FEASIBILITY STUDY REVIEWING THE USE OF $CO_{2(G)}$ AS A TRACER GAS FOR LEAK DETECTION IN GENERATORS

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Abstract

Generator stator leak tests are performed during post-maintenance preparation to run-up procedures to mitigate hydrogen coolant leaks during operation.Existing leak detection practices utilize thin films and gas sniffers to detect tracer gas in an air based mixture. A feasibility study assessed theuse of $CO_{2(g)}$, as an alternative leak detection tracer, with new Optical Gas Imaging (OGI) Cameras. Non-nuclear industry Operating Experience(OPEX) identified that OGI provide improves leak detection over existing practices by allowing faster and more frequent inspection campaigns.OGI also provides more accurate leak location detection, especially from inaccessible or well ventilated areas.Use of OGI with $CO_{2(g)}$ tracer in an operational hydrogen filled generator has been performed internationally, providing a new method for implementing online preventative maintenance.Specific application of OGI during stator winding leak tests promises a significantly quicker leak detection technique compared to traditional vent bagging and sniffing.

1. Introduction

Generator casing pressure tests are typically performedafter maintenance work has been performed on major system components to test for leaks prior to start-up.For hydrogen cooled generators, leaks of hydrogen into the local environment during operation pose various hazards.In particular, $H_{2(g)}$ under pressure can self-ignite, creating an invisible flame that poses a combustion or burn hazard for personnel.If enough hydrogen leaks and collects in a concentration of 4-75% in air [1], the hydrogen poses a potential explosive hazard.

Current practice atNPPs is to purge the generator of $H2_{(g)}$cooling gas with $CO2_{(g)}$ and then air to avoid an explosive mixturein preparation for maintenance.Generator casing pressure tests are completed in air using a gas tracer such as $He_{(g)}$with a gas sniffer and thin film liquids to detect leaks.After any potential leaks have been identified and corrected, the air is purged with $CO2_{(g)}$and then purged with $H2_{(g)}$prior to operation.New technological developments indicate that $CO2_{(g)}$can be used as a replacement for traditional tracer gases to provide faster and more accurate leak detection.Specifically, that Infrared (IR) thermography can identify leak location and size using live video detection versus commonly used gas sniffer detectors, reducing time spent searching for leaks when trying to return the system or unit to service.

This feasibility study reviews the use of $CO2_{(g)}$ as an alternative gas tracer, to be used during operation or outage to improve leak detection of NPP generator casings. The study will review current technology available on the market and whether leak detection using$CO2_{(g)}$as a tracer in air or hydrogen is a more efficient means of detecting leaks.

2. Technology Overview

2.1 Methods of Detecting $CO_{2(g)}$

A number of different technologies are available to measure $CO_{2(g)}$leakage[2], [3].A high level review of available technologies is provided inTable 1. Existing CANDUNPPs use a combination of pressure drop tests, thin films (e.g., snoop, leak tek, etc.), and gas sniffer methodologies.Dependent on leak location, inspection campaignscan take days or weeks to fully execute due to complicating equipment geometry, inaccessible areas, internal leaks that require disassembly to identify, local air flow patterns, or ineffective tools.Prolonged inspection times may extend unit outages and significantly increase costs associated with existing inspection campaign techniques.

The primary technology investigated in this report was passive IR thermography. Other technologies were either not available, not feasible, provided no additional benefits, or may be difficult to implement at NPPs.

Table 1: General $CO_{2(g)}$ Leak Detection Methods Available[2],[3]

