PERSONAL GAS DETECTION SELECTION AND OPERATION FOR GEOTHERMAL POWER AT MIGHTY RIVER POWER

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ABSTRACT

The presence of toxic and dangerous gas environments is a risk to the health and safety of workers and visitors at many geothermal fields. Naturally occurring gases associated with geothermal fields in New Zealand are typically dominated by carbon dioxide and to a lesser extent hydrogen sulfide. In addition a number of power plants make use of n-pentane as a working fluid, which is flammable. Mighty River Power undertook a review of the risks presented by these gases to the health and safety of workers and visitors to its geothermal fields. This review identified that while the gas risks were similar across its geothermal fields, the approaches to managing the gas risks varied between fields. Mighty River Power used this review as an opportunity to develop a standardised portable gas monitoring approach to managing the gas risks that could be used across the geothermal fields. This approach included the standardisation of portable gas monitoring equipment, processes and procedures as well as an increased focus on staff training.

This paper discusses the issues Mighty River Power identified in the portable gas detection processes and the process Mighty River Power went through to develop and standardise personal gas detection and monitoring at its geothermal fields.

1. INTRODUCTION

Mighty River Power (MRP) along with its joint-venture partners own and MRP operate five power stations across four different geothermal reservoirs in the Taupo Volcanic Zone (TVZ). At present there are seven geothermal reservoirs within the TVZ that have been developed for power generation purposes. These are shown in Figure 1.

Across geothermal fields in the TVZ there are varying quantities of gas, generally with the eastern side of the TVZ having a higher quantity (fields such as Rotokawa, Ohaaki and Kawerau). Many fields were explored by the crown from the 1950's onwards and therefore a number of early wells still exist today. Many of these early wells exhibit deep well cellars, increasing confined space risks of gas accumulation. Some fields exhibit clay caps that are generally continuous, however some fields don't have a consistent clay cap and exhibit deep geothermal fluid rising and boiling in shallower aquifers causing the existence of significant surface features. This boiling and groundwater interaction has the potential to significantly alter deep geothermal gas ratios.

Each geothermal field is unique, varying in size, enthalpy and chemistry discharge, location of wells etc. Therefore the ideal power station often differs between each geothermal field and other commercial inputs may result in power plant designs that would not otherwise be expected. Across the TVZ there is a mix of standard flash steam turbine plants which have a condenser cycle. Other plants make use of heat-exchanger designs heating a working fluid of n-pentane, with or without a non-condensing steam turbine. All these varying power plant designs increase complexity for standardising procedures and equipment, as the risks can vary.

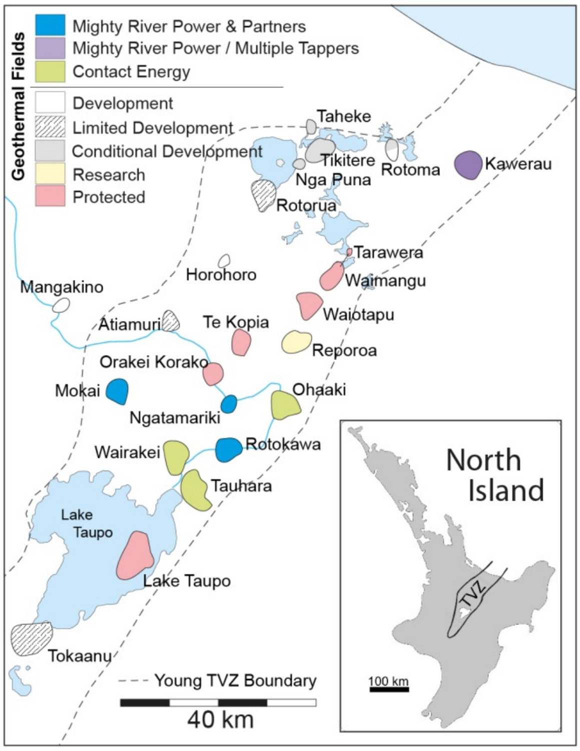

Figure 1: Location of known geothermal fields in New Zealand in the Taupo Volcanic Zone (TVZ) on the North Island of New Zealand.

Introduction to Geothermal Gas Risks

There are five identified main gases that pose risks within a geothermal environment, these being hydrogen sulfide, carbon dioxide, carbon monoxide, oxygen and flammability (pentane, methane etc).

Carbon Dioxide (CO_2) and Hydrogen Sulfide (H_2S)

As steam separates due to boiling, many geothermal gases, such as hydrogen sulfide and carbon dioxide, will partition predominantly within the steam phase. This leads to risks of gas exposure across geothermal sites from wellpads through to the plant. In addition to this, there are significant risks around geothermal surface features depending on below-ground processes.

