Health and Safety Aspects of the Kawerau Project, Mighty River Power

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ABSTRACT

Mighty River Power (MRP) has recently completed a 100MW geothermal power station in Kawerau, New Zealand.

This project was constructed under an Engineer-Procure-Construct (EPC) contract and presented a number of challenges from a health and safety perspective. MRP was proactive in establishing a number of initiatives to address these challenges. The health and safety outcomes of the project are discussed.

During commissioning of the plant an incident occurred which involved the discharge of non condensable gas. This incident and the resulting investigation are reviewed and the outcomes are presented. A number of lessons have been taken forward to MRP's next project. These lessons are also pertinent for the wider geothermal industry.

1. INTRODUCTION

MRP's 100MW geothermal power station at Kawerau is the largest single geothermal development in New Zealand in more than 20 years.

Construction of the project began in January 2007 and at its peak 27 companies and 400 people were working on the site. The power station was fully operational by the end of August 2008.

The Kawerau geothermal power station has significantly increased generation capacity in the Eastern Bay of Plenty region, meeting about one-third of residential and industrial demand in the region. It provides electricity supply and cost certainty to important local industry.

Figure 1 shows the Kawerau power station during commissioning.

Kawerau was a $300 million project (New Zealand dollars). MRP have an ongoing development program in geothermal. The company is currently building a 132MW, $450 million dollar, geothermal power station called Nga Awa Purua.

1.1 Contracting Structure

The Kawerau power station was built for MRP under a Fédération Internationale Des Ingénieurs-Conseils (FIDIC) EPC contract with Sumitomo Corporation. A set of MRP employer's requirements accompany the FIDIC contract. They are specific technical and management specifications for the project.

Separate smaller design-build FIDIC type contracts were in place for the steam gathering and disposal system and electrical transmission facilities.

2 ROLE OF THE EPC CONTRACTOR

The EPC contractor was both the organization responsible for activities on the site and principal in charge of sub-contractors. This infers full control over the site health and safety systems, access, and management of construction activities

2.1 Role of MRP as a Principal

Under its internal policy, and New Zealand legislation, MRP as a principal had a duty to take all practicable steps to ensure no employee of a contractor or subcontractor is harmed while doing any work that the contractor was engaged to do.

This level of care also extended to people in surrounding locations of the project including neighbors and site visitors.

MRP needed to ensure it did not transfer liability from the EPC contractor to itself, or worse still cause confusion in work activities by taking too much of a "hands-on" directing role. The EPC contractor was in control of the site (i.e. place of work).

Figure 1: Kawerau Geothermal Power Plant

2.2 Relevant New Zealand Legislation

MRP's employer requirements in the contract were specific in its reference of New Zealand acts, regulations, and bylaws including:

- Health and Safety in Employment Act;
- Hazardous Substances and New Organisms Act (HSNO);
- Toxic Substances Regulations;
- AS/NZS 2430 – Hazardous Area Classification;
- AS/NZS 2381 – Hazardous Area Equipment.

3. ESTABLISHING HEALTH AND SAFETY EXPECTATIONS THROUGH AN EPC CONTRACT

3.1 Contract and Employer's Requirements

The Kawerau project was the first major construction contract undertaken by MRP in recent times. As such the MRP organization experienced a learning period at all levels up to and including the board of directors.

Being cognisant that the station construction was an EPC contract MRP needed to define their level of involvement from a health and safety perspective. There was concern that the key contractor, being an overseas vendor, was not fully conversant with New Zealand legislation, industry and MRP standards.

The project included many contractors from different countries and industries working together. MRP positioned itself with support from the EPC contractor to take a proactive and more involved approach than would normally be anticipated. MRP worked with all parties to raise the level of understanding, expectations, and establish a strong health and safety culture throughout the project.

MRP's employer requirements specified detailed health and safety management systems, reporting and performance be provided by the EPC contractor.

3.1.1 Project Specific Health and Safety Goal

The health and safety specific goal for the project was "No Lost Time Injuries (LTI) to anyone at anytime". The definition of an LTI is given in section 4.1.

3.1.2 Hazard and Operability Reviews

MRP's employer requirements specified Hazard and Operability reviews (HAZOP) will be conducted on the plant lead by the EPC contractor. A HAZOP is a formal and rigorous means of identifying risks considering a wide range of process parameters for each plant system component, the risks for which are subsequently mitigated through design or operating procedures changes.