Method	Proximity to Leak	Detection Method	Description
1	Close	Pressure Drop/Density Alarm/Fill Records	Loss of pressure, or various process alarms identify that a leak is occurring.In certain systems, fill records can be used to identify which component has required the largest make-up.This is a common method used by utilities to locate equipment with leaks and calculate leak rates.The method is not able to identify leak location if repairs are required.
2	Close	Thin Film/Bubble (Visual)	Thin film liquids are placed on areas where leaks are suspected and visually monitored for the formation of bubbles.This is a common method used to determine leak location.A Leak can only be detected at its source and requires personnel to have accesses to the leak area.This method requires little training and is inexpensive.However, it can be labour intensive to implement and cannot identify leaks from inaccessible areas.Large leaks do no form bubbles and may cause mischaracterization of leak locations.
3	Close	Gas Sniffers	Common gas sniffers may operate by using Thermal Conductivity, Ionic Discharge, or Radioactive Electron Capture techniques.Generally this method has greater sensitivity compared to thin film methods and provides operators with more reach via a probe to otherwise inaccessible areas.Equipment geometry and local air currents can cause errors in location detection, especially in well ventilated areas common to generators.This method requires little training and detectors may have a lower cost.However, it can be labour intensive to implement.
4	Close	Ultrasonic/Acoustic	Uses high frequencies produced by small leaks for detection.There is a potential for interference, especially in the vicinity of other electrical equipment which may produce sound at those particular ultrasonic frequencies.In the absence of interference, this method can help narrow down the general direction of leaks to determine leak location.This technique may also be used in conjunction with thin films to detect the sound of a bubble bursting.This method can be labour intensive to find the exact leak location.

Method	Proximity to Leak	Detection Method	Description
5	Close	Photo Acoustic	Gasses are irradiated with a modulated IR light source that aligns with the resonant vibration frequency of the gas molecule.Gas molecules excited to higher vibrational energy states eventually return to their original state and release heat.The heat causes gas to expand rapidly and produce acoustic waves that are detected by sensitive microphones.Interference can occur due to other gas molecules and leak location may be difficult to identify.This method can be labour intensive to find the exact leak location.
6	Close	Mass Spectrometer	Mass spectrometers use electron beams with sufficient energy to fragment the molecule.Positively charged fragments are accelerated in a vacuum using a magnetic field and are sorted by mass to charge ratio.Compounds will have a distinct mass to charge ratio allowing identification.This method can be complex and often requires extensive training.Mass Spectrometers may require vacuumed spaces to remove other trace elements from the area.The vacuum systems used are often costly or require elaborate set-ups making it difficult to implement.
7	Close / Remote	IR (Active)	A pulsed IR source is contained in the detector and tuned to a specific frequency.The frequency is set based on wavelengths that align with absorption peaks as per the absorption spectrum of the gas tracer.The loss in reflected IR back to the camera due to presence of the gas tracer indicates presence of the gas.The addition of an IR source generally means additional cost, more complicated set-up, and potentially decreased flexibility during implementation.Multiple scattered lights due to the IR source can become a source of errors during measurements.
8	Close / Remote	IR (Passive)	Instead of using an IR source, background or natural light is used as a source term.The difference between background and what is observed at the camera at a particular frequency indicates the presence of the gas.Similar to active IR detectors, the frequency is set based on wavelengths that align with absorption peaks as per the absorption spectrum of the gas.
9	Close	Event Bagging	Sealed bags are tied off across multiple joints, hoses, nozzles, or assemblies. A leak is indicated by inflation of the event bag with tracer gas. This method is very labour intensive and may be ineffective for complex equipment geometries.

2.1.1 Detection of$CO_{2(g)}$ Using Passive IR Thermography Detectors

Many molecular gases have unique absorption bands in the IR spectral range that correspond to the rotational-vibrational transitions of the molecule [4].These absorption peaks can be used to identify and differentiate between various gaseous molecules.In commercial IR detectors there are traditionally two spectral ranges used for gas leak detection.The first is the Mid-Wavelength Infrared (MWIR) band between 3-5 μm.The second is the Long-Wavelength Infrared (LWIR) band between 8-14 μm.

IR detectors for $CO_{2(g)}$ utilize the characteristic absorption spectrum of $CO_{2(g)}$ shown inFigure 1.As perFigure 1, $CO_{2(g)}$ has a large absorption peak at approximately 4.3 μm corresponding with a unique asymmetric stretching mode of $CO_{2(g)}$[4].The absorption peak at 4.3 μm for $CO_{2(g)}$ is beneficial as other common atmospheric gasses do not have overlapping absorption peaks or sufficient concentrations in airthat would significantly attenuate the measured signal using an IR detector [4].Other absorption peaks for $CO_{2(g)}$ correspond to the spectral range of 14-16 µm.These peaks align with absorption peaks of H_2O and are not as large as or discrete as the MWIR peak. As verified during this feasibility study, in general, traditional commercial LWIR detectors target the 8-14 µm band and would otherwise not overlap the required14-16 µm spectral range.This makes MWIR detectors ideal for detecting $CO_{2(g)}$ in atmospheric conditions.

