UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

OFFICE OF
AIR QUALITY PLANNING
AND STANDARDS

Mr. David Barron
Chief Technology Officer
Sniffer Robotics, LLC
330 E. Liberty St.
Ann Arbor, MI 48104

12/15/2022

Dear Mr. Barron:

I am writing in response to your letter dated December 9, 2021 and the additional information received on March 29, 2022 and July18, 2022, on behalf of your company Sniffer Robotics, LLC as well as owners and operators subject to Federal landfill regulations, in which you seek broad approval of a new test method for determining compliance with the surface methane operational standards in Federal landfill regulations. You propose this new method as an alternative to the surface emission monitoring procedures currently set forth in the following Federal landfill regulations:

- 40 CFR Part 60, Subparts WWW, XXX, and Cf (Emission Guidelines),
- 40 CFR Part 62, Subpart OOO (Federal Plan), and
- 40 CFR Part 63, Subpart AAAA.

The U.S. Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards is the delegated authority for approval/disapproval determinations on any major alternatives to test methods and other compliance determination procedures required under 40 CFR parts 59, 60, 61, 63, and 65 as well as Federal Plans under 40 CFR part 62.[1]

Background

The Federal landfill regulations (40 CFR Part 60, Subparts WWW, XXX, and Cf, 40 CFR Part 62, Subpart OOO, and 40 CFR Part 63, Subpart AAAA) all contain similar requirements for the surface emission monitoring (SEM) test procedures; the specific citations for these requirements for each subpart are listed in Table 1. These provisions require that certain affected landfills -- some with a gas collection and control system installed to comply with applicable landfill standard -- must perform SEM test procedures on a quarterly basis to demonstrate compliance with a 500 parts per million (ppm) above background concentration operational standard at the surface of the landfill. The SEM test procedures involve using a detector to (1) traverse the entire perimeter of the gas collection area, (2) traverse a pattern on the landfill collection area at a maximum of 30-meter intervals, and (3)

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[1] The part 62 general provisions incorporate section 60.8(b) by reference.

sample areas of the landfill where visual observations indicate elevated concentrations could be present such as distressed vegetation or cracks or seeps in the landfill cover. Areas of the landfill with steep slopes or other dangerous areas may be excluded.

The traverses/sampling must be conducted using a portable organic vapor analyzer, flame ionization detector, or other portable monitor meeting the specified criteria in each subpart and procedures in Method 21 (40 CFR 60, appendix A) with the exception that methane replaces 'VOC' as the target analyte (see Table 1) and as the calibration gas. The methane detector is calibrated prior to each day of application to a landfill using a nominal 500 ppm methane in air reference gas. When sampling, the probe inlet must be 5-10 cm above the surface of the landfill.[2] As per Method 21, Section 8.3.1, if an increased meter reading is observed, the area is slowly sampled until the maximum meter reading is obtained. The probe inlet is held at this maximum reading location for approximately two times the instrument response time. If the maximum observed meter reading is greater than the operational standard of 500 ppm above the background methane concentration, the location must be marked, and the concentration recorded and reported as an exceedance as required by the applicable subpart.

Table 1. Sections in 40 CFR Parts 60, 62, and 63 Addressing SEM for Landfills

40 CFR Part	Subpart	Relevant Testing Provision Citations
60	WWW	§§60.753(d) and 60.755(c) – (e)
60	XXX	§§60.763(d) and 60.765(c)-(d)
60	Cf	§§ 60.34f(d) and 60.36f(c)-(e)
62	OOO	§§62.16716(d) and 62.16720
63	AAAA	§§63.1958(d) and 63.1960(c)-(d)

<u>Proposed Alternative Test Method</u>

According to the information provided, you are requesting approval for use of an unmanned aerial system (UAS)-based alternative method to conduct the SEM. Your alternative seeks to replicate the SEM-related testing requirements including Method 21 in the referenced Federal landfill regulations to the extent possible but use a UAS based approach in order to improve safety and performance by automating a portion of the SEM procedures. You state that Sniffer Robotics' approach to SEM produces results adequate to determine compliance with the surface methane operational standard as required by the definitions of an alternative test methods in 40 CFR 60 §60.2 while providing better precision and control of the SEM operation and greatly reducing the operator safety risks inherent in the currently deployed SEM procedures.

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[2] Note: For sampling conducted for Tier 4 landfills under Subparts Cf, OOO, and AAAA, the probe inlet must be no more than 5 cm above the surface of the landfill and certain additional wind conditions must be met; Tier 4 sampling is not being addressed by this determination.

