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Risk mitigation of H_2S exposure at ON Power

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ABSTRACT

The biggest threat to ON Power's power plants' employees is H_2S, a colorless, flammable and toxic gas which can cause death in high concentrations. H_2S is one of the NCGs (non-condensable gases) contained in the geothermal fluid. Each employee has their personal H_2S monitor which ON Power collects data from for analysis. Initial studies have found that certain groups of employees are at a significantly more risk than others.

ON Power has strict safety procedures for employees when working in conditions with a significant risk of H_2S. All power plant employees are trained in safety procedures and awareness of H_2S and employees out in the field get specialized training which focuses on these dangers. Employees have gotten annual doctor's check-up since 2012, which assesses the effect of H_2S on ON Power's employees.

This article presents the measures ON Power has taken to mitigate the risk of H_2S exposure at the company's plant sites.

1. INTRODUCTION

Each year approximately 7 people die as a result of H_2S (hydrogen sulfide) poisoning in the US alone (US Bureau of Labor Statistics, 2017). H_2S is a colorless gas which, in low concentrations, smells like rotten eggs. At higher concentrations it will cause olfactory paralysis, loss of consciousness and respiratory depression. This makes H_2S a particularly subtle threat that needs to be approached as the toxin it is.

As H_2S is one of the NCGs (non-condensable gases) commonly found in the geothermal industry it is hard to eliminate its threat to workers in the industry. The NCGs originate in the reservoir and are carried up with the geothermal fluid in the wells. The gas stays in the steam that is separated in the separators, goes through the turbine and finally gets extracted from the separator via a gas extraction system. In many geothermal power plants these NCGs are then released into the atmosphere from the cooling towers. At Hellisheiði, one of ON Power's geothermal power plants, the H_2S (and CO_2) is separated from other NCGs and reinjected into the reservoir.

EU-OSHA (European Agency for Safety and Health at Work) and Vinnueftirlitið (the Icelandic Administration of Occupational Safety and Health) set two limitations on time spent working in conditions where workers are exposed to H_2S. The lower limit is H_2S concentration of 5 parts per million (ppm) for 8 hours of work, that is you can work up to 8 hours in these conditions. The higher limit is a H_2S concentration of 10 ppm for 15 minutes, that is you should be out of the contaminated area within 15 minutes, EU-OSHA (2009) and Vinnueftirlitið (2018). As such, these limits set the limit for the maximum exposure level where work can proceed as normal (8-hour limit) and at which exposure level workers should get out immediately 15-minute limit. These are the limitation that ON Power enforces for all workers at its power plants.

ON Power owns and operates two geothermal power plants in Iceland, Nesjavellir and Hellisheiði. Both plants are combined heat and power plants located around the Hengill central volcano in the southwest of Iceland, about 25 km east of Reykjavík. Nesjavellir is located northeast of Hengill and has an installed capacity of 120 megawatt electric (MW_e) and 300 MWth. The plant was commissioned in 1990. Hellisheiði is located southwest of Hengill and has an installed capacity of 303 MWe and 133MWth, the plant was commissioned in 2006. This paper will focus on H_2S risk mitigation in and around these plants.

2. WHAT HAS BEEN DONE

2.1 H_2S monitors

In 1993 and 1994 ON Power set up H_2S monitors at Nesjavellir, warning bells and lights were connected to these monitors. In case of H_2S concentrations reaching a certain threshold, the warning bells would go off and blue lights would start flashing, indicating that the area should be evacuated. The same type of system was set up at Hellisheiði during its construction. Monitors, lights and warning bells are added to the system as needed in collaboration with employees. For example, they have been added beneath turbines and other equipment and high voltage line cellars. Monitors that continuously monitor and log air quality have been installed outside both power plants since then.

