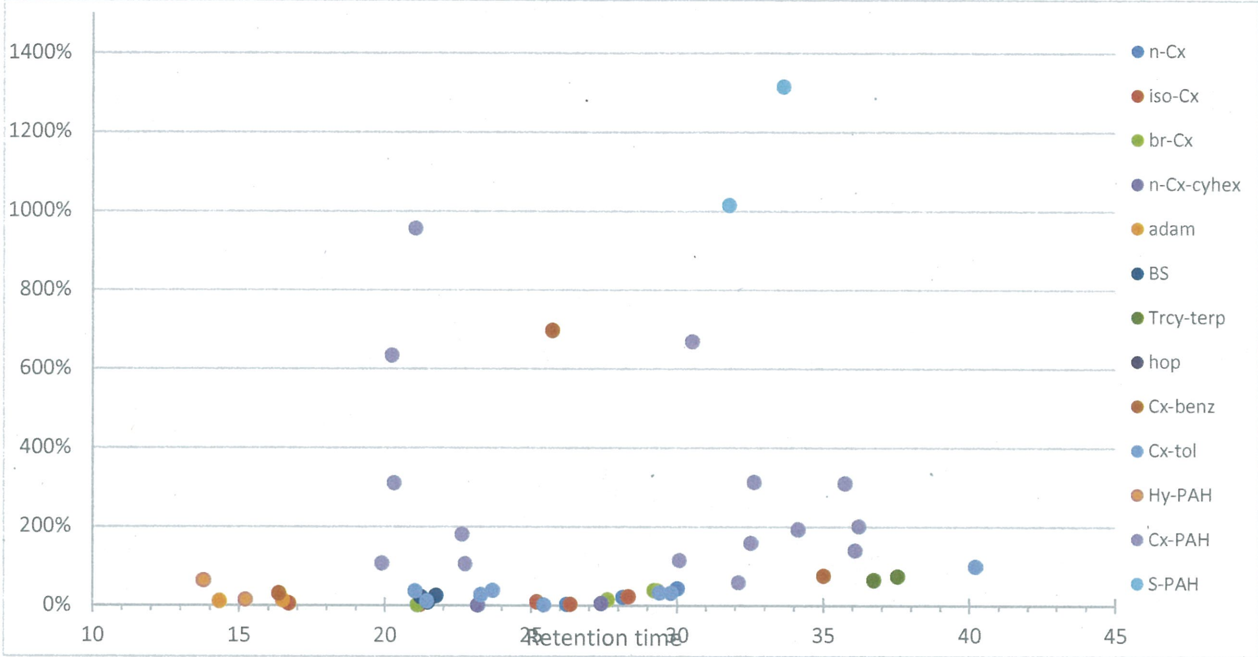
The PW plot in Figure 8 shows that sample 1 and sample 2 are the same diesel, with different weathering patterns impacting the ratios. Sample 2 is more evaporated, as shown by the lower points to the left of the plot. The alkyl-PAH and alkyl-benzene compounds are reduced in sample 1, likely due to water washing.

Figure 8: PW plot of sample 20S3454/002 (BRT-01) compared to sample 20S3454/001 (BRT-SP01)



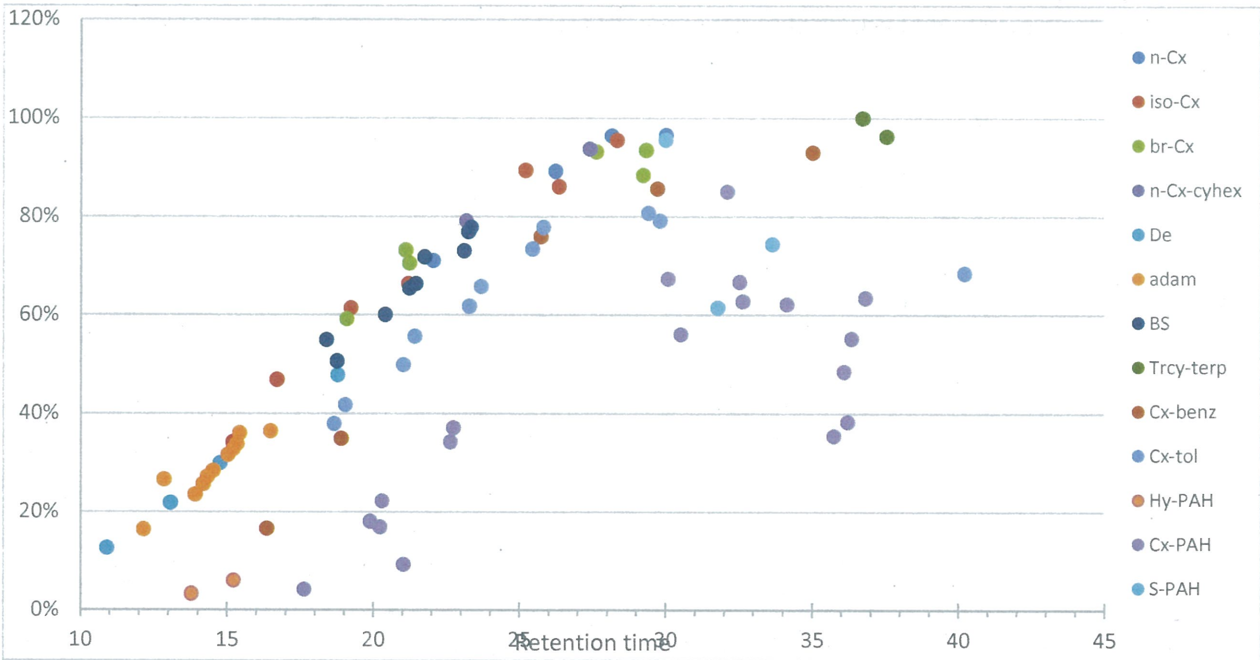
The PW plot in Figure 9 shows that sample 1 and sample 3 appear to be different hydrocarbons. There are some trends visible, indicating that they may have had a common source, with extreme weathering reducing the more volatile compounds, and water-washing enhancing the more soluble compounds (noting that sample 3 was a water sample).

Figure 9: PW plot of sample 20S3454/003 (BRT-03) compared to sample 20S3454/001 (BRT-SP01)



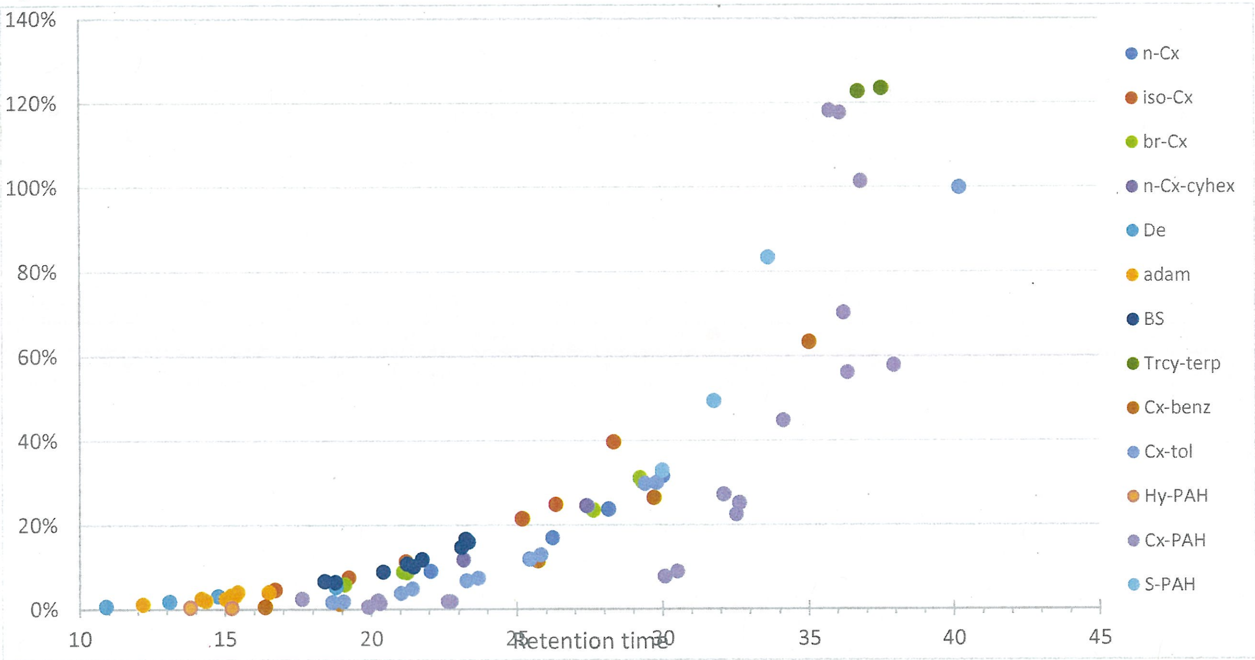
The PW plot in Figure 10 shows that sample 1 matches the reference diesel, with the water-washing of the alkyl-PAH and alkyl-benzene compounds more apparent, and some evaporation of sample 1 also visible.

Figure 10: PW plot of sample 20S3454/001 (BRT-SP01) compared to reference diesel 20S0458/001 (BYT 5)



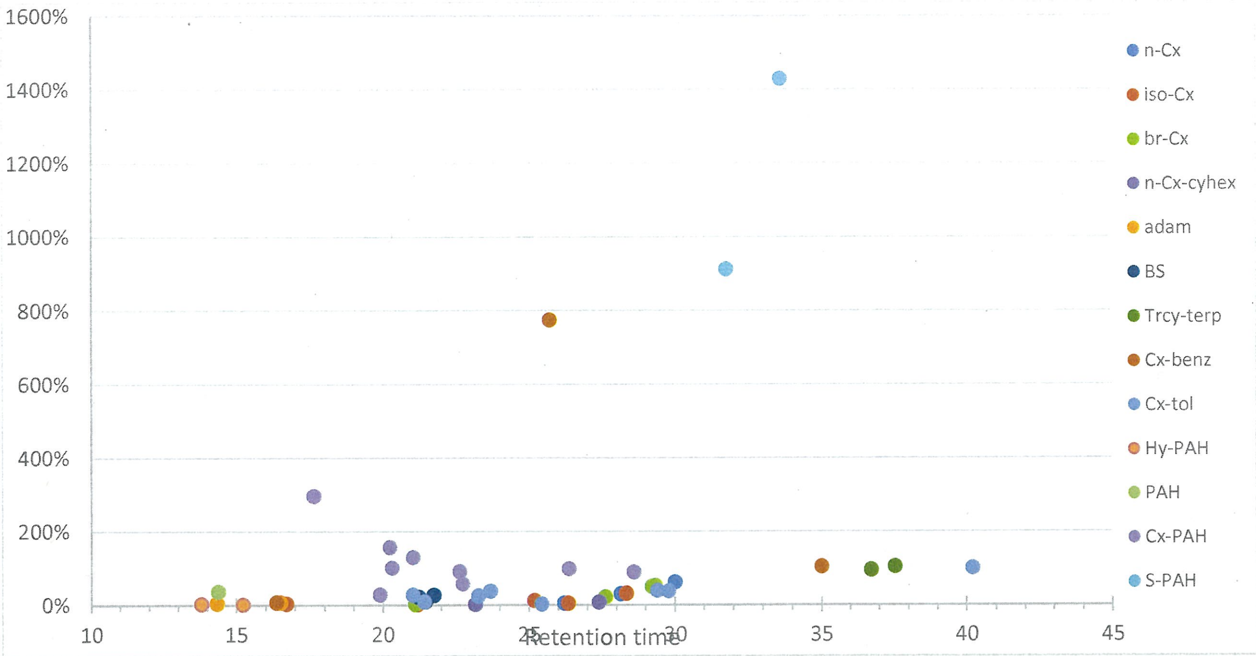
The PW plot in Figure 11 shows that sample 2 matches the reference diesel, with a similar pattern of degradation to sample 1. Comparing Figure 11 to Figure 10 shows that sample 2 is more impacted by evaporation, and sample 1 is more impacted by water-washing of the alkyl-PAH and alkyl-benzene compounds.