Both hydrogen sulfide and carbon dioxide are naturally produced from geothermal systems, with variation between fields in their intensity. Across the Taupo Volcanic Zone generally composition of geothermal gases typically is ~95% CO_2 and 3-4% H_2S in deep geothermal reservoirs. As both gases are heavier than air, they pose risks of settling in low places and having dangerous concentrations.

Depending on the geologic setting of the geothermal environment, geothermal areas around the world vary greatly in their deep geothermal feed of gases, both in terms of quantities and also in the ratio of various gases. Some fields, such as the Hengill area in Iceland feature significant concentrations of hydrogen sulfide as a part of their gas discharges. Due to the low concentrations required for the gas detectors to alarm on hydrogen sulfide (discussed later), this means that some countries can consistently use hydrogen sulfide exclusively as the probability of generating a hazardous gas environment with just carbon dioxide without hydrogen sulfide is extremely rare.

The boiling and interaction of geothermal gases with groundwater also poses risks of varying levels of hydrogen sulfide and carbon dioxide being present. Due to solubility effects, hydrogen sulfide is generally depleted relative to carbon dioxide within geothermally impacted groundwaters. An example of this is shown in Figure 2 from the Rotokawa geothermal field from a study by Bloomberg *et al.* (2012) where CO_2:H_2S ratios were higher than found in the deep reservoir (Addison *et al.*, 2015).

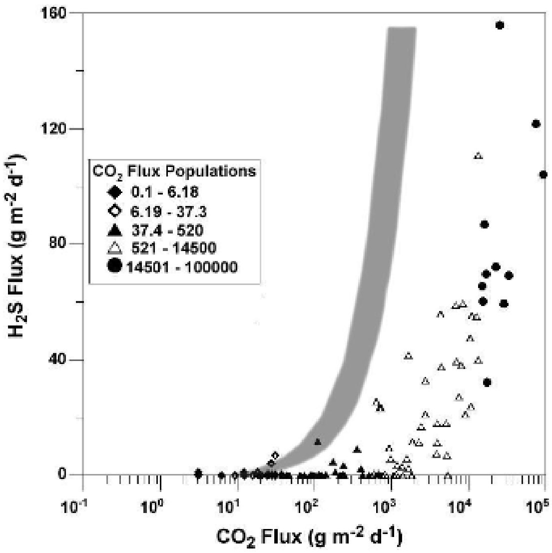

Figure 2: H_2S and CO_2 gas flux for thermal features area around Lake Rotokawa on the Rotokawa geothermal field (Bloomberg *et al.*, 2012). The solid grey bar is the estimated fluxes based on fumarolic gas ratios (deep sourced). These values are diffuse soil gas analyses rather than analyses of actual surface feature discharges.

In geothermal fields where there are boiling conditions at depth, this can lead to a build-up of gas at the top of the wellbore. With external conductive cooling from shallower aquifers this can create a cold gas-cap within the well, which can increase risks when wells that have been shut-in, or are on bleed are opened up as the gas will be cold and stay low. The gas expansion as it is produced also generally leads to cooling of the produced gases, resulting in a higher density than would otherwise be the case at ambient temperatures. These gas caps within wells can either be highly enriched hydrogen sulfide or carbon dioxide, or a combination thereof, at the hundreds of thousands of parts per million level.

Carbon dioxide is also generated as people breathe and therefore within confined spaces they consume oxygen and generate carbon dioxide. Many older fire suppression systems also make use of just carbon dioxide, meaning that if the fire suppression system had a leak or was used this could cause risks to individuals on site at the time, in addition to re-entry to the site following the release of the fire suppression system. Carbon dioxide is best measured with the use of an infrared (IR) sensor, as the use of electrochemical sensors results in the sensor needing to be replaced every 6-12 months due to the continued consumption of electrolyte within the sensor. IR sensors look for absorption at a particular wavelength to determine the concentration of carbon dioxide present, or any other gas that the IR sensor has its wavelength set to. When compared to electrochemical sensors, IR sensors are around three times faster at responding to gas presence.

