# PFAS solid burn trial report v.0

*26th February 2019*

**Revision register**

| Revision | Date | Issuer | Recipient | Comment |
|---|---|---|---|---|
| Draft 1 | 12/04/2019 | H Macready | J Barka | Draft |
| v.0 | 10/05/2019 | H Macready | J Barka | Separate solid burn trial report including amendments |

# Executive Summary

PFAS contaminated waste was incinerated in Adelaide under the conditions approved by the EPA and outlined in the burn plans submitted.
The trials were carried out under normal operating conditions with minimum temperatures and emissions to air, water and waste testing requirements.

On the 26th of February, 2,618kg of contaminated carbon was incinerated together with 2,975kg of medical waste during 9h40 min of operation. It was observed that the temperature on step 1 of the incinerator was highly unstable, especially after a full ash push onto step 2. In order to comply with the minimum temperature set by the burn plans, a corrective action was designed and implemented. Medical waste only was loaded into the incinerator every 4th load allowing the temperature required for PFAS loading to be reached and maintained. All licensed air emissions were compliant and no PFAS was found in the fly ash. PFBA and PFPeA were found in the stack results, however PFPeA was also found in the blank stack samples. A very high number of PFAS compounds were found in the bottom ash and leached into the quench waters. Incomplete combustion due to insufficient oxygen is the most likely cause preventing destruction of PFAS compounds . Composite sampling was also identified as a better method for assessing average contamination for the trial. Contamination of sampling equipment was shown to be occurring and the use of two different analytical laboratories would likely increase the quality control and accuracy of results. Under normal operating conditions, the incineration of PFAS contaminated carbon did not reach the 99.9999% target destruction and removal efficiency (DRE) established for persistent organic pollutants.

No complaints from the community were received during the three days of the trial. Options for the treatment and disposal of the contaminated quench waters and ashes are being investigated at the time of writing and will be communicated to the EPA via an Addendum to this report.

Going forward, a number of improvements can be reviewed and implemented in order to reach a higher DRE. One such improvement would be to engage a combustion specialist to advise on the best operating conditions for the trials to ensure complete combustion is ascertained. Another improvement would include a composite sampling programme and the use of two different analytical laboratories therefore increasing the validity of results.

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# Introduction

Incineration trials of waste contaminated with PFAS were carried out at the Veolia high temperature incinerator in Dry Creek, South Australia. Contaminated carbon was incinerated on the 26th of February.

Following extensive consultation with the EPA, burn plans were approved and implemented.

This report gives details on the quantities and properties of the waste incinerated each day, summarises operational steps, provides extensive data collected from the Continuous Emissions Monitoring and SCADA systems, laboratory analysis of bottom and fly ashes, quench waters and the results of the stack testing. The analysis of data leads to the identification of potential non compliance with the trial burn plans and actions taken to rectify them. The conclusion includes lessons learnt and if the trials were deemed successful as per criteria approved by the EPA.

# Description

The contaminated carbon was received from the Brooklyn Veolia site in Victoria and stored at the liquid plant at Kilburn in SA. The carbon was packaged into 20L (plastic) pails and the metal handles removed. Each pail was weighed and the weight recorded on the lids. The pails were placed on wooden pallets, shrink-wrapped and labelled. The pallets were then transported to the incinerator site. The day prior to the burn trial, the pails were stacked in groups of 3 or 4 depending on weight to get as close as 60kg per lift as approved in the burn trial plan.

The trial started at 7h46. Each bin lift, loading times and weights were recorded. The trial concluded at 17h26 with 2,618 kg of carbon burnt together with 2,975kg of medical waste.

# Operational details

At the beginning of the day, we encountered one main operational challenge resulting in the temperature in step 1 falling below the minimum temperature trigger of 850°C. Prior to each waste load into the furnace from the hopper, the ash pusher on step 1 completes 3 half stroke pushes at different intervals to agitate the step 1 waste to optimise combustion. The ash pusher then performs a full stroke push of step 1 waste onto step 2. As a result of this full push, there is no waste left on step 1 of the incinerator and therefore no calorific value. The gas burner on step 1 also has a purge programme that delays its firing. The combination of these two constraints led to step 1 not reaching the temperature stipulated by the trial burn plans at every 4th load ash pusher cycle. The loading of PFAS waste therefore was interrupted and only medical waste loaded. When the pattern became clear, it was decided, after the 14th cycle, to load the incinerator with only medical waste after the full ash push, removing the risk of any non-compliance with the trigger temperature on step 1.