Figure 11: PW plot of sample 20S3454/002 (BRT-01) compared to reference diesel 20S0458/001 (BYT 5)



The PW plot in Figure 12 shows that sample 3 and the reference diesel appear to be different hydrocarbons. There are some trends visible, indicating that they may have had a common source, with extreme weathering reducing the more volatile compounds, and water-washing enhancing the more soluble compounds (noting that sample 3 was a water sample).

Figure 12: PW plot of sample 20S3454/003 (BRT-03) compared to reference diesel 20S0458/001 (BYT 5)



The recommended diagnostic ratios were calculated and are presented in Table 5. For samples 1, 2, and the reference diesel, all diagnostic ratios were within the 14% limit specified in the method as a significant difference, except for the ratios known to be affected by weathering. Sample 3 was more complex, and no definitive match was able to be found for this sample.

Table 5

	20S3454/001 BRT-SP01	20S3454/001 BRT-SP01 Duplicate	20S3454/002 BRT-01	20S3454/003 BRT-03	20S0458/001 BTY-5 Ref. diesel
1-M-Adm/1,2-DM-Adm	0.739	0.830	0.688	0.000	1.420
1-M-Adm/2-E-Adm	0.621	0.775	0.415	0.000	1.377
i-C13/2-M-tetralin	2.103	2.208	3.789	0.000	0.369
c-1,3,4-TM-Adm/2-E-Adm	0.615	0.689	0.566	0.000	0.684
C6-/C7-Benz	0.542	0.567	0.517	0.000	1.139
2-E-Adm/i-C14	0.134	0.122	0.150	0.323	0.172
BS1/BS2	1.259	1.135	1.204	0.000	1.160
C3-de peak/BS2	0.888	0.855	0.775	0.000	0.940
Bi/2-EN	0.000	0.000	0.000	0.000	4.047
2-E-N/2,6+2,7 DM-N	0.000	0.147	0.000	0.000	0.207
BS4/BS5	0.423	0.445	0.458	1.053	0.429
Br-Alk 169-3/n-C15	1.042	1.057	1.013	0.000	1.049
BS5/BS6	2.224	2.275	2.064	0.781	2.407
BS8/BS9	1.135	1.222	1.062	0.000	1.195
m-/o-C8-Tol	1.461	1.492	1.432	1.051	1.556
BS10/Norpri	0.636	0.673	0.543	0.000	0.730
Norpri/m-C9-Tol	2.488	2.719	3.672	9.237	2.044
C10-Benz/n-C11-CyC6	0.154	0.138	0.089	19.622	0.190
n-C17/Pri	1.704	1.587	1.122	1.718	1.644
Pri/Phy	1.369	1.427	0.952	0.223	1.519
n-C18/Phy	2.219	2.176	1.316	2.066	2.198
4-M-Dbt/1-M-Dbt	0.000	0.000	0.000	0.000	0.000
2-MPhe/1-MPhe	2.292	1.852	1.636	0.396	1.908
FAME 16:0/18:0	0.000	0.000	0.000	0.000	0.000

REFERENCES

Daling, PS, Faksness L-G, Hansen AB, and Stout SA, Improved and standardized methodology for oil spill fingerprinting. *Environ. Forensics*, 2002, 3, 263-278.

Douglas GS et al, "Environmental Stability of Selected Petroleum Hydrocarbon Source and Weathering Ratios" (1996) 30 (No 7) Environmental Science and Technology 2332

Faksness LG, Weiss HM and Daling PS, Revision of CEN/TR 15522-2 Methodology for Oil Spill Identification (SINTEF Applied Chemistry, 2002, Norway), SINTEF Report STF66 A02028, CEN/TR 15522-2 Technical Report 498

Leeder JF, et al, Five Year Study of the Changes of Bunker Fuel in a Mangrove Environment (Environment Protection Council, Australia, 1992)

National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPM)

Philp RP, Fossil Fuel Biomarkers. Applications and Spectra: Methods in Geochemistry and Geophysics (Elsevier, 1985) Vol 23

CONCLUSION

Six samples were received by ChemCentre on the 18 February 2021. The samples were analysed along with a reference diesel sample provided previously by NT EPA (Ref 20S0458/001, received 31/07/2020). The samples were compared to each other using the CEN/TR 15522-2 methodology, with analysis conducted by GC-FID and fingerprinting analysis by GC-MS-SIM.

Three samples did not contain a significant amount of hydrocarbon and fingerprinting analysis was not undertaken on these samples.

The remaining samples were compared and two of them displayed a positive match, both to each other, and to the reference diesel sample. Differences in the chromatographic patterns and/or diagnostic ratios of samples were lower than the variability of the method or can be explained as being the result of expected weathering processes.

The third sample was inconclusive – due to extreme weathering, a positive match could not be unequivocally made.

COMMENTS

This report applies only to the sample(s) as received and may only be reproduced in full.

Leif Cooper
Senior Chemist and Research Officer
Scientific Services Division

APPENDIX 1

Chain of Custody for samples received on 18 February 2021

CHEM CENTRE.

ntepa Northern Territory Environment Protection Authority

2053454

SAMPLE INFORMATION & ANALYSIS REQUEST

Customer	Department of Environment & Natural Resources
Contract Number	N/A
Project Name	Berrimah Rail Terminal – PRL9059
Reference Number	NTEPA2020/0007-193
Contact Name	Claudia Bennett
Phone	8924 4161
Email	pollution@nt.gov.au & claudia.bennett@nt.gov.au
Invoice to	pollution@nt.gov.au

Laboratory	ChemCentre, WA
Quote Number	**2102026**
Lab Contact Name	Leif Cooper
Lab Address	ChemCentre, Scientific Services Division, Building 500, Resources and Chemistry Precinct, Cnr Manning Rd & Townsing Drive off Conlon Street, Bentley, WA 6102 Refer to map and delivery instructions – Esky Label
Lab Phone	9422 9900
Lab Email	ssd@chemcentre.wa.gov.au
Turnaround time	Standard TAT
Sample retention time	Retain as evidence under secure chain-of-custody; dispose only on instruction from the NT EPA

Type and Number of Bottles

Various bottled and Jars

Sample Information

Lab Sample ID	Sample ID	Date Sampled	Time Sampled	Container Type	Type of Sample	Sample Preservation	Analysis Required	Comments
2053454/ 001.	BRT-SP01	04/02/21	~10 00	1 x Jar	Soil	Locked refrigerator	TRH	
002.	BRT-01	04/02/21	~10 15	1 x Jar 2 x bottles 2x Vials	Soil and Liquid	Locked refrigerator	TRH GC-FID Screen GC-MS Fingerprinting (against SP01 sample)	Did not receive bottles & vials.
003.	BRT-03	04/02/21	~10.20	2 x bottles 2x Vials	Liquid	Locked refrigerator	TRH GC-FID Screen GC-MS Fingerprinting (against SP01 sample)	

2058454/004.	BRT-08	04/02/21	~11.15	2 x bottles 2x Vials	Liquid	Locked refrigerator	TRH GC-FID Screen GC-MS Fingerprinting (against SP01 sample)	
005. 006.	BRT-09	04/02/21	~11 40	1 x Jar 2x bottles 2xVials	Soil + liquid	Locked refrigerator	TRH	Pending Results (TRH present) will analyse for: GC-FID Screen GC-MS Fingerprinting

ntepa Northern Territory Environment Protection Authority

CHAIN-OF-CUSTODY

Relinquished		Received		Notes
Name:	Claudia Bennett.	Name	Dale Carter	
Date:	16/02/21	Date	18/02/2021	
Time:	13:30pm.	Time	09:45	
Organisation:	NT EPA.	Organisation:	ChemCentre	
Sample Status	Chilled.	Sample Status	Cold ≈17°C	
Signature	[signature]	Signature	[signature]	

Relinquished		Received		Notes
Name:	Baifern .T	Name		
Date:	16-2-21	Date		
Time:	1:31	Time		
Organisation:	Tnt	Organisation:		
Sample Status		Sample Status		
Signature	[signature]	Signature		

APPENDIX 2 – PHOTOGRAPHS OF SAMPLES

Figure 13: 20S3454/001 (BRT-SP01)

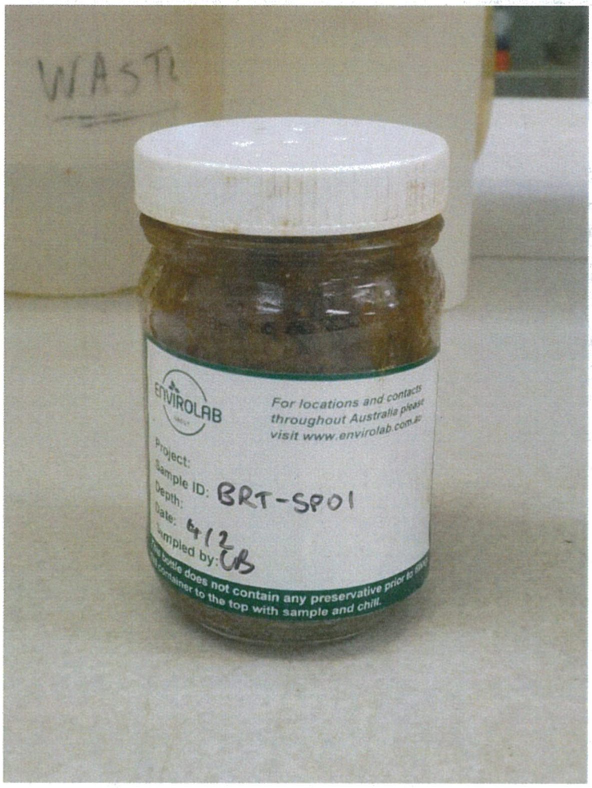


Figure 14: 20S3454/002 (BRT-01)

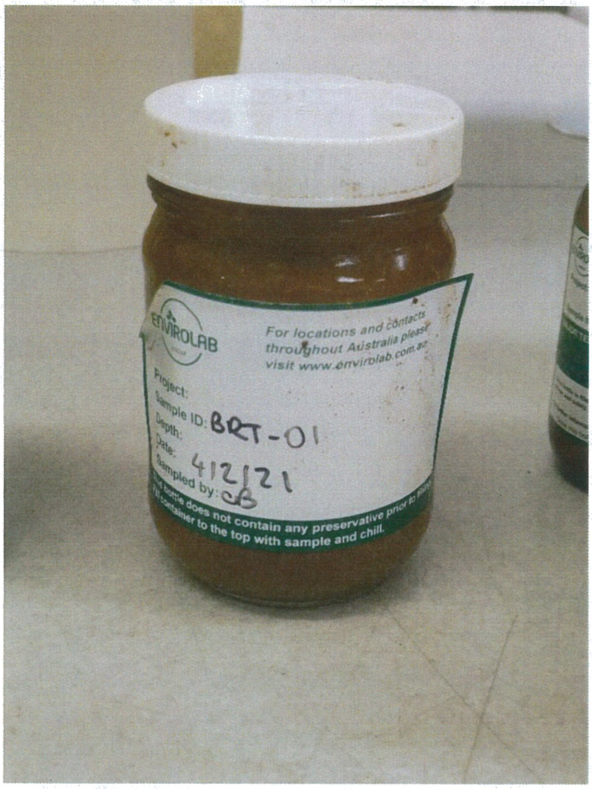


Figure 15: 20S3454/003 (BRT-03)