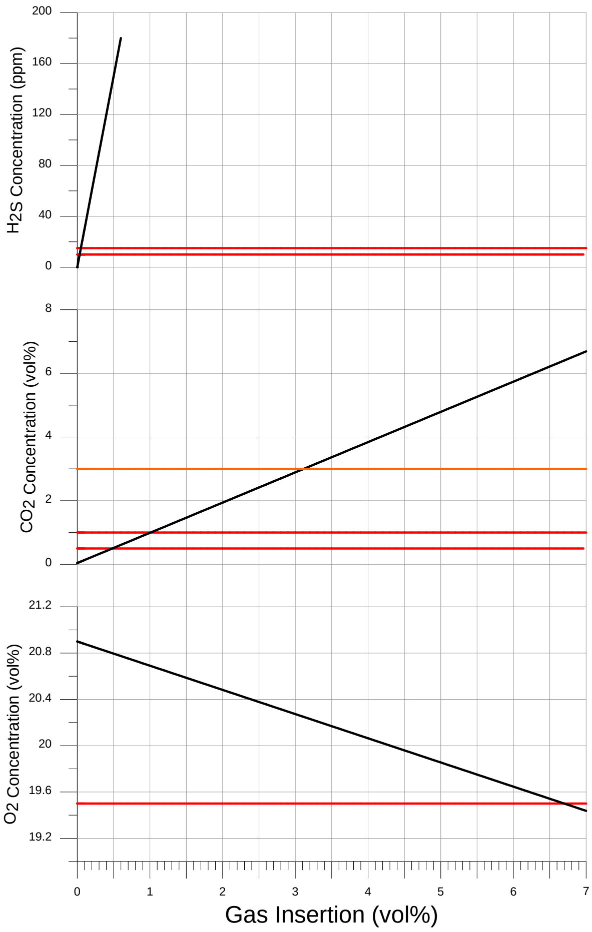

Figure 3: Graphs of Oxygen (O_2), Carbon Dioxide (CO_2) and Hydrogen Sulfide (H_2S) concentration. A solid red line indicates the main-alarm, a dashed red line indicates the pre-alarm and an orange line indicates the Short Term Exposure Limit. In instances where the Time Weighted Average alarm or Short Term Exposure Limit are the same as the main-alarm or pre-alarm they are then not shown.

Typically hydrogen sulfide will trigger alarm levels before other gases. A typical reservoir gas insertion, using 95% carbon dioxide and 3% hydrogen sulfide (therefore 2% other gases) is shown in Figure 3. Hydrogen sulfide in this instance has its pre-alarm go off with an insertion of 0.02% of inserted gas and its main alarm with 0.04% of inserted gas. It takes an insertion of around 0.5% before carbon dioxide will alarm and over 6.5% before oxygen will alarm. Whilst hydrogen sulfide will typically alarm before other gases, it is not recommended to rely on this as there may be other factors causing a non-standard insertion of gases such as people breathing within a confined space or partioning within a well or within groundwater.

It is therefore important that if a risk of carbon dioxide is present that it is independently read on a gas detector. Displacement of oxygen cannot be relied upon as both H_2S and CO_2 will reach dangerous/lethal levels before oxygen will alarm.

Carbon Monoxide (CO)

Carbon monoxide is a toxic gas that generally poses risks where combustion engines are used. Carbon monoxide is a colourless, odourless and tasteless gas which is only slightly lighter than air. The carbon monoxide binds to haemoglobin like oxygen, but forms carboxyhaemoglobin and can prevent the uptake of oxygen by haemoglobin. Measurement of this gas for confined space work is important.

Oxygen (O_2)

Oxygen is essential to life, therefore we need to have a suitable concentration available for breathing. If the concentration of oxygen is high then this also poses risks as this impacts the flammability of other combustible components, including other combustible gases. Therefore oxygen is both measured for a low concentration and a high concentration. Any presence of displacement gases, such as nitrogen, will impact on the concentration of oxygen.

Flammability

Flammability can be caused my numerous gases on any site, hence there is a general measurement of flammability rather than individual gas. For geothermal the greatest risk is that of n-pentane and other flammable working fluids used in binary plants. Each geothermal field that MRP operates has plants that contain n-pentane. Flammability is measured as a function of the percentage of the lower explosive limit, this being the range where the fuel is too lean to combust.

Due to not having any heat transfer across the pentane sensor there is less likelihood of the sensor becoming impacted by reactants getting stuck to the sensor and therefore affecting its performance. This results in a longer expected lifespan of the sensor and the overall detector. Infrared sensors are expected to last at least 6 years if the detector has not been damaged due to events such as dropping. Infrared sensors do not require the presence of oxygen to detect flammable gases, unlike catalytic sensors, however as they detect the carbon-hydrogen bond they cannot measure hydrogen. No MRP operated power plants make use of hydrogen cooled generators and therefore hydrogen isn't considered a risk for MRP unless it is introduced to site for a specific purpose. In this instance a specific hydrogen sensor can be fitted to detect hydrogen.

Internal Review of Gas Detection

A review was undertaken to benchmark our gas detection processes. This was conducted as a series of informal discussions with people around the business by asking a number of questions when on site for other work, thereby getting honest answers from operations, maintenance and contractors.