The second minor operational challenge encountered was linked to alarms from the carbon and lime load cells. The load cells on the carbon and lime triggered alarm messages and inhibited loading as designed. The occurrences were once for lime and five times for the carbon over the course of the day. This triggered operator checks where issues were rectified allowing loading to resume.

The weights of medical and PFAS carbon were recorded together with the times the bins were lifted into

the hopper and the times the waste was loaded into the incinerator as per table below.

| Load | Waste | Time bin lift | Time load | Weight PFAS | Weight med | Load | Waste | Time bin lift | Time load | Weight PFAS | Weight med |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | PFAS | 07:46 | 07:55 | 57 | 46 | 29 | PFAS | 12:46 | 12:55 | 59 | 46 |
| 2 | PFAS | 07:56 | 08:05 | 56 | 40 | 30 | PFAS | 12:56 | 13:13 | 61 | 45 |
| 3 | PFAS | 08:06 | 08:15 | 59 | 46 | 31 | PFAS | 13:14 | 13:23 | 60 | 40 |
| 4 | PFAS | 08:16 | 08:25 | 58 | 46 | 32 | Medical | 13:24 | 13:32 | 0 | 101 |
| 5 | PFAS | 08:26 | 08:35 | 60 | 41 | 33 | PFAS | 13:34 | 13:42 | 57 | 44 |
| 6 | Medical | 08:43 | 08:52 | 0 | 84 | 34 | PFAS | 13:43 | 13:52 | 61 | 31 |
| 7 | PFAS | 08:53 | 09:02 | 58 | 42 | 35 | PFAS | 13:53 | 14:01 | 55 | 45 |
| 8 | PFAS | 09:03 | 09:12 | 57 | 43 | 36 | Medical | 14:03 | 14:11 | 0 | 103 |
| 9 | PFAS | 09:13 | 09:22 | 59 | 47 | 37 | PFAS | 14:13 | 14:22 | 60 | 45 |
| 10 | PFAS | 09:24 | 09:35 | 60 | 42 | 38 | PFAS | 14:23 | 14:32 | 56 | 47 |
| 11 | PFAS | 09:38 | 09:44 | 61 | 42 | 39 | PFAS | 14:33 | 14:41 | 60 | 45 |
| 12 | PFAS | 09:46 | 09:54 | 56 | 41 | 40 | PFAS | 14:43 | 14:57 | 61 | 32 |
| 13 | PFAS | 09:57 | 10:05 | 59 | 43 | 41 | PFAS | 14:59 | 15:08 | 59 | 44 |
| 14 | PFAS | 10:08 | 10:15 | 60 | 38 | 42 | PFAS | 15:09 | 15:18 | 61 | 48 |
| 15 | Medical | 10:18 | 10:26 | 0 | 110 | 43 | PFAS | 15:19 | 15:28 | 58 | 51 |
| 16 | PFAS | 10:27 | 10:35 | 61 | 41 | 44 | Medical | 15:29 | 15:37 | 0 | 74 |
| 17 | PFAS | 10:37 | 10:45 | 61 | 40 | 45 | PFAS | 15:38 | 15:47 | 61 | 46 |
| 18 | PFAS | 10:47 | 10:53 | 53 | 44 | 46 | PFAS | 15:48 | 15:57 | 57 | 50 |
| 19 | PFAS | 10:59 | 11:10 | 50 | 50 | 47 | PFAS | 15:58 | 16:07 | 59 | 54 |
| 20 | Medical | 11:11 | 11:20 | 0 | 101 | 48 | Medical | 16:08 | 16:16 | 0 | 99 |
| 21 | PFAS | 11:23 | 11:30 | 57 | 52 | 49 | PFAS | 16:17 | 16:26 | 59 | 47 |
| 22 | PFAS | 11:33 | 11:41 | 57 | 47 | 50 | PFAS | 16:27 | 16:35 | 58 | 39 |
| 23 | PFAS | 11:42 | 11:57 | 59 | 50 | 51 | PFAS | 16:37 | 16:45 | 58 | 43 |
| 24 | Medical | 11:58 | 12:07 | 0 | 96 | 52 | Medical | 16:47 | 16:55 | 0 | 104 |
| 25 | PFAS | 12:07 | 12:15 | 56 | 45 | 53 | PFAS | 16:57 | 17:05 | 59 | 55 |
| 26 | PFAS | 12:17 | 12:26 | 57 | 41 | 54 | PFAS | 17:06 | 17:16 | 60 | 42 |
| 27 | PFAS | 12:28 | 12:36 | 50 | 43 | 55 | PFAS | 17:17 | 17:26 | 58 | 52 |
| 28 | Medical | 12:38 | 12:45 | 0 | 102 | | | | TOTAL | 2,618 | 2,975 |