The team of people selected to evaluate the design needed to have appropriate experience and expertise. The team comprised MRP operators from existing stations, representatives from an Indonesian plant with a similar process, the designers of the steam separation plant (Sinclear Knight Mertz - SKM), and technical representatives (Fuji Electric Systems) of the EPC contractor. The HAZOP's were run by experienced facilitators from SKM.

3.1.2 Mobilisation Meeting

Prior to construction commencing pre-site establishment meetings were held with each of the key contractors including the station EPC contractor to:

- validate MRP's review and acceptance of the contractor's health and safety management system; and
- handover the site

The review of the contractor's documentation enabled a detailed assessment of the proposed establishment of health and safety processes on site and for MRP to influence where it was seen as appropriate.

3.1.3 Inspections and Audits

During the project MRP performed scheduled inspections and audits of the contractors and sub contractor's (where applicable) health and safety management system. The intent was to monitor for compliance against the standards set in MRP employer's requirements. Specifically

- hazards and substandard conditions are either eliminated, isolated or minimised and or monitored;
- site areas are safe to work in;
- work activities are conducted in a safe and responsible manner;
- tools, power tools, personal protective clothing and associated safety equipment are compliant and safe to use;
- identify areas for improvement of the specific contractor's processes or identify good practices that could be applicable elsewhere.

With regards to safety a no blame culture was promoted with opportunity to learn and improve. As the principal MRP promoted a culture of continuous improvement across the project.

3.2 Positive Initiatives

3.2.1 Lead Performance Indicators

Generally health and safety statistic for reporting purposes are retrospective, i.e. they report what has happened in terms of accident and incidents. Lead performanace indicators (LPI's) are a set of quantitive performance measures to help proactively anticipate and manage health and safety on the site. The LPI's covered eleven diffierent health and safety aspects such as measuring the number of new HS initiatives each month, attendees at the HS committee meetings, and actions remaining open from HS meetings.

The lead performance indicators serve to:

- are lead indicators rather than retrospective;
- create and maintain a culture of management ownership;
- have set of metrics reflecting Health and Safety performance;
- focus on accountability for performance; and

- focus on behaviour

In an independent review (Reeves (2008)) commended the practice of setting HSE Lead Performance Indicators as "best practice".

3.2.2 Reward system for reporting

Initially there was a strong reluctance of contractors to report near misses. Considerable encouragement was required by MRP to demonstrate the purpose of continuously improving health and safety on site. The message was of "providing a safer working place for everyone".

To this end MRP established a reward system (based on small prises for positive actions) to encourage reporting of near misses.

Near miss reporting helped keep health and safety awareness high through feedback in site meetings. Near miss feedback is an essential tool in the prevention of accidents.

3.2.3 Health and Safety committee

A health and safety committee was established for the project to ensure there was regular and effective communication between MRP, key contractors including the EPC contractor and subcontractors. More specifically the committee served to:

- communicate cross contract health and safety issues and experiences;
- create consistency across the various project work fronts;
- identify and allocate initiatives and improvements;
- promote the continuous improvement of health and safety processes and practices;
- act as a forum for escalating health and safety issues to MRP project management.

3.2.4 Internal Training

To raise awareness of the role of a principal under the New Zealand HSE Act MRP facilitated a number of seminars by external providers (e.g. Johnston (2008)). These seminars were designed to help each of the key contractors understand their role in relation to MRP and their subcontractors.

4. SUMMARY OF PERFORMANCE

4.1 Lost Time Injury

MRP define an LTI as an occurrence that results in a fatality, a permanent disability or time lost from work of one (whole) day/shift or more due to injury or disease.

4.2 Metrics

Health and safety performance throughout the project was measured by a number of leading and lagging metrics.

Generally in industry a growing emphasis is being placed on the need for organisations to use Health and Safety lead performance indicators as opposed to traditional Health and Safety lagging performance indicators such as Lost Time Injury Frequency Rate (LTIFR).

Health and Safety lagging performance indicators in isolation do not provide an early warning of issues, or a reliable and accurate measurement of Health and Safety performance. At best, lagging performance indicators represent an "after the event" measurement.

The recent focus on leading performance indicators is driven by the opportunity to improve Health and Safety performance by promoting actions to correct potential weaknesses prior to accidents occuring rather than taking retrospective action based on demonstrated failures or outcomes.