This review highlighted the following points:

1. The risks of hydrogen sulfide were well understood, however there was inconsistent, and often limited, knowledge of carbon dioxide risks. A number of people incorrectly assumed carbon dioxide could be detected safely through oxygen displacement. Oxygen would only alarm at levels at which carbon dioxide concentration was immediately dangerous to life and health.
2. A significant portion of gas detection equipment deployed on sites did not detect carbon dioxide and individuals didn't know when they should, or shouldn't use gas detectors that measured carbon dioxide, and often didn't know what detectors measured carbon dioxide.
3. Due to the range of gas detection equipment across the sites there was limited familiarity with equipment across the business, with no synergies in training or procedures. With significant portions of 4-gas detectors (don't read carbon dioxide) these were often personally issued PPE due to their relatively low cost. Because of the significant quantities of gear the servicing costs and spare parts were significant considering the low utilisation rates of the equipment on most sites.
4. Only one site had bump testing capability which is considered best-practice. Calibrations were done 6-monthly. There is more on bump testing and calibrations later in this paper.
5. Pumped units were not consistently available on sites for confined space pre-entry testing. This had the risk of people measuring just the atmosphere in the immediate vicinity of the confined space opening rather than the atmosphere within the confined space at various levels.
6. There was no defined requirements to wear gas detectors in particular areas other than when gas was identified as a hazard as part of the work controls process.
7. Due to the range of equipment across all sites, confined space training often was not able to be targeted to the specific gas detectors that were used for pre-entry testing.

Following this review it was recommended to firstly standardize on carbon dioxide measurement for all gas detectors and for a selection process to be undertaken to standardize the gas detection equipment across the geothermal sites.

2. GAS DETECTION SELECTION PROCESS

A Project Team was put together, which included representation from chemistry and also from health and safety. All three members of the team had experience and history in gas detection, using a range of brands previously. A major decision proposed by the project team and endorsed by management was the standardisation on carbon dioxide monitoring, with a desire for all detectors to be the same.

The selection process was initiated, whereby the Project Team put together yes/no criteria to determine what personal gas detectors would be suitable. The yes/no criteria were determined as:

1. The gas detector must be wearable, i.e. can clip onto a shirt;
2. The gas detector must have been able to detect carbon dioxide (with an infrared sensor), oxygen, hydrogen sulfide, carbon monoxide and flammability all within the one detector;
3. The gas detector must have a data-logger functionality that can be downloaded in the event of an event to determine causation;
4. The manufacturer needed to have a network-capable docking station that could be used for bump testing and calibrations that would electronically record details of test;
5. The gas detector either had to have a built-in pump, or an external pump that could work with the standardised gas detector;
6. Spare parts, consumables and repair services must be locally available (within New Zealand). The gas detector battery had to consistently last for longer than 8-hours (expected up to Year 3); and,
7. The gas detector had to have support for the product within NZ

Four main vendors, representing MSA, BW Technologies, Draeger and Industrial Scientific were selected for further assessment. For this further assessment a 2-3 hour discussion was held with the Project Team, where all details of their respective gas detectors were covered including significant levels of technical detail about the gear and how it worked.

An agreement was made with each vendor that a gas detector would be loaned to Mighty River Power for two months to enable testing and feedback. The project team promised to supply a summary of feedback to the vendor based on the trials, testing and site feedback. In addition each vendor would provide details of other customers for the project team to get in contact with to discuss their experiences with the vendor and the products.

Following the initial meeting an initial review was conducted by the project team for the assessment criteria that could be answered. Cost was not factored into the process at this stage and detectors were to be assessed based on some pre-detailed categories including:

1. The size and shape of the detector, and the ability for this to clip easily onto the user. The smaller the detector the better;
2. How user friendly the detectors were
3. The feedback and reputation of the gear and the vendor;
4. The quantity and quality of extras, for example: man-down alarms, glow-in dark functionality, screen readability etc;
5. How user-serviceable the gear was;
6. The length and quality of the warranty of the gear and the accessibility of servicing personnel;
7. The quality of the vendor training package and the availability of this for our use;
8. If the detector could be programmed to have lock-out functionality after being overdue for a calibration or bump-test
9. Whether the detector could accept additional sensors in the event of additional gases wanting to be measured for and the ability of tracking sensors swapped between instruments;
10. Rental options from the company supplying the gear, so these can be used in shuts etc.

Each of the four gas detectors were taken out to each operational site and given to site staff to provide feedback on. This was done as a two stage approach: firstly give them the gear and get their first-impressions, which tested how intuitive the gear was; and secondly, to inform them of how to use the gear and what its functionality was. This feedback from site staff was extremely important as it assisted with ensuring high levels of buy-in to the gas detection selection process. All feedback was written down and analysed for themes allowing the identification of any important factors that were overlooked. By taking gear to each site it became apparent what site staff were interested in gas detection and who had previously looked after gas detectors on site and in previous jobs. These people were identified as site-champions.

Based on the feedback from the teams it was pointed out that operators were expected to carry more equipment whilst doing rounds and that this would be a significant limitation in the future. Therefore site-based staff felt that the size and weight of the detectors should be one of the primary measures of the equipment once it has met its minimum criteria. Therefore the rating for size and shape of the detector was increased in the evaluation process. The result of this change is shown in Table 1, with both original scores and adjusted scores shown as a percentage.