2.2 Personal H_2S monitors

In 2005 all employees started carrying personal H_2S monitors at ON Powers' plant sites. The first monitors required manual calibration, a process that was time consuming and not feasible in the long run. Therefore, in 2012 the company started phasing in monitors that did not require calibration. These monitors were single use monitors that lasted 24 months. In 2015 the company started phasing in a new monitor system from Industrial Scientific, these monitors were fully implemented for all employees in 2017. These monitors require calibration every 2 weeks. To do this they are docked in a docking station where gas is used to automatically calibrate the monitor. These docking stations, see Figure 1, also read data from the monitors and upload to a database. The data consists of logs of all incidents where the monitor has measured any H_2S, the maximum value, average value, duration of exposure, time of incident and more. This allows for better oversight of incidents, which has allowed the company to emphasize changes of equipment and working procedures where these changes are most needed.

Figure 1: A personal H_2S monitor docked for calibration.

In 2015-2017 regulations regarding H_2S exposure at work in Iceland was strengthened to match the regulations of the EU-OSHA. Before that the 15-minute limit was 20 ppm. ON Powers' policy towards contractor's safety was strengthened in 2018 and the company now requires everyone that is working in or around one of their plants to have a personal H_2S monitor. This applies to all contractors, as well as all employees, regardless of where they are working at the plants.

2.3 Standardized personal protection equipment and procedures for certain jobs

Over the last few years ON Power has systematically worked on assessing the dangers of each job at its plants. To do this the company has hired consultants to assess these dangers with employees and set up standardized procedures and equipment for certain kinds of jobs. In cases of risk of H_2S exposure, for example when work is being conducted on gas rich systems, workers are required to have a supplied air breathing apparatus (SABA) while working, see Figure 2A. Further, they are required to work in pairs and have a third worker standing at a safe distance ready to respond to emergencies, ready to call in any emergencies via radio. The workers working in gas use SABAs that are connected via a hose to the building's fresh air system. The third worker on the other hand has a self-contained breathing apparatus (SCBA) that includes a fresh air tank, allowing the worker to move freely where needed, see Figure 2A. The third worker also carries an emergency SCBA with a small air supply intended to allow others to get the air needed to get out of the building in case of emergencies, see Figure 2B. These emergency SCBAs are also placed at strategic locations around the plants and can be easily reached in emergencies.

2.5 Training of employees

In the past years ON Power's plant operations have become increasingly aware of the importance of education and training in safety matters, both for employees and contractors. From 2015 specialized courses have been taught at the company with an emphasis on the biggest hazard at the company's plant sites. This includes H_2S contamination, hot steam, pressurized fluids, heights, high voltage and enclosed spaces to name a few.

Figure 2: Example of supplied air breathing apparatus (SABA) and self-contained breathing apparatus (SCBA) used by ON Power employees. A) On the left is a worker using a SABA that connects to an air supply via a hose, on the right is "the third worker" using the a SCBA during work on gas systems. B) Emergency SCBA used by workers in emergencies to get out of contaminated areas.

These courses are mandatory for employees and contractors that work at or around ON Power's plants. The courses focus on making people aware of, and get them to consider, the hazards around them by using real world examples of near misses and accidents. As well as the courses specific to the hazards around geothermal power plants, workers are required to have a valid first aid certificate, which are valid for 24 months, and take a lock-out tag-out course. All courses need to be renewed annually, except the first aid class which must be renewed biannually. A great emphasis is placed on workers conducting risk assessments before jobs, big or small. These assessments are done by the workers themselves before they start the job using either a booklet listing various risks for various jobs made by Reykjavík Energy, or a phone app that does the same made by the National Power Company of Iceland, and is intended to give them time to consider the hazards of the job. All workers are also encouraged to stop and consider the hazards again if conditions change or anything unplanned needs to happen. Further, ON Power's plant operation employees are required to take courses in the use of SABAs and the plant operators are required to take a more extensive course on the subject as well as smoke diving. As these courses take a significant amount of time, they are not a requirement for those that are only coming to attend meetings and will not go outside the office area of the plants. These visitors, however, are required to watch a short video on the hazards at the plants, evacuation procedures and so on and sign a confirmation that they have done so. All such visitors are expected to be the responsibility of a specific plant employee (any plant employee that has finished the courses can take that responsibility) and the visitors have no access to any areas except the offices without an escort.