Figure 16: 20S3454/004 (BRT-08)

Figure 17: 20S3454/005 (BRT-09, soil)

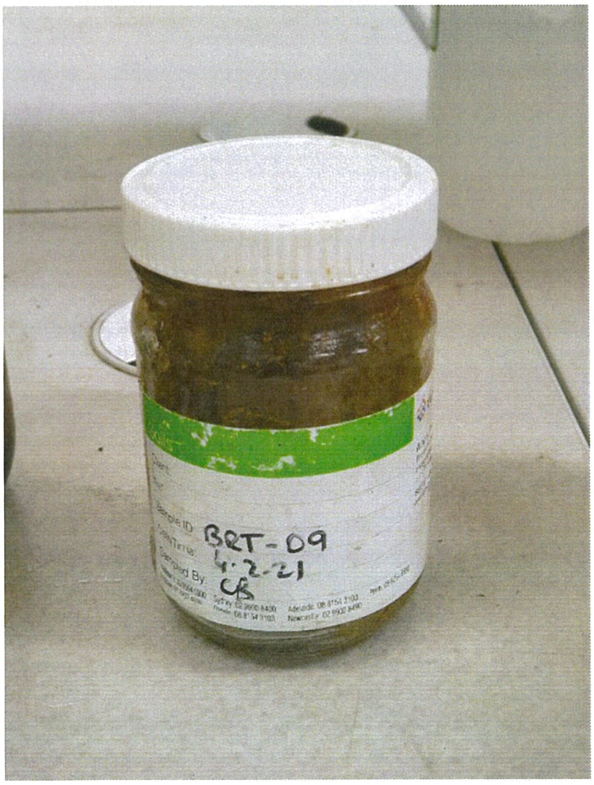
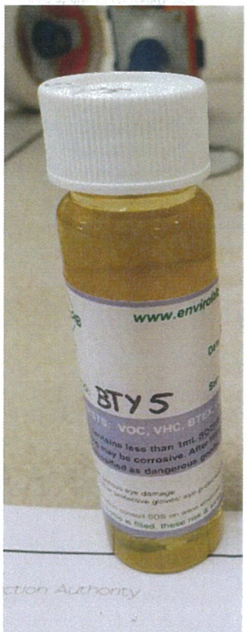


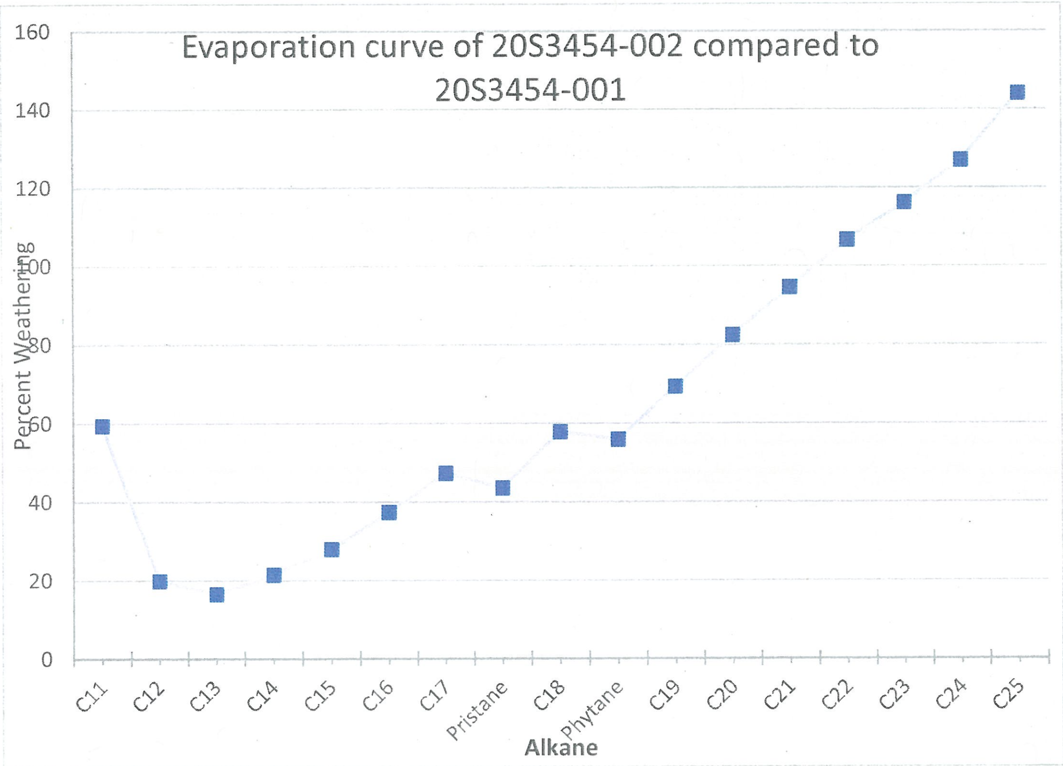
Figure 18: 20S3454/006 (BRT-09, liquids)

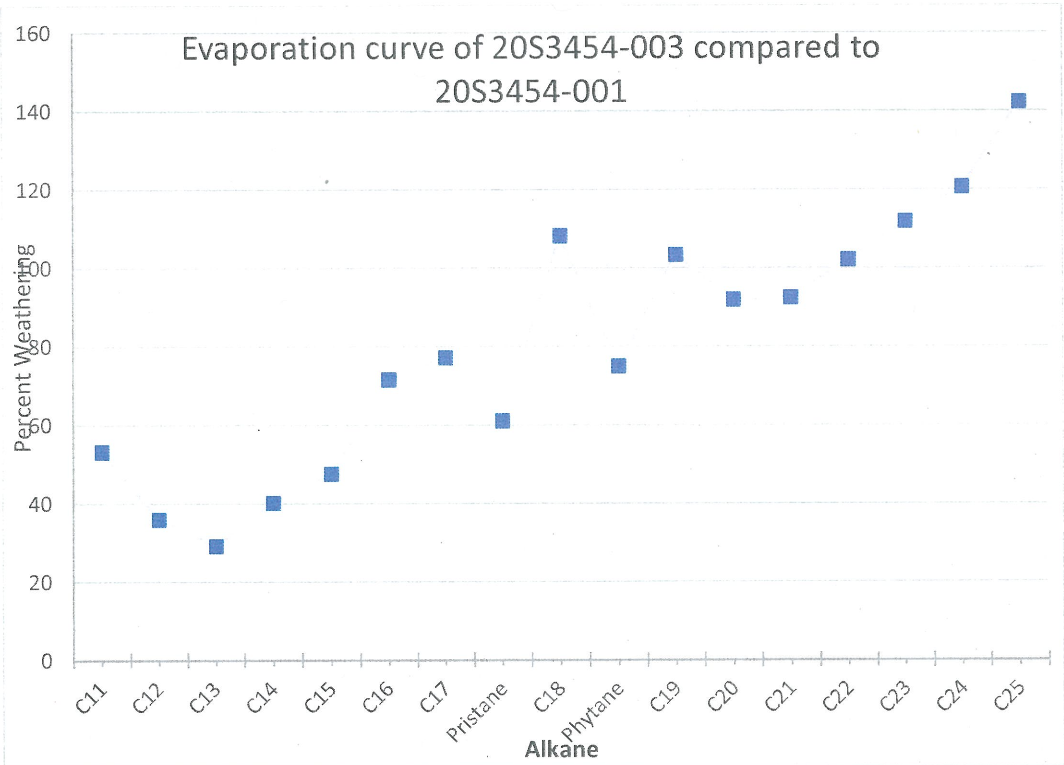
Figure 19: Reference diesel 20S0458/001 (BTY 5)



