NSW GOVERNMENT

NSW Resources Regulator

CAUSAL INVESTIGATION REPORT

PIN EJECTION INCIDENT

Ravensworth Open Cut Mine

NSW Resources Regulator

Document control

Published by NSW Resources Regulator

Title: Pin ejection incident – Ravensworth Open Cut Mine

First published: October 2019

Authorised by: Chief Inspector

CM9 reference: DOC19/857639

AMENDMENT SCHEDULE		
Date	Version	Amendment
October 2019	1	First published

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Executive summary

A Caterpillar haul truck was taken to Ravensworth open cut mine's workshop for a 40,000-hour programmed component replacement on 4 July 2019.

Four days into the work schedule, fitters tried to remove the front, lower left-hand side, rear suspension link pin. They withdrew the pin about 70 millimetres with the available tools, before deciding it had become seized. The fitters then asked a boilermaker to lance the pin.

Thermal lancing is a regular practice to remove seized pins and involves piercing a hole through the axis of the pin followed by water quenching. Quenching rapidly cools the pin, reducing the outer diameter, making it easier to remove.

At 1.15am on 9 July 2019, a boilermaker spent about 20 minutes lancing the pin. Having driven a hole, he used water to quench the pin. Fitters tried to pass a pry bar through the hole to knock out the inner collet but could not get the pry bar all the way through. Removing the inner collet was required to install the nut on the pull rod. The fitters then asked the boilermaker to open up the hole by lancing it a second time.

At 1.49am, the boilermaker spent a further six minutes enlarging the hole. The moment the boilermaker applied water to the face of the pin, rapidly forming steam ejected the pin under pressure. The pin – weighing 46.7kg - was propelled at the boilermaker, hitting him in his left hip and knocking him over.

An emergency response was activated. The spotter who was working with the boilermaker rushed to isolate the oxygen supply to the lance, while the fitters contacted the workshop supervisor. The boilermaker was taken to Singleton hospital and later transferred to Newcastle's John Hunter Hospital. The boilermaker suffered a large hematoma and small crack to his left hip, a greenstick fracture to his left thumb and minor facial and eye injuries from the slag spray. The spotter was uninjured.

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Investigation findings

The key findings from the investigation were:

- The incident occurred from the rapid expansion of water into steam.
- The pin ejected because it was the weakest barrier in containing the steam expansion formed by the pin clevis, inner collet and pin.
- Following the incident, the mine operator strengthened the mine's risk controls for thermal lancing through revised procedures, incorporating an escalation process when removal of pins by mechanical means failed.
- Thermal lancing is not a large component of formal trade qualifications and some boilermakers only learn the skills to perform lancing through on-the-job training. Nationally recognised units of competence for thermal lancing are not available in NSW.
- Procedures for removing pins did not offer an alternative should the method described in the procedure prove unsuccessful in removing the collet or pin or if access is restricted due to other machine components.

Recommendations

Mine operators and persons conducting a business or undertaking (PCBUs) have a duty to identify hazards and manage risks to health and safety associated with the maintenance and repair of plant and equipment in accordance with the *Work Health and Safety Act 2011* and the *Work Health and Safety (Mines and Petroleum Sites) Act 2013* and Regulations. Furthermore, designers, importers and suppliers of plant have similar duties under these legislative provisions regarding risks to people carrying out any reasonably foreseeable activity in relation to plant such as inspection, cleaning, maintenance and repair.

It is recommended that mine operators, contract service providers and equipment suppliers:

- Implement strategies to eliminate or minimise risks associated with the rapid expansion of steam or possible hydrocarbon combustion events during thermal lancing and quenching activities.
- Implement strategies to identify and eliminate cavities where molten slag can pool and store thermal energy before quenching.
- Implement strategies to identify safe standing zones for thermal lancing and quenching activities.

- Review hot work permit systems and thermal lancing procedures to include risk controls for steam or possible hydrocarbon combustion events.
- Review systems for appointing workers authorised to perform thermal lancing and quenching activities.
- Review systems of work associated with removing pins mechanically.

Mine operators should also read the ‘Post incident actions’ section in this report as it provides additional detail about what the mine has done and plans to do in response to this incident.

It is recommended that the following industry wide actions are undertaken:

- Make a submission to the Manufacturing and Engineering Industry Reference Committee for the development of a unit of competency for thermal lancing – plant repair.

