Periodic screening alternative test method (ATM) for Kuva GCI360 infrared camera solution

1. Scope and Application

1.1 Scope

This method is applicable for demonstrating compliance with the procedures in 40 CFR §60.5398b for fugitive emissions components affected facilities and compliance with periodic inspection and monitoring requirements for covers and closed vent systems, specifically demonstrating compliance through periodic screening in 40 CFR 60.5398b(b), as approved, per 40 CFR §60.5398b(d). Affected facilities could include but are not limited to, single wellhead only sites, small well sites, multi-wellhead sites, well sites with major production and processing equipment, centralized production facilities, and compressor stations. This method details the procedures and information required for the implementation, operation, and use of the Kuva GCI360 Methane Monitoring System as a tool for periodic screening, in accordance with the regulations set forth in §60.5398b(b) and §60.5398b(d).

1.2 Application

1.2.1. This method describes the Kuva emissions monitoring system used for periodic screening at minimum detection thresholds of 15 kg/hr of methane. The Kuva emissions monitoring system is used for the detection of methane emissions using a fixed installed camera on a site designed to detect and locate methane emissions. This method uses technology that consists of three components: (i) a stationary camera housing a SWIR spectrometer, a visible camera and an anemometer. The camera converts sensor data into imagery and transmits data to the cloud via wireless or wired networks, (ii) a cloud-based platform that conducts false positive screening and generates alerts to oil and gas operators, and (iii) a web-based dashboard that aggregates critical insights of the analyzed data. The Kuva camera is placed on a site with equipment to be monitored within a 100 m radius.

1.2.2. The application of this technology is per the Environmental Protection Agency's 40 CFR part 60 New Source Performance Standards (NSPS): Subparts OOOO, OOOOa, and OOOOb, and Emissions Guidelines (EG): OOOOc, for the Oil and Natural Gas Source Category.

1.2.3. The test method is applicable to methane (CH_4, CAS No. 74-82-9) emissions from oil and gas facilities. This method can be used, as approved by the Administrator, in lieu of the applicable fugitive monitoring requirements in either §60.5397a or §60.5397b and inspection and monitoring of covers and closed vent systems in either §60.5416a or §60.5416b. This test method may be used for fugitive monitoring requirements in §60.5397c and monitoring of covers and closed vent systems under §60.5416c when a state, local, or tribal authority incorporates the model rule (i.e. OOOOc) for the emission guidelines as part of their State Implementation Plan (SIP) or elsewhere approved as applicable.

1.2.4. The test method is a performance-based method to determine whether individual component emissions remain below prescribed thresholds.

1.3 Sensitivity

1.3.1 The method has a 90% probability of detection of 15 kg/h at a 100 m distance as demonstrated in blind testing at Texas Tech University. The probability of detection is significantly improved at shorter distances and if VOC emissions are present in conjunction with methane emissions.

1.3.2 The spatial resolution of the method is area-level (as defined in §60.5398b(b)(5)(iii)). The solution has the ability to confirm detection of fugitive emissions within a 2 m radius of the emission source.

1.3.3 This method applies to well sites, centralized production facilities, and compressor stations in the crude oil and natural gas source category in all basins of the United States.

1.3.4 This method relies on wind speed and direction as a data quality indicator to determine when to conduct a periodic screening.

1.4 Data Quality Objectives

Adherence to the requirements of this method will ensure the data supporting the technology's objective will be accurate and of quality. The technology's objective is to screen for fugitive emissions from oil and gas sites with the following screening frequency listed in Table 1 and provide an alert to an operator that triggers a leak detection and survey response.

Table 1: Method Detection Limits and Screening Frequencies

Site Type	Periodic Screening Frequency
Oil and gas multi-wellhead sites, well sites with major production and processing equipment, centralized production facilities, and compressor stations	Monthly
Oil and Gas Single Wellhead Sites and Small Well Sites	Bi-monthly or quarterly

2. Summary of Method

The method requires the use of a Kuva GCI360 camera instrument, the Kuva cloud solution as well as a tower / pole, power supply and data connectivity for the camera.

The key Kuva system components are illustrated in Figure 1 below. Details are described in section 6.

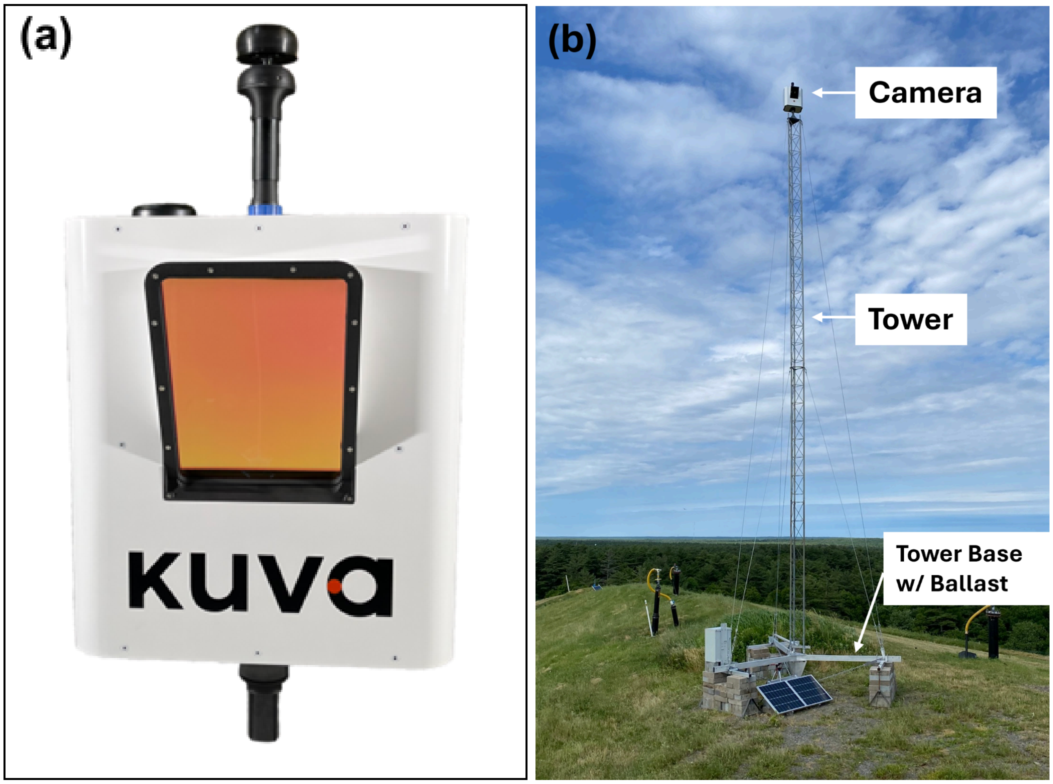

Figure 1: (a) Closeup of the Kuva GCI360 camera with integrated ultrasonic anemometer and LTE antenna visible on the top side, (b) A Kuva GCI360 installed atop the optional 40-foot Kuva Tower with ballasted base and guy wires for increased stability.