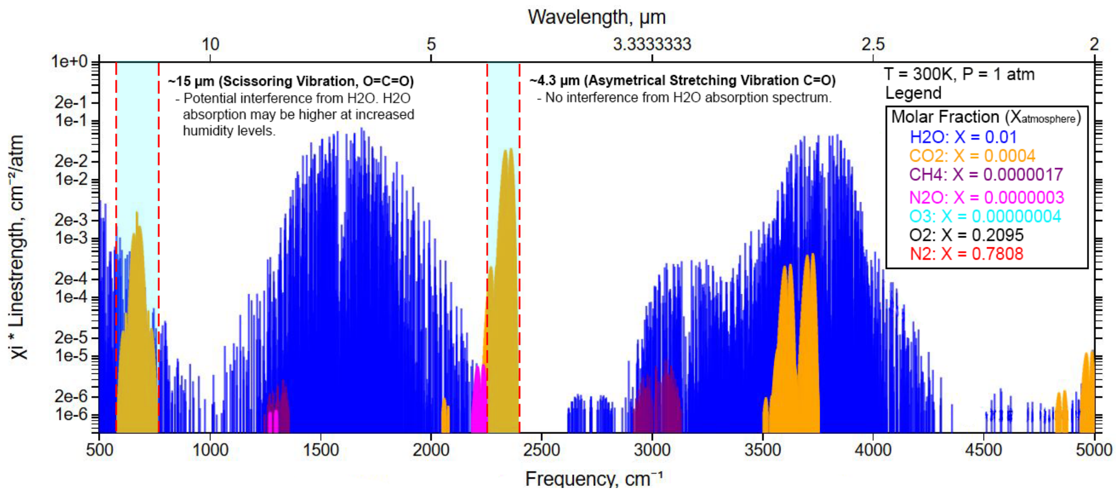

Figure 1:Overlay of Infrared (IR) Absorption Spectrum of Common Atmospheric Gasses [5]

2.2 Available Manufacturers and Overall Rankings

A review of twenty two IR detectormanufacturers was performed and only six were identified as having a product capable of detecting $CO_{2(g)}$ using MWIR (SeeTable 2).While many of the manufacturers reviewed had commercial IR detection products, the majority of products utilized the LWIR spectrum or otherwise stated that the product specifically filtered out $CO_{2(g)}$ to increase the detectors Signal to Noise (SNR) for detecting other gases.

Table 2: Available Manufacturer Products

Manufacturer	Product
FLIR	GF-343[6]
Jenoptik	VarioTHERM® InSb[7]
OPGAL	EyeCGasCO2[8]
Rebellion Photonics Inc.	GCI[9]
Specim	MWIRF-CL-380-M50M-OEM[10] MWIRF-CL-120-M50M-OEM[10]
Xenics	Onca-MWIR-InSb-320/-640[11]

For each available manufacturer product, a qualitative assessment was performed to assign an overall ranking for each product based on product specification sheets, discussions with manufacturers, and available manufacturer Operating Experience (OPEX).More detailed discussion for each product has been provided in Sections 2.3.1 to 2.3.3.The following key evaluative criteria were used to assess each product:

1. Portability (e.g., weight, set-up requirements, etc.).
2. Sensitivity (e.g., detection limits, proximity to leak requirements, etc.).

3. Is it an Integrated Solution (e.g., does it require external power sources or data logger, etc.)?
4. Combustion Risk (i.e., is the detector intrinsically safe).
5. Manufacturer Product Availability.
6. Field Testing (has the detector been used for the same or similar applications).
7. Improved Inspection Campaign Speed over existing station practices.
8. Implementation Requirements (i.e., are there any onerous requirements to have the product working on site).