You explain that the proposed UAS-based approach consists of a two-step method: first, the UAS carrying a methane detector payload, compliant with Method 21, traverses the landfill along properly spaced traverse routes with the detector sampling the landfill surface per the Federal landfill regulations in order to identify any areas with increased methane detector readings – you propose to define these as greater than 200 ppm methane – and, second, the areas of increased readings are manually sampled by an operator on the ground using the existing Method 21 compliance procedures described above where the area is slowly sampled until the maximum meter reading is obtained and exceedances are marked and documented.

Along with your request, you have provided a detailed methodology for conducting your proposed alternative presented in EPA method format based on Method 21. The proposed method follows Method 21 and the provisions in the referenced subparts with the following key modifications:

- Use of UAS-based sampling system to traverse the landfill and detect elevated levels of methane. This includes a longer probe to reach from the ground to the UAV and a specially designed weighted ground level sampling system to ensure contact with the ground and that the distal end of the nozzle (or inlet) is within 10 cm of the landfill surface.

- The UAS, along with the modified Method 21 system, carries a data acquisition system for logging GPS coordinates, time/date, methane concentration and a camera so the operator may discern elevated concentrations of landfill gas, such as distressed vegetation, cracks or seeps in the landfill cover, and cover penetrations. The UAV system is programmable to conduct the landfill traverses automatically and also controllable by the operator in case it is necessary to deviate from the traverse such as to investigate areas of possible elevated methane concentrations.

- Addition of a definition for the concept of 'increased meter reading' in Method 21 as 200 ppm methane; when an increased meter reading is observed or recorded by the UAS data system the condition triggers a ground-based Method 21 survey conducted by a technician on foot of the landfill area within 15 meters of where the increased meter reading was detected as per Section 8.3.1 of Method 21.

- Addition of procedure to be used once operator notes indications of elevated concentrations of landfill gas in which the traditional surface emissions monitoring is done in a spiral pattern out from area of elevated concentration.

- UAS is moved upward by operator to avoid obstacles (standing water, deep mud, excessively dense vegetation, etc.) similar but not identical to how Method 21 operators on foot will circumvent these types of obstacles.

Justification

As justification for your alternative method, you first explain that the current SEM procedures are physically demanding and laborious. You claim that, in practice, the industry standard SEM procedures consist of an operator on foot, carrying the required detector that meets the Method 21 performance criteria, along paths tracking the entire perimeter and traverses separated by 30 meters over the landfill gas collection area. Considering an average landfill size requiring the SEM is 100 acres, an operator will end up walking about 15 miles in varying environmental and weather conditions (snow/ice/rain/extreme temperatures) over varying terrain with steep slopes and dense vegetation. You note there are many slip, trip, and fall hazards as well as wild animals (e.g., snakes, dogs, alligators, rats) and dangerous/nuisance vectors (e.g., ticks, scorpions) as well as exposure to landfill gases. An operator must monitor the output of the detector while maintaining the traverse path (typically using a GPS device) and ensuring that the probe nozzle position is at the proper height above the landfill surface. A typical SEM quarterly inspection requires two technicians due to the physical demands. You also note that the Federal landfill regulations do not necessarily mandate that the SEM be performed by an operator while walking.

As further justification, you also claim several additional deficiencies in the industry standard SEM procedures including:

- Potential injury, lost time, and increased costs caused by the safety and health concerns detailed above.
- As allowed by the subparts, sections of the landfill may be omitted from the SEM due to steep slopes and other safety concerns.
- There is a high degree of subjectivity in the current SEM procedures due to inherent biases and preferences of the SEM operators.
- There is a high degree of variability in conducting the SEM scan, therefore, results may not always represent actual conditions; for example, the SEM walking path is imprecise resulting in significant gaps in the 30-meter spacing.

To support your contention that Sniffer Robotics' UAS-based alternative approach to SEM produces results adequate to determine compliance with the surface methane operational standard in the subparts listed in Table 1 while providing better precision and control of the SEM operation, you have provided the results of two studies that you conducted in your report entitled 'SEM Alternative Method Adequacy Testing'.