The Kuva GCI360 camera is based on a single pixel detector. In order to collect one image the Kuva GCI360 camera moves in an x-y scan pattern using an integrated pan-tilt system and covering a vertical field of view of 54 degrees and a horizontal field of view of 46 degrees. Up to 8 fields-of-view can be defined allowing coverage of up to 360 degrees.

The scientific principles and underlying physics of the gas detection of the Kuva System are based on imaging spectroscopy in the Shortwave Infrared (SWIR) portion of the electromagnetic spectrum. This principle is widely used in aerial and satellite-based solutions for methane emissions detection as well as gas safety equipment for the oil and gas industry, such as open path detectors. In addition, the Kuva System contains a visible RGB camera that takes a color image together with each infrared image.

Data is processed inside the GCI360 camera, and processed infrared and visible images generated in the camera are uploaded to the Kuva Cloud Solution, where they are screened to eliminate false positive detections. After this false positive screening, emission events (if any) are automatically generated by the Kuva cloud solution and the results of the periodic screening (irrespective if emissions are detected or not) are transmitted to the operator.

The distance for this method is limited to a 100 m radius around the camera installation point. In order to ensure that the periodic screening is conducted within the environmental conditions suitable for detecting methane emissions at or below 15 kg/h, the camera is utilizing a Detection

Capability Score that is dynamically calculated based on the SWIR light signal received at the camera and the wind speed and direction measured by the anemometer attached to the camera.

At the 1st of every month or every other month (depending on the requirements for the applicable site type) or at a date chosen by the operator the camera automatically enters the periodic screening mode. The screening is conducted using five successive images for each field-of-view and is completed only if the average Detection Capability Score meets or exceeds a threshold value. The collected images are then processed for gas detections, uploaded to the Kuva cloud and screened for false positives. For detection candidates that pass the false positive screening a validation screening is conducted automatically on the following day. Upon validation a detection candidate is registered as an "Emissions Event". All results are transmitted to the operator as evidence that the periodic screening has been conducted. An "Emissions Event" triggers a follow-up OGI survey by the operator. A periodic screening is typically completed automatically in 2 days of start. Times of bad weather may extend the duration to ensure the screening is conducted within appropriate operating conditions. If the screening has not been completed within 2 weeks since the start of the screening, a diagnosis of the cause is conducted as a quality control measure (see Table 4).

3. Definitions of Method

3.1 Definitions

3.1.1 Detection candidate: An infrared image containing at least one methane plume created by processing algorithms running inside the Kuva camera. Detection candidates are sent to the Kuva cloud for screening as a true positive or false positive.

3.1.2 Detection Capability Score: A numeric value from 0 to 1 representing the instantaneous, local conditions and their impact on the probability of detecting a given emissions rate of hydrocarbons within the field of view of the image.

3.1.3 Emission event: Once a detection candidate has been screened as a true positive through the cloud-based false positive screening and confirmed through a validation screening, it is classified as an emission event. The emission event is then transferred to the operator for follow-up.

3.1.4 Validation candidate: An infrared image containing at least one methane plume that has passed false positive screening in the Kuva cloud. A validation screening is conducted on the following day for validation candidates.

3.2 Abbreviations

3.2.1 API**:** Application Programming Interface used to exchange data between multiple cloud solutions.

3.2.2 CBI: Confidential Business Information.

3.2.3 DCS: Detection Capability Score. See definition in 3.1.

3.2.4 GIF*:* Graphics Interchange Format, a bitmap image format that allows for the visualization of a series of images as video-like animations by playing multiple images in successive order and allowing to present them repeatedly by looping.

3.2.5 MQTT**:** Message Queuing Telemetry Transport, a standards-based messaging protocol used for machine-to-machine communication in the oil and gas industry for process sensing and automation.

3.2.6 OGI: Optical Gas Imaging.

3.2.7 SWIR*:* Short Wave InfraRed portion of the electromagnetic spectrum.

3.2.8 VOCs*:* Volatile Organic Compounds.

4. Method Interferences and Envelope of Operation

The Kuva GCI360 camera operates under almost all conditions prevalent in US basins, including temperature ranges of -40 °C (-40 °F) to +50 °C (122 °F), 0 to 95% non-condensing relative humidity, and snow-covered ground. Because the camera relies on receiving SWIR from sunlight, operation is limited to daytime and times of sufficient SWIR light being present. A Detection Capability Score is calculated by the camera for every image collected and is used together with measured wind speed to determine when conditions are favorable such that a periodic screening can be successfully conducted.

The Kuva System is a multispectral system that detects both methane and other hydrocarbon emissions around the 2.3 um band based on absorption spectroscopy. The Kuva camera does not have cross-sensitivity or interference from water vapor, CO_2 or N_2. The camera does have limited cross-sensitivity to ammonia gas. Ammonia is toxic and is rarely if ever present at upstream or midstream oil and gas sites. The camera does not rely on heat signatures, does not measure temperatures of gas or objects (“Delta-T”) and has no cross-sensitivity to hot exhaust.

The following list of parameters can affect the detection capabilities of the camera:

1. Line of sight

The camera measures the path-integrated methane concentration, typically expressed in parts per million times meters (ppm-m) along the light beam. For such measurements, the light beam must reflect off background scattering surfaces and pass through the plume of methane. The light beam may pass through the plume before reflecting off a background or after reflection. If the plume is completely obstructed from the camera’s line of sight by equipment or structures, the light beam will not pass through the gas. The camera can measure methane emissions that are at least partially in the direct line of sight of the camera. The system need not have a fully unobstructed view of all sides or parts of a piece of equipment in order to detect emissions, as gas plumes can be detected as they emerge from behind an obstruction, however it needs to have line-of-sight to the equipment. To mitigate line of sight issues, the camera is generally mounted on a tower, mast, utility pole or existing equipment taller than the equipment to be monitored to get a vantage point. See Appendix A for the camera siting procedure.

2. Insufficient SWIR illumination received by the camera

For the camera to detect emissions it needs to receive sufficient infrared illumination emitted from the sun. To be received by the camera, the light beam needs to be reflected off a background. Both reflective and diffuse surfaces work as a background object. Common real world reflecting surfaces including ground, buildings and structures, vegetation, etc. An exception is liquid water as it absorbs shortwave infrared light. In general, onshore oil and gas facilities do not have standing water surrounding the equipment.