Table 3: Manufacturer Product Overall Ranking

#	**Evaluative Criteria**	**Manufacturers**[6],[7],[8],[9],[10],[11]					
		FLIR	**Jenoptik**	**OPGAL**	**Rebellion**	**Specim**	**Xenics**
1	Portable	Yes	Maybe	Yes	No	Maybe	Maybe
2	Sufficient Sensitivity	Yes	Maybe	Yes	Yes	Maybe	Maybe
3	Integrated Solution	Yes	No	Yes	No	No	No
4	Combustion Risk	Maybe	Maybe	Maybe	No	Maybe	Maybe
5	Product Availability	Yes	Yes	Maybe	Yes	Yes	Yes
6a	Field Testing (Same Application)	Yes	No	No	No	No	No
6b	Field Testing (Similar Application)	Yes	No	Yes	Yes	Yes	No
7	Improved Inspection Campaign Speed	Yes	Maybe	Yes	Yes	Maybe	Maybe
8	Significant Additional Implementation Requirements	No	Maybe	No	Maybe	Maybe	Maybe
Overall Ranking		**1**	**5**	**2**	**3**	**4**	**5**

2.3 Effectiveness and Limitations of Manufacturer Products

2.3.1 Jenoptik, Xenics, Specim and Rebellion Detectors

The Jenoptik, Xenics, Rebellion, andSpecimdetectors are all standalone camera units.Each have limited portability as they require external power sources and data logging devices.Some of these cameras are further limited in portability due to weight making them impractical for field use.Many MWIR cameras may filter out $CO_{2(g)}$ through post processing or a notch filter between 4.2-4.4 μm to increase the SNR.Only the Rebellion detector was confirmed to be able to detect $CO_{2(g)}$ and not specifically filter out $CO_{2(g)}$[9].The Jenoptix and Xenics both had a large spectral sensitivity (i.e., 2-5 μm[7]and 3-5 μm[11]respectively) but did not provide any additional signal filteringto eliminate interference or noise as a result of other gases with absorption peaks in the MWIR spectral range.Both the Specim and Rebellion detectors are multispectral cameras which can detect multiple gasses at once.The Rebellion detector has the additional benefit of being able to measure leak location and concentration simultaneously.

Due to the size and lack of an integrated solution, these four cameras would be better suited to being installed as permeant fixtures in the facility to monitor leaks from the generators autonomously.The best camera for this purpose would be the Rebellion GCI as it can measure leak concentration and location simultaneously. Manufacturer detection limits, as provided by the vendor, for various gases identified that the Rebellion GCI is able to detect $CO_{2(g)}$ in concentrations of 1079 ppm-m (i.e., 1079 ppm in a 1 m cloud or 107.9 ppm in a 10 m cloud) compared to the background concentration of 400 ppm (0.4%) $CO_{2(g)}$ in atmospheric air.

Although these cameras have been identified as possible product solutions to detect $CO_{2(g)}$ tracer gas, there may be various implementation hurdles required to test or correct signal processing, integrate various hardware interfaces, and potentially require a more involved Engineering Change Control processfor implementation at NPPs.

2.3.2 FLIR GF-343

The FLIR GF-343 is a ready-made commercially available industrial product that has been tested in the field.The GF-343 model is a fully integrated package and does not require: an external power source, an external data logger, or any additional signal processing to eliminate interferences with other gasses in the MWIR spectral range.The GF-343 is a portable handheld device, providing maximum flexibility to detect leaks around a generator. The GF-343 model has already been implemented to detect $CO_{2(gas)}$ tracer from $H_{2(gas)}$ filled generators in concentrations of 3-5%(See section3.2)[12].Fielddemonstrations held at Bruce Power in April 2016 showed that the camera would be capable of detecting $CO_{2(g)}$ during outage pressure tests set in air(See section3.1).

The GF-343 allows remote viewing of leaks, which can increase staff safety by maintaining additional distance between staff any potential combustible leaks. Note that at this time the camera has not been confirmed as intrinsically safe and may pose a risk as an ignition source during operational use.Standard work practices regarding work performed in areas with a combustibility risk should be adhered to mitigate risks if the camera is used for online leak detection.

Successful identification of leaks requires an understanding of the images produced by the camera and how to arrange the camera frame to have the most contrast possible for easier leak identification. FLIR GF-343 operators will require appropriate training to detect leaks using the detector.This camera does not allow for quantification of the leak size.