Phone calls were made to other major users of each product type and this was primarily to identify issues that were found with their detectors, in addition to seeing how they rated the support and servicing functions of their respective vendor(s). If there were any concerns raised then these were noted and addressed with the vendor. One such issue was that the infrared sensors do not detect hydrogen and an assessment was conducted as to if we had any hydrogen risk on site. This assessment concluded that we had no hydrogen-cooled generators, therefore no risk was present unless hydrogen was brought to a site. Hydrogen could be measured with an additional electrochemical sensor if required, but one brand did not allow for an extra sensor, therefore this marked that detector down further.

The project team then individually concluded their vendor scoring for each product and this was then added together. This was to prevent group-think bias. Based on the feedback from sites the size and shape assessment weighting was increased. The results of this vendor selection is shown in Table 1, with both the original score provided and the adjusted score.

Table 1: Vendor scores from assessment, with original score and adjusted score following an increased weighting for size on score.

Vendor	1	2	3	4
Original Score	56%	80%	62%	62%
Adjusted Score	56%	81%	54%	53%

Upon completion of the scoring negotiation then commenced with the vendor who came out on top. This was primarily around the procurement of equipment and training and the rollout of this equipment. In hindsight this should have also included a formal pricing list for the future, with clear terms on price change with currency, in addition to a servicing package. Instead, servicing has had to be negotiated afterwards when there isn't as much pressure on the vendor. General full life-cycle costs were calculated, which is important mainly if there is a difference in the expected lifespan of sensors, batteries and the gas detection gear itself. For example having electrochemical sensors only last two years instead of three years can be a major impact on the full life-cycle cost of the gas detector.

The results of the vendor assessment were endorsed by both MRP management and health and safety, and the gear was procured. This took around 6-8 weeks before the gear was available and training could commence for staff. Specialist training was provided to a site champion and a deputy site champion for each site, helping to ensure buy-in from all sites. Software was also procured and installed as a network database through the IT department.

Feedback to each vendor was sent through highlighting a direct summary of user feedback, what people liked and what they didn't like. In addition the project team put comments about why they rated them high or low in different areas. For one vendor in particular it was highlighted that the project team considered the risk of the gear being superseded in the near-term was a major cause for concern.

Following the deployment to geothermal the rest of MRP also standardised on the same gear around 6-months later as many sites had fire suppression systems that made use of carbon dioxide and wanted to standardise on gear. This ensured standardisation across the business on both gear and systems, providing the opportunity to share gear between sites.

3. CURRENT SETUP

Gear Deployed

Mighty River Power currently operates over 80 standardised five-gas personal gas detectors across its overall business, 16 docking stations for automated bump testing and calibrations and 32 external pump units. Each geothermal plant has 1 docking station, two external pumps and between 8-12 personal gas detectors on site for normal operations, with the number varying depending on the number of staff on site that use the detectors and the number of gas hazards that require gas detectors to be worn. A site that includes n-pentane, as the working fluid for Ormat binary plants, generally has a higher utilisation of personal gas detectors.

The geothermal groups Rotorua office also has 6 personal gas detectors, allowing Rotorua-based staff to take a gas detector with them when conducting work on site that requires them. In addition the Rotorua office has a docking station, allowing for bump testing and calibration of gas detectors prior to heading to an operational site, or for going to fields not yet developed for geothermal power generation. The office gear is the first deployment of new firmware updates on both the docking station and the personal gas detectors, which generally takes place annually. This enables testing prior to deployment to operational sites.

The quantity of personal gas detectors was selected based on looking at previous utilisation rates, factoring in the number of staff on site and the size of operation. Previously many sites had issued gas detectors as personal issue PPE, mainly as the four-gas detectors (those excluding CO_2 measurement) were relatively inexpensive. Gas detectors with infrared measurement for carbon dioxide measurement generally cost 3-4 times as much as a single four-gas detector. By having such large quantities of gear the servicing costs were considerable.

Two external pumps were purchased per site to cover confined space testing needs with some redundancy in the event of a pump being inoperable. Only one dock per site was chosen due to the high reliability factors for this gear and due to having numerous other sites in close proximity in the event of faulty gear. The vendor also has gear readily available in the event of an issue and the Rotorua dock can be swapped-out as a back-up in the event of an operational site having a fault with its dock.

Bump Testing, Calibration and Dock Setup

It is very important to remember that gas detectors are used to protect life and are therefore used in the course of work being undertaken. Incidental damage does happen from time-to-time, for example through dropping a detector and damaging it or blocking the membrane, thus resulting in the gas detector not providing an accurate reading. Bump testing prior to use and calibrating frequently are both mechanisms to ensure the gas detector is functioning as it should be and that in the event of coming across an unsafe atmosphere it will actually analyse the gases present and subsequently alarm.