Situations of insufficient infrared illumination occur during heavy precipitation (rain, snow, sleet, fog, etc.), thick cloud cover, at night, with standing water as well as with shadows. To mitigate issues with insufficient shortwave infrared illumination the camera continuously monitors the amount of SWIR light received and no periodic screening is performed when insufficient SWIR light is received by the camera (see flow chart in Figure 5).

3. Extreme wind conditions

At high wind speeds, smaller emissions are sufficiently diluted by the air flow to make them more difficult for the camera to detect, resulting in less obvious visualization. To mitigate issues with high wind speeds the camera continuously monitors the wind speed and no periodic screening is performed when the wind speed is unsuitable (see wind speed limit in Table 4 and flow chart in Figure 5).

4. Hydrocarbon interferences

The Kuva camera directly measures gas absorption tuned to hydrocarbons in the shortwave infrared around 2.3 um. The system therefore measures both methane as well as hydrocarbon (VOC) emissions. While methane and VOCs are usually co-emitted at oil and gas sites, it is possible that only VOC emissions are present and may generate an emission event. Moreover, the system occasionally creates detection candidates that contain false detections based on thin objects made of hydrocarbons (e.g., plastics and polymers) and certain types of glare spots, as these tend to reflect and absorb sunlight similarly to hydrocarbons. Typical examples are windsocks, flying plastic bags, and glare spots on surfaces painted with hydrocarbon-based paint and corrugated metal. To mitigate issues with hydrocarbon interferences, detection candidates generated by the Kuva camera are screened for false positives in the Kuva cloud.

Table 2: Method Interferences and Envelope of Operation

Condition	Summary	Mitigation
Line of sight	Camera requires line of sight either to an emission plume or the shadow of an emission plume on a surface for detection	Follow installation guidelines
Insufficient SWIR illumination received by the camera	Method requires SWIR light for robust detection	Conduct periodic screening only when Detection Capability Score indicates

		presence of sufficient SWIR illumination, as indicated by the average DCS for all fields of view >=0.6 and DCS for any field of view >=0.5
High wind conditions	Gas disperses faster at high winds complicating detection	Conduct periodic screening only when wind speed is at 9 m/s or lower
Wind direction	Plume shape varies with wind direction	Conduct periodic screening only when Detection Capability Score indicates that combination of wind speed, wind direction and SWIR light received is adequate, as indicated by the average DCS for all fields of view >=0.6 and DCS for any field of view >=0.5
Hydrocarbon interferences	Hydrocarbon based objects can occasionally create false positive detections	Screen false positive detections in Kuva cloud

5. Safety

This method may not address all potential safety scenarios 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. The Kuva GCI360 camera is an automated system that does not require regular on-site personnel, minimizing the safety risks typically associated with standard field operations for inspection based emissions monitoring. This method is executed using instrumentation that does not require reagents or standards. The two main safety risks related to this method are installation and presence of equipment onsite. The sections below describe the safety risks associated with both.

5.1. Installation and Maintenance

The main safety concern related to the camera is the support structure required to elevate the camera to a sufficient height. Camera installation procedures and rare on-site maintenance procedures carry comparable safety risks to other activities at oil and gas facilities like the installation of floodlights, security cameras or microwave communication towers. These risks include exposure to hazardous gasses such as methane and other toxic substances. Following all site specific safety protocols during installation and maintenance activities mitigates these risks. This begins with thorough hazard assessments before starting any field work. Ensuring all personnel are equipped with appropriate personal protective equipment (PPE) is also essential.

This includes gas detectors, fire-resistant clothing, hard hats, safety glasses, and gloves. By adhering to industry standard safety measures, the risks associated with installation and maintenance activities in oil and gas facilities can be significantly reduced, ensuring the safety and well-being of all personnel involved. Moreover, Kuva offers an optional tower for the camera (see Figure 1 above). The Kuva tower allows for installation of the camera onto the tower while lying sideways. The tower is then raised to the vertical position using a hand winch. This eliminates the safety risk of working at heights, reduces equipment needs and speeds up installation.

5.2. Presence of equipment onsite

The presence of monitoring equipment on the site can introduce safety risks, such as:

- Traffic obstruction
- Structural hazards
- Electrical hazards
- Fire and explosion risks

These risks can be addressed by following industry standard engineering and operating practices applicable for oil and gas sites. Risk of traffic obstruction is addressed by a suitable camera placement. Structural hazards are addressed by the use of a mounting structure that is suitable for the respective wind rating applicable to a site and by installation following instructions. Electrical hazards are addressed by following industry standard work practices in connecting power and data to the camera. The Kuva camera is not designed or rated for use within hazardous areas where combustible or flammable concentrations of gasses may be present. However, these areas may still be monitored by the camera as long as the camera and support equipment are located in a safe area.

6. Equipment and Supplies

The key Kuva system components are illustrated in Figure 1 above. The components that make up the system can vary depending on the context of the installation, especially the tower/pole, power supply, and data connectivity. For example, masts can have different heights. The Kuva GCI360 camera can be mounted to different structures with an attachment, power can be provided by site power or solar power, and communication can be provided externally or by an integrated cell modem. Therefore, the following description is for reference only. The equipment and supplies consist of the elements listed below.

6.1 Kuva GCI360 camera - The camera is a highly integrated solution that includes a proprietary shortwave infrared sensor and infrared optics, integrated tilt functionality, a 5MP visible RGB camera, an integrated processing unit, an integrated pan stage, an ultrasonic anemometer (mounted on top of the camera) for wind speed and direction measurement, power-over-ethernet connection, ethernet data output (via power over ethernet) as well as optional LTE modem and cell antenna.

6.2 Mast/tower - A tower (sometimes referred to as a “mast” or “pole”) provides the support structure for the camera and for the routing of the ethernet cable from the ground to the camera. It is typically 40’ high and capable of withstanding high wind speeds as required by local regulations. The tower may incorporate guy wires that can be secured to the foundation of the tower to minimize the footprint and eliminate the need for ground penetrations. Other tower variations may be used to support the Kuva camera as well as existing structures, like utility poles. Kuva offers an optional tower for mounting the GCI360 camera, which allows for fast installation.

6.3 Power Source - The Kuva GCI360 camera is powered by 24Vdc via 802.3 bt power-over-ethernet. Power is provided either by a solar installation with battery backup (typically at the base of the pole) or by a connection to site power, if available. Power is routed via an ethernet cable from the bottom of the pole to the camera. The power consumption of the Kuva camera including all integrated accessories is approximately 25 watts.