2.3.3 OPGALEyeCGasCO2

The OPGALEyeCGasCO2 is a ready-made commercially available industrial product that has been tested in the field.The EyeCGasCO2 model is a fully integrated package and does not require: an external power source, an external data logger, or any additional signal processing to eliminate interferences with other gasses in the MWIR spectral range.The EyeCGasCO2 is a portable handheld device, providing maximum flexibility to detect leaks around the generator.Labdemonstrations, at the request of Bruce Power, were performed offsite by the manufacturer for various$CO_{2(g)}$ concentrations and showed the camera would be capable of detecting $CO_{2(g)}$ during outage pressure tests set in air (See section 3.1).

TheOPGALEyeCGas detector has not been specifically implemented for $CO_{2(gas)}$ detection from generators (as compared to the FLIR GF-343), however it is commonly used for Volatile Organic Compound (VOC) detection in the oil and gas industry.Note that the detectors and mathematical algorithms will differ between VOC detection units and units intended for $CO_{2(gas)}$ detection.

Benefits of the FLIR GF-343 also apply to theOPGALEyeCGasCO2, however the OPGAL model also has a few additional benefits.The OPGAL camera utilizes hot optical filters that can be swapped in the field to detect gases with different absorption peaks.This would allow the addition of a $CO_{(g)}$ optical filter to be bought with the camera, increasing the cost benefit of implementing the camera at NPPs. Contrarily, the FLIR GF-343 utilizes fixed filters unique to the specific GF camera model and can only detect$CO_{2(g).}$ The OPGAL camera is identified by the manufacturer as non-incendive as per CSA 22.2-M1987 for use in Class 1, Division 2 hazardous locations. This will minimize the potential of this camera of the camera to pose a potential ignition source hazard for leaked $H_{2(g)}$, however as it is not intrinsically safe it may still pose a risk as an ignition source during operational use.

Successful identification of leaks requires an understanding of the images produced by the camera and how to arrange the camera frame to have the most contrast possible for easier leak identification. EyeCGasCO2 operators will require appropriate training to detect leaks using the detector.This camera does not allow for quantification of the leak size.

3. Applicable OPEX

Gas leak detection using passive IR thermography is a common practice in the oil and gas industry.A number of gas leak detectors have been developed for identifying various VOC gasses that represent product or process generated materials that could leak from processing plants and pipelines.With respect to electrical utilities, many cameras have been developed for the detection of $SF_{6(g)}$ as it is a common insulation gas used in high voltage equipment.Leaks of $SF_{6(g)}$ impact equipment efficiency and facility emission targets.

The use of IR thermography to detect VOCs or $SF_{6(g)}$ does not differ greatly from using IR thermography to detect $CO_{2(g)}$.$CO_{2(g)}$ detection only varies in that it requires filtering or signal processing of the MWIR spectrum to exclude non-$CO_{2(g)}$ gases.As such, best practices and lessons learned from using IR thermography to detect VOCs and $SF_{6(g)}$ can be applied to detecting $CO_{2(g)}$.

3.1 Bruce Power Field Demonstrations

Field demonstration of the FLIR GF-343 $CO2_{(g)}$ camera was held on site at Bruce Power in March 2016.Similar results to what are shown in Figure 3 of Section 3.2 were exhibited for non-generator assemblies.Off-site laboratory tests from OPGAL in April 2016 were requested with certified cylinders with mixtures of 20%, 13%, 10%, and 5% $CO2_{(g)}$.The OPGAL camera was capable of observing all concentrations, but it was more difficult to observe gases at 5% concentrations compared to the other higher concentrations via video.This was likely due to poor contrasting as a result of the experimental set-up.

Figure 2shows two separate time lapse image reels of breath tests for the FLIR GF-343 (image sequence FLIR1-5) and the OPGALEyeCGasCO2 (image sequence OPGAL1-4).Time progression of gasvapours (seen as black and white wisps)from an average adult male are shown using the high contrast mode on both cameras.Hypothetic norms for $CO2_{(g)}$ exhalation concentrations in healthy human adults are between 4.2-6.3% ± 3.0 Standard Deviations in air[13].The breath tests show that in concentrations of approximately 4-6% $CO2_{(g)}$ in air will be visible at comparable levels with both cameras.Note that for both cameras, detecting $CO2_{(g)}$ is much easier using live video than can be depicted in the time lapse image reels provided.