The first study you provided presents data from side-by-side testing conducted using the existing SEM compliance test procedures required under the Federal subparts compared to your proposed UAV-based alternative method. The two methods were applied in a field test covering a known 11-acre swath of landfill surveyed multiple times in a tight temporal window (one day) to reduce environmental variability. The test program was conducted to look at the probability of finding an increased meter reading per the existing SEM compliance test method as compared to the proposed UAS alternative method; the existing SEM compliance test method was performed as described in the 'Background' section above. The UAS-based alternative method was also performed according to the existing SEM procedures with the exceptions listed in the 'Proposed Alternative Test Method' section. Both methods used the same SEM traverse route with 15-meter spacing, but the UAV-based alternative method used the waypoints loaded into a flight computer on the UAS to fly programmatically. Testing was performed on March 17, 2021 (cloudy, 50° F, 15 mph wind max, and barometric pressure of 29.35 in. Hg). The existing SEM compliance test method was performed twice (surveys a and b) while the UAS-based alternative method was performed four times (surveys 1- 4). The UAS flew at 3.35 meters per second (7 mph), operated with a instrument response time of 1 second and data output frequency of 3 Hz, resulting in an ground sample interval of 3.35 feet and a datapoint output every 1.12 meters. The exceedance localization procedure required under Method 21, Section 8.3.1, which is conducted when an increased meter reading is observed to locate the maximum reading, was not performed. The data from the SEM compliance test method and the UAS alternative method (taking response time into account) surveys were plotted on maps for methane concentrations <200 ppm, ≥200 ppm and <500 ppm, and ≥500ppm. Table 2 below summarizes the results of these surveys. The results show that the surveys performed using the UAS-based alternative method were more effective at identifying increased meter readings (60%) when compared to the existing SEM compliance test method. Also, even without performance of the maximum concentration localization step from Method 21, Section 8.3.1, the UAS-based alternative method identified more 'exceedances' than the existing SEM compliance test method.

Table 2. Results of Side-by-Side Testing – Existing SEM Procedures vs UAV-Based Alternative

	Number of Increased Meter Readings (200 – 499 ppm)	Number of Exceedances (≥500 ppm)	Total Readings (≥200 ppm)
Existing SEM a	7	1	8
Existing SEM b	9	0	9
UAS-based Alt 1	8	5	13
UAS-based Alt 2	16	2	18
UAS-based Alt 3	12	3	15
UAS-based Alt 4	13	1	14

As you note, from a visual review of the maps of increased meter readings/exceedances generated from the surveys conducted using the existing SEM compliance test method and the proposed UAS alternative method, it is readily apparent that neither of the two SEM approaches are very repeatable. In examining overlaid paths from the existing compliance test method, you noted that was difficult for the operator to walk the exact same path twice and thus the locations of increased meter readings were not aligned. On the other hand, the UAS-based method allows for closer alignment of multiple surveys (+/- 1 meter by your account) and did show the majority of increased meter reading areas in common; however, there were still some areas of increased meter readings that were not found in all surveys.

You also note that because of the imprecision in the traversed paths for the existing SEM method, it actually provided a more 'dense' survey of the test area. In this regard, one might expect to identify more increased meter readings (and perhaps more exceedances from multiple surveys as compared to the UAS method which repeated the traverses more precisely and thus the unique square meters surveyed was less, but this was not the case.

The second study you provided compares data from applications of your UAS-based alternative method to data from full SEM method surveys conducted for quarterly compliance at four landfills. For this second study, the two methods were conducted at the same facilities, but the surveys were separated in time from 2 to 40 days. The data from the two types of surveys were compared to examine the efficiency of surface methane detection between the two methods. The quarterly SEM compliance method surveys were conducted by Sniffer Robotics as well as third party organizations. Because (1) the reports developed for quarterly SEM compliance testing typically only report the locations for identified exceedances and not the areas of increased meter readings as this concept is not defined by the Federal rules and (2) the UAS alternative method was conducted for research and development purposes with some customers choosing only to document ‘increased meter readings’ and not exceedances, we understand that you had to use a modified approach to compare the UAS alternative method data to the quarterly SEM compliance method. Considering this lack of exactly parallel data between the two methods, you developed the following approach to enable the comparison:

- First, using past SEM reports from application of your UAS alternative method to full landfills and where the maximum concentration localization step from Method 21, Section 8.3.1. was applied, you performed an analysis of how often ‘increased meter readings’ identified by the UAS alternative method resulted in an exceedance (>500 ppm methane) using the maximum concentration localization step. You wanted to be able to project how many exceedances one would expect in other cases where the maximum concentration localization step from Method 21, Section 8.3.1 had not been applied.
- Then, based on the analysis above, you developed a comparison of the number of <u>projected</u> exceedances from the UAS method surveys to the number of <u>reported</u> exceedances found during the quarterly surveys conducted using the existing SEM compliance test method. Comparisons were landfill-specific for surveys conducted within the following time periods chosen to avoid modifications to the landfill between the compared surveys:
    a. A UAS method survey performed up to 5 days after a quarterly survey conducted using the existing SEM compliance method, or
    b. An existing SEM compliance test method survey performed up to 45 days after a UAS alternative method survey.

In the first phase of the second study, you reviewed your reports from January 2019 through October 2021 using the proposed UAS-based alternative method couple with the ground-based maximum concentration localization step from Method 21, Section 8.3.1 and came up with the following probabilities, as a function of increased meter readings levels, of identifying source concentrations greater than 500 ppm methane (exceedance level) (see Table 3).