6.4 Data via Ethernet - In cases where the operator prefers to use locally available data connectivity or when no cell data is available at a site, site data connectivity is connected to the camera via a power-over-ethernet injector and then connected to the camera via the same ethernet cable that also provides power.

7. Reagents and Standards

This method is executed using instrumentation that does not require reagents or standards.

8. Data Collection and Method Input Sourcing

The data collected to conduct a periodic screening with the Kuva system is listed in Table 3 below.

Table 3: Data collected

Instrument / Source	Variables	Use
Multiband photodetector (integrated into the camera)	Radiance Data and Reference Data	Radiance data processed to identify and visualize methane plumes
Visible camera (integrated into the camera)	RGB visible images	Visible imagery used during false positive screening
Anemometer (attached on top of the camera)	Wind speed (m/s) and wind direction (degrees)	Parameters used in calculating the detection capability score

Camera siting and commissioning are described in Appendix A. Installation is conducted such that each potential leak source is within 100m range of the vertical axis of the Kuva camera and within the 54 degrees vertical field-of-view as per the process laid out in Appendix A. The camera is mounted on a support structure. The Kuva System collects data for up to eight field-of-view segments of 46 degrees horizontal each. The field-of-view segments are fixed to 46 degree horizontal each but can be freely chosen in their pan position up to 360 degrees of coverage (i.e. 8 fields of view). Due to the large 54 degree vertical field of view, no vertical adjustments are required.

After the installation, a commissioning procedure is performed to ensure that the Kuva system can upload images to the Kuva Cloud Solution. During this procedure, a panoramic 360-degree visible RGB image of the site is captured by the camera. This panoramic image can be accessed via the Kuva Cloud Solution on a laptop or mobile device, and it is used to select and program the desired fields of views to ensure coverage of all components, covers and closed vent systems to be monitored.

9. Quality Control

The quality-control measures listed in Table 4 are implemented to secure the ability to consistently implement a quality periodic screening.

Table 4: Quality control measures

Instrument	QC Procedure	Acceptance Criteria	Frequency of QC Procedure	Corrective Action
Multiband photodetector	Linearity	Digital output for each sensor band must be between the threshold identified in CBI	Once, by Kuva	Do not deploy
Anemometer	Wind Speed Accuracy	± 5% at 4 m/s	Once, by anemometer manufacturer	Do not deploy
Anemometer	Anemometer Active	Signal is received by camera from Anemometer	Once per image	Temporarily suspend data collection
Visible camera	Check for presence of imagery	Presence of visual imagery	Once per periodic screening	Remote diagnosis, service visit or replace camera if necessary

Multiband photodetector	Dark Calibration	Sensor mean of dark value: the threshold identified in CBI Standard deviation of dark value <= the threshold identified in CBI	Once by Kuva during camera manufacturing	Do not deploy
Multiband photodetector	Dark Calibration	Sensor mean of dark value: the threshold identified in CBI Standard deviation of dark value <= the threshold identified in CBI	Once for every site scan	If dark calibration fails more than three times during a periodic screening, the operations team is notified, and the periodic screening is terminated until diagnosis and corrective action is performed
Multiband photodetector	Temperature	Temperature within +- the value identified in CBI of set point	For each image	Remote diagnosis, service visit or replace camera if necessary
Camera	Detection Capability Score	average DCS for all fields of view >=0.6 and DCS for any field of view >=0.5	For each set of 5 images per field of view	Continue screening until DCS is acceptable
Camera	Sufficiently high DCS to enable completion of periodic screening within a 2 week period	Notice that periodic screening has been generated by Kuva cloud within 2 weeks from starting the screening	Once per periodic screening (monthly or bi-monthly)	Remote diagnosis, if cause for time exceedance is weather related, then continue screening for up to one additional week; otherwise remote maintenance, service visit or replace camera

				if necessary
Anemometer	Windspeed at or below maximum	Wind speed <= 9 m/s	For each image	Temporarily suspend data collection
Anemometer	Calibration stability	Aggregate field deployment time of anemometer <= 8 years	Once per calendar year	Replace anemometer with a new one or inspect and recalibrate
Function test (optional)	See appendix B	The camera transmits a detection event to the operator	Prior to each periodic screening	Remote diagnosis, service visit or replace camera if necessary

10. Calibration and Standardization

10.1 Calibration Procedures

10.1.1 The InGaAs sensor technology used in the Kuva GCI360 camera is well established and widely used in the oil and gas industry for infrared gas safety detectors, especially in open path detectors. InGaAs-based sensors are certified by safety approval bodies for 10 years or longer use in harsh environments in the oil and gas industry such as offshore without any continuing or as-needed calibration other than automatic dark calibration by the sensor itself.

10.1.2 An optional check to verify Kuva GCI360 detection and alert functionality is included in Appendix B.

10.1.3 Calibration during manufacturing of the Kuva GCI360 camera is performed as part of final testing and consists of ensuring that the dark calibration value is within the limits stated in Table 4 above.

10.1.4 Dark calibration during operation is performed automatically by the camera after completing one set of image collections for all fields of view. Calibration during operation consists of ensuring that the dark calibration value is within the limits stated in Table 4 above. If the camera fails a dark calibration during operation, the last image data set collected since the last valid calibration is invalidated, and data collection is repeated. If dark calibration fails more than three times during a periodic screening, the Kuva network operations team is automatically notified by the camera, and the periodic screening is terminated until the dark calibration has been demonstrated to be operating normally again.

10.2 Threshold Metrics for As-Needed Calibration

No as-needed calibration is required. An optional procedure to check Kuva camera functionality is described in Appendix B.

10.3 Standardization: Training Requirements

No training is required as calibration is conducted automatically by the sensor.

11. Analytical Procedure

[Reserved]

12. Detection and Alerting

12.1 Detection

12.1.1 Overview of Detection Method

Methane detection with the Kuva GCI360 is based on imaging spectroscopy. Each pixel of an image collected by the camera contains multiple spectral bands of information. Detection is based on multiple photosensors with spectral filters. At least one spectral filter is tuned to absorption features outside the absorption of methane, hydrocarbons, and water vapor and provides reference information. At least one spectral filter is tuned to absorption features of methane and hydrocarbons in the 2.2 to 2.4um shortwave infrared band and provides signal information. By comparing signal information with reference information, a differential absorption spectrum is generated that is proportional to the amount of hydrocarbons present. Column density is computed based on the factory calibration of the detector and the known spectral absorption of hydrocarbons at the spectral wavelength in question. An optional procedure to check Kuva camera functionality is described in Appendix B.