At Mighty River Power bump tests, often referred to as function tests, are conducted prior to each use of the gas detector. A bump test is where a gas mix is applied across the detector and a gas measurement response is required. Depending on the bump test setup, this may be simply to achieve a particular reading, which may or may not be the full gas concentration. This test may have a time check whereby the detector needs to achieve a particular gas concentration reading within a set timeframe. Some bump tests also look for sensor stability, whereby the dock checks that the detector reads a gas concentration within a particular concentration range for a set timeframe. Either a delayed timeframe for a response and/or sensor instability are indications of a need to in most circumstances to replace an electrochemical sensor. In addition to tests on sensors, the data logger is reset, both time-weighted average and short-term exposure limit calculations are reset and the alarms are tested (visual, vibration and sound). If the detector fails any of the tests for the sensors then the dock is set up to allow automatic repair, which generally results in the sensor being recalibrated. With a detector fully warmed up a bump test takes around 30 seconds. If not warmed up a bump test can take around 1 minute 30 seconds, but may take longer if a more rigorous bump test is conducted with tests such as sensor stability included.

Gas detectors require calibration at least 6-monthly. Vendors supplying gas detectors are often conflicted when recommending service frequencies, as on the one hand they want to show their gear to be reliable and therefore have the gas detectors not require calibrations very frequently, then on the other hand they have service teams who want business in servicing the gas detectors. Within industry accepted best practice is to calibrate detectors every 28 days, if facilities are available to do this, otherwise to do calibrations 6-monthly. With docking stations at each power station Mighty River Power conducts calibrations every 28 days, with the detectors set to "lock-out" after 28 days since its last calibration. During a calibration the detector is time synchronised, the data-logger downloaded and cleared and each sensor is calibrated. Each sensor is calibrated with a two-point calibration.

Connected to each dock is two low-pressure calibartion bottles, one being a nitrogen bottle which is used for zeroing the sensors and another being a mixed bottle with set concentrations of oxygen (18 %), carbon dioxide (2.5 %), carbon monoxide (100 ppm), hydrogen sulfide (15 ppm) and pentane (0.35 %). These bottles are safe to have inside a building and with concentrations and volumes so low the exhaust does not need to be external to the room. All measured values in percentage are as volume percent. Initially pentane concentrations were 0.7 %, however due to the boiling temperature of pentane it was found that this would partially condense on the sensor and the personal gas detector would read pentane for around two minutes after the bump testing or calibration. This would cause the gas detector to often go into alarm after its alarm block-out period would end. For this reason the concentration was initially reduced to 0.14 %, however this was too slow to respond during bump tests and calibrations, therefore 0.35 % was chosen.

Each dock is connected to the secure Mighty River Power business network through wired connections. Installed on the server, at a static-IP address, is a database application which can be accessed through client software. Upon bump testing and calibrating the information from these tests is sent electronically to the database and any downloaded data-logger information is also sent through. When disconnected from the network the dock works in "island mode" whereby records are stored on the dock. Upon connection to the network these are sent through to the server database. The client software allows for seeing information on settings and status of the dock, in addition to calibration and bump testing data of the detectors.

Alarm Settings

There are a range of alarms set within the gas detectors.

The first type are instantaneous alarm set points, which are based on industry standards. Generally these are made up of two different alarms, Alarm 1 being a pre-warning and Alarm 2 which is the main alarm. Alarm 1 is able to be acknowledged, which means you can click a button and the alarm is silenced (whilst still flashing). Alarm 1 allows for an orderly response to the gas alarm. Alarm 2 is a latching alarm that is not-acknowledgeable whilst gas levels are above the Alarm 2 level, whereby the gas detector will continue to alarm until the gas levels are no longer above the Alarm 2 set point and the gas detector is then acknowledged. The set points for Alarm 1 and Alarm 2 for each gas is given in Table 2.

In addition to the instantaneous alarm set points, there are also Time Weighted Average (TWA) alarms and Short-Term Exposure Limit (STEL) alarms. The set points for these alarms are detailed in the New Zealand Workplace Exposure Standards and Biological Exposure Indices (Ministry of Business, Innovation and Employment, 2013). The values for the gases measured by our gas detectors are shown in Table 3.

Table 2: Instantaneous Standard Alarm Set Points for each gas

Gas	Alarm 1 (acknowledgeable)	Alarm 2 (not-acknowledgeable)
Carbon Dioxide	0.5 vol%	1 vol%
Hydrogen Sulfide	10 ppm	15 ppm
Carbon Monoxide	25 ppm	50 ppm
Oxygen	N/A	19.5 vol% (low) 23.5 vol% (high)
Flammability ^	5 LEL%	10 LEL%

^ Gas detectors are calibrated to n-pentane. 5 LEL% for pentane equates to around 2.5 LEL% for methane, therefore is conservative when methane is present.

Table 3: Time-Weighted Average (TWA) alarm values and Short-term exposure limit (STEL) alarm values given in the NZ Workplace Exposure Standards (Ministry of Business, Innovation and Employment, 2013).