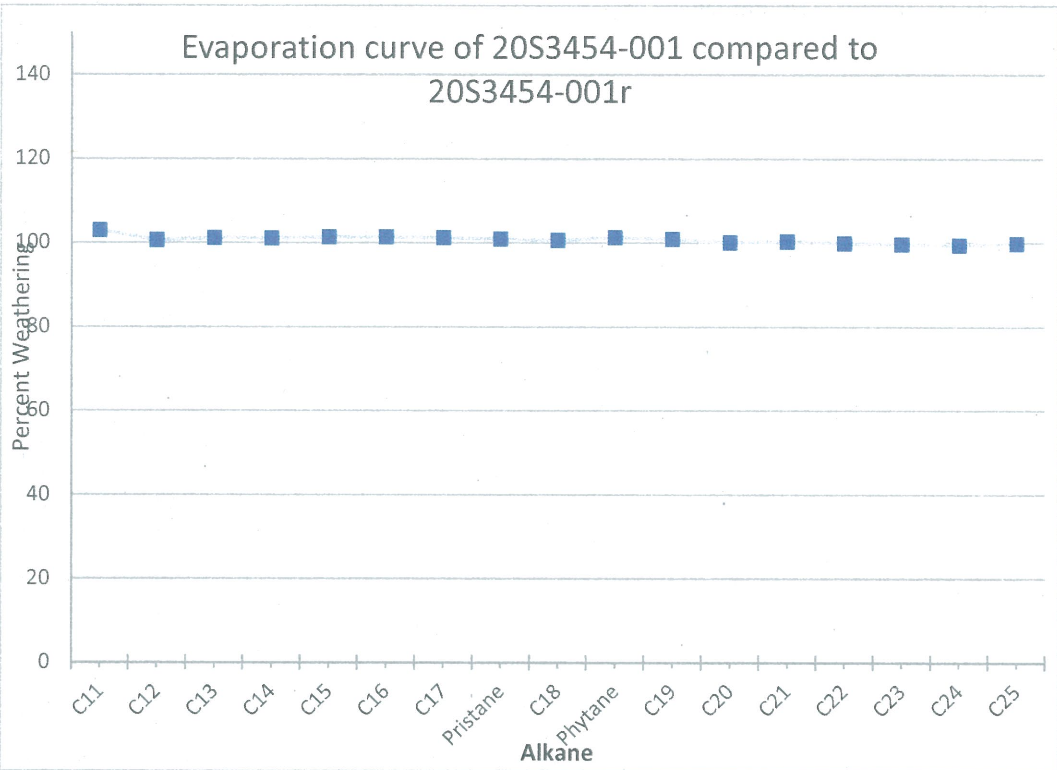
APPENDIX 3

GC PW plots





QC – GC PW plots



APPENDIX 4

GC-MS scan – Selected Ion Monitoring (SIM) chromatograms

Figure 20: Sample 20S3454/001, bicyclic sesquiterpanes

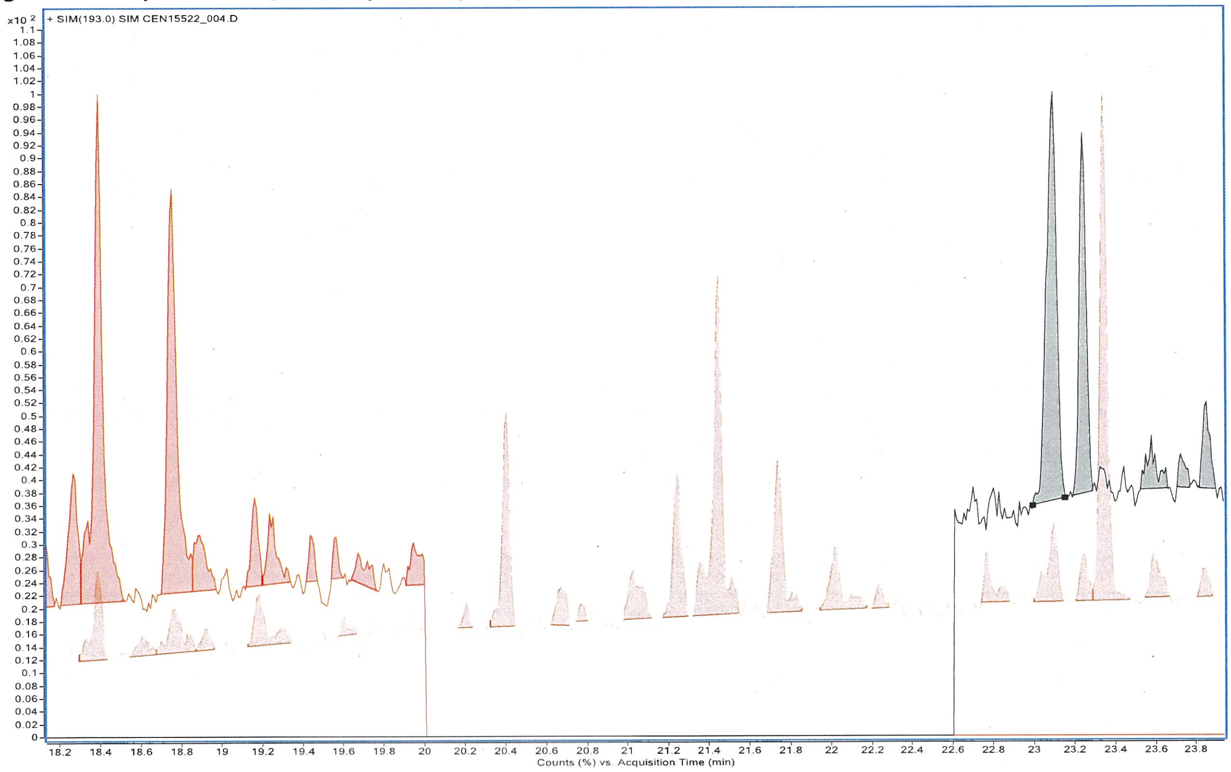


Figure 21: Sample 20S3454/002, bicyclic sesquiterpanes

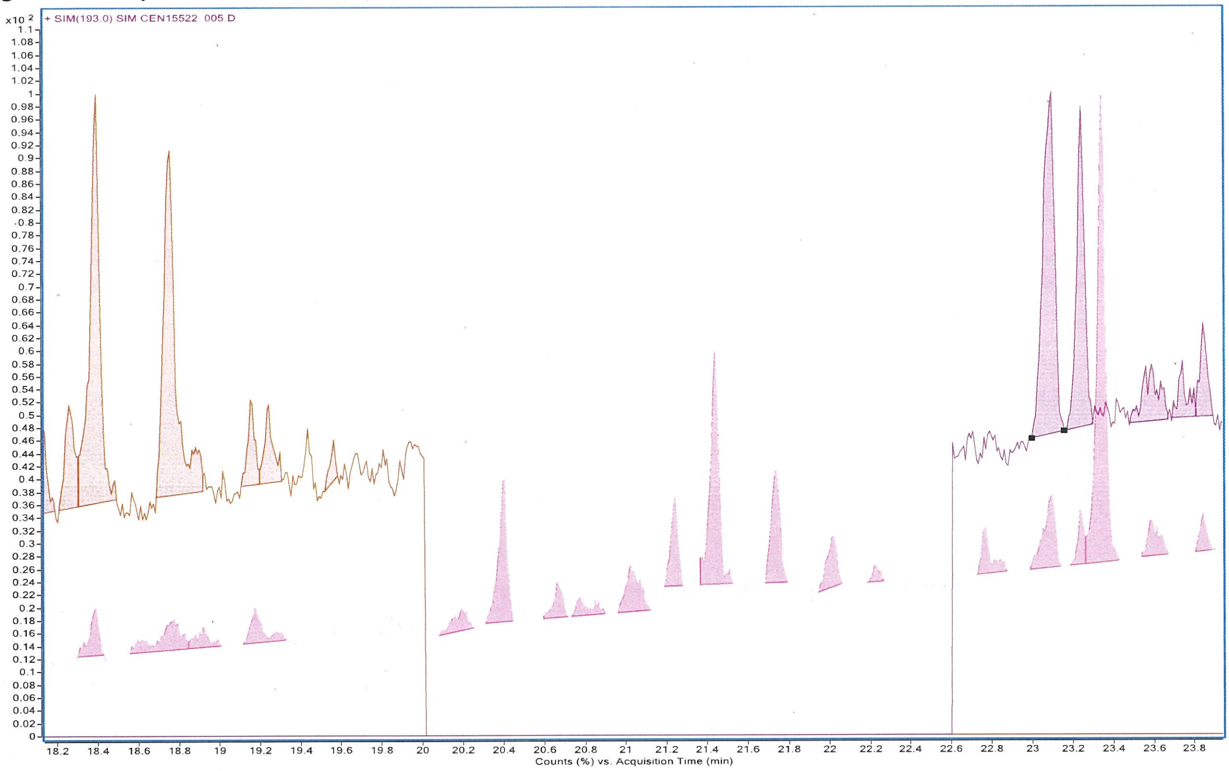


Figure 22: Sample 20S3454/003, bicyclic sesquiterpanes

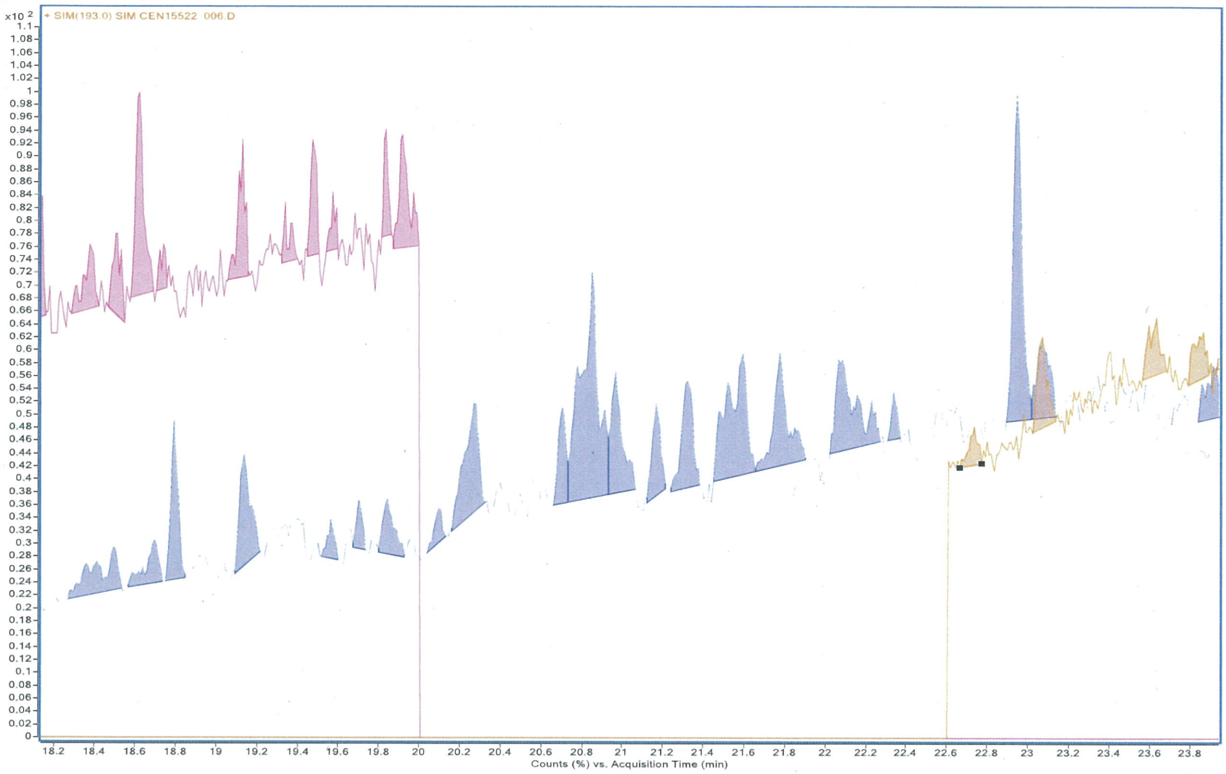


Figure 23: Reference diesel sample 20S0458/001, bicyclic sesquiterpanes

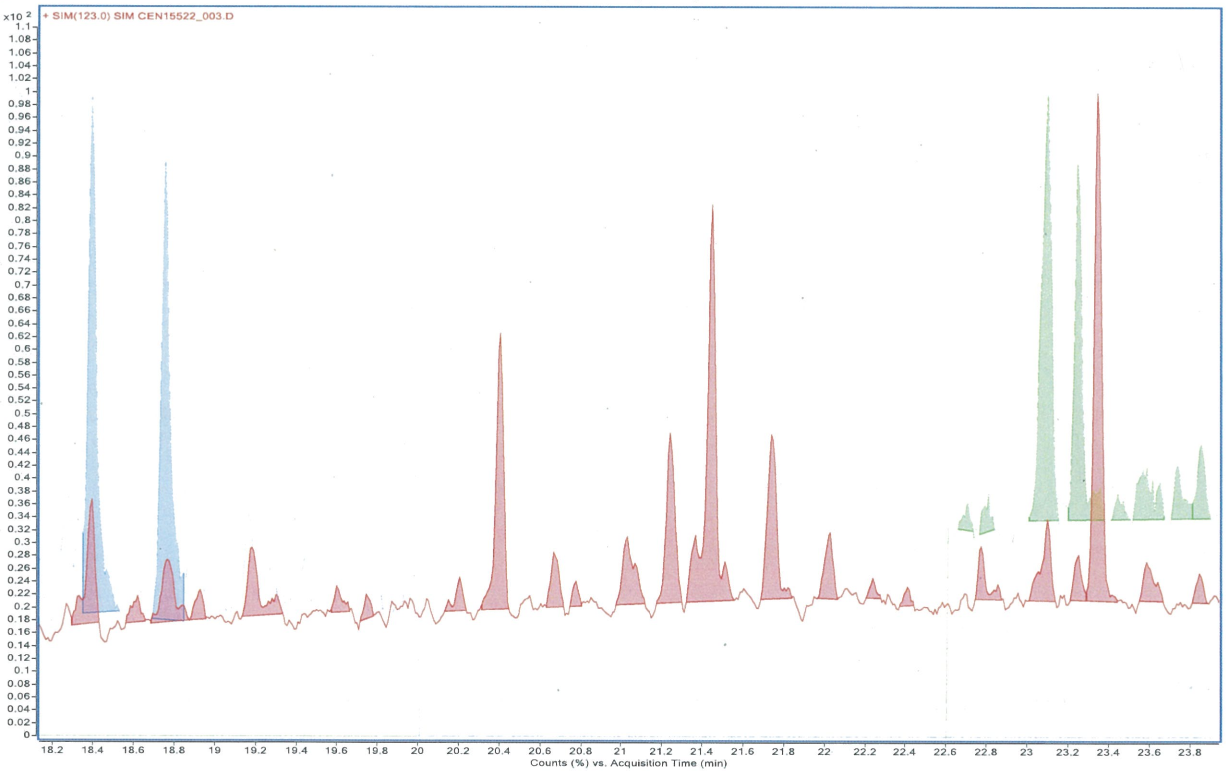


Figure 24: Sample 20S3454/001, methyl- and dimethyl-adamantanes

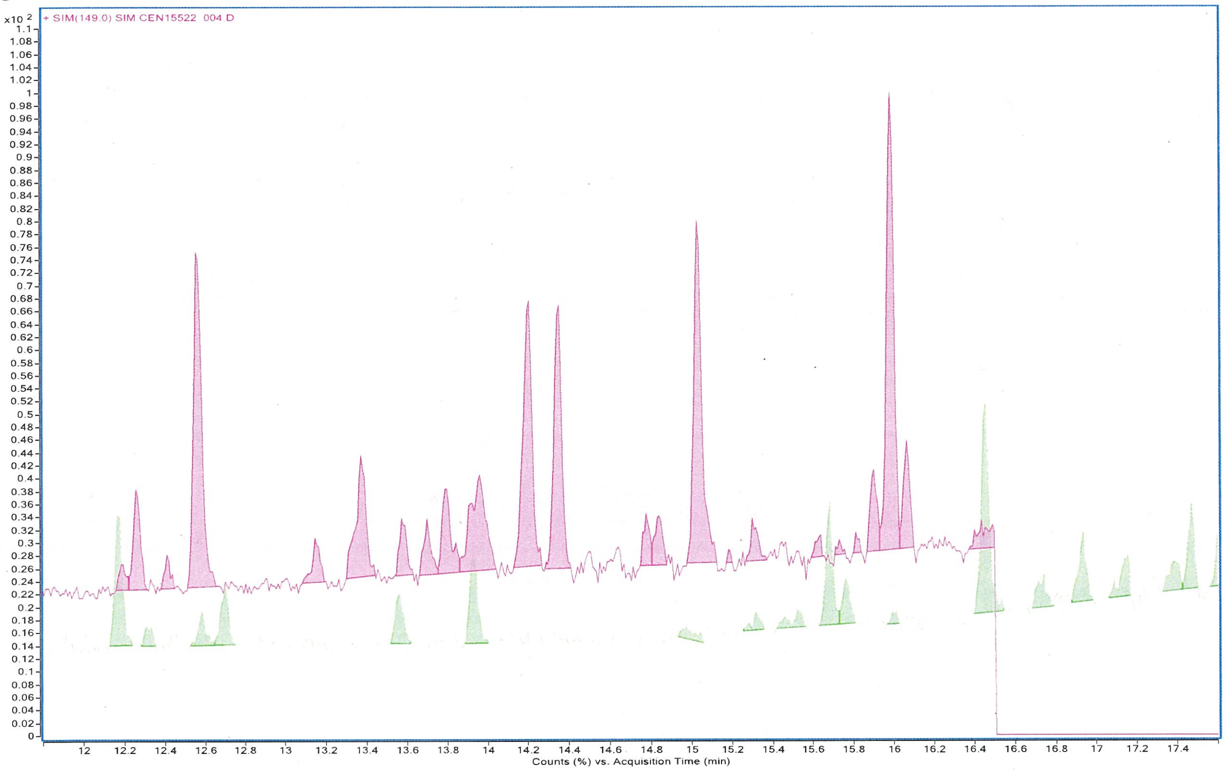


Figure 25: Sample 20S3454/002, methyl- and dimethyl-adamantanes

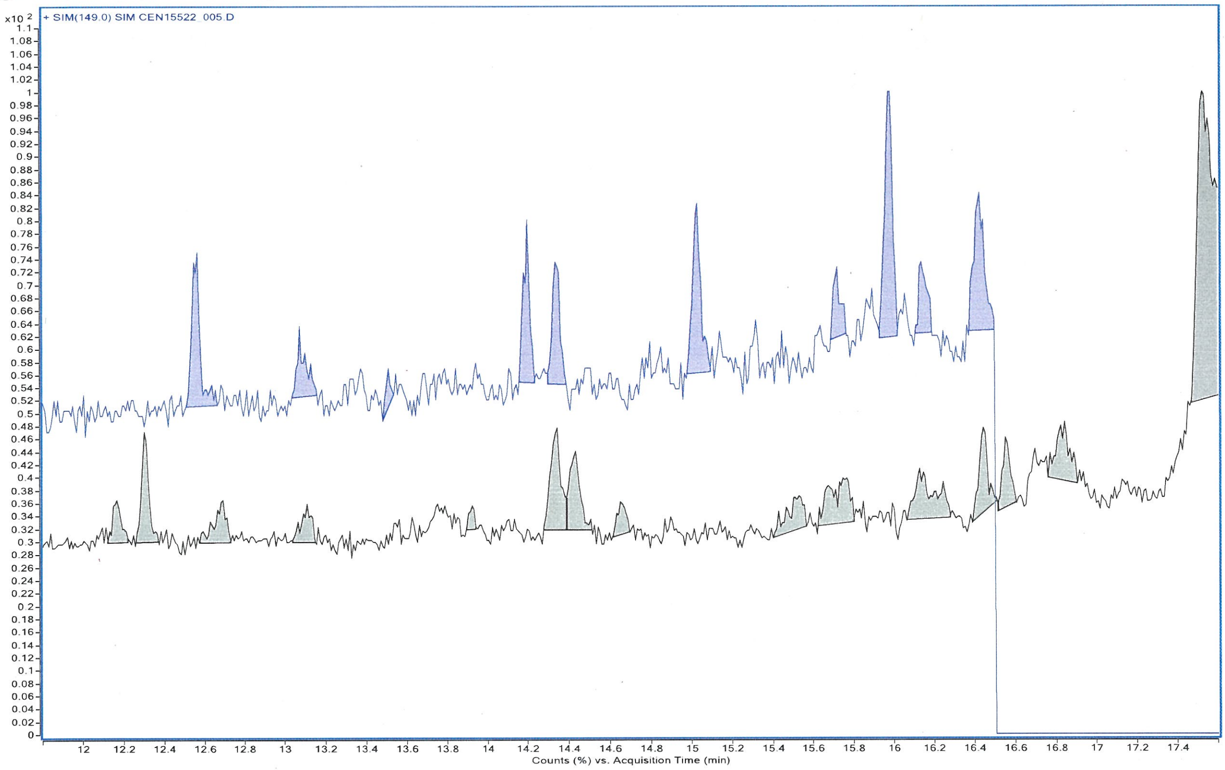


Figure 26: Sample 20S3454/003, methyl- and dimethyl-adamantanes

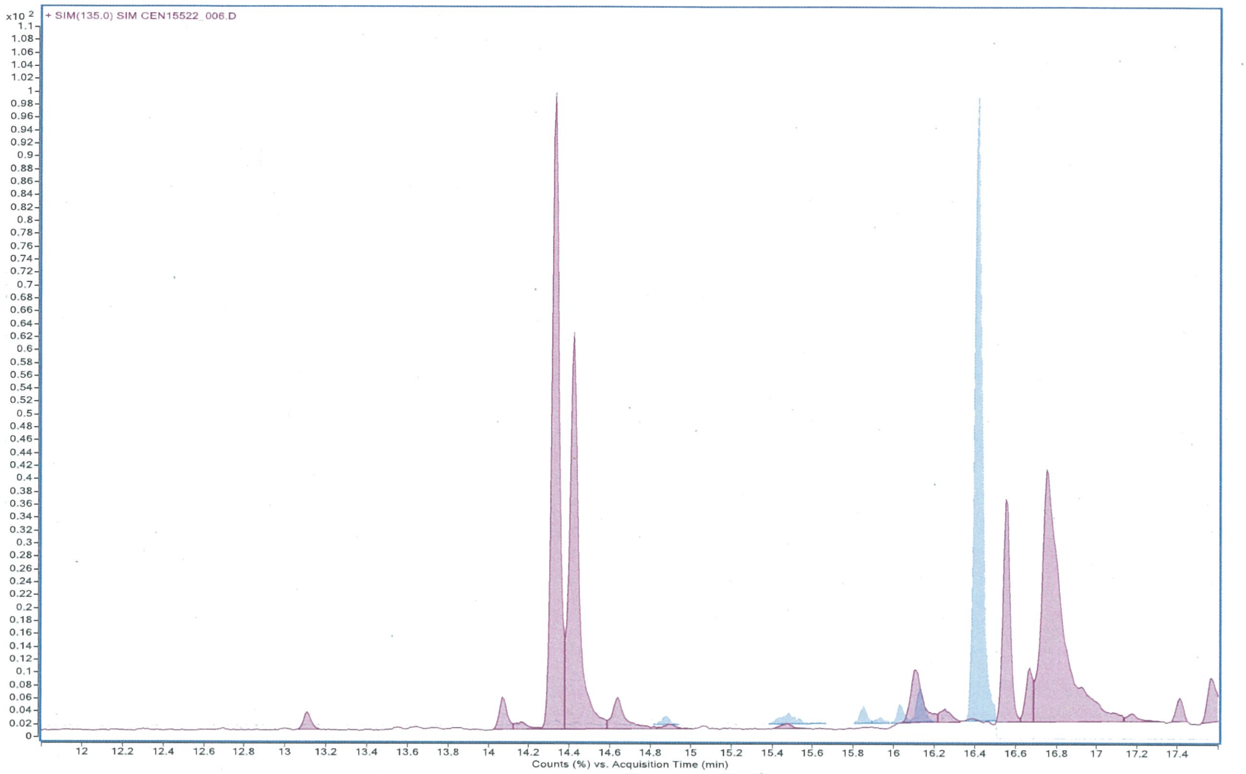


Figure 27: Reference diesel sample 20S0458/001, methyl- and dimethyl-adamantanes

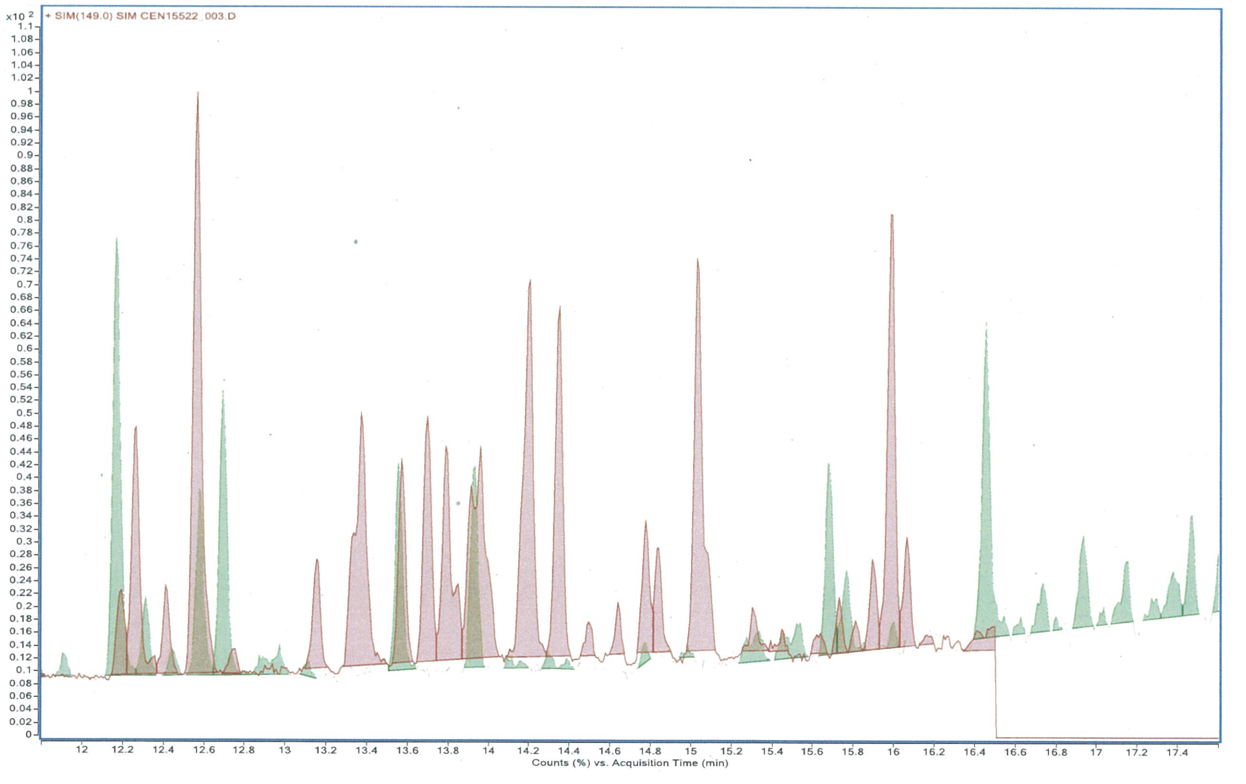


Figure 28: Sample 20S3454/001, C3- and C4-adamantanes

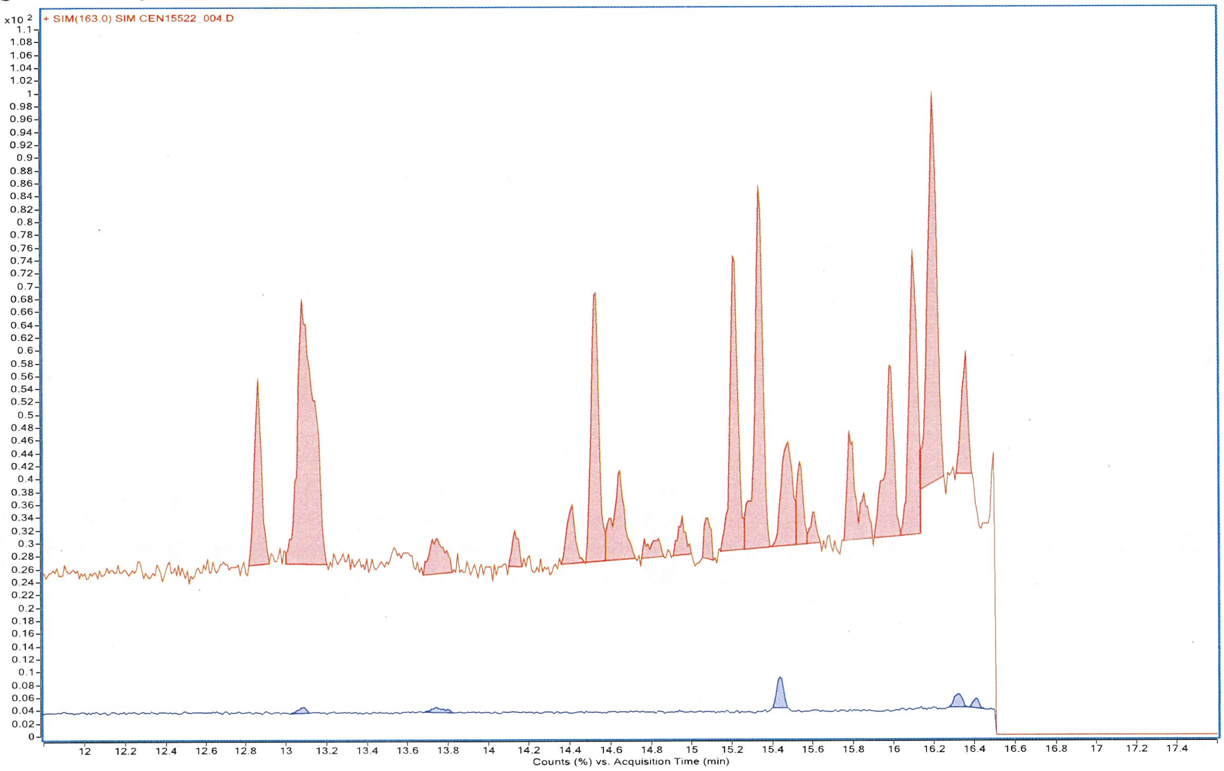


Figure 29: Sample 20S3454/002, C3- and C4-adamantanes

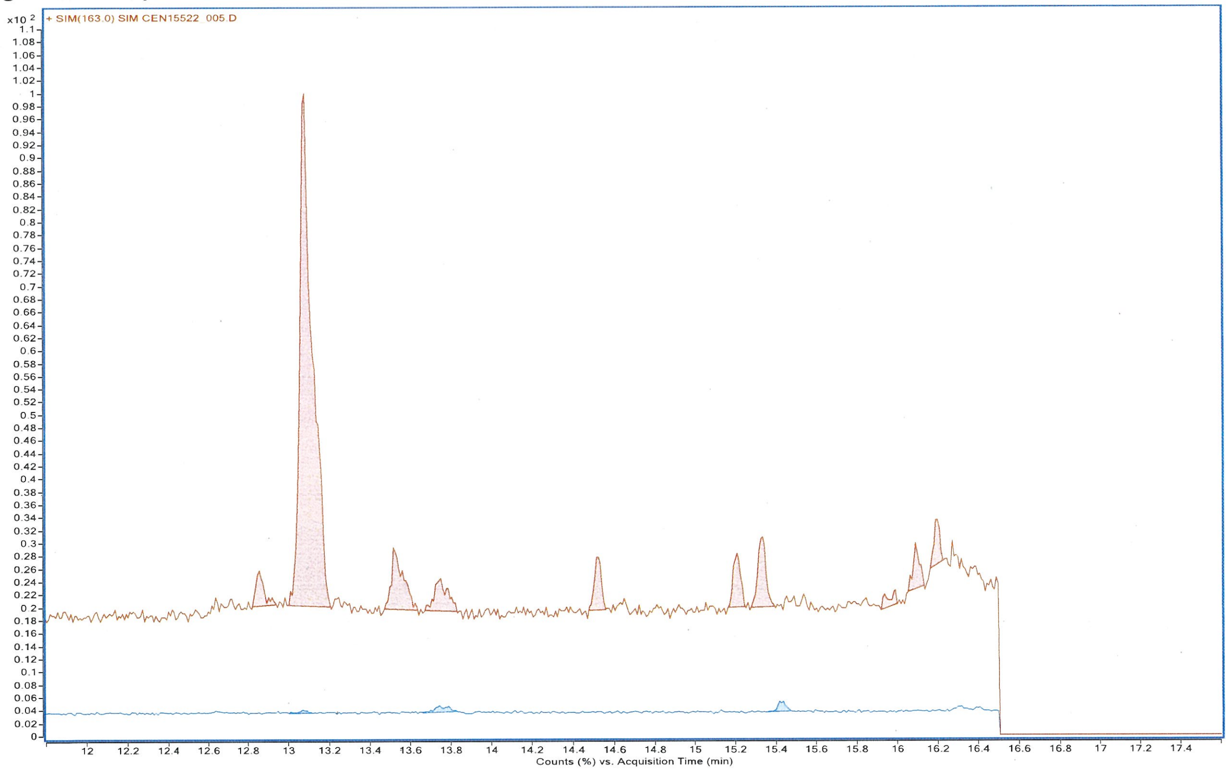