In order to generate an infrared image for a given field-of-view, the GCI360 Camera features integrated pan and tilt stages with full control of the slow and fast-axis sampling, respectively. The raster scan is conducted in a zig-zag pattern, as shown in Figure 2 below. The horizontal scan speed is approx. 2° per second. The scan speed for a 46-degree field-of-view is approximately 26 seconds.

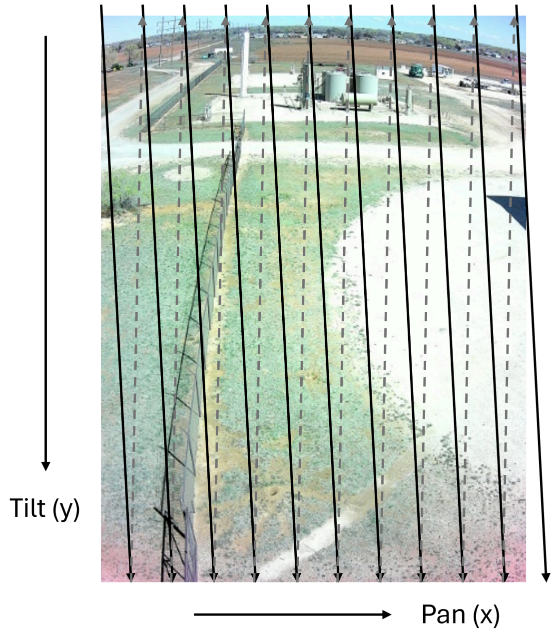

Figure 2: Raster scan pattern employed by the Kuva GCI360. Full field of view is 46° (H) x 54° (V)

The collected pixel-by-pixel infrared data is represented in a rectangular image format representing 46 x 54 degrees. The generated infrared image is then automatically processed inside the camera by applying a plume detection algorithm that identifies and separates out regions of elevated hydrocarbon presence. Once a plume is identified, it is visually represented with color coding representing different levels of column density for each pixel. Readings with gas detections are converted into images of gas based on a color scale where colors towards the red spectrum indicate higher column density and colors towards blue indicate lower column density. For an image to be created, the gas does not have to be blown to the camera, as the camera is a standoff detection solution.

The optical pathway creating an image is based either on direct imaging with daylight reflecting off a background, then passing through a gas plume before reaching the camera lens (see Figure 3) or on shadow imaging with daylight passing through the plume first, before being reflected off the ground towards the camera lens (see Figure 4). This second optical pathway results in the plume being visualized as the shadow of the emissions on the ground and it enables the camera to detect emissions from points that are above its field of view, such as high flare stacks or the top of vapor recovery towers.

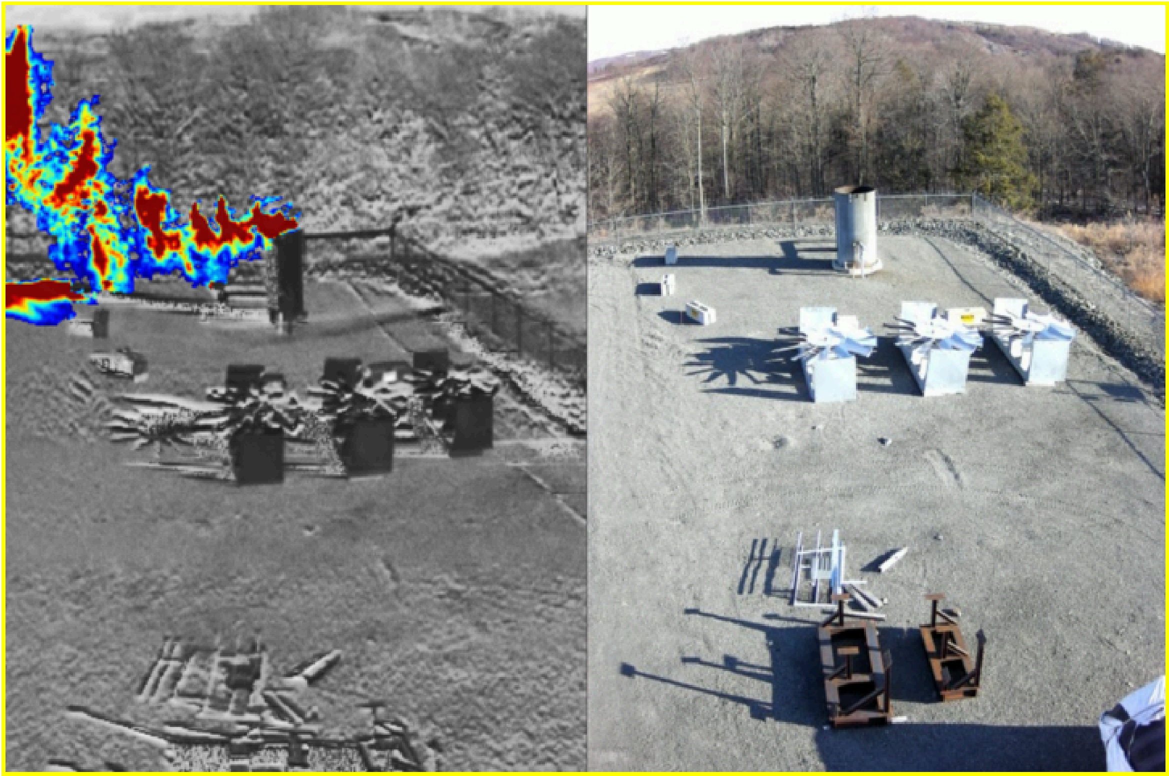

Figure 3: Infrared and visible image of a methane detection

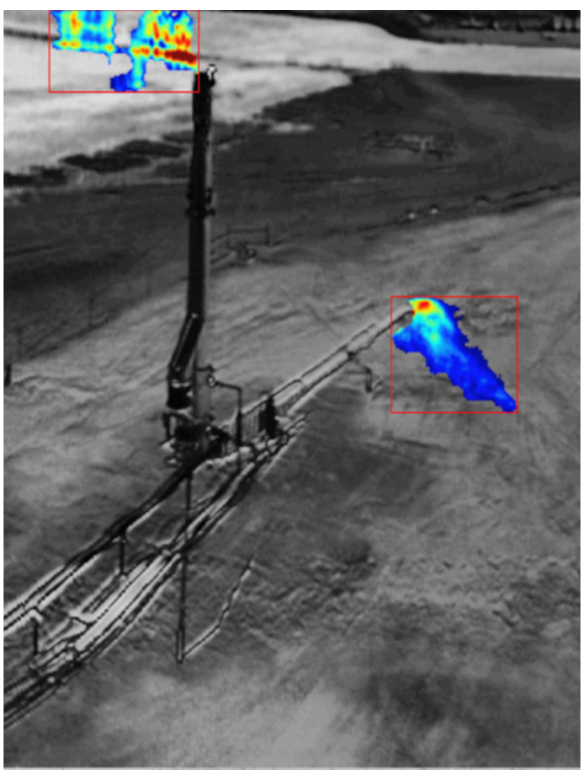

Figure 4: Infrared image of a methane detection both at the source (flare stack tip) and at the shadow of the emissions plume

12.1.2 Detection of Emissions

The process followed by this method to detect emissions and to generate alerts during a periodic screening is modelled on the process of conducting an image-based periodic screening with a plane overflight. Specifically, the periodic screening is only conducted when environmental conditions are such that the screening is conducted within the operating envelope of the Kuva camera and a validation screening is conducted for detected emissions for quality assurance. The process is visualized in the flow chart in Figure 5 in chapter 17.