Table 3. Probabilities of Exceedances as a Function of ‘Increased Meter Readings’

Increased Meter Reading Concentration Range (ppm Methane)	Probability Emission Source Concentration Was Measured at Greater Than 500 ppm Methane
200 - 299	49%
300 - 399	46%
400 - 499	87%
>500	89%

Because the results in Table 3 above did not follow a clear trend, you decided to collapse the data and adopt the following more conservative values (see Table 4) for use in projecting exceedances for the comparison of the number of <u>projected</u> exceedances from the UAS method surveys to the number of reported exceedances found during the quarterly surveys conducted using the existing SEM compliance test method.

Table 4. Conservative Probabilities Used to Project Exceedances from 'Increased Meter Readings'

Increased Meter Reading Concentration Range (ppm Methane)	Probability Emission Source Concentration Was Measured at Greater Than 500 ppm Methane
200 - 499	45%
>500	85%

As noted above, you used the probabilities in Table 4 to develop a comparison of the number of projected exceedances from the UAS method surveys to the number of reported exceedances found during the quarterly surveys conducted using the existing SEM compliance test method as presented in Table 5. A total of twelve comparisons were conducted for four landfills (A, B, C, and D) with the UAV-based alternative method and existing SEM compliance method within the time periods explained above.

Table 5. Comparison of Projected Exceedance Detection for UAV-Based Alternative Method and Actual Exceedances Determined for Existing SEM Method at Four Landfills

Run	Site ID	Surveys Using UAV-based Alternative Method Date of Test	UAS based method Increased Meter Readings (≥500ppm)	UAS based method Increased Meter Readings (≤500ppm)	UAS based Method Nominal Projected Exceedances	Surveys Using Existing SEM Compliance Method Date of Test	SEM Compliance Method Reported Exceedances	Difference (Projected Exceedances from UAV Method – Reported Exceedances from Existing SEM Method)
1	A	2/19/2020	46	41	58	3/11/2020	3	+55
2	B	3/3/2020	15	41	31	3/10/2020	10	+21
3	B	5/11/2020	1	11	6	6/17/2020	28	-21
4	A	6/13/2020	1	35	17	6/11/2020	2	+145
5	B	8/7/2020	16	44	33	9/15/2020	11	+22
6	A	9/25/2020	3	23	13	9/22/2020	4	+9
7	A	11/23/2020	12	39	28	11/11/2020	4	+35
8	B	4/22/2021	4	83	41	5/5/2021	15	+26
9	C	5/12/2021	15	36	29	6/16/2021	5	+24
10	D	5/10/2021	3	9	7	5/12/2021	0	+7
11	B	7/15/2021	3	16	10	8/24/2021	22	-14
12	B	9/1/2021	9	18	16	8/24/2021	22	-8
		Totals	128	396	287	Totals	126	

The second study comparisons were consistent with the first study, in that the number of projected exceedances for the proposed UAS alternative method was typically significantly greater than the actual exceedances determined during the corresponding quarterly SEM compliance testing. In addition, on average the UAS alternative method would find more than two times as many exceedances as the existing SEM method. Out of the twelve survey pairs, there were three where the projected exceedances for the proposed UAS alternative method did not exceed the actual exceedances determined during the quarterly SEM compliance testing; all three of these survey pairs were from the same landfill (Site B on Table 5). You note that this same site was surveyed in three additional other instances. You explain that if one sums the projected exceedances and actual exceedances from all six of the Site B survey pairs, then overall for Site B the projected exceedances for the proposed UAS alternative method are greater than the actual exceedances from the SEM compliance testing, 137 to 108 and thus over the longer term the proposed UAS alternative method does not appear to negatively bias the compliance measurement.

Determination

Based on a thorough review of the subject Federal landfill subparts and your submittal, including the supporting data along with a detailed methodology for your proposed UAS-based alternative for conducting SEM, we conclude that UAS-based alternative method yields results that are typically no less stringent and often more conservative when compared to those of the existing SEM compliance procedures and is thus adequate to determine compliance with the operational limit. Therefore, we believe that UAS-based alternative method is suitable for application to landfills subject to the surface methane operational standards cited below and, with this letter, approve the use of the UAS-based alternative method, which is posted as ‘Other Test Method 51’ or OTM-51 on EPA’s Air Emission Measurement Center website at https://www.epa.gov/emc/emc-other-test-methods and attached to this letter, as an alternative to the SEM procedures required under the cited sections of the subparts listed immediately below and subject to the specific limitations and caveats explained thereafter.