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1. Causal investigation

A preliminary investigation and assessment of the incident was carried out by the NSW Resources Regulator. It did not identify any material breaches of the work health and safety laws. Following this assessment, the Regulator determined that an investigation under the Causal investigation policy would be appropriate.

A causal investigation is an investigation into a safety incident that has been notified to the Regulator under work health and safety laws. It is not to obtain evidence for a prosecution, but to identify the causal factors of safety incidents, the effectiveness of the controls used and the factors which may have contributed to the failure of these controls. Timely communication helps to ensure that duty holders, under the work health and safety laws, can better understand the risks they must manage and the necessary controls needed to prevent reoccurrences of similar incidents.

The Regulator invited relevant stakeholders to participate in the causal investigation process and an investigation team comprising representatives from Ravensworth Open Cut mine, Westrac, MMS Engineering, the Construction Forestry Maritime Mining Energy Union (CFMMEU), Mine Safety Technology Centre and the Regulator was established.

1.1. Purpose

The report has been published under section 70(1)(b) of the *Work Health and Safety (Mines and Petroleum Sites) Act 2013* to share safety lessons about the incident and prevent similar incidents from reoccurring.

1.2. The mine

Ravensworth Open Cut mine is in the NSW Hunter Valley, between Muswellbrook and Singleton. It incorporates an open cut mine and a coal handling and preparation plant. The mine is a joint venture between Itochu (10%) and Glencore (90%). The mine produces about 14 million tonnes of run of mine (ROM) coal. It also operates more than 50 large haul trucks and 100 items of heavy earth moving plant.

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1.3. Parties involved

1.3.1. Mine operator

Ravensworth Operations Pty Limited is the appointed mine operator of the Ravensworth Open Cut coal mine.

1.3.2. Equipment supplier and maintenance contractors

The Caterpillar haul truck was supplied and maintained under a service contract by Westrac. Fitters from Westrac were conducting the programmed component changeout works when the incident occurred.

1.3.3. Labour hire contractors

The injured worker was employed by MMS Engineering. The spotter was a trades assistant employed by Mainstream Industries Pty Ltd.

1.3.4. The injured worker

The injured worker was employed as a qualified boilermaker and worked at the Ravensworth Open Cut mine.

- He had nine years' boilermaker trade experience.
- He had worked at Ravensworth open cut for about three years between 2008 and 2011 and again from July 2018.
- His site competency and training records included general inductions and fatal hazard protocols, fabrications tradesperson, light vehicle operation, transport rules, fluid power safety, job safety analysis, working at heights, confined spaces, Certificate III heavy fabrication and work under permit.
- It was estimated that he had undertaken more than 100 pin lancing operations.
- He was on his second night shift following three days rostered off.

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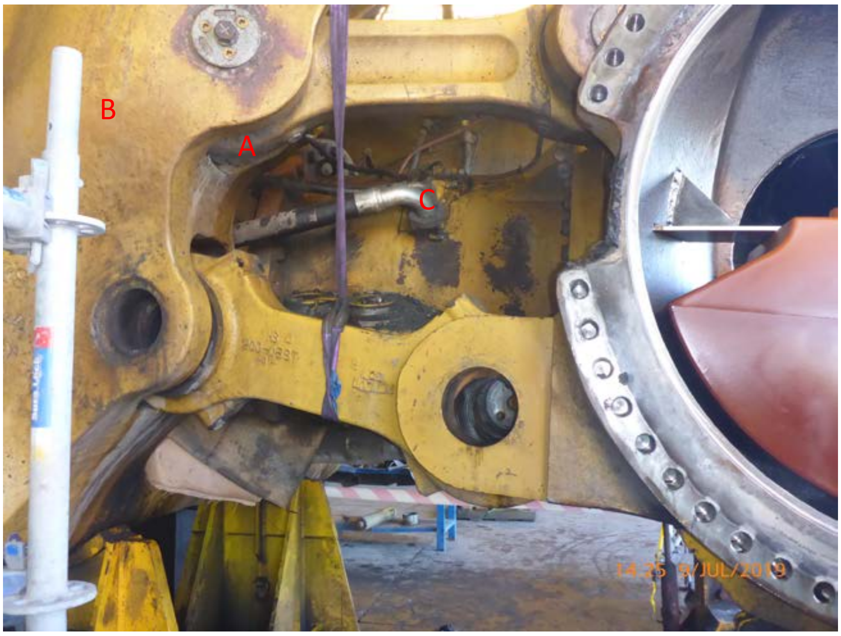
2. The incident