12.1.2.1 For each screening period (monthly or bi-monthly) the periodic screening begins on the first calendar day of the period or on a day selected by the operator. Once the screening starts, it is conducted automatically. Detection of emissions is accomplished by the camera cycling through all commissioned Fields-of-View (FoV) as part of a screening. The screening starts at the first FoV with the camera collecting five infrared images and calculating the average detection capability score (DCS) for these images. The process is repeated for all commissioned FoVs and the average DCS is calculated for each FoV. The number of FoVs required to monitor all equipment at a given site will vary with site complexity and camera positioning. It can range from one FoV (for a 46-degree horizontal coverage, typically sufficient for a single well-head) to eight FoVs (for a 360-degree horizontal coverage, typical for a complex site). The number of FoVs are defined during installation and commissioning as per Appendix A.

12.1.2.2 The average DCS for all FoVs is calculated. If the average DCS across all FoVs is above 0.6 and each individual value for a FoV is above 0.5, gas detection algorithms are run, otherwise image collection is repeated for FoVs with low DCS until the average DCS across all FoVs is above 0.6. Under adverse weather conditions (high winds, persistent rain, etc.) this step may take several days / until the weather improves. Depending on the number of FoVs, a complete set of infrared images can be anywhere from 5 images (for one FoV) to 40 images (for eight FoVs). The time of image collection is stored with each infrared image as metadata.

12.1.2.3 The infrared images are processed in-camera for potential gas detections for a complete set of infrared images, images with potential detections are tagged as “Detection candidate”.

12.1.2.4 The complete set of processed images is uploaded to the Kuva cloud and images tagged with “Detection candidate” are screened for false positives. Images who pass the false positive screening process are then also tagged as “FP screening passed”.

12.1.2.5 If there is at least one image in the complete set that is tagged as “Detection Candidate” and as “FP screening passed”, a validation screening is conducted for all FoVs that contain image(s) tagged as “FP screening passed” on the next calendar day, following the steps 12.1.2.1 to 12.1.2.4 above.

12.1.2.6 Any image from the validation screening with a tag “FP screening passed” is then tagged in addition as a “Detection Event”.

12.2 Alerting

12.2.1 After completion of the steps listed in 12.1.2 the complete set of infrared images including time stamps for both the initial screening and the validation screening (if any) is transmitted to operators as a .gif file or a similar format by email, API, MQTT, or similar methods, depending on the operator's preferred communication method.

12.2.2 In case there is at least one image with a “detection event” in the transmitted files the operator is also informed about the presence of a detection event separately by email, API, MQTT, or similar methods.

12.2.3 In case of a detection event the operator will conduct an OGI screening and follow applicable regulations thereafter.

12.2.4 In case no detection events are transmitted, the operator stores the transmitted files for record keeping purposes as proof that the periodic screening has been conducted and that no detection events have been found.

13. Method Performance

The detection sensitivity of the Kuva solution is dependent on distance to the source, wind speed and on the amount of shortwave infrared illumination received by the camera. Kuva has developed and validated a detection capability score (DCS) that is calculated for each collected image based on the applicable wind and illumination conditions for that image. The DCS is a numerical value between 0 and 1. The combination of distance to equipment and the DCS define the envelope of operation for this method.

The method sensitivity has been evaluated in blind testing at Texas Tech University for the worst-case distance of 100 meters and for a DCS of 0.6 or higher. The blind testing confirmed that the Kuva system detects 14.8 kg/h methane with 90% probability at a distance of 100m with a DCS of 0.6 or higher. This combination of maximum distance and minimum DCS defines the envelope of operation.

For installations at a site a 100m distance represents a 200m diameter as the camera rotates 360 degrees around its own axis. In installations at actual sites the effective, average detection performance under this method will be far better than the 14.8 kg/h methane, that were confirmed in blind testing, for three reasons:

1. Shorter detection distances for most equipment
2. Detections below 90% PoD
3. No quantification cut-off limit
4. Co-emitted VOC emissions

1. Distance

Detection capability improves significantly at shorter distances. In installations at typical upstream and midstream sites almost all equipment is located much closer to the camera than 100m maximum distance. The Kuva system participated in testing at an average of 20m distance in ADED testing at METEC, where a minimum detection limit (MDL) of 0.25 kg/h and a 90% probability of detection of 3.5 kg/h was established in a 5-month blind test in weather conditions in Colorado and utilizing an older detection algorithm. With Kuva’s current detection algorithm the 90% PoD at 20m is approximately 2.2 kg/h methane based on the same METEC dataset.

2. Detections below 90% PoD
As shown in METEC testing the Kuva camera is capable of detections as low as 0.25 kg/h methane. During period screening five images for every field of view are collected. If any one of these images contains any amount of detectable hydrocarbons, and the detection candidate is confirmed by subsequent false positive and validation screening, a "Detection event" is created and submitted to the operator.

3. No quantification cut-off limit
This method does not employ a lower cut-off limit for detections based on emissions quantification. Accordingly, "Detection Events" can be far smaller than 15 kg/h.

4. VOC content
The Kuva camera also detects other hydrocarbon gas emissions (VOCs). For example, the SWIR absorption strength of propane is about 90% of the absorption strength for methane, across the same shortwave infrared wavelengths and as demonstrated by controlled release testing. As VOCs are usually co-emitted with methane the effective detection limit as attributed to methane only will be significantly more sensitive. Emissions from closed vent systems and covers (i.e. tanks) in particular have significantly elevated VOC content and will thereby be detected much more often than expected by the methane PoD curve alone.

The method performance is summarized in Table 5.