Figure 30: Sample 20S3454/003, C3- and C4-adamantanes

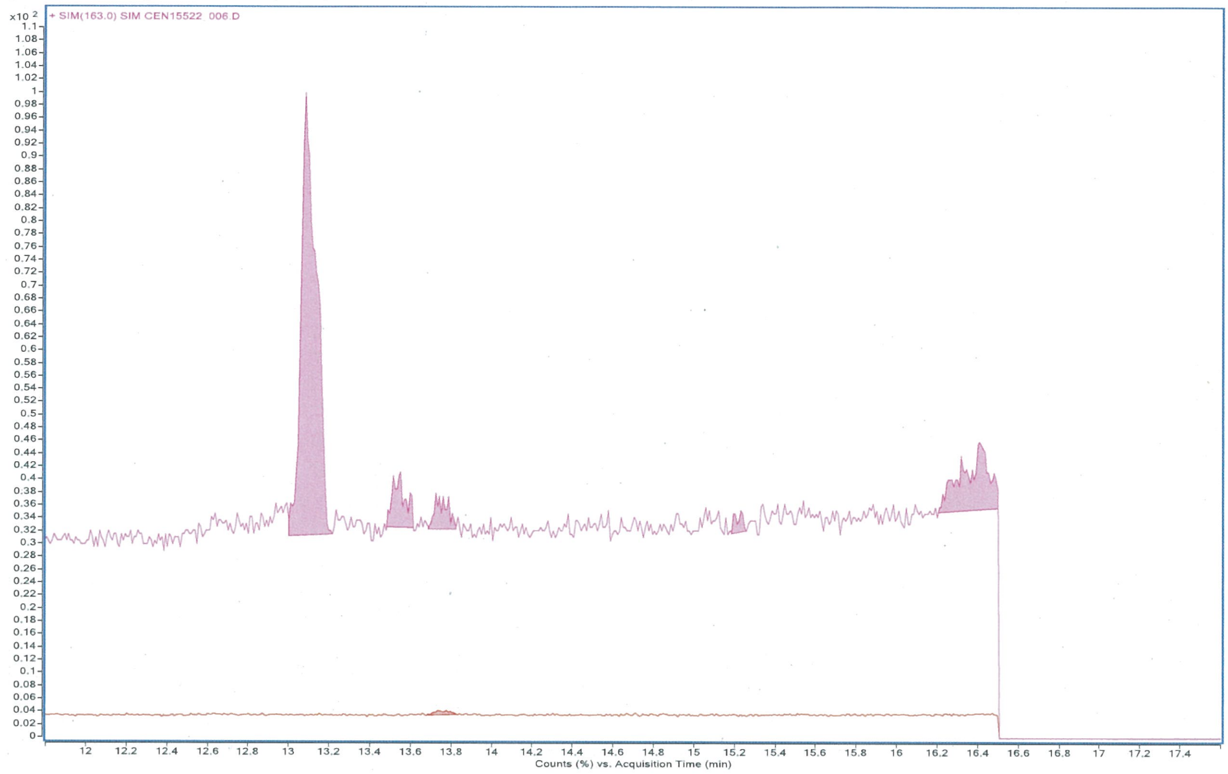


Figure 31: Reference diesel sample 20S0458/001, C3- and C4-adamantanes

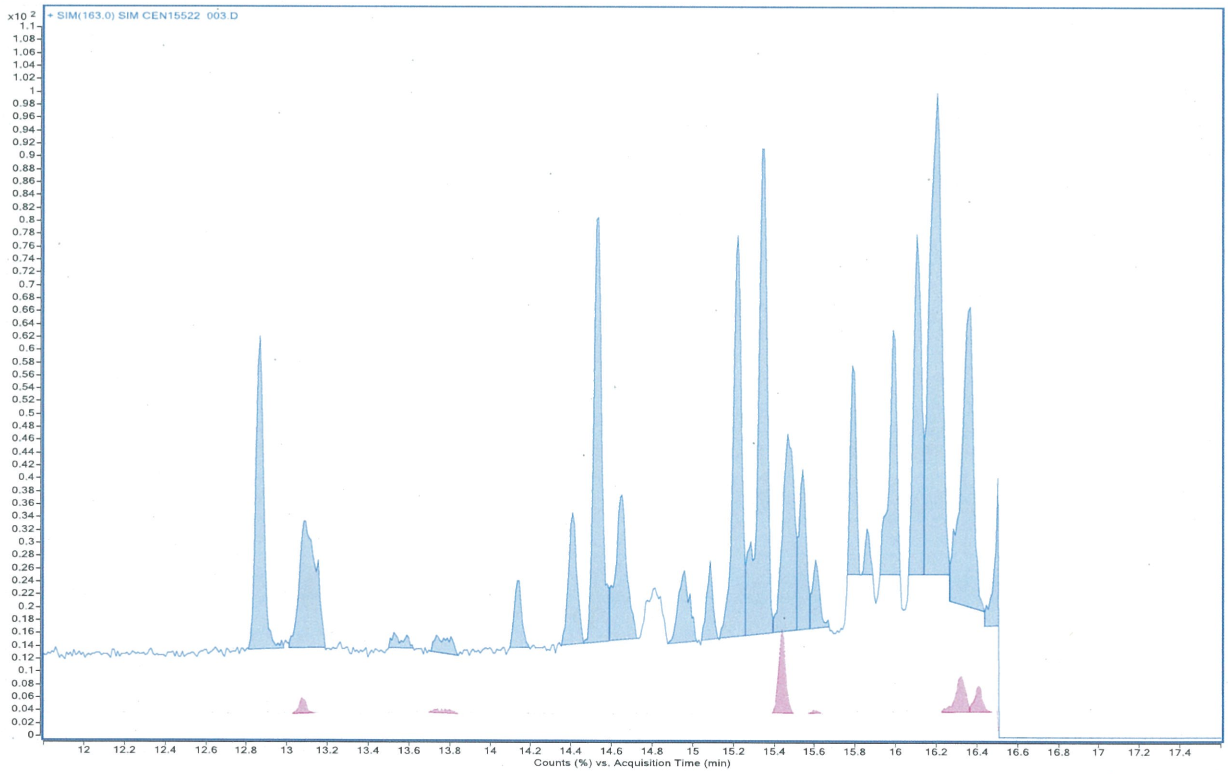


Figure 32: Sample 20S3454/001, C2- and C3-naphthalenes

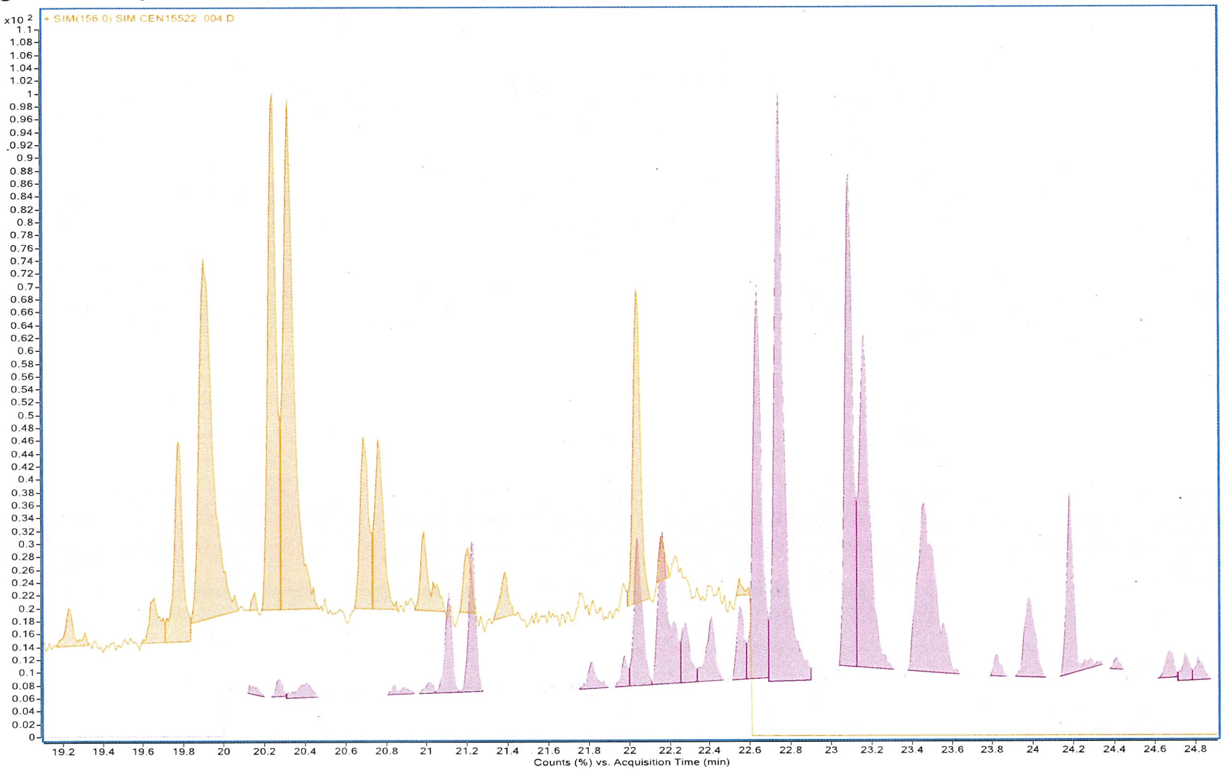


Figure 33: Sample 20S3454/002, C2- and C3-naphthalenes

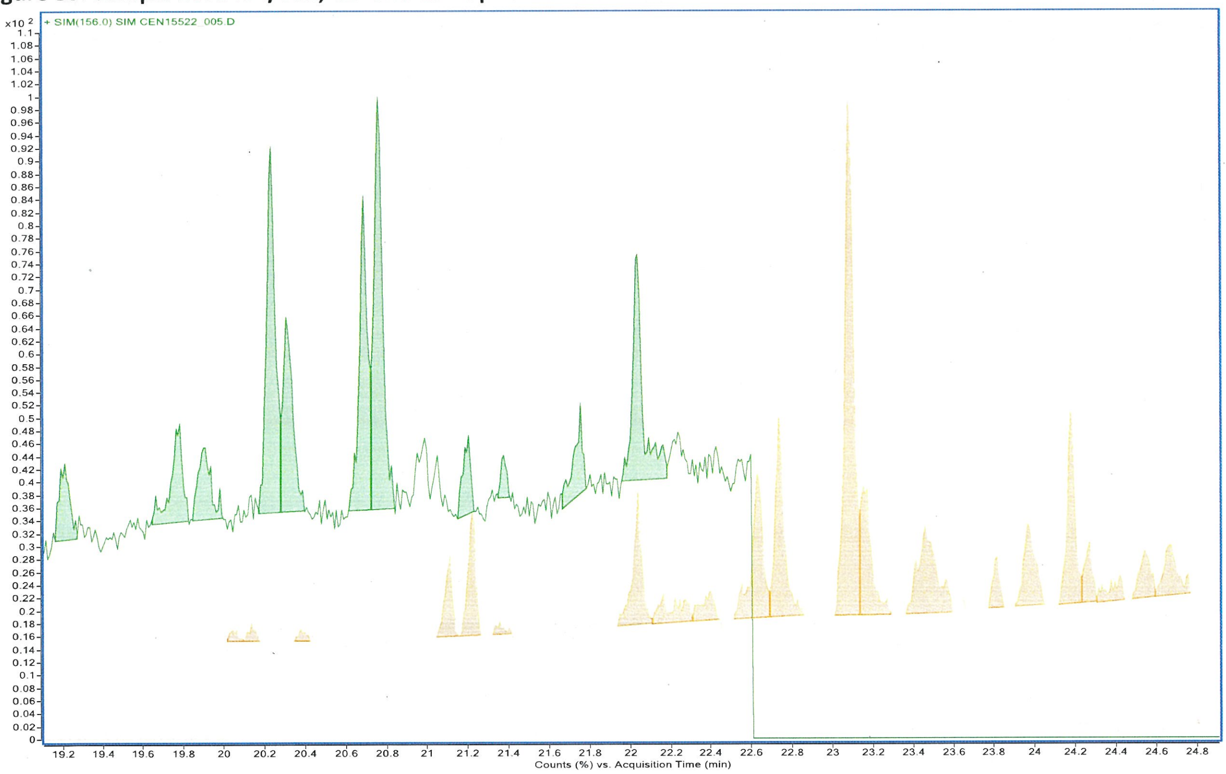


Figure 34: Sample 20S3454/003, C2- and C3-naphthalenes

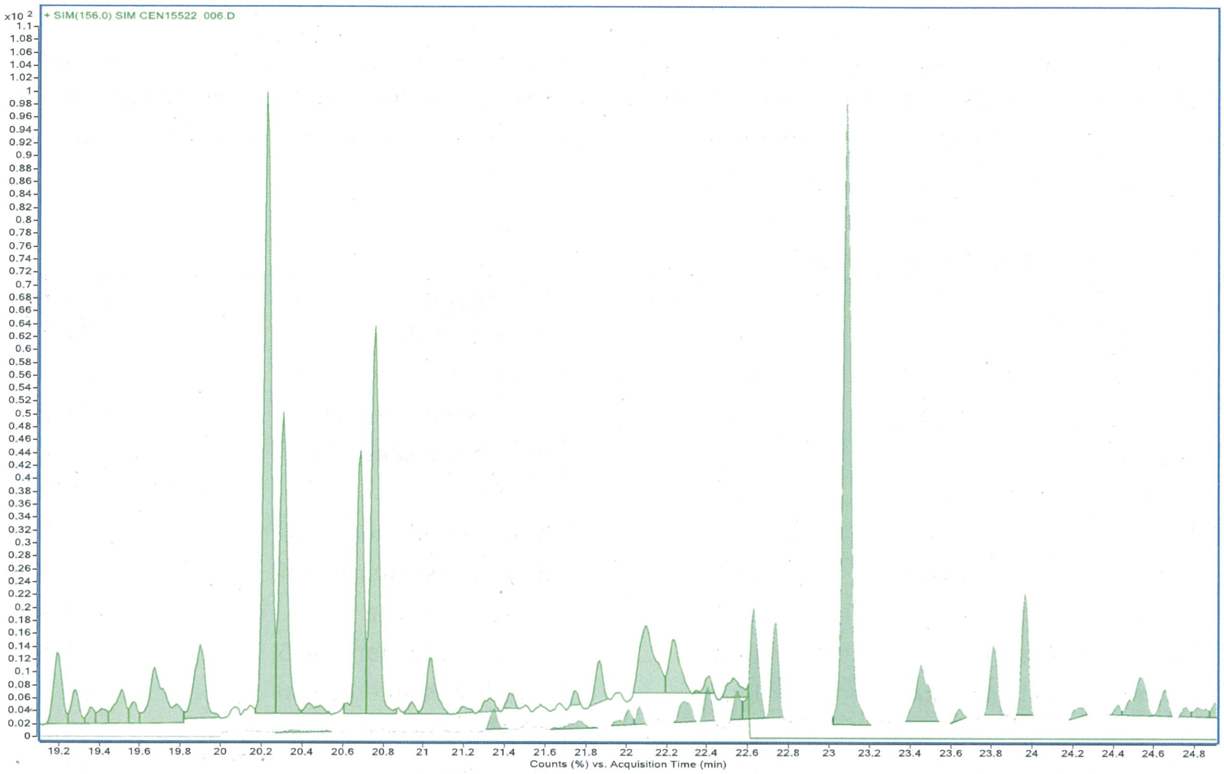
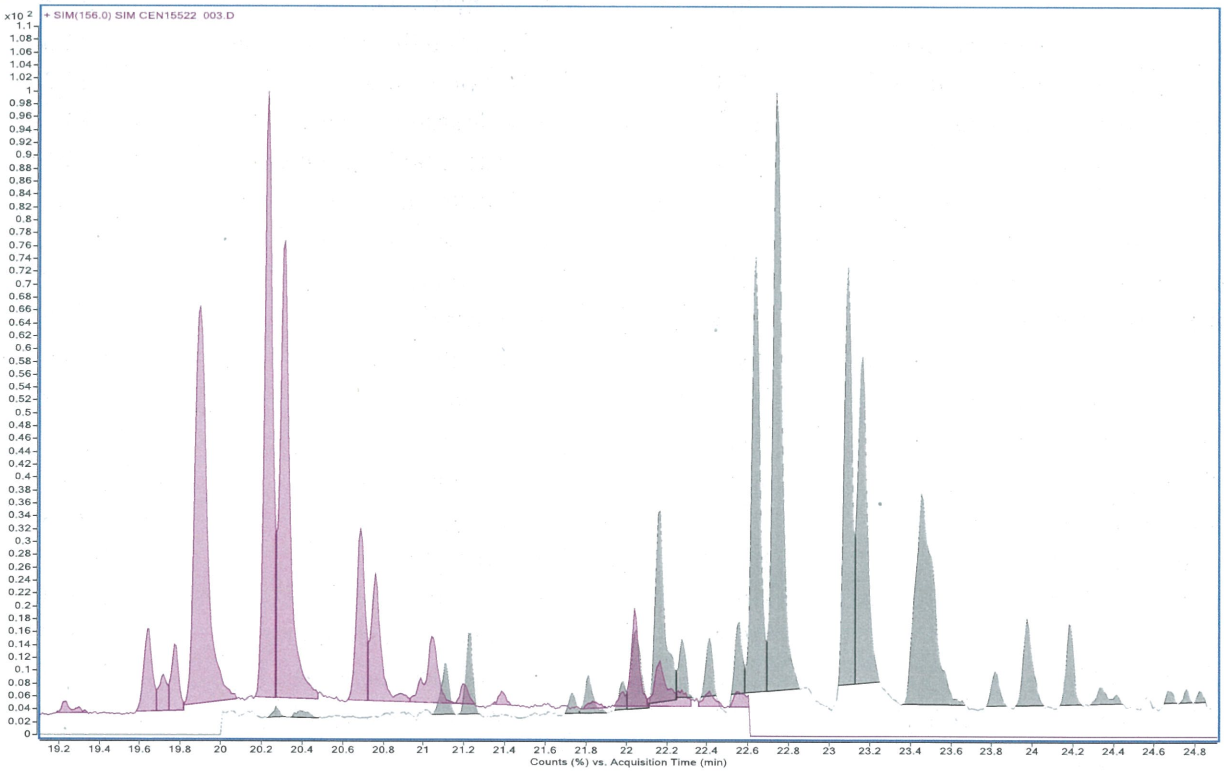


Figure 35: Reference diesel sample 20S0458/001, C2- and C3-naphthalenes



APPENDIX 5

Table 6 shows the PAHs and Biomarkers used for GC-MS SIM analysis, and GC-MS PW plots. The table also shows each compound's expected retention time when analysed under the conditions specified in Annex B of CEN/TR 15522:2, where the oven conditions are adjusted to ensure that 3-methylphenanthrene and 30ab hopane elute at 30.0 and 47.8 minutes respectively.

Table 6: PAH and biomarker compounds

Compound	RT (mins)
Decalin	10.9
1-Methyladamantane	12.1
1,3,5-Trimethyladamantane	12.8
C1-decalins	12.9
2-Methyladamantane	13.9
Tetralin	13.8
cis-1,4-Dimethyladamantane	14.2
Naphthalene	14.4