40 CFR 60, Subpart WWW, §§60.753(d) and 60.755(c)-(e)
40 CFR 60, Subpart XXX, §§60.763(d) and 60.765(c)-(d)
40 CFR 60, Subpart Cf, §§60.34f(d) and 60.36f(c)-(e)
40 CFR 62, Subpart OOO, §§62.16716(d) and 62.16720
40 CFR 63, Subpart AAAA, §§63.1958(d) and 63.1960(c)-(d)

Use of OTM-51 is subject to the following limitation/caveats:

- For Subpart Cf of 40 CFR 60, which is an Emission Guideline to be used by delegated state and local authorities to develop an individual State Plan, the availability or applicability of this alternative method must be determined on a case-by-case basis.

- Entities other than Sniffer Robotics, LLC must submit data comparing OTM-51 and the test method specified by the regulation(s) to the Method Technology Group for review before this alternative test method may be used in lieu of SEM test procedures specified by the applicable regulations.

- The approved alternative method does not apply under the Tier 4 surface emission monitoring provisions in the following Subparts and cited sections:
    - 40 CFR 60, Subpart XXX, §60.764(a)(6)
    - 40 CFR 60, Subpart Cf, §60.35f(a)(6)
    - 40 CFR 62, Subpart OOO, §62.16718(a)(6)

- Increased meter readings must be documented as prescribed by OTM-51. When an exceedance of the operational standard is identified, the location of the monitored exceedance must be marked, and the location and concentration recorded as specified in all the applicable subpart(s). When an increased meter reading is not identified as exceedance of the operational standard, there must be at a minimum a traditional surface monitoring pattern either in a spiral or serpentine pattern with 3-meter intervals that covers a 30 meter radius from the increased meter readings to confirm no exceedance of the operational standard.

- Affected facilities using OTM-51 must notify the responsible agency before use of this alternative method and notification must include a copy of this letter.

- Landfill facilities must include a copy of this letter and method with each quarterly report presenting SEM results using OTM-51.

- Once a facility chooses to use OTM-51 under one or more of the Subparts cited above, the facility must continue to use the alternative method in meeting the provision(s) until the owner/operator receives approval from this office for use of a new alternative method or the responsible agency for use of any other options in the applicable Federal subpart (see also §63.7(f)(5)).

Because the alternative method described herein may be of use to other landfills subject to one or more of the Subparts cited at the beginning of this section and we believe it is reasonable to apply it broadly to other landfills, we will post this letter as ALT-150 on the EPA website at *https://www.epa.gov/emc/broadly-applicable-approved-alternative-test-methods* for use by interested parties.

If you have any questions regarding this approval or need further assistance, please contact Jason DeWees at (919) 541- 9724 or *dewees.jason@epa.gov*.

Sincerely,

STEFFAN JOHNSON
Digitally signed by STEFFAN JOHNSON
Date: 2022.12.15 07:16:30 -05'00'

Steffan M. Johnson, Group Leader
Measurement Technology Group

Attachment

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Other Test Method 51 - UAS Application of Method 21 for Surface Emission Monitoring of Landfills

Scope and Application

1.1. Analytes

Analyte	CAS No.
Methane (CH_4)	74-82-8

1.2. Scope. This method is an alternative test method for determining compliance with the surface methane operational standard for landfills in lieu of the procedures set forth in the regulations presented in Table 1, including EPA Method 21 by reference. Note: This alternative method does not apply to the Tier 4 surface emission monitoring provisions in the following Subparts and cited sections, 40 CFR 60, Subparts XXX and Cf, §60.764(a)(6) and 60.35f(a)(6) and 40 CFR 62, Subpart OOO, §62.16718(a)(6).

TABLE 1: SECTIONS OF 40 CFR PARTS 60, 62 AND 63 CONTAINING APPLICABLE REGULATIONS

WWW (NSPS)	XXX (NSPS)	Cf (EG)	AAAA (NESHAP)	OOO (Federal Plan)
40 CFR §60.753(d)	40 CFR §60.763(d)	40 CFR §60.34f(d)	40 CFR §63.1958(d)	40 CFR §62.16716(d)
40 CFR §60.755(c) - (e)	40 CFR §60.765(c) - (d)	40 CFR §60.36f(c) - (e)	40 CFR §63.1960(c) - (d)	40 CFR §62.16720

1.3. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods and provide a means to bring new technology to quarterly mandated surface emissions monitoring without sacrificing measurement rigor.

2. *Summary of Method*

2.1. This alternative test method seeks to replicate, to the greatest extent possible, EPA Method 21 and the applicable method clarifications (leak concentration definition, pattern definition, etc.) to EPA Method 21 in the regulations identified in Table 1, but automate Surface Emission Monitoring (SEM) by utilizing a methane detection payload on an unmanned aerial system (UAS) coupled with a ground level to UAS sampling system. The methane detector payload includes a hose and custom nozzle design that, when carried by the UAS, places the nozzle inlet within 5-10 cm of the ground. The UAS transmits the geo-located methane readings to the operator via a wireless communication system. The UAS is used to sample large areas for increased meter readings, each of which are then inspected in the existing method of manual inspection defined in the Subparts listed in Table 1 coupled with EPA Method 21.