# Temperatures from SCADA

All the temperatures were recorded and the graphs are included in Appendix 1.

Several non-compliances were recorded, compared to the loading times and analysed:

| Item | Time of non compliance | Comment |
|---|---|---|
| Step 1 | Between 7:46 and 8:30 with a minimum of 691ºC at 8:20 | 4 loads of PFAS, all other steps compliant. No PFAS during minimum temperature. Lowest temperature with PFAS loading estimated at around 800ºC. |
| Step 1 | Between 9:06 and 9:36 with a minimum of 724ºC at 9:10 | 3 loads of PFAS, all other steps compliant except step 4 at loading time. Lowest temperature with PFAS loading estimated at around 750ºC. |
| Step 1 | Between 9:50 and 10:50 with a minimum of 592ºC at 10:40 | 5 loads of PFAS, all other steps compliant//full push identified//medical load decided. Lowest temperature with PFAS loading estimated at around 800ºC (sharp drop to minimum and sharp lift) |
| Step 1 | Between 11:15 and 11:25 with a minimum of 738ºC at 11:20 | no PFAS loaded |
| Step 1 | At 13:26, 824ºC | no PFAS loaded |
| Step 1 | Between 13:54 and 14:20 with a minimum of 808ºC at 14:10 | 1 load of PFAS, all other steps compliant. Lowest temperature with PFAS loading estimated at around 810ºC. |
| Step 1 | Between 14:43 and 15:27 with a minimum of 782ºC at 14:50 | 3 loads PFAS, all other steps compliant. Lowest temperature with PFAS loading estimated at around 790ºC. |
| Step 1 | At 15:30, 807ºC | no PFAS loaded |
| Step 1 | At 16:20. 735ºC | no PFAS loaded |
| Step 2 | At 11:20, 828ºC | no PFAs loaded |
| Step 4 | At 9:10, 733ºC | no PFAS loaded |
| PC chamber | Between 7:59 and 8:16 with a minimum of 945ºC at 8:10 | 1 load of PFAS, Step 1 non compliant. Lowest temperature with PFAS loading estimated at around 1,090ºC. |

The majority of the non-compliances impacted step 1. Indeed, step 1 has a direct opening on the hopper and cools down after each load. Moreover, it was identified that the gas burner has a longer purge time compared to the other burners, delaying its activation when the temperature dropped under the trigger set in the programme. It also took some time to identify the impact of the full ash push every 4$^{th}$ load and implement the corrective action of loading only medical waste after every full ash push. The corrective action could not be implemented straight away as the operators routinely prepare 3 loads after each bin lift and are logged in the bin scale system in advance. This resulted in a delay to replace a PFAS load with a medical only load to assist in temperature recovery.