t-1,4-Dimethyladamantane	14.3
1,3,6-Trimethyladamantane	14.5
C2-decalins	15.5
1,2-Dimethyladamanatane	15.0
i-C13	15.2
2-Methyltetralin	15.3
c-1,3,4-Trimethyladamantane	15.2
t-1,3,4-Trimethyladamantane	15.3
1,2,5,7-Tetramethyladamantane	15.4
n-Hexylbenzene	16.4
i-C14	16.4
2-Ethyladamantane	16.4
1-Methylnaphthalene	17.7
Bicyclic sesquiterpane 1	18.4
m-hexyltoluene	18.7
C3-decalin range peak	18.8
Bicyclic sesquiterpane 2	18.7
n-Heptylbenzene	18.9
branched alkane 169-1	19.1
o-Hexyltoluene	19.1
i-C15 (Farnesane)	19.3
Biphenyl	19.3
2-Ethylnaphthalene	19.7
2,6- + 2,7-Dimethylnaphthalene	19.9
1,3- + 1,7-Dimethylnaphthalene	20.3
1,6-Dimethylnaphthalene	20.4
Bicyclic sesquiterpane 3	20.4
C2-Benzothiophenes	19.9

Compound	RT (mins)
Acenaphthylene	20.9
m-Heptyltoluene	21.1
1,2-Dimethylnaphthalene	21.1
branched alkane 169-2	21.1
i-C16	21.2
branched alkane 169-3	21.3
Bicyclic sesquiterpane 4	21.2
o-Heptyltoluene	21.5
Bicyclic sesquiterpane 5	21.4
Bicyclic sesquiterpane 6	21.7
n-C15	22.1
Diamantane	22.4
1,3,7-Trimethylnaphthalene	22.8
4-Methyldiamantane	22.6
1,3,6-Trimethylnaphthalene	22.8
n-Nonylcyclohexane	23.2
Bicyclic sesquiterpane 8	23.1
Bicyclic sesquiterpane 9	23.2
m-Octyltoluene	23.3
Bicyclic sesquiterpane 10	23.3