For Kawerau the leading metric used is the lead performance indicators described in section 3.2.1. Traditional lagging metrics were also used including:

- the LTI frequency rate;
- the LTI severity rate; and
- the number of reported incidents or near-misses.

4.2.1 LTI Frequency Rate

The LTI frequency rate is a measure of accident frequency and is calculated as follows:

$$LTIFR = 10^6 \frac{a}{h} \qquad (1)$$

where a is the number of lost time accidents, and h is the total number of person-hours worked. The factor of 10^6 is applied to scale the rate to an order of unity (i.e. close to 1)

4.2.2 MRP LTI Frequency Rate Target

The MRP LTI frequency rate target, $LTIFR_t$, for the Kawerau project was assigned through consideration of available data from other New Zealand and Australian construction projects across 11 different industries.

$$LTIFR_t = 3 \qquad (3)$$

In other words a maximum of 3 LTIs per million person-hours worked. This is an internal target only.

It is noted the project goal stated in section 4.1 reflects a target rate of zero. This was appropriate as a vision for the project and established the expectations for the general population of contractor engaged on the project..

4.2.3 LTI Severity Rate

The LTI severity rate is a measure of the consequence of accidents, through lost time, and is defined as follows:

$$LTISR = 10^3 \frac{l}{h} \qquad (4)$$

where l is the total number of person-hours lost due to accident. The factor of 10^3 is applied to scale the rate to an order of unity (i.e. close to 1).

4.2.4 MRP LTI Severity Rate Target

The MRP LTI severity rate target, $LTISR_t$, for the Kawerau project was defined by a similar means to the MRP frequency rate target.

$$LTISR_t = 0.15 \qquad (5)$$

4.3 Performance Outcomes

A summary of performance is as follows:

- No fatalities occurred during the project;
- 400 people on site at peak of construction;
- 4 LTIs during the project;
- 231 lost time hours;
- 209 reported incidents or near misses and;
- 718,839 person-hours worked on the project.

4.3.1 Summary of Lead Performance Indicators

The score of lead performance indicators for Kawerau are shown in figure 2. The 90% target was seen as anappropriate stretch target based on review of data from limited construction industries and projects.

Explanation of why targets were not achieved???

4.3.2 Summary of LTI Frequency Rate

The LTI frequency rate for Kawerau is shown in figure 3. The rate is shown as a twelve month rolling average incorporating the cumulative number of person hours worked to date over the period.

The LTI frequency rate shows a trend downwards towards the target value across the life of the project. This is reflective of the understanding and experience gained by the EPC contractor both in maturation of systems/process but also in an increased awareness in safety culture across all those involved in the project.

The benchmark LTI frequency rate for Kawerau given in equation (3) was not met during the project. This indicates the benchmark is set at the appropriate level, as a stretch target, for future projects.

4.3.3 Summary of LTI Severity Rate

The LTI severity rate for Kawerau is shown in figure 4. The rate is shown as a twelve month rolling average incorporating the cumulative number of person hours worked to date over the period.

The LTI severity rate trended downwards over the life of the project. This indicates the rehabilitation program was effective and workers were able to return to work promptly.

4.3.4 Summary of Near Miss Reporting

The number of incidents or near misses reported is shown in figure 5. As discussed in 3.2.1 a number of initiatives designed to encourage the reporting of near-misses were implemented by MRP. For the project a total of 209 incidents or near misses were reported. The shape of the curve follows to some extent the.

4.4 Additional Comments

It was clear that MRP as the eventual operator, with experienced operational staff, were suited to take a proactive role in health and safety during hot work and live commissioning.

The EPC contractor led the commissioning process but cultural/language barriers and lack of understanding of NZ industrial safety requirements influenced the approach that MRP took.