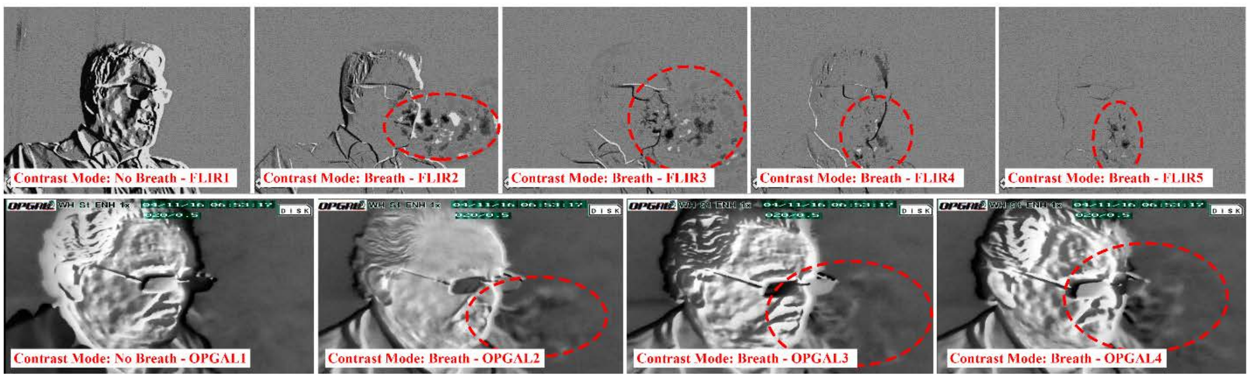

Figure 2: FLIR and OPGAL$CO_{2(g)}$ Breath Test Time Lapse Image Reels (FLIR1-5, OPGAL1-4)

3.2 FLIR GF-343 $CO_{2(g)}$ Leak Detection from Hydrogen Cooled Generators

To date, only the FLIR GF-343 has been field tested for the specific application of $CO_{2(g)}$ tracer gas leak detection from a hydrogen cooled generator.Units of the camera has been used for $CO_{2(g)}$ detection in the U.S.Aand Italy [12].

Follow-up with the Generator System Engineer at the Energy Northwest Nuclear Columbia Generating Station (i.e., the U.S.A facility) identified that online testing using both $CO_{2(g)}$ and $SF_{6(g)}$ have been successfully completed for the past four years[14]. During online testing various leaks were readily identified using the FLIR GF series cameras.Only 3% $CO_{2(g)}$ in $H_{2(gas)}$ was required for effective observation.For this facility, 3% $CO_{2(g)}$ equates to 15.62 lbs of $CO_{2(g)}$ at 125 psi(g) for a generator with a volume of 4550 ft^3[14].The Generator System Engineer identified that the cameras are very capable at detecting leaks stating that comprehensive leaks checks can now be performed by one individual in 1-3 hours with the camera.Whereas in the past, a similar comprehensive check using thin films or gas sniffers would have taken a team of people four to six hours to complete[14].The facility plans to use the GF series cameras for outage testing during the next refueling cycle.It is speculated that a further increase in $CO_{2(g)}$concentrations above 3% will increase resolution and contrast making it even easier to observe leaks[14].

The Generator System Engineer at the Energy Northwest Nuclear Columbia Generating Station also identified that leak location detection is much more accurate with the Optical Gas Imaging (OGI) cameras [14]. In one particular case, whilecoming out of an outage in May 2013, Energy Northwest staff identified a large leak on a generator frame terminal board[14].Due to the equipment geometry, use of thin films could not positively identify the leak location and it was concluded that the leak was due to the terminal board perimeter gasket[14].Several months later, a GF series camera was used to image the area and positively identified that the leak was on one of the individual temperature element penetrations on the interior of the terminal board[14].The camera was also used during tightening of the assembly and it was possible to observe the leak stopping due to maintenance staff's actions[14].Without the use of a GF series camera the leak may have gone unnoticed for a much longer time period and pose a potential workplace hazard to staff.