o-Octyltoluene	23.7
Norpristane	25.2
m-Nonyltoluene	25.5
n-Decylbenzene	25.8
o-Nonyltoluene	25.9
Octahydroanthracene	26.2
n-C17	26.3
Pristane (Pr)	26.4
1-Methylfluorene	26.4
Octahydrophenanthrene	26.7
n-Undecylcyclohexane	27.4
branched alkane 225-1	27.6
n-C18	28.2
Phytane (Ph)	28.4
C2-Fluorenes	28.7
branched alkane 225-2	29.3

Compound	RT (mins)
4-methyldibenzothiophene (4-MDBT)	29.2
branched alkane 225-3	29.4
m-Undecyltoluene	29.5
Dodecylbenzene	29.8
o-Undecyltoluene	29.8
n-C19	30.1
1-methyldibenzothiophene (1-MDBT)	30.0
2-methylphenanthrene (2-MP)	30.1
2-methylanthracene	30.3
1-methylphenanthrene (1-MP)	30.5
C2-dibenzothiophenes	31.5
C2-phenanthrenes	32.4
1-Ethylphenanthrene	32.2
1,7-Dimethylphenanthrene	32.8
C3-dibenzothiophenes	33.0
C21 Tricyclic diterpane	33.9
C3-phenanthrenes	34.4
2-Methylfluoranthene	34.9
C15-benzene	35.1
Benzo(a)fluorene	35.3
C4-phenanthrenes	36.8
Retene	35.4
2-Methylpyrene	35.7
4-Methylpyrene	36.1
1-Methylpyrene	36.2
Tetramethylphenanthrene	36.8
C2-fluoranthenes/pyrenes	37.9
Benzonaphthothiophene	37.9
C17-benzene	38.3
Phytanyltoluene	40.3
C1-chrysenes	40.8
Benzo(e)pyrene	44.2
Benzo(a)pyrene	44.4
C23Tr	36.7
C24Tr	37.6
C25Tr(ab)	39.2
C28 (22S)	43.1
C29 (22S)	44.0
27Ts hopane	44.7