3. WHAT IS BEING DONE

3.1 Mapping the number of H_2S incidents

In order to assess the level of threat that H_2S poses to ON Powers' employees, an analysis of the number of incidents was made. This work was initially done in the fall of 2018. The analysis has been updated for this article using data from the beginning of 2015 through June of 2019. All data for the analysis was taken from the database that gathers data from H_2S monitors when they are docked. A single incident is defined as any number of logs in the database which happens on the same H_2S monitor, a new incident begins when a H_2S monitors starts reading H_2S again after more than 15 minutes of no reading. The incidents are then classified by their highest H_2S reading. The reading classifications are 500 ppm or more, 100-500 ppm, 50-100 ppm and 10-50 ppm. Incidents with a highest reading lower than 10 ppm were not considered as the H_2S monitor gives of a warning signal at 10 ppm.

This analysis primarily revealed two things. Firstly, the number of incidents, and therefore the threat, was higher than anyone expected. Secondly, certain groups were at significantly more risk than others, namely the steam field operators. Figure 3 shows the number of incidents per employee each year, 2019 has been excluded as only half the year is included in the data (number of incidents per employee for the first half of 2019 is 10.88). The year 2015 has a lower number of incidents than the others which may be attributed to the system being implemented that year and many employees didn't have H_2S monitors which upload data to the database. By the end of 2017 all employees had received these monitors and it is therefore to be expected that, as more employees carry the monitors and upload data, the number of incidents in the database increases. The lower number of incidents per employee may indicate that employees are involved in fewer incidents, but more data is needed to say for certain.