3. *Definitions*

3.1. *Calibration gas* is the reference compound (in this case, methane at nominally 500 ppm) at a known concentration approximately equal to the operational limit of 500 ppm above background.

3.2. *Calibration precision* means the degree of agreement between measurements of the same known value, expressed as the relative percentage of the average difference between the meter readings and the known concentration to the known concentration.

3.3. *Increased meter reading* means a single or series of meter reading(s) above 200 ppm of methane.

3.4. *Response time* means the time interval from a step change in methane concentration at the input of the sampling system to the time at which 90 percent of the corresponding final value is reached as displayed on the instrument readout meter with the instrument configured with all impedance and tubing of the desired field sampling configuration.

3.5. *Instrument-only response time* means the time interval from a step change in methane concentration at the input of the sampling system to the time at which 90 percent of the corresponding final value is reached as displayed on the instrument readout meter with the instrument configured with the minimal amount of tubing for sample transport.

3.6. *Unmanned aerial system (UAS)* commonly known as a drone, is an aircraft without any human pilot, crew or passengers on board. In this context, a UAS includes multiple rotors such that the minimum speed is not limited by stall and can be reduced all the way to zero (hover).

3.7 *Nozzle offset distance* is the horizontal distance between the UAS and the distal end of the nozzle when flown at a fixed above ground level (AGL) and a known nozzle tube length.

4. *Interferences [Reserved]*

5. Safety

5.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to performing this test method. Operators of the UAS must have proper accreditation and clearance to fly UAS at any applicable location.

5.2. Hazardous Pollutants. Methane, leaks of which may be determined by this method, and other compounds commonly found in the municipal solid waste sector may be irritating or corrosive to tissues or may be toxic. Nearly all are fire hazards. Compounds in emissions should be determined through familiarity with the source. Appropriate precautions can be found in reference documents, such as reference No. 4 in Section 16.0 of EPA Method 21.

6. Equipment and Supplies

6.1. The methane detection payload shall have the following specifications:

6.1.1. The methane detection payload shall collect and respond to methane in the air samples; standoff or remote detection technologies are not applicable. Detector types that may meet this requirement include, but are not limited to, flame ionization, non-dispersive infrared absorption (NDIR) and tunable diode laser absorption spectroscopy (TDLAS).

6.1.2. The methane detection payload shall be capable of measuring methane in the range from zero through the increased meter reading up to and above the operational limit of 500 ppm specified in the regulation.

6.1.3. The scale of the methane detection payload shall be readable to ±2.5 percent of the increased meter reading level of 200 ppm methane.

6.1.4. The methane detection payload shall be equipped with a pump that provides the detector a constant sample flow rate. The nominal sample flow rate, as measured at the sample probe nozzle, shall be at least 0.5l /min when the probe is fitted with the full impedance stack of tubing, filters, and nozzle.

6.1.5. The methane detection payload shall have a known instrument-only response time. Instrument-only response time shall be measured for the methane detection instrument prior to being placed into service but does not have to be repeated at subsequent intervals. Instrument-only response time shall be measured by measuring the T90 response time for a minimum of 5 unique tube lengths less than 10m, fitting a linear regression to the measured T90 response times and recording the y-intercept as the instrument only response time if the r^2 of the linear regression is greater than 0.95.

6.2. The ground level sampling system shall have the following specifications:

6.2.1. The ground level sampling system shall be equipped with a single nozzle with inside diameter such that the air speed into the nozzle (per the nominal sample flow rate defined in Section 6.1.4) is at least 0.3 m/s.

6.2.2. The ground level sampling system shall be designed to maximize the time the distal end of the nozzle is within 10 cm of ground level during flight. The nozzle shall be sufficiently weighted and the final 30 cm of the distal end of the nozzle shall be rigid.

6.2.3. The ground level sampling system shall include a hose of sufficient length to drag the nozzle on the ground such that the nozzle is in fluid communication with the methane detection payload.

6.2.4. Before putting the ground level sampling system into service, determine the nozzle offset distance. If the tube length of the ground sampling density changes or the planned AGL for the ground level sampling system changes, repeat measurements to determine the nozzle offset distance.

6.3. The UAS shall have the following specifications:

6.3.1. The UAS shall carry the methane detection payload and the ground level sampling system and use an automated, real-time measurement and control system to fly at a constant AGL of ±1 meter.

6.3.2. The UAS shall include a data acquisition system to record both timestamped drone position (GPS coordinates with an accuracy of no worse than ±2 meters) and methane concentration. The data shall be logged at a frequency of at least the instrument-only response time per 6.1.5.