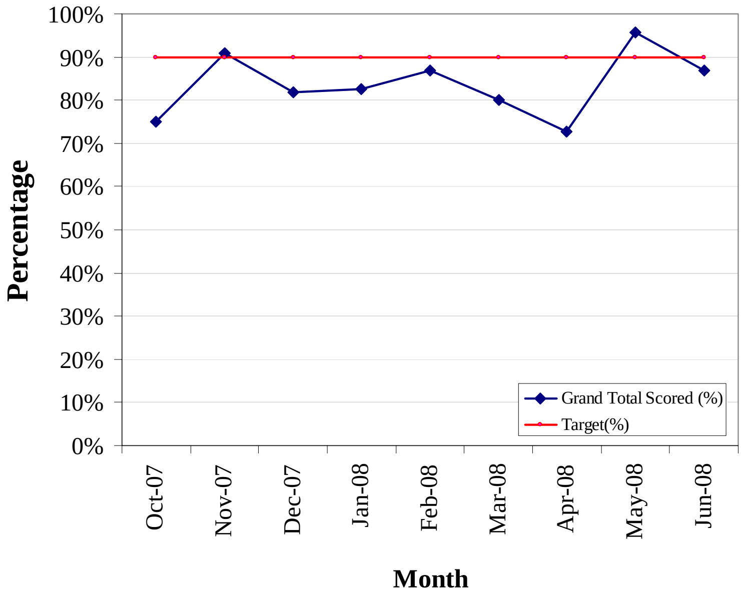

Figure 2: Kawerau Project Lead Performance Indicators

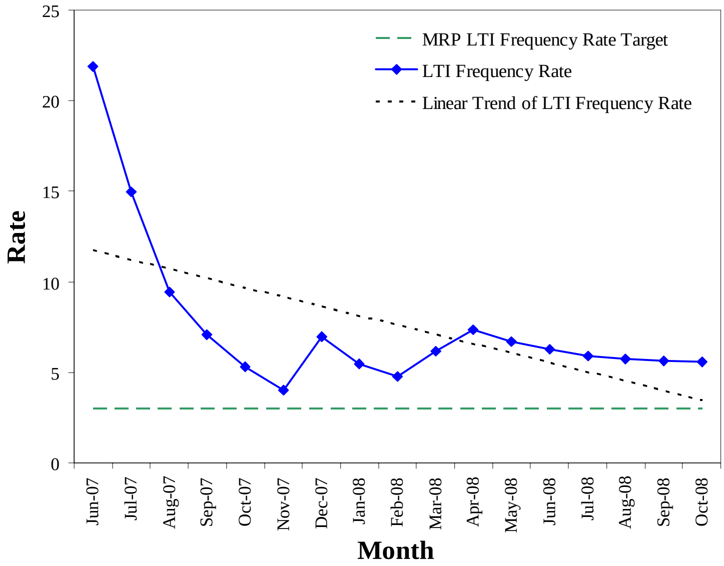

Figure 3: Kawerau Project 12 Month Rolling Average Lost Time Injury Frequency Rate

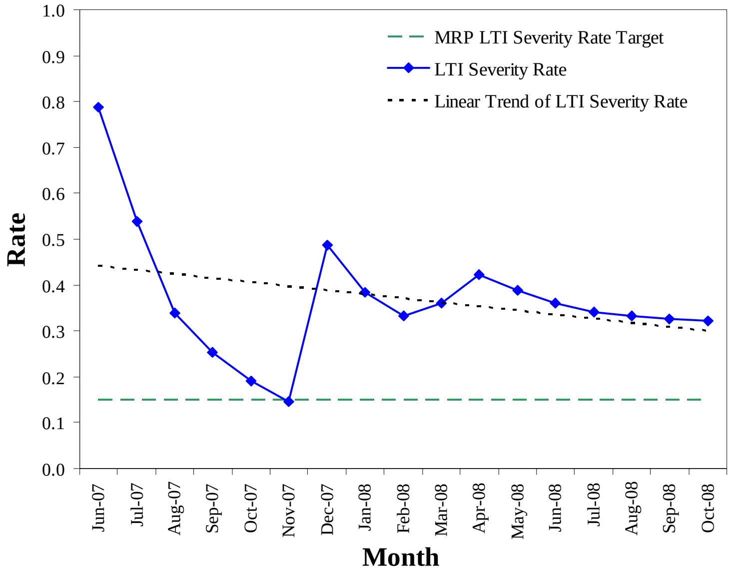

Figure 4: Kawerau Project 12 Month Rolling Average Lost Time Injury Severity Rate