Gas	TWA value	STEL value
	(not-acknowledgeable)	
Carbon Dioxide	0.5 vol%	3 vol%
Hydrogen Sulfide	10 ppm	15 ppm
Carbon Monoxide	25 ppm	50 ppm^

^ NZ Workplace Exposure Standards define the STEL value for 200 ppm for 15 minutes, 100 ppm for 30 minutes and 50 ppm for 60 minutes.

Setup and Other Settings on Gas Detectors

Each gas detector has a maximum of four sensor slots, with one being for the dual-infrared sensor that detects carbon dioxide and also flammability (excluding hydrogen). With a split dual electrochemical sensor that detects both hydrogen sulfide as well as carbon monoxide, this takes up only one sensor slot and allows for an additional electrochemical sensor to be fitted if required. A hydrogen sensor can be used and its reading added to the flammability measurement, or other electrochemical sensors such as ammonia or chlorine can be used.

Each gas detector has a number of settings that can be activated or deactivated when set up by a technician. Mighty River Power has deactivated the life-signal horn, which in simple terms means the detector doesn't beep periodically to tell you it is functioning. The detector does flash periodically to show the user it is still on.

Each gas detector has been allocated a unique Mighty River Power number "MRPXXX" which is labelled on the front of the gas detector and included in internal instrument electronic settings. This allows a simple tracking for the gas detectors without going to the more complex serial code for the detector, allowing operators to use this for when gear is issued out to individuals and tracking on the database software interface.

Shuts and Specific Major Projects

Shuts in geothermal are generally conducted for around one week per year per site. During this time significant levels of confined space work is undertaken and often wireline work is also conducted. This significantly increases the need for gas detectors due to the additional work being undertaken on site. As we don't have rolling shuts all the time it is inefficient for us to own extra gear to cover shuts, therefore we generally rent additional gear for these shuts as do several of our contractors.

The use of external pumps, or internal if gas detectors have these, along with extendable sample probes allows for safe testing of confined spaces. Pumps and sampling probes are used for confined space entry testing, unless the gas detector is being lowered down from the top of a confined space. These pumps require battery replacements periodically and occasional filter changes. Care must be taken to prevent crimping of the tubing within the extension probe when it is being retracted. Some probes have exhibited damage at Mighty River Power from being retracted too quickly for the tubing to retract without crimping.

The use of area monitoring has been used on a number of projects. Area monitoring has the advantage that alarms can be sent between area monitors, through either wireless or wired arrangements and the needs for individuals to wear gas detectors is reduced as the areas have gas detection coverage. Gas detectors plug into these area monitors and the battery of the area monitor trickle-feeds the gas detector, thereby allowing the gas detector to last around 4 days before needing to be swapped out. An issue identified on one site with this was that we found the TWA and STEL alarms need to be deactivated as many gas detectors work as a totaliser for TWA alarm purposes thereby causing alarms to go off after a period of time in, particularly for carbon dioxide, as the value creeps up to the TWA alarm amount.

Gas Detectors within Procedures and Policies

Gas detection has been added as a specific section within the Mighty River Power PPE Policy (Mighty River Power, 2015). In this it defines what gases are required to be measured (as a minimum), where the gas detectors are to be worn (as a minimum) and details around the frequency of both bump testing and calibrations. It is important to note that whilst areas have been defined that require gas detectors to be worn, any risk assessment (Hazard ID) that highlights gas risk needs an appropriate control and this is often to wear a gas detector, thus gas detectors are often worn in areas outside the mandatory areas.

Often there are large tour groups that visit geothermal sites, from overseas government delegations to school groups and it was considered not to be practicable for every person to wear a gas detector, thereby there has been an acknowledgement of work group within the PPE policy.

The wording under the gas detection section is (Mighty River Power, 2015):

> *Mighty River Power requires gas detectors to be used in circumstances where the risk of gas being present has the potential to cause injury or death.*
>
> *At all operational sites, 5-gas-sensor gas detectors are required for detection of Oxygen (O2), Hydrogen Sulphide (H2S), Lower Explosive Level (%LEL), Carbon Monoxide (CO) and Carbon Dioxide (CO2).*
>
> *It is mandatory that all work groups will have a gas detector in use at all times when present within a confined space, when present in all pentane hazardous areas (hazardous zones 1 and 2), when present near geothermal surface features, and when present on steam field pads. Any person managing a gas detector will endeavour to position themselves between any gas risk and the work group.*
>
> *All gas detectors are to be bump tested prior to each use. Mighty River Power gas detectors are to be calibrated monthly. Contractors' gas detectors are to be calibrated no less frequently than six-monthly, or to the manufacturers' guidelines if required more frequently than six monthly.*
>
> *Note – the %LEL parameter for Mighty River Power detectors are tuned to n-pentane as this is our largest explosive risk. This is a conservative approach as pentane is explosive at lower concentrations than methane. Detectors tuned to methane are still accepted on site.*

Contractors working on Mighty River Power sites also needed to have gas detectors capable of reading carbon dioxide, if they were working in areas that required personal gas detection or if they had identified a risk of hazardous gases being present. Whilst Mighty River Power selected a vendor for its own reasons it did not require contractors to also use that vendor.