6.3.3. The UAS shall have a gimbaled camera that is remotely viewable and controllable by a remote operator in near real-time. The camera and display shall have high enough resolution for the operator to discern indicators of elevated concentrations of landfill gas, including distressed vegetation, cracks or seeps in the cover and cover penetrations from the defined flight AGL. Pictures taken shall be georeferenced via metadata or similar to the GPS accuracy defined in 6.3.2.

6.3.4. The UAS shall be in communication with an operator display that shows the methane concentration, as measured by the methane detection payload.

6.3.5. If automated flight plans are used to control the path of the UAS, the UAS shall be controllable by the remote operator to deviate from said flight plans to inspect areas where visual observations indicate potential elevated concentrations of landfill gas, such as distressed vegetation, cracks or seeps in the cover and cover penetrations.

6.3.6. The UAS shall be equipped with a method to control the forward speed to the value determined to meet the limit under Section 8.3.1.

7. Reagents and Standards

7.1. Two gas mixtures are required for methane detection payload calibration and performance evaluation:

7.1.1. Zero Gas. Air, less than 10 parts per million by volume (ppmv) methane.

7.1.2. Methane Calibration Gas. Obtain a known standard in air at a concentration approximately equal to the 500 ppm above background operational limit specified in the regulation.

7.2. Cylinder Gases. If cylinder calibration gas mixtures are used, they must be analyzed and certified by the manufacturer to be within 2 percent accuracy, and a shelf life must be specified. Cylinder standards must be either reanalyzed or replaced at the end of the specified shelf life.

8. Sample Collection, Preservation, Storage, and Transport

8.1. Methane Detection Payload Performance Evaluation. Assemble and start up the methane detection payload according to the manufacturer's instructions for recommended warm-up period and preliminary adjustments.

8.1.1. Calibration Precision. The calibration precision test shall be completed prior to placing the methane detection payload into service and at subsequent 3-month intervals or at the next use, whichever is first.

8.1.1.1. Make a total of three measurements of both the zero and the methane calibration gas by alternately introducing them where the measurement is collected via the ground level sampling system with all filters, the full tube length, and nozzle present. The introduction of the gas must be done such to not change the flow rate of the system or to pressurize the measurement cell. Record the meter readings. Calculate the average algebraic difference between the meter readings and the known value. Divide this average difference by the known calibration value and multiply by 100 to express the resulting calibration precision as a percentage.

8.1.1.2. The calibration precision shall be equal to or less than 10.0 percent of the calibration gas value.

8.1.2. Response Time. The response time test shall be completed prior to placing the methane detection payload and ground level sampling system into service and at subsequent 3-month intervals or at the next use, whichever is first. If a modification to the sample pumping system or flow configuration is made that would change the response time, a new test is required before further use.

8.1.2.1. Introduce zero gas into the nozzle of the ground level sampling system. When the meter reading has stabilized, switch quickly to the specified calibration gas. After switching, measure the time required to attain 90 percent of the final stable reading. Perform this test sequence three times and record the results. Calculate the average response time.

8.1.2.2. The response time shall be equal to or less than 30 seconds. The instrument pump, ground level sampling system with all filters, tubing, and nozzle lengths, which will be used during testing shall all be in place during the response time determination.

8.1.3. Nozzle Offset Distance. The nozzle offset distance shall be measured prior to placing the methane detection payload into service by recording the time between the UAS passing a known point in space and the nozzle passing the same point in space at a known, consistent speed, hose length and AGL. The horizontal offset distance is the measured temporal offset of the UAS to the nozzle, multiplied by the known, consistent speed.

8.1.4. Offset Calculation. Derive the temporal offset from UAS GPS measurement to receipt of quantified methane measurement for each combination of AGL and methane detection payload configuration by adding the response time to the nozzle offset distance divided by speed. Record this time offset for input to the data acquisition system and offset the reported location of all methane measurements along the actual traversed path by this offset (i.e., if the offset is "X" seconds, the location of the measurement shall be reported as the location of the UAS "X" seconds in the past).

8.1.5. Flow Rate. The flow rate test shall be completed prior to placing the methane detection payload and ground level sampling system into service and at subsequent 3-month intervals or at the next use, whichever is first. If a modification to the sample pumping system or flow configuration is made that would change the flow rate, a new test is required before further use. Measure the flow rate at the distal end of the collection nozzle with a flow meter readable to at least 0.1 l/min per the flow meter manufacturer's specification. Record the flow rate; the flow rate shall be greater than 0.5 l/min.