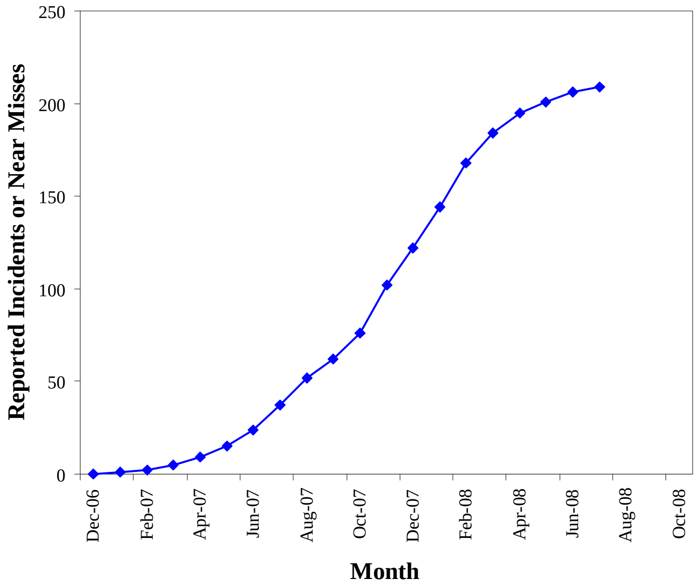

Figure 5: Kawerau Project Cumulative Reported Incidents or Near Misses

5. NCG INCIDENT AT START UP

5.1 Overview

During Thursday 24 April 2008 and Monday 28 April 2008 two separate incidents occurred on the Kawerau project involving a NCG discharge. Both incidents are believed to come from the venting of steam during the steam blowing process.

Kawerau features a steam separation system within the power station to partition two-phase fluid into brine and steam.

The steam blow process occurs during the initial phase of plant warm-up during commissioning, or after a shut. During this time steam including NCGs are discharged from the high and low pressure silencers as shown in figure 6.

During normal operation NCGs are extracted and discharged from the top of a cooling tower dispersed into the airstream by cooling tower fans. The silencers do not operate during normal plant operation.

The Kawerau plant is constrained by the site geography and the silencers are located within the steam separation area. In other geothermal plants, if space permits, the silencers are located away from the main plant in the area of geothermal brine soak pits.

At the same time some construction activities were being performed at the same time as steam blowing (commissioning) activities.

5.2 Non Condensable Gas (NCG) Hazards

At Kawerau the fluid from the geothermal reservoir contains a number of gases. The predominant gases are carbon dioxide (CO_2) and hydrogen sulphide (H_2S), with the balance comprising of smaller amounts of hydrogen, nitrogen, methane, ammonia, boron, arsenic and mercury. In high concentration (in air) both H_2S and CO_2 are known hazards.

Figure 6: High Pressure and Low Pressure Silencers in Operation during plant startup.

5.2.1 Physical Properties of Hydrogen Sulphide Gas

Hydrogen Sulphide is an extremely toxic gas in high concentrations. The effect of H_2S on people can be categorized, by concentration, as shown in table 1 (OSH, NZ DOL (1999)).

The gas is colourless, flammable, heavier than air, and rapidly dispersed by wind or air movement. At low concentrations, under 100 parts per million (ppm), it is identified by a pungent rotten egg smell. However at higher concentrations, over 100ppm, no smell can be detected because of paralysis of the olfactory nerve (Olson (2003)).

Hydrogen Sulphide is highly corrosive to certain metals and material components. While special attention to plant protection was made on the project this is outside the scope of this paper.

At the Kawerau site all H_2S alarms were set to activate at a value of 10ppm. To avoid confusion this was deemed an appropriate level to set the threshold for evacuation.

5.2.2 Physical Properties of Carbon Dioxide Gas

Carbon dioxide is colourless and odourless. It is non flammable and heavier than air with a potential to accumulate in confined spaces or areas below ground level. It will displace Oxygen.

Table 1 – Effect of H_2S gas on people classified by exposure level

Concentration [ppm]	Effect
0.13	Minimal perceptible odour.
4.6	Easily detectable, moderate odour
10	Beginning eye irritation
27	Strong, unpleasant odour, but not intolerable.
100	Coughing, eye irritation
200-300	Marked conjunctivitis (eye inflammation) and respiratory tract inflammation after one hour.
500-700	Loss of consciousness and possible death in 30 minutes to one hour
700-1000	Rapid unconsciousness at once, cessation (stopping or pausing) of respiration and death.
1000-	Unconsciousness at once, with early cessation of respiration and death in a few minutes.

In high concentrations CO_2 gas is toxic. Symptoms of high or prolonged exposure to carbon dioxide include headache, reduced hearing acuity, increased blood pressure, increased pulse, and inability to concentrate. Exposure to higher levels, 100,000ppm in air, may cause unconsciousness or death within seconds of exposure (McManus (1998)).

5.2.3 Chemical Composition of the Kawerau Field

The content of NCGs within the geothermal fluid, and therefore the concentration of H_2S and CO_2, can vary markedly between wells within a reservoir. The expected ranges for Kawerau are listed in table 2.