Figure 3 shows two separate time lapse image reels taken from operational equipment at the Nuclear Columbia Generating Station.Image sequenceA1:A5 shows a time progression of gasvapours (seen as black wisps) from a Dryer Skid Temperature Indicator.SequenceB1:B5 shows a time progression of gas vapours from a Dryer Skid Four-Way Valve.In video, both leaks are readily observable, but the FLIR GF-343 camera also provides a contrast mode to further help operators (see sequenceB2:B5).Note that detecting $CO_{2(g)}$ is much easier using live video than can be depicted in the time lapse image reels provided.

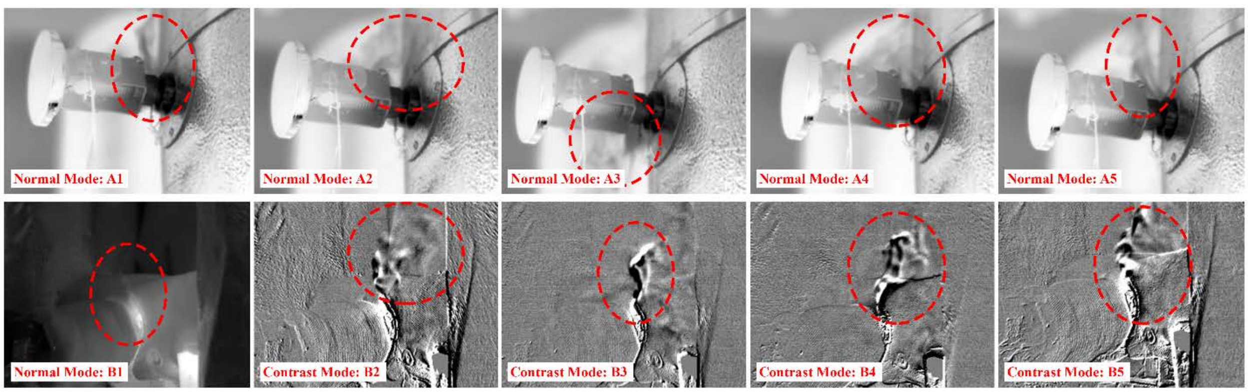

Figure 3:FLIR GF SeriesCamera Time Lapse Image Reels (A1-5, B1-5)

3.3 NMVOC Leak Detection Using FLIR and OPGAL Cameras

In 2015 the results of an independent field test were published by CONCAWE.The field test compared the efficacy of sniffer methodologies versus OGIcameras for detecting Non-Methane Volatile Organic Compound (NMVOC) leaks [15].During the test aFLIR GF-320 (comparable to a GF-343) and an OPGALEyeCGaswith a NMVOC optimized optical filter were used [15].The survey used four large field trials and confirmed that the OGI cameras are equally capable at detecting NMVOC emissions.The study identified that:

- OGI detectors are better at identifying leaks with a high mass emission above a 6 g/h threshold[15].The study indicated that some newer cameras can detect, with a high probability, leaks on the order of a few g/h and that 6 g/h threshold was particularly conservative estimate of a 'leak/no-leak' threshold[15].
- Leaks not identified by OGI detectors were from accessible components and small in size.These leaks only represented a small fraction of the total NMVOC mass emissions in the survey sites.Thus, OGI detectors can detect equivalent or larger overall volumes of

NMVOC mass emissions, where sniffers may have missed larger leaks at inaccessible access points[15].

- OGI detectors can detect any leak above the 'leak/no-leak' threshold in a surveyed area, including leaks from inaccessible areas [15].
- OGI leak detection campaigns are much faster, allowing more frequent campaigns to be employed than using sniffing techniques and at a comparable overall cost [15].
- There was no practical difference in efficacy between the FLIR model and EyeCGas model for NMVOC leak detection.This was also confirmed by various operators [15].