8.2. Instrument Calibration. Calibrate the methane detection payload according to Section 10.0.

8.3. Individual Source Surveys.

8.3.1. Surface Emission Monitoring via UAS and Follow-up Ground-based Surveys

Set the UAS terrain following system to fly at the constant AGL for the ground level sampling system characterized in Section 6.2.3. Ensure the remote operator can control the gimbaled camera on the UAS and that the resolution is adequate to make visual observations that indicate elevated concentrations of landfill gas, such as distressed vegetation and cracks or seeps in the cover and cover penetrations.

Take off and fly the UAS (at the predefined constant AGL) at a speed such that the instrument-only response time multiplied by the forward flight speed does not exceed 4 meters along a pattern that traverses the landfill at 30-meter intervals (or a site-specific established spacing). The aggregation of all the surface sampling traverses shall include the perimeter of the collection area, and all locations where visual observations from the gimbaled camera or aerial imagery taken within 120 days indicate elevated concentrations of landfill gas, such as distressed vegetation and cracks or seeps in the cover. Surface sampling traverses in accordance with this test method shall only occur during typical meteorological conditions.

During flight, take georeferenced pictures from the UAS gimbaled camera of features that indicate elevated concentrations of landfill gas, such as distressed vegetation and cracks or seeps in the cover and cover penetrations. Inspect these locations per Section 8.3.1.1.

8.3.1.1. Increased Meter Readings. If an increased meter reading is observed or recorded by the UAS data acquisition system refer to Section 8.3.1 of Method 21 as well as the applicable subpart list in Table 1 to survey the area of the GPS coordinate of the increased meter reading and the area within a radius of at least 15 meters. While inspecting the increased meter readings and traversing the landfill between said increased meter readings, make visual observations to identify areas that indicate elevated concentrations of landfill gas, such as distressed vegetation, cracks or seeps in the cover and cover penetrations and inspect said areas as increased meter readings.

8.3.1.2. Cover Penetrations. In addition to conducting ground-based surveys where increased meter readings were detected, refer to Section 8.3.1 of Method 21 as well as the applicable subpart list in Table 1 to survey applicable cover penetrations or openings within the landfill area.

8.3.1.3. Monitoring Route. All measurement points compliant with the specifications of this alternative method shall be plotted on a map that encompasses and includes the perimeter of waste. Any points that deviate from this test method, including but not limited to, manual deviations to the AGL that exceed the specification of 6.3.1, GPS accuracy worse than 6.3.2, presumed or measured flowrate less than that defined in 6.1.4, ground sampling density worse than that required in 8.3.1, etc. shall not be plotted. Any location on the map greater than 15m from a measurement point shall be noted and justified (e.g., noted as an active area, noted hazards that prevent inspection detail, etc.).

8.3.1.4. Re-monitoring. Refer to Method 21 and the applicable subpart for re-monitoring of previously identified exceedances.

9. Quality Control

Section	**Quality control measure**	**Effect**
8.1.1	Instrument calibration precision check	Ensure precision and accuracy, respectively, of instrument response to standard.
10.0	Instrument calibration	

10. Calibration and Standardization

10.1. Calibrate the methane detection payload as follows. After the appropriate warm-up period and any internal zero calibration procedure, introduce the calibration gas at the inlet of the ground level sampling system to include all filter, tubing, and the nozzle. Per the manufacturer’s guidelines ensure the instrument readout corresponds to the calibration gas value within 10.0%.

Note: If the meter readout cannot be calibrated to the proper value and/or a malfunction of the methane detection payload is indicated, corrective actions are necessary before use.

11. 11.0 Analytical Procedures [Reserved]

12. 12.0 Data Analyses and Calculations [Reserved]

13. 13.0 Method Performance [Reserved]

14. 14.0 Pollution Prevention [Reserved]

15. 15.0 Waste Management [Reserved]

16. 16.0 References

1. Dubose, D.A., and G.E. Harris. Response Factors of VOC Analyzers at a Meter Reading of 10,000 ppmv for Selected Organic Compounds. U.S. Environmental Protection Agency, Research Triangle Park, NC. Publication No. EPA 600/2–81051. September 1981.

2. Brown, G.E., *et al.* Response Factors of VOC Analyzers Calibrated with Methane for Selected Organic Compounds. U.S. Environmental Protection Agency, Research Triangle Park, NC. Publication No. EPA 600/2–81–022. May 1981.

3. DuBose, D.A. *et al.* Response of Portable VOC Analyzers to Chemical Mixtures. U.S. Environmental Protection Agency, Research Triangle Park, NC. Publication No. EPA 600/2–81–110. September 1981.

4. Handbook of Hazardous Materials: Fire, Safety, Health. Alliance of American Insurers. Schaumberg, IL. 1983.

17.0 Tables, Diagrams, Flowcharts, and Validation Data [Reserved]