Table 2 – Content of CO_2 and H_2S in Kawerau Geothermal Fluid

Compound	Expected Point [mg/kg]	Range[mg/kg]
CO_2	5600	3400 - 8600
H_2S	200	66 - 250

5.3 Sequence of Events

Each incident is examined in turn.

5.3.1 Incident 1 – 24 April 2008 (3p.m.)

Two workers were overcome by a plume of gas while working within a few metres of a vent (high pressure silencer) being used for steam blowing.

The station steam field had been shut down over night to allow for the fitting of orifice plates.

This incident resulted in a full site emergency evacuation.

Both personal who collapsed were treated by an ambulance on site. As a precaution they were taken to Whakatane hospital and subsequently discharged. At the hospital the personnel were washed and a yellow substance (elemental Sulphur) was noted (refer section 5.4.2)

New Zealand Occupational Safety and Health/Department of Labour were notified of the incident.

5.3.2 Incident 2 – 28 April 2008 (8:30a.m. to 9:30a.m.)

The second incident involved two workers feeling unwell and again resulted in a full site emergency evacuation. This incident occurred during normal operation.

That morning a dedicated operator was monitoring the steam separation area with a gas monitor. At no time was elevated H_2S detected from the operator nor from any of the other monitors on site. During the evacuation the fire department did a walk through of the site wearing full breathing apparatus and declared the site clear of elevated levels of H_2S.

One of the un-well workers was one of those that had collapsed in the first incident. He subsequently was diagnosed by medical personnel as being sensitive to exposure of small amounts of geothermal gases as a result of the first incident. The diagnosis was this to be a short term condition.

The other worker was later found to be suffering from an unassociated ailment.

Both incidents were taken very seriously. MRP and the EPC contractor worked closely to develop steps to further minimize the risk associated with gas discharge on the construction project.

5.4 Investigation

5.4.1 Debrief Process

Following the incidents a number of meetings were held between MRP, the EPC contractor, and other project stakeholders. An incident report was generated, the site workers briefed, and the process for steam blowing revised to mitigate the risk for the previously unknown hazard.

5.4.2 Direct Cause

Through discussion with those affected and others in the immediate vicinity it was clear gases exited from the high pressure silencer and spilled to the ground engulfing the workers.

As a result of the investigation the direct cause was ascertained as follows. When the plant is shut-down the fluid in the steamfield pipelines is drained. This can leave NCGs in the pipeline which, being heavier than air, do not vent. If the NCGs remain there for a period of time some H_2S could have been converted into elemental Sulphur. This is a known phenomenon through the reaction of CO_2 to form carbonic acid and in turn a reaction with H_2S to form elemental sulphur.

When the plant is brought on line the steam blow pushes the concentrated slug of NCGs out which then exhausts from the silencers.

The hazard around the silencers exists during the steam blow process on startup and not during normal operation.

5.4.3 Root Cause

The HP/LP silencer hazard was not detected in the HAZOP process. The HAZOP process around the steam separation system, which included the silencers, was comprehensive.

A number of H_2S specific hazards were identified in these sessions. However they were based around the industrial viewpoint that H_2S is a hazard in pits and low points due to it being heavier than air.

The hazard of an unconfined cloud of dense cold gas during plant startup has not, to our knowledge, been previously identified in geothermal plants.

The hazard was compounded due to the location of the silencers within the plant (due to site land constraints). In addition Kawerau has reasonably long production pipelines from the geothermal wellheads to the plant. This gives rise to a high "process inventory" of NCG giving rise to significant exposure time (20-30s) to high concentrations of gas.

During commissioning the EPC contractor ran a Job Safety Analysis (JSA) process with MRP participation. The intent of the JSA process is to identify significant hazards in a specific work activity. These include hazards that may not have been considered within the scope of the HAZOPs.

As the direct cause of the hazard (*in situ* NCG within the steamfield pipeline) was not detected in the HAZOP this process also failed due to the collective "knowledge-gap" of the issue.

5.5 Mitigations Action Steps for Kawerau

A number of outcomes and steps were identified and implemented in the revised steam blow procedure.