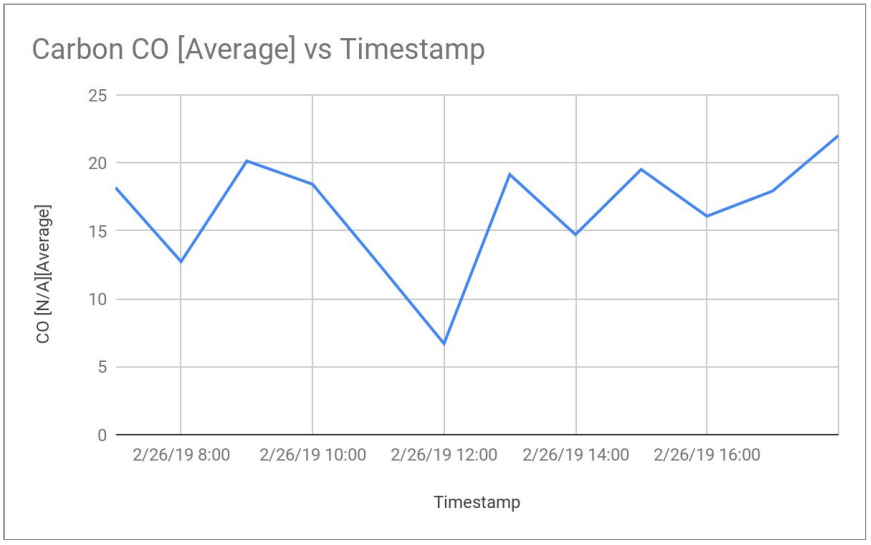
The main non compliance potentially having an impact on the destruction efficiency is the combined temperature non-compliance of step 1 and the post combustion chamber. But at the time of loading PFAS waste at 8:15, step 1 was at 800ºC and the post combustion chamber just under 1,100ºC having recovered from a significant drop in temperature. The PC chamber temperature drop could not easily be explained and not necessarily related to the low temperature on step 1 as the heat dynamics are different (solid versus gas). The gas burners in the PC chamber are very efficient and the temperature

profile shows a sharp drop followed by a sharp lift. The PC chamber temperature was then maintained above the trigger by the production of carbon monoxide from the primary chamber and the gas burners.

# Emissions from CEMS

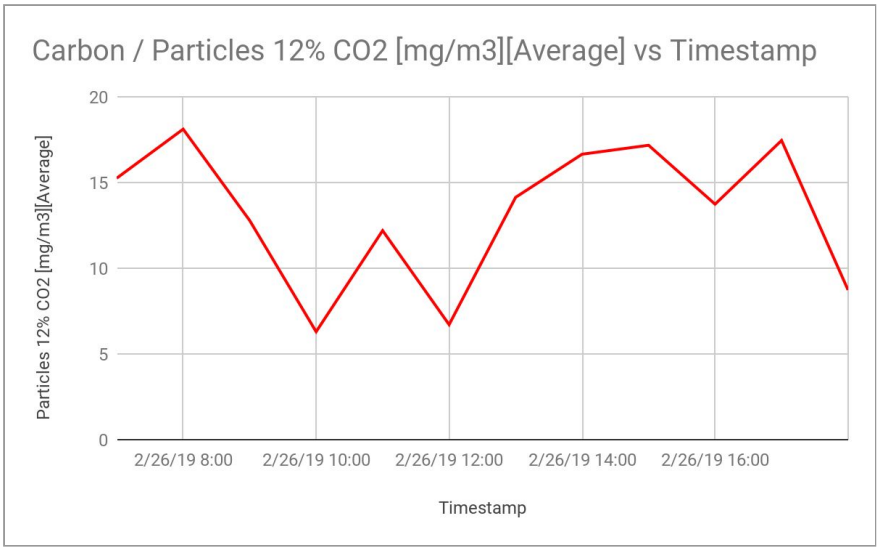
All the emissions recorded by the CEMS were also plotted against PFAS carbon loading times.