Training

A training package was arranged to be provided from the vendor. This is generally a two-hour training package, focussing on gas risks and details about how gas detectors measure these gases, then the practical element of how the specific gas detector functions (including practical work). Two main sets of training to site-champions, and a back-up, was provided. The first was train-the-trainer, which was aimed at significantly increasing the knowledge of the gear for people from each site. The second was maintenance training. Maintenance training was provided principally to enable better fault-finding from staff as a first screen in the event of a gas detector having a fault or other issue. This training worked principally to increase buy-in to the gear of selected individuals from each site.

An initial deployment of training was provided to all individuals across the geothermal business. A smaller refined presentation was created for teaching people how to specifically use the gear we deployed, enabling individuals to quickly come up to speed on how the detectors work.

Confined space training providers were informed of our selection of gas detectors and were provided with Mighty

River Power specific training packages and documentation to ensure they were able to train our staff with our gear.

Servicing of Gear

A full annual service to each docking station is conducted, where checks are made to the dock in addition to the seal pads and filters being swapped out. This is done at each respective site to reduce business interruptions. If a firmware update is due it is conducted at the same time, however in the future it appears as though firmware updates can be deployed through the network configuration of the docking stations.

4. CHALLENGES

The gear chosen by MRP was relatively new to the market and the docking station was brand new to the market. This had the benefit of meaning the gear would be highly unlikely to be superseded within the lifespan of the procured gear, however it did pose risks of early deployment issues. The docking stations deployed at MRP were the first in New Zealand and significant learning has been undertaken on these. The major concern was that the network software and the docks had very limited functionality and the software had not necessarily been designed with remote management in mind, at least for early versions. Significant levels of interaction between MRP and the vendor has taken place with MRP providing feedback on wishes and wants for the software and feedback on product issues. One area that could not be overcome was that the docks were not WiFi capable and need a physical network cable connection. On old power stations this can be a challenge, as they were built in a time before computer networks existed. On brand new stations, due to the dominance of WiFi, this can also pose a challenge as there are often very few network ports installed. Even if the docks were to contain WiFi, these WiFi networks also often have significant firewalls in place that need to be considered in any possible setup.

One such issue on the new docks was vibration on our hydro power stations. Detectors were failing on their vibration check, as the background vibration meant the ambient noise within the dock was significant and it was through sound that vibration was detected. A rapid firmware update by the vendor assisted in fixing this, along with placing the docking stations on top of thin foam pads.

Carbon dioxide capable gas detectors are quite rarely used around the world for general purposes, being mainly used for confined space entries. This results in more stress on batteries than perhaps would otherwise be the case. The Ni-MH batteries used were originally anticipated to last around 24-36 months but we are seeing significant degradation of battery-life on some sites at around 10 months. Battery-life significantly decreases on a significant portion of gear and battery-life can rapidly reduce to as little as 3-4 hours and the detectors batteries then fail. We are currently working with the vendor to rectify this, but at this stage it is being covered by more frequent battery swap-outs.

5. KEY LEARNINGS

As an industry we share a lot of contractors and sub-contractors. We need standard settings and messaging to ensure consistency. Carbon dioxide needs to be acknowledged as being a risk within the geothermal environment in New Zealand, just as hydrogen sulfide is, and therefore have the risk of carbon dioxide appropriately managed.

When going out to procure gear such as gas detectors it is important to do a wide-ranging assessment of gas detectors, both within your company and industry as well as outside your company and industry. By understanding how people use gas detectors within your company and all the operational modes you will be able to define your requirements accurately. By doing this assessment you will come across people with extensive knowledge on gas detectors and how they are used and these people are incredibly important for a successful rollout of any new gear. Asking a lot of questions from other companies will also assist in developing an accurate requirements list. Conducting a full life-cycle cost estimate assists in making decisions for what gear to procure.

Obtaining staff and contractor buy-in to any change such as gas detectors is imperative. Besides having input into the requirements gathering, having staff involved in product testing is important. Knowledge and training are key components to ensuring that once gear is procured and deployed that it will be successful. Gas detectors can be complex to understand and it is important staff have good knowledge on the gear. Training for just one product can make this process much easier.

Package your servicing into any buying deal up-front – negotiate replacement prices for parts and servicing costs. Gear comes from overseas so ensure there is a price adjustment factor for currency in any pricing list. As part of this negotiation consider requiring the vendor to hold a minimum amount of spare parts, gas bottles and readily available rental units.

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