5.5.1 Actions Steps in Revised Steam Blow Procedure

The revised steam blow procedure included the following mitigation steps:

- the EPC contractor to install permanent H_2S monitors within vacinity of silencers;
- prior to cold start-up of the steam-field and steam separation system the site and all offices shall be cleared of personal. Essential EPC contractor and MRP operators to be stationed in the control room (ventilated H_2S protected environment);
- during the steam blow process all unauthorized personnel to assemble. The wind speed and direction to be taken into account when considering alternative assembly points;
- for the purposes of rescue one set of breathing apparatus is to be held in the control room and at least one MRP operator present at all times;
- regular visual checks of the area are to be made from the control room;
- one hour after steam flow commences from the silencers two MRP operators in breathing apparatus sets and carrying monitors are to sweep the area and check gas levels. No construction activities or site access are to recommence until the following safe levels were observed: H_2S < 10ppm, O_2 >19.5%, CO_2 < 3%, CO < 25ppm.

5.5.2 Improvements to Site Evacuation Processes

The following improvements to site evacuation were implemented as a result of the incident:

- to improve notification of site evacuations the number of air horns on site was increased (from 6 to 16) and locations were accessible;
- installation of wind socks on site to ensure wind direction can be ascertained by workers in all areas of the site;
- increase and extend alarm activation points for existing building siren on the site;
- update site induction process to include map with location of air horns and alarm activation points;
- reinforced site requirements for individual sign-in/sign-out procedures;
- updated site emergency plan and control of site evacuations;
- a register of materials (including Material safety data sheets) to be available at main entrance for use by the fire department during an evacuation.

5.5.3 Elimination of Hazard

Prior to project handover a bypass system to vent the NCGs to the cooling tower on startup was installed at Kawerau. This serves to eliminate the hazard when the plant undergoes a shut and subsequent cold start-up.

5.6 Independent Review of Investigation

An independent risk and safety management company was engaged to conduct a review (Atkinson and Gibson (2008)) of the MRP investigation.

The review of the investigation concluded the incident occurred due to a “knowledge based mistake” by the design and safety review. Both the high level 3D safety study and HAZOPs failed to identify the hazard during the initial phase of plant start-up.

This lack of hazard awareness extended to the site emergency procedures. This resulted in the open-air rescue of the two unconscious workers without breathing apparatus.

The independent review noted once the hazard was identified the site was well managed and adequate control measures were put into place to prevent reoccurrence.

The review made a number of recommendations and these are included in section 6.2.

6. CONCLUSIONS

6.1 Overall HS Outcomes

The health and safety outcomes for the project were good considering this was the first major geothermal construction project in New Zealand for a number of years.

Both the EPC contractor and MRP gained valuable experience - beneficial for the Nga Awa Purua project currently under construction.

6.1 Lessons Learned for MRP next project

MRP require a project specific health and safety management plan as a prerequisite for tendering.

For Nga Awa Purua the health and safety expectations and requirements are higher. Updated employer’s requirements are in place. This fits with MRP policy of continuous improvement in health and safety.

Specifically the EPC contractor is required to provide a full time health and safety officer for the duration of the project. Additionally common site management systems such as JSA, work permits, access and control are not to be delegated to other parties.

6.2 Recommendations arising from the NCG discharge incident

The following specific recommendations are applicable to future geothermal power developments at fields with significant levels of NCGs.

Physical controls should be in place to prevent access to areas of exposure during cold NCG discharge scenarios. The points of egress are not limited to vertical silencers but may include vents and/or rock muffler arrangements.

Commissioning personal required to access potentially hazardous (by air) areas at this time should be required to wear breathing apparatus.

Controls should be in place so H_2S concentrations at the site boundary are within local workplace exposure standards during cold NCG discharge scenarios. Gas dispersion mathematical modeling would be a valuable predictive approach.

Safety and HAZOP studies should explicitly consider the incident detailed in this paper. In a broader sense process sources and potential egress points of H_2S and other hazardous gases should be considered in all phases of a geothermal development.

MRP have put in place all of these recommendations for Nga Awa Purua. Gas dispersion modeling was completed. The selected solution, based on the dispersion modeling, is the same as adopted at Kawerau, where a vent pipe was installed and discharging gases over the cooling tower giving wide dispersion and avoiding unsafe concentrations of gases.

The performance of the cooling tower gas venting system at Kawerau will be monitored and any further refinements will be incorporated into the Nga Awa Purua design. A review of the construction and commissioning sequence will be completed as the Nga Awa Purua project progresses. This is to ensure that the gas venting system to the cooling tower will be operational before the steam blows and commissioning of the steam separation system.

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