27Tm hopane	45.2
28ab hopane	46.3
25nor30ab hopane	46.5
29ab hopane	46.8
29Ts hopane	46.9

Compound	RT (mins)
30O hopane	47.6
30ab hopane	47.8
30ba hopane	48.3
31abS hopane	48.9
30G hopane	49.4
32abS hopane	49.9
27dbS sterane	41.7
27dbR sterane	42.2
28aaR sterane	45.6
29aaS sterane	46.0
29aaR sterane	46.7
27bb(R+S) steranes	43.9
28bb(R+S) steranes	45.2
29bb(R+S) steranes	46.2
C20TA	38.7
C21TA	40.1
SC26TA	45.1
RC26TA + SC27TA	45.9
SC28TA	46.7
RC28TA	47.9

Table 7: Diagnostic ratios

1-M-Adam/1,2-DM-Adam
1-M-Adam/2-E-Adam
i-C13/2-M-tetralin
c-1,3,4-TM-Adam/2-E-Adam
C6-/C7-Benz
2-E-Adam/i-C14
BS1/BS2
C3-de peak/BS2
Bi/2-EN
2-EN/2,6- + 2,7-DMN
BS4/BS5
Br-Alk 169-3/n-C15
BS5/BS6
BS8/BS9
m-/o-C8-Tol
BS10/Norpri
Norpri/m-C9-Tol
n-C17/Pri
Pri/Phy
n-C18/Phy
4-M-Dbt/1-M-Dbt
Br-Alk-225-3/n-C19
2-MPhe/1-MPhe
MA/1-MP
C2-dbt/C2-phe
2-M-Fl/4-M-Py
C15/C17-Benz
BaF/4-M-Py
Retene/ T-M-Phe
2-M-Py/4-M-Py
1-M-Py/4-M-Py
BNT/ T-M-Phe
C23Tr/C24Tr †
27dbR/27dbS †
27bb/29bb †
27Ts/30ab †
SC26/ RC26+SC27 TA †
27Tm/30ab †
28ab/30ab †
SC28/RC26 + SC27 †
29ab/30ab †
30O/30ab †
RC28/RC26+SC27 †
31abS/30ab †
30G/30ab †

Notes:

* These ratios can be affected by biodegradation, and have been removed from comparisons of weathered samples