Table 5: Summary of Method Performance

Emissions	Distance	Detection Limit	Comment
100% Methane	100 meters	14.8 kg/h Methane 90% PoD	For detection capability score >= 0.6
100% Methane	20 meters	~2.2 kg/h Methane 90% PoD	METEC results, reprocessed with current detection algorithm
100% Methane	20 meters	~0.25 kg/h Methane, minimum detection limit	METEC results, minimum detection limit

14. Pollution Prevention

The method does not require a specific pollution prevention protocol. No physical samples are collected, which avoids generating waste. Additionally, the method reduces regular site visits, reducing transportation-related emissions compared to traditional inspection methods.

15. Data Management and Recordkeeping

Data under this method is stored in four locations: in the Kuva camera, in the Kuva cloud, with Kuva company records and by the operator. Data management for the Kuva camera and Kuva cloud as well as transmission to the operator are automated by the Kuva solution.

15.1 Local Camera Data

Raw image and wind data are processed inside the camera to perform periodic screenings as per the flowchart in Figure 5 in Chapter 17. Any required raw and processed data resulting from the initial screening and the validation screening are transmitted automatically from the camera to the Kuva cloud for further processing. Data is not permanently stored inside the camera. In case of a communications outage preventing transmission to the cloud, data related to periodic screenings is stored for up to 10 days inside the camera and sent to the cloud automatically upon resumption of data connectivity.

15.2 Cloud data

Data received from the camera is stored and processed in the Kuva cloud as per the flowchart in Figure 5 in Chapter 17 for the purpose of conducting a periodic screening. Upon completion of the screening data is transferred to the operator as described in Chapter 12.2.

15.3 Operator data

Once the periodic screening data has been received from the Kuva cloud by the operator, the operator stores the received data for a period of 5 years to comply with the recordkeeping requirements as specified in §60.5420b(c). The transmitted image sequence files described in Section 12.2 in conjunction with the time stamps of such files serve as evidence that a period screening has been conducted within the applicable time period. For example, files may show no emission events and thereby confirm the absence of emissions. In this case the files serve to document that no further follow-up is to be conducted by operators for this given periodic screening.

15.4 Siting data

Camera siting is conducted in accordance with Appendix A. The related siting data is stored by the operator as required by applicable regulations.

15.5 Quality control data

For cameras deployed at a site the follow-up actions taken due to the failure of quality control metrics listed in Table 4 (excluding for “Temporarily suspend data collection”) are recorded and stored as electronic or written company records.

16. References

1. Waxman, A. M., Bylsma, J. M., & Vaitses, A. (2019). Scanning IR sensor for gas safety and emissions monitoring (United States Patent US10436710B2).
2. Bell, Clay, et. al, Performance of continuous emission monitoring solutions under single-blind controlled testing protocol, https://doi.org/10.1021/acs.est.2c09235. Solution “J” in the publication.

17. Tables, Diagrams, Flowcharts and Validation Data

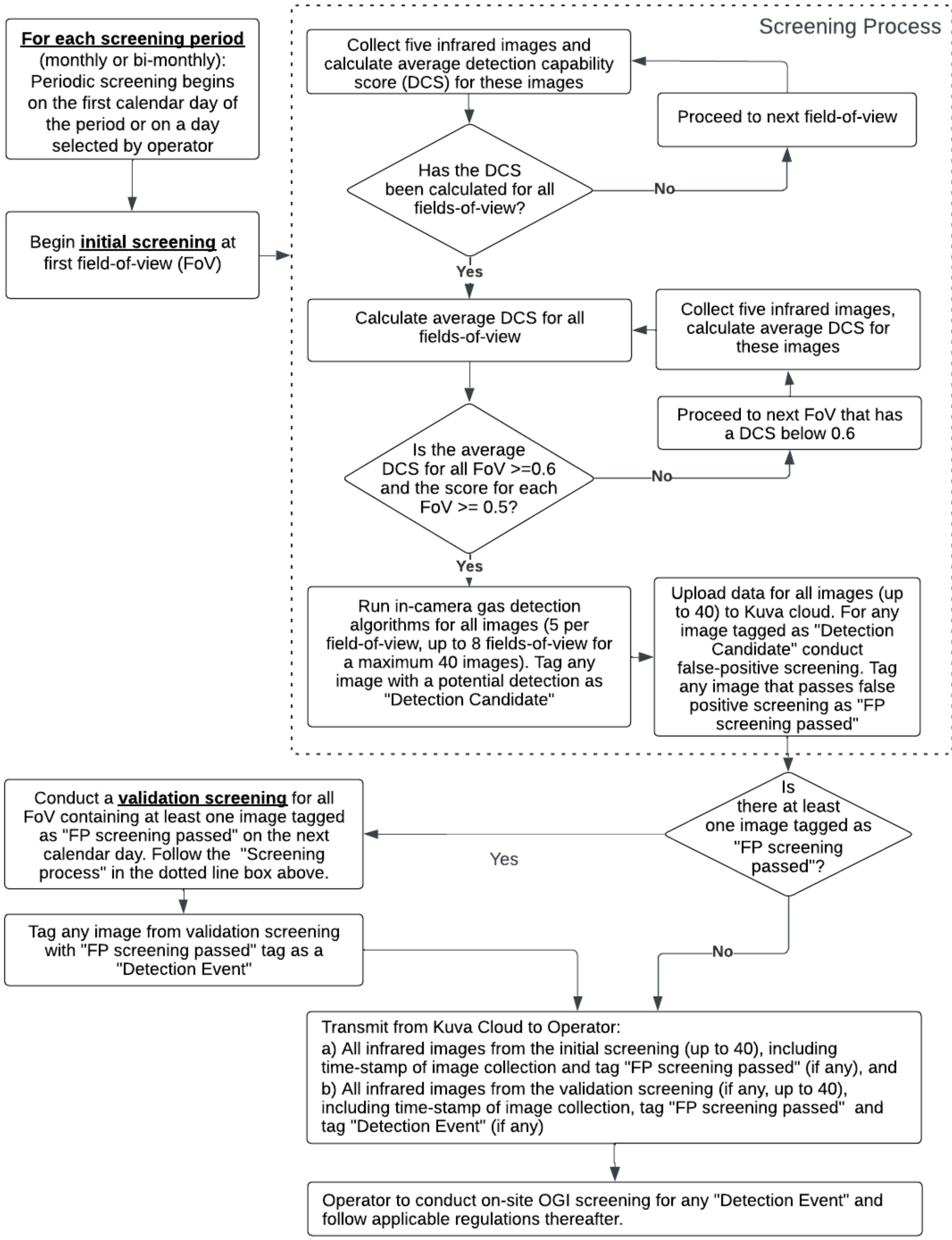

Figure 5: Visual workflow of the detection and alerting process of the Kuva method