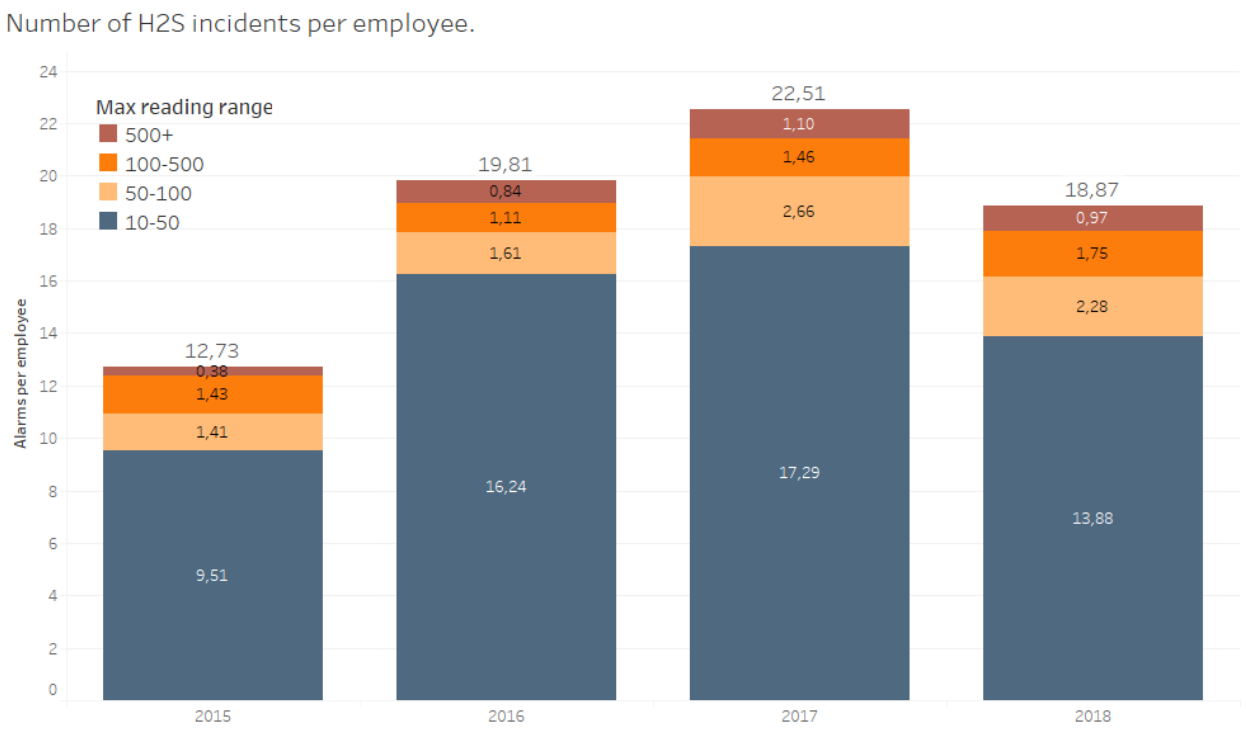

Figure 3: Number of H_2S incidents per employee at ON Powers' Plant Operations per year. The incidents are grouped by the highest reading of each as seen by the color legend. Blue indicates incidents with a highest reading of 10-50ppm of H_2S, the light orange the ones with highest reading of 50-100ppm, the dark orange the ones with highest reading of 100-500ppm and the red the ones with highest reading of 500ppm or more. The number of incidents has risen since the systems inception in 2015 but seems to remain relatively unchanged from 2016-2018.

Plant operations employs 48 workers (as of July 2019). Looking at the 10 people (21% of employees) with the highest number of incidents recorded shows that these employees were involved in 931 out of the 1376 incidents, or 67.6%, that happened in 2018 and 2019. These people are therefore at significantly more risk than other employees. All but one of the steam field operators are part of this group. The rest of the group consists of plant operators and repair specialists.

3.2 Workshops with steam field operators

As mentioned in section 3.1, one group of employees at ON Power's plant operations at particular risk are the steam field operators. Their job revolves mainly around maintaining and monitoring the boreholes and steam pipelines that supply the powerplants. After mapping the number of H_2S incidents a decision was made to work specifically with this group of employees in order to reduce their risk of exposure. This work started in November 2018 and takes the form of weekly workshops with the employees and a safety specialist.

The workshops focus on identifying and eliminating risk factors, especially fatal dangers. To this end, the employees discuss the way they work on various jobs and what potential risks these jobs include. During these discussions it became evident that it varied how employees performed many jobs. This gave a good basis for discussing what would be the best-known approach for each job which then served as the basis for standardized working procedures, which the employees establish themselves. It is vital that employees create these work procedures for two main reasons:

1. It gives them a sense of ownership of their own work procedures and they will therefore be more inclined to follow them.

2. It gets them to think about their own safety and how they can act to minimize risk. Once these procedures are established, a copy of them is attached to each work order for these jobs which the employees bring with them.

3.3 Mapping the nature of H_2S incidents

To understand the nature of the H_2S threat at ON Powers' powerplants all employees are expected to make a report of each time their H_2S monitor alerts them. This has not, however, been done reliably and as such different methods have been sought to map the nature of the incidents. The first such initiative was to attempt to map the nature of all H_2S incidents in May of 2019. This was done by talking to each employee that had an incident and ask them about it. This assessment will be performed again later in 2019 to get a broader dataset. The questions asked were:

- Where were you when the incident took place?
- Did you get hit by gas (for example while opening a valve some gas leaked out and hit you) or did you walk into a contaminated area?

- If you walked into a contaminated area, were you wearing a SABA?
- Did you use the H_2S monitor as a sniffer (put it into a potentially contaminated area before entering to check for gas)?
- Did you feel any physical symptoms as a result of the incident?

Out of the 39 incidents that took place that month, 19 have been mapped. As can be seen in Figure 4, most of the incidents, 11 out of 19, were in the lowest range of 10-50 ppm H_2S. However, in 3 cases the monitor maxed out at 500 ppm, a potentially lethal level. In the first incident the monitor was used to check for gas in a pipe after a valve was opened, the valve was closed immediately after the user saw that gas was coming out of the pipe. The second incident was the result of the monitor being used as a sniffer, it was lowered into an area suspected of contamination and the user was out of harm's way while doing so. The third incident took place during work on a gas extraction system, the person involved was wearing a SABA and all protocol was followed to minimize the danger. In 9 of the 19 incidents the H_2S monitor was used as a sniffer to minimize risk to workers.