Before the incident, the haul truck has lost oil from the front pin bearing of the lower left-hand side rear suspension link (see figure 1). The oil is normally retained by seals installed on both sides of the bearing in the link. Failure of the seals, resulting in the loss of lubricating oil, has occurred with enough regularity to warrant releasing a Caterpillar technical information bulletin TIBU7881-00 dated 10 February 2015. The bulletin advised haul truck operators of that model truck to fill the oil cavity with grease until the seals could be replaced. This was done to the haul truck involved in the incident, but the mine was unable to confirm how long before the incident this occurred. Prolonged operation with grease was not advised in the bulletin because of the potential for bearing failure. There was no indication that the bearing had failed in this case.

Figure 1 Left hand side lower link and pin assembly (A), front pin location (B), rear pin location (C)



The haul truck was taken into the workshop on 4 July 2019. During the 40,000-hour programmed component replacement, the rear suspension links and pins were to be replaced.

Four days into the work schedule, fitters tried to remove the lower left-hand side rear suspension link by first removing the outer collets. Collets are used to secure the pin on either side. The collets have a taper corresponding to the taper on either end of the pin and act as a wedge to secure the pin and prevent it from rotating during service. To remove the collets, three jacking screws are used to push the collet away from the pin, but sometimes the ‘fingers’ break, complicating the removal process. The standard Caterpillar link removal procedure does not provide advice on what the fitters should do if they break.

Figure 2 Rear suspension link pin and bearing cross section

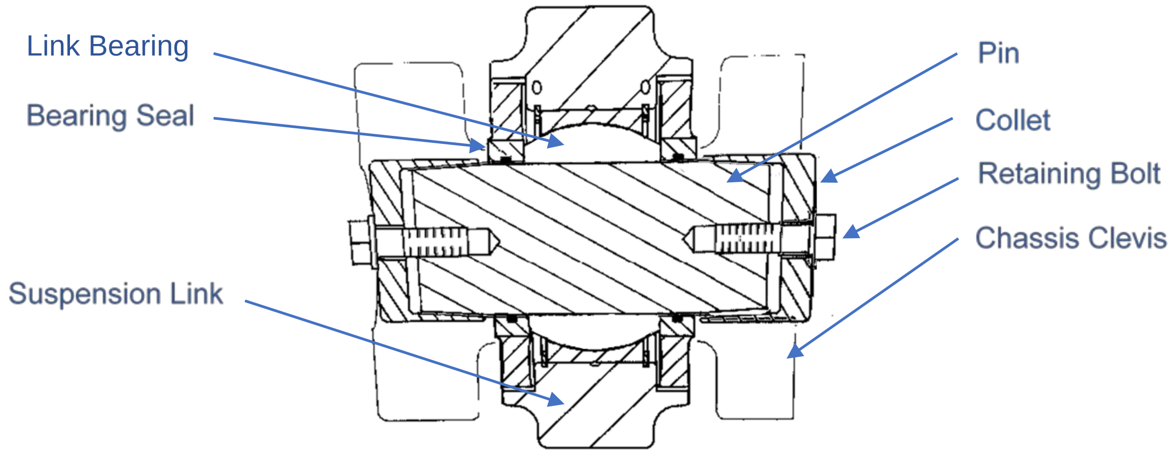
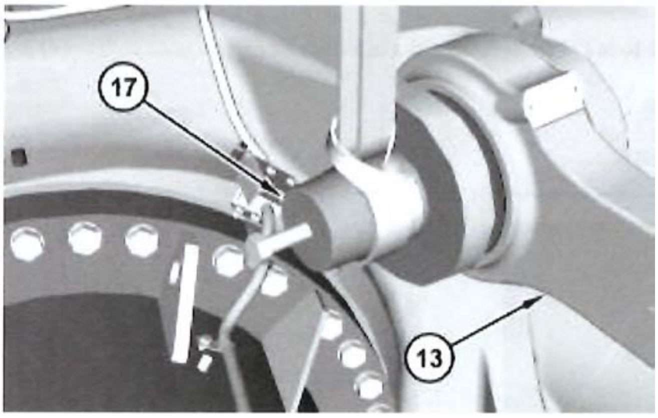


Figure 3 Pin collets

The fitters successfully removed the rear pin outer collet but had difficulty with the front outer collet. They asked that a boilermaker remove the collet by gouging it with an oxy-acetylene torch. A boilermaker performed this task between 7.30am and 10.20am. The fitters tried to extract the pins at 3.20pm, using a hydraulic porta-power and sleeve. Both pins were withdrawn about 70 millimetres, which was the limit of travel for this set of tooling.