## CO (Limit 150 mg/m$^3$)



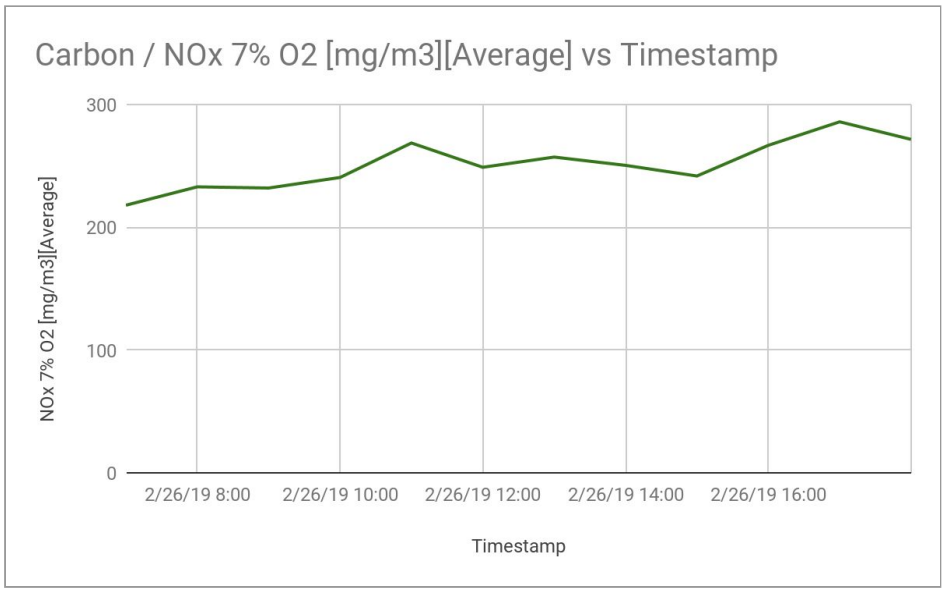

The measured emissions of carbon monoxide during the carbon trial burns were compliant with the EPA licence. No notable peaks could be noticed corresponding to the influence of PFAS injected.

## Particles (Limit 70 mg/m$^3$ corrected)



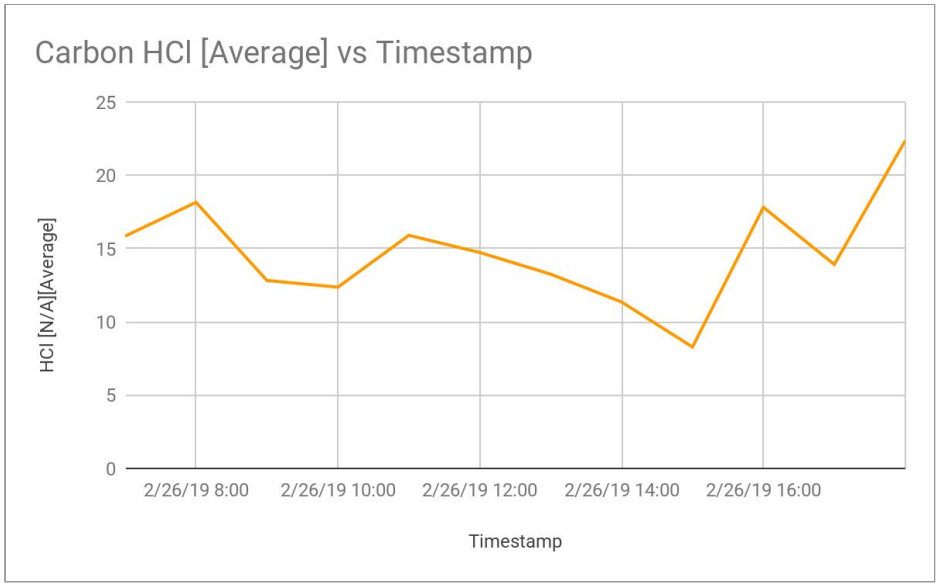

The emissions of particles were compliant with the EPA licence limits throughout the day.