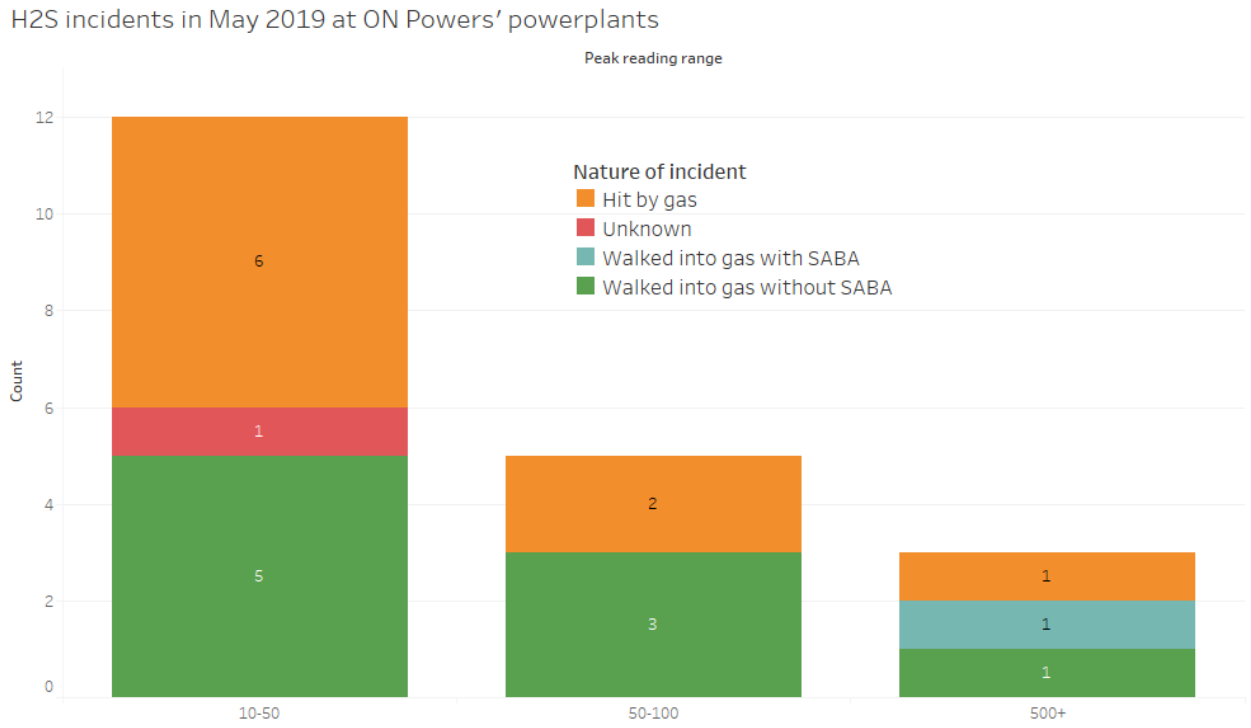

Figure 4: Number of H_2S incidents at ON Power's powerplants in May 2019. The figure only shows those incidents that received a response during inquiry. The incidents are shown in 3 ranges depending on the highest H_2S reading during the incident: 10-50 ppm, 50-100 ppm and 500 ppm+. No incidents in the 100-500 ppm range received a response. Most of the incidents are in the 10-50 range. The 3 incidents with 500 ppm+ measurements posed little threat to the people involved due to the nature of the incidents (see section 3.3). The incidents are categorized by their nature into 3 categories: hit by gas (where gas was unexpectantly released close to the worker), walked into gas with SABA (where the worker walked into a contaminated area with a SABA or SCBA) and walked into gas without SABA (where the worker walked into a contaminated area without a SABA or SCBA).