3.4 Non-Canadian Regulatory OPEX

A white paper by FLIR has been published discussing a variety of Optical Gas Imaging Regulations applicable in the U.S. and Europe[16].These regulations or findings are applicable to the oil and gas or chemistry industries but can be applied to the nuclear industry.The white paper discusses the timeline and development of these regulations, providing a high level summary of each regulatory development.In general it has been identified that:

- OGI techniques permit remote leak detection with hand held, relatively simple to use, cameras. All components can be scanned and surveys can be completed at a much faster rate. An OGI leak detection survey can identify the 'significant emitters' permitting focused equipment maintenance and subsequent emission reductions[16].
- Relatively simple OGI equipment can scan all fugitive emission point sources on a process plant, which is not possible using conventional hydrocarbon leak detection instruments[16].
- Adoption of OGI equipment is preferred by industry and regulatory bodies as the state-of-the art system for identifying leaks, especially from inaccessible areas and with respect to unexpectedly high discharges[16].
- Commenters on various regulatory proceedings expressed support for the use of optical gas imaging instruments, stating that using this equipment would result in cost savings to industry as it would reduce burden and time by quick survey of all emissions sources at one time[16].

3.5 Example Application for OGI Cameras – Event Bagging

An example application where an OGI camera would save significant time is with respect to event bagging during stator winding leak tests. As shown in Figure 4, in many cases, component geometry is too complex to provide accurate leak location using sniffer technologies.

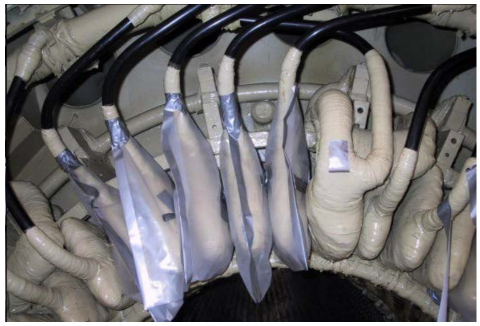

Figure 4:Stator Winding Leak Test Using Event Bagging (Bags shown on left hand side)

In these cases event bagging may be required across multiple joints, hoses, nozzles, or assemblies. A leak is indicated by inflation of the event bag with tracer gas. Establishing event bags and running tests can take many days to properly execute and if the event bag is not properly sealed or appropriately located a test may produce erroneous results. A comparable inspection campaign with an OGI camera might take an a few hours or less to complete and provide very accurate leak location identification despite complicated geometries.

4. Conclusion

This feasibility studyhas reviewed the use of $CO2_{(g)}$as an alternative gas tracer, to be used during operation or outage to improve leak detection of NPP generator casings. Review of existing leak detection technology was performed, identifying passive IR thermography as the ideal method for detecting $CO_{2(g)}$ leaks.IR thermography cameras, also known as Optical Gas Imagers (OGIs) provide the following benefits over the existing sniffer and thin film detection methods used in NPPs:

- OGIs, in testing, detect equivalent or larger overall volumes or numbers of leaks compared to existing practices.
- OGIs can identify leaks from inaccessible access points which would otherwise have been missed by existing practices.
- OGIs can identify with a high level of accuracy any leak above the ‘leak/no-leak’ threshold.For Volatile Organic Compounds (VOCs) this conservatively estimated as 6 g/h, however further field testing would be required to determine minimum leak size for $CO_{2(g)}$ tracer applications at specific NPP sites.
- OGI leak detection campaigns are much faster, allowing more frequent campaigns to be employed than using sniffing techniques and at a comparable overall cost.This is especially true for existing practices that require event bagging (e.g., during stator winding hydrogen leak searches).In these instances, event bagging would not be required and significantly decrease detection campaign times.
- OGI leak detectors can be used to detect $CO_{2(g)}$ from a hydrogen filled operational generator (i.e., detectors can be used as part of preventative maintenance to identify leaks while they are small and the unit still operational).OGI leak detectors can be used during outage for leak detection during generator casing pressure tests. Detection of $CO_{2(g)}$ in concentrations of 3-5% has been demonstrated from operational generators. Field testing

of $CO_{2(g)}$ concentrations ≥ 5% in air has been confirmed as possible using non generator specific experimental set-ups.

- OGIs provide live video feedback, allowing identification of leak location more accurately and provide a rough estimate of leak size.
- OGIs can detect leaks that otherwise, due ventilation drafts blowing the leak gas away from existing detectors, may have been missed by existing practices.

5. References

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