# NOx (Limit 500 mg/m$^3$ corrected)



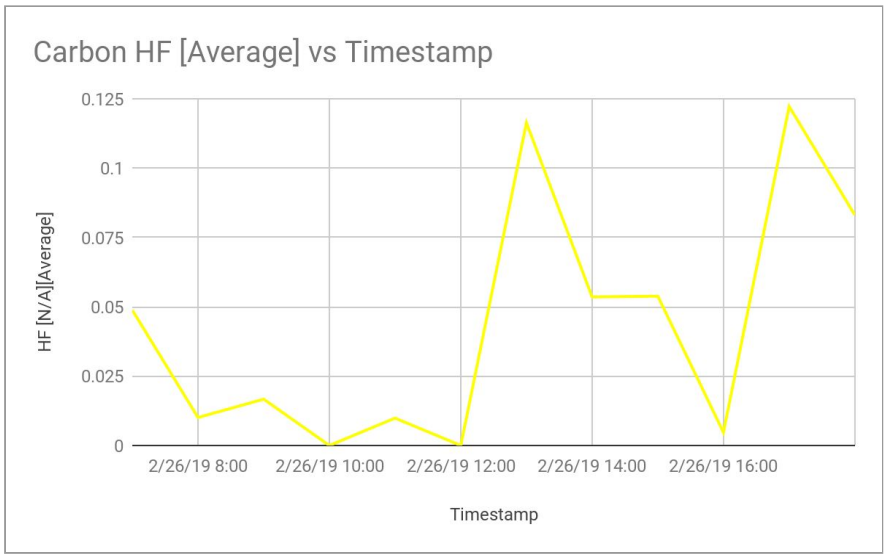

The NOx emissions were compliant with the licence limits during the trial.

# HCl (Limit 50 mg/m$^3$)



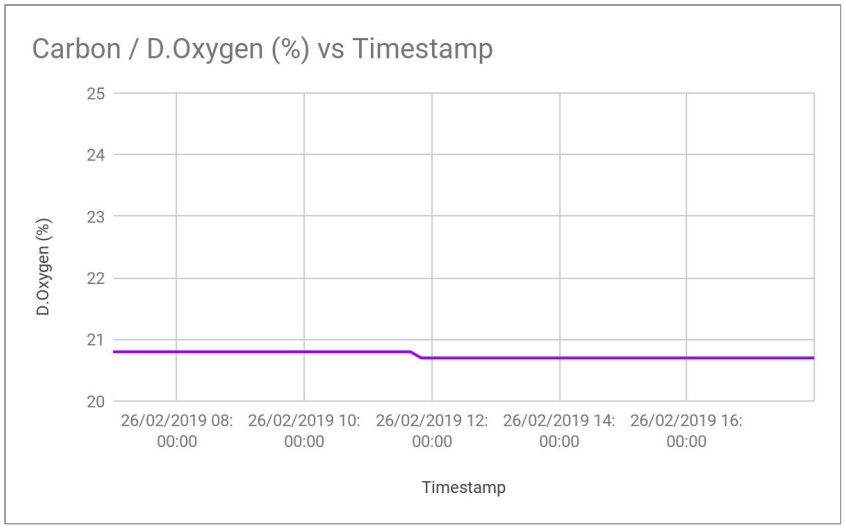

The HCl emissions are compliant with the licence limits with no noticeable peak.

# HF (Limit 5 mg/m$^3$)




The HF emissions were compliant with the licence limits with two peaks around 13:00 and 17:00 both corresponding to a carbon inhibit message linked to poor loading of chemicals in the scrubbing system.

# $O_2$ (10% volume in stack)




The level of oxygen in the combustion gases were compliant with the 10% minimum limit.

# Bottom/Fly ashes and quench waters analytical results

Samples of bottom/fly ashes and quench waters were taken during the trial. The quench water samples were taken at midday and at the end of the day. The bottom and fly ash samples were taken in duplicates at the end of the day. They were tested for 28 PFAS suite, TOPA 28 PFAS suite and TOF as per trial burn plans. The full analytical results are attached in Appendix 2. The samples IDs were:

- QCAR 26/02-1 Quench water, carbon trial, 26/02, midday
- QCAR 26/02-2 Quench water, carbon trial, 26/02, end
- BCAR 26/02-1 Bottom ashes, carbon trial, 26/02
- BCAR 26/02-2 Bottom ashes, carbon trial, 26/02, duplicate
- FACAR 26/02 -1 Fly ashes, carbon trial, 26/02
- FACAR 26/02 -2 Fly ashes, carbon trial, 26/02, duplicate

No detectable amount of PFAS were found in the fly ash. The quench waters and bottom ashes contained PFAS compounds above the laboratory limit of detection and are summarised in the table below.