It is worth mentioning that during interviews and correspondence with employees in this assessment the interviewer asked why people had not used fresh air SABAs in cases where they knew or suspected there was an H_2S contamination. Most answered that they probably should have but have become accustomed to not using it. In one case the workers went to search for a suspected gas leak without fresh air SABAs. This tells us that workers are still, in some cases, stuck in "older ways of doing things", a habit that is hard to break.

3.4 Study of long-term health effects of H_2S exposure

Since 2012 a study of the long-term effects of H_2S on employees has been conducted. The study consists of an annual check-up conducted by medical professionals. The following are checked (not a comprehensive list): visual acuity, color vision, hearing, blood pressure, heart rate, waistline, height, weight, BMI, blood test (variety of parameters tested), urine sample (variety of parameters tested), sense of smell, sense of taste and breathing test. Most plant operations employees participate in the study, the number of participants can be seen in Table 1, and 24 employees have participated in every study.

Year	2012	2013	2014	2015	2016	2017	2018
Number of participants	44	42	46	44	42	42	46
Number of new participants	0	0	0	0	4	10	14

Table 1: Number of participants in the study of the long-term effects of H_2S exposure. The table lists the total number of participants as well as the number of participants participating for the first time each year. 24 employees have participated every year of the study.

Each year 2-9 participants were experiencing some mild respiratory symptoms that could be attributed to other sources and no indications of long-term respiratory issues were found to relate to H_2S exposure. Each year some participants had experienced symptoms of H_2S exposure, like irritation in eyes and throat, nausea and headaches, but in all cases only during exposure. The main result of the study so far is that long-term exposure of low concentrations of H_2S has no significant effect on employee's health.

4. ACCIDENTS

In 2017 several of ON Power's senior employees went over and discussed all H_2S related accidents they could recall between 1985 and 2010. During this period, they could recall 6 serious incidents 4 of which involved more than 1 person, however, none of these incidents resulted in fatalities. Only one of these incidents took place after the company started using personal H_2S monitors, this incident was in 2010. One of these senior employees was consulted for this article and he said that incidents where people lost consciousness had been a regular occurrence before the implementation of the personal H_2S monitors. He does not recall any other incidents, aside from the one in 2010, after the implementation of the personal H_2S monitors.

Looking at data from ON Power's health and safety report register (an online form that employees can fill out to report accidents, near misses, hazards and so on) between 2015 and 2019 shows no accidents related to H_2S in this period. Further, in all reports of near misses, except one which occurred in 2019, the workers involved fled from the gas and/or stopped the exposure by some other means. This seems to indicate that the measures ON Power has taken to mitigate the risk of exposure are having an effect.

The near miss in 2019 is particularly concerning because the workers involved were scientists that work almost exclusively in the geothermal industry. They had SABAs in the car close to where they were working but had no training in the use of that equipment. Despite being fully aware of the H_2S hazard during the job, and having measured high levels of gas during work, they kept working without any protection and simply "held their breath as needed". Lastly, it is only by chance that these workers were approached during a routine random check.

5. SUMAMRY AND RECOMMENDATIONS

ON Power has made changes on multiple fronts to mitigate the risk of H_2S exposure at the company's power plants. The company has implemented strict procedures when working with gas systems to minimize the risk of serious accidents. Everyone working at the plants, employees and contractors, are required to attend a series of courses to educate them and make them aware of the hazards at the plants, including H_2S. Monitors, warning lights, alarms and emergency fresh air SCBAs have been placed in key locations around the plants and everyone is required to carry a personal H_2S monitor at the plant sites.

Only one accident involving H_2S has occurred since the implementation of personal H_2S monitors, indicating the mitigation measures have had an effect. It is however concerning that some workers seem to not use adequate protection when they are aware that they are going into a H_2S contaminated or potentially contaminated area, despite being fully aware of the dangers involved. The road to a safe workplace, however, is a never-ending project that ON Power is fully committed to undertake.

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