Appendix A: Camera siting and installation

A.1) Planning

a) Sites using this method are identified by the operator and Kuva is informed.

b) Kuva obtains a satellite image of the site. If a satellite image is not available, the operator provides a plot plan or equivalent information. The operator provides the height of tall structures on the given site and provides operational and safety requirements to be considered.

c) The camera is placed on the image or plot plan ensuring that all fugitive components, covers and closed vent systems to be monitored are within a 100m radius from the base of the camera tower / mounting point, that power and data connectivity are accessible and that operational and safety requirements from the operator are addressed. Installation height is chosen such that emissions from tall flares, combustors, blow down stacks and vapor recovery towers can be monitored either by direct imaging or by shadow imaging (see discussion of imaging methods in 12.1.1), that all other equipment to be monitored (including all tank tops) is within the vertical field of view for direct imaging and that at least four infrared image pixels remain above the visual edge of any equipment to be monitored by direct imaging. The number and position of fields of view are chosen to ensure that all fugitive components, covers and closed vent systems are also within the horizontal field of view (or that shadows fall within the horizontal field of view in case of equipment monitored by shadow imaging) and to provide for at least four infrared image pixels of additional horizontal field-of-view beyond the edge of equipment so plumes that are potentially emanating sideways from leak points situated behind and covered by equipment can be monitored.

d) If conditions of c) cannot be met, additional Kuva camera(s) are added to the plot plan or multiple approved methods to conduct periodic screenings may be used to ensure full site coverage, per the requirements in 40 CFR 60.5398b(b)(1)(v).

e) Equipment located inside enclosed buildings such as compressor buildings, is not considered for camera placement and is required to be covered by a different approved method to conduct periodic screenings per the requirements in 40 CFR 60.5398b(b)(1)(v), for example OGI inspections.

A.2) Installation

a) Installers verify that site conditions match the plan. In case of deviations, the camera placement may be adjusted in order to meet conditions under A.1.c).

b) The camera and optionally also a tower / pole, power supply and local data connection are installed.

c) The installer verifies that the maximum range conditions are met by using a laser range finder, tape measure, equivalent tool or validation with geographical data to ensure all equipment to be monitored is within 100m from the base of the mounting point of the camera.

d) The installer ensures data connectivity of the camera, turns on power to the camera, logs into the camera remotely via the Kuva cloud, conducts a panoramic 360-degree image of the entire site, ensures that the camera operates normally (no error codes) and selects the desired fields-of-view.

e) The installer starts camera operation and waits until the camera collects at least one image per field of view. By reviewing the collected images for each field of view the installer validates that the site coverage conditions listed under A.1.c) are met. In case the conditions are not met, the camera is relocated until conditions are met.

f) Kuva support personnel configures the camera and the Kuva cloud to conduct periodic screenings in accordance with this method and informs the operator about the completed installation and the start to using this method for periodic screening.

Appendix B: Optional Camera Function Test

B.1 List of Equipment

- Compressed methane cylinder with regulator (industrial grade purity or better, size 300 cylinder)
- Alicat MCR-500SLPM-D/5M mass flow controller or equivalent
- Several meters of ¾” flexible PEX tubing
- ½” steel nipple mounted to a stand as the emission point

B.2 Test Setup

Connect one compressed methane cylinder to a line of PEX tubing. Connect the tubing to the MCR-500SLPM-D/5M mass flow controller and connect several meters of additional tubing to the ½” nipple as the methane release point. Place the release point at 10 meters distance from the base of the camera mounting location, approximately centered within a programmed field of view of the camera, and with direct line of sight from camera to the release point. Programmed field of views can be observed via a user interface in the Kuva cloud solution or by watching the camera rotate and confirming it is looking into the direction of the release point as part of its scan path. The release point can aim vertically or horizontally, but should not be located in front of standing water.

B.3 Conducting the Function Test

Ensure the camera is operational and scanning (rotating) and that operator can receive alerts. Ensure that the wind speed is below 4 m/s and the test is conducted during the day under clear sky conditions (no clouds) with sunlight visible. Open the regulator of the methane cylinder and, using the Alicat mass flow controller, conduct a methane release of at least 15 minutes at a flow rate of at least 15 kg/h methane. Observe if the camera transmits a detection event to the operator.

Appendix C: Quality Requirements for False Positive Screening

False positive screening in the Kuva cloud is conducted by trained image reviewers. In order to meet quality standards, each reviewer is trained over a period of approximately 4 weeks by a senior reviewer. The training includes:

- Studying the image review process handbook to understand the system.
- Familiarizing themselves with the reviewing process.
- Reviewing several dozen days of candidate alarms that represent a broad range of site types and emissions events and demonstrating successful evaluation of these datasets.
- Shadow / parallel review of live datasets that have been reviewed by other trained reviewers.

Image reviewers are certified to work alone (with ongoing oversight and mentorship) after they have successfully completed 2 weeks of parallel review without any errors.

Appendix D: Example Site Monitoring Plan

This site monitoring plan outlines the response actions that the owner/operator must perform in response to periodic screening results from the use of this alternative test method.

Response Requirements for use of Kuva Camera: Periodic Fugitive Methane Emission Monitoring

The site plan is maintained by the owner/operator to demonstrate the location of each Kuva camera and potential emission source for the site as well as areas of the site covered by OGI inspections instead of Kuva cameras (if any). When equipment is added, removed, or repositioned, the site plan must be evaluated and updated as necessary. This update is performed by the owner/operator or by Kuva upon notification by the owner/operator.

If a "Detection Event" as per section 12.2 of the ATM is transmitted by the Kuva camera to the owner/operator, the owner/operator must initiate a follow-up inspection/investigation to make repairs. A detection at the area-level triggers a follow-up inspection by the owner/operator as required in 40 CFR 60.5398b(b)(5)(iv), as follows:

1. The owner/operator conducts a monitoring survey of all fugitive emissions components located within 2 m radius of the location of the periodic screening detection using either OGI or EPA Method 21 and following the procedures in the owner/operator company-defined monitoring plan.

2. If the detection occurred in a portion of the site containing a storage vessel of a closed vent system, the owner/operator must inspect all covers and closed vent systems connected to all storage vessels that are within a 2m radius of the location of the periodic screening detection by inspecting the whole system connected to the portion of the system in the radius of the detected event.

a. Covers and closed vent systems must be inspected with OGI or Method 21.

b. Covers and closed vent systems must have a visual inspection to identify defects.

Additional requirements for repair, recordkeeping, and reporting apply to the owner/operator and must be included in the company-defined monitoring plan required by 40 CFR 60.5398b(b)(2).