| PFAS | LOR | Unit | Bottom ashes 1 BCAR 26/02-1 | Bottom ashes 2 BCAR 26/02-2 | LOR | Unit | Quench waters 1 QCAR 26/02-1 | Quench waters 2 QCAR 26/02-2 |
|---|---|---|---|---|---|---|---|---|
| 8:2 FTSA | 5 | µg/kg | 98 | 230 | 0.01 | µg/L | 0 | 0 |
| 4:2 FTSA | 5 | µg/kg | 6 | 6.2 | 0.01 | µg/L | 0 | 0 |
| 6:2 FTSA | 10 | µg/kg | 7400 | 17000 | 0.05 | µg/L | 2.2 | 0.22 |
| PFBA | 5 | µg/kg | 1400 | 5000 | 0.05 | µg/L | 2.4 | 170 |
| PFPeA | 5 | µg/kg | 2500 | 9700 | 0.01 | µg/L | 1.9 | 53 |
| PFHxA | 5 | µg/kg | 7800 | 25000 | 0.01 | µg/L | 1.5 | 30 |
| PFHpA | 5 | µg/kg | 900 | 2100 | 0.01 | µg/L | 0.03 | 0.53 |
| PFNA | 5 | µg/kg | 36 | 78 | 0.01 | µg/L | 0 | 0 |
| PFOA | 5 | µg/kg | 2100 | 5300 | 0.01 | µg/L | 0.04 | 0.26 |
| FOSA | 5 | µg/kg | 19 | 21 | 0.05 | µg/L | 0 | 0 |
| PFBS | 5 | µg/kg | 1500 | 5000 | 0.01 | µg/L | 0.27 | 8.4 |
| PFPrS | 5 | µg/kg | 360 | 1800 | 0.01 | µg/L | 0.03 | 17 |
| PFPeS | 5 | µg/kg | 2700 | 6600 | 0.01 | µg/L | 0.06 | 1.3 |
| PFHxS | 5 | µg/kg | 13000 | 32000 | 0.01 | µg/L | 0.29 | 2 |
| PFHpS | 5 | µg/kg | 1200 | 3000 | 0.01 | µg/L | 0.01 | 0 |
| PFOS | 5 | µg/kg | 5900 | 18000 | 0.01 | µg/L | 0.07 | 0.15 |

The two bottom ash samples have returned very different results raising the possibility of a hot spot detection in sample 2. This could only be confirmed if more sampling of the ash was carried out.

# Stack testing results

During the carbon burn trial, the stack was tested for total solid particles, CO, NOx, HCl. HF, heavy metals, mercury, lead and dioxins and furans as per EPA licence conditions. PFAS and PFAS TOP were also performed. The full report is attached in Appendix 3.
In summary, the incinerator was compliant with all air emissions listed in the EPA licence.
Some PFAS were detected in the stack as per table below:

| PFAS | Result (ng/Nm$^3$) | Blank result (ng/sample) | Reference | Emission rate (g/min) |
|---|---|---|---|---|
| Perfluorobutanoic acid (PFBA) | 1.3 | <1.0 | STP | 3.8E-07 |
| Perfluoropentanoic acid (PFPeA) | 1.7 | 2.7 | STP | 5.0E-07 |

It should be noted that the uncertainty measurement in the stack is +/-30% (refer to Appendix 3, Table 23) and that PFPeA was found in the blank samples throughout the trial.

# Destruction Removal Efficiency (DRE)

A DRE for this trial could not be calculated as the total amount of PFAS in the bottom ashes exceeded the total amount of PFAS in the waste burnt. Refer to Appendix 4. This could be due to a number of combined or independent factors:

- Incomplete combustion (no production of CO) in the primary chamber due to a lack of $O_2$, leading to a recombination of PFAS molecules with a source of additional fluorine (potentially in the co-burnt medical waste or fluoride ions in the cooling water), and/or;
- Unburnt carbon containing concentrated amount of PFAS found in the ashes, and/or;
- A lack of comprehensive sampling of the waste and ashes could lead to the detection of hot spots, a composite sample might be more representative of the average contamination levels and/or;
- An error at the analytical lab.

# Conclusion

Although step 1 of the incinerator had several temperature non-compliances with the burn plan and corrective action was difficult to identify and implement, the PFAS carbon was exposed to the required temperatures on steps 2, 3 and 4 for a minimum of 2h, (on the assumption made in the burn plan that the transfer from one step to the following step provided sufficient mixing and exposure to heat). The emissions in the stack were all compliant with the EPA licence and a small amount of PFAS was detected in the samples as well as in the blanks. We can therefore assume that the scrubbing system performed well.
The large quantity of PFAS found in the bottom ashes and that leached in the quench water is unlikely to be due to temperature settings or the scrubbing system. At these trial temperatures, activated carbon should not have been found in the ashes. The photos in Appendix 5 show a large amount of carbon, indicating incomplete combustion likely due to a lack of stoichiometric $O_2$ required to achieve complete

combustion. The operators also reported a larger amount of unburnt medical waste during the day, which could confirm the hypothesis of incomplete combustion due to a lack of $O_2$. The trial was therefore unsuccessful.

## Condition U-705 of EPA Licence 2672

### Site suitability

The site was suitable for the receipt and storage of the PFAS contaminated carbon and enough space was available to set up the pails for half a day of incineration. The site was also suitable for the discharge of ashes and quench waters for the trial.

### Equipment suitability

- The bin lifter and hopper were suitable for the loading of PFAS carbon packaged in 20L pails. The operators did not report any issues related to loading the waste in the incinerator.
- The equipment was able to maintain the temperatures above the triggers except for the occurrences detailed in section “Temperature from SCADA”. The co-incineration of medical waste was instrumental in keeping the temperatures in the range specified in the burn plans.
- The lime and carbon load cells also worked well and inhibited loading of waste when an alarm was on.
- The amount of PFAS found in the bottom ashes reveals that not all carbon was combusted. This is likely to be due to a lack of stoichiometric oxygen in the primary chamber leading to poor CO production. Air lines are available above each step of the primary chamber to vary its injection during incineration in the future.

### Emissions compliance (conditions U-88 and U-87)

All air emissions were compliant with the conditions listed in the EPA licence.

# Final Recommendations

The successes and lessons learnt from the trial days are summarised below.

## Successes

1. Loading of the PFAS waste and communication with the operators went smoothly.
2. The cause of temperature drop on step 1 was identified and corrective action implemented with successful results.
3. Communication with the stack testing operators was efficient.
4. Air emissions where all compliant with the conditions listed in the current EPA licence, especially HF and dioxins, proving the efficiency of the scrubbing system.

## Challenges

1. Temperature on step 1 of the incinerator is unstable and medical waste needs to be loaded on its own after every full ash push to assist the burners.
2. The gas burner on step 1 has a long purge cycle and does not fire promptly after a temperature drop requiring extended time to recover.
3. The high carbon content of the waste consumed more oxygen than during normal operation and

we suspect that carbon monoxide was not allowed to form in the primary chamber resulting in a recombination of PFAS compounds and high concentration in the ashes.

4. Spot sampling revealed hotspots in both the waste and the ash media leading to inconsistent analytical results.

# Actions

1. The remaining 79 x 20L pails of contaminated waste will be stored at the Kilburn liquid plant awaiting decision for a potential second trial;
2. The treatment and disposal of quench waters and ashes is currently being investigated and will be communicated via an Addendum to this report.

# Lessons learnt

If another burn trial of solid was carried out, the following actions would be implemented:

1. Improve labelling;
2. Improve segregation of ash, quench waters and fly ash to allow further additional sampling and a more detailed conclusion;
3. Always load medical waste only after a full ash push on step 1 in order to maintain the required temperature on step 1;
4. Consideration for a shorter purge cycle on the gas burner of step for more accurate temperature control;
5. Engage a combustion specialist for advice on the optimum $O_2$ content in the primary and secondary chambers for complete combustion of waters without compromising the licensed air emissions as well as providing a complete assessment of the equipment's suitability to incinerate PFAS contaminated carbon;
6. Sample the waste, ash and quench waters using composite samples to better represent the average PFAS contamination throughout the media and engage an analytical lab in the planning process;
7. Ensure the external laboratory analytical method is quality checked by sending duplicate samples to different providers.

# Appendix list

Appendix 1: Carbon trial temperature recording
Appendix 2: Ashes and quench waters analytical results
Appendix 3: Stack testing report
Appendix 4: DRE calculation for carbon trial
Appendix 5: Photos