Day shift handed over to night shift at 6.30pm to continue removing the pins. The night shift workers managed to fully remove the rear pin using the original equipment manufacturer (OEM) bolt and sleeve method. In this method, a sleeve is placed over the pin and a bolt inserted into the end of the pin. Torque is applied to the bolt via a pneumatic torque wrench turning the bolt and withdrawing the pin.

Figure 4 OEM bolt and sleeve pin removal tooling



They then used an overhead crane to rotate the suspension link and watch for movement in the front pin. The night shift fitters thought the front pin was seized and again used the OEM bolt and sleeve but could not move it. They then tried to use the hydraulic porta-power set, but could not get the pin to move. Finally, fitters attached a fork lift jib and chain assembly to the pin, but this method also failed. Failure to remove the pin by any of these methods confirmed the pin was seized. The time was now about 8pm.

One of the fitters approached a boilermaker at 10pm to inspect the pin with the view to having it lanced. Thermal lancing is a common approach to remove seized pins. This method uses a consumable metal tube or lance that is supplied with pure oxygen and sustains a burning tip at temperatures greater than 2000°C. The lance pierces a hole through the axis of the pin and is usually quenched using water. The quenching rapidly cools the pin, reducing the outside diameter. The combination of heat and contraction make it easier to remove the pin.

A boilermaker and assistant arrived at the haul truck to inspect the pin at 12.40am. The work area was prepared by clearing and washing the floor, erecting scaffolding and covering the area behind the pin with heat blankets to protect hydraulic hoses and other components.

At 1.15am, the boilermaker spent about 20 minutes lancing a hole through the pin. It was then quenched with water. Fitters tried to pass a pry bar through the hole to knock out the inner collet but could not get the pry bar all the way through. Due to restricted access to the rear of the pin, the inner collet is normally removed by this method, either after the pin has been removed or after the hole is lanced through the pin. Removing the inner collet is required for installing the nut on the porta-power pull rod. Consequently, the fitters asked the boilermaker to enlarge the hole by lancing it a second time.

At 1.49am, the boilermaker spent a further six minutes trying to open up the hole. The boilermaker turned off the oxygen supply and hung the lance over the scaffold rail. His spotter handed the water hose to the boilermaker, who initially applied water to the heat blanket and components behind the pin, and then to the front of the pin. At that moment, the ejection occurred, propelling the pin towards the boilermaker and knocking him over.

An emergency response was activated. The spotter rushed to isolate the oxygen supply to the lance while the fitters contacted the workshop supervisor. The boilermaker was taken to hospital.

3. Investigation

Following the incident, the Regulator conducted an initial site assessment with an Industry Safety and Health Representative and mine representatives.

The initial investigation established the basic timeline and parties involved. The assessment found:

- The shift supervisor issued a hot work permit, which was activated by the injured boilermaker (and permit holder).
- A job safety analysis (JSA) was in place for the work planned for the shift. This did not include the pin lancing, as it was not part of the planned work.
- Welding, grinding, oxygen and fuel gas equipment and gauging equipment had all passed inspection.
- The injured boilermaker was wearing a full complement of personal protection equipment at the time of the incident including a leather jacket, gloves and air stream welding helmet.
- The pin had been partially extracted before the lancing began.
- The injured worker had carried out many pin lancing operations previously.
- The mine had a thermal lancing procedure.
- A personal risk assessment ‘SLAM’ was undertaken by the boilermaker and spotter before starting the work.
- There were no springs, wedges or hydraulic rams applying axial force to the pin at the time of the incident.
- The inner collet remained in position and slag was found to be covering one of jacking screw holes (refer to Figure 5).
- Video footage from the workshop cameras showed the moment the incident occurred.

- While the boilermaker was hidden from camera view, the footage did show the timing of various events, the scale of the incident and the response of the workers.
- The boilermaker was injured midway through his second shift after three days rostered off.
- No-one at the site assessment had witnessed or heard of this type of incident occurring previously.

Figure 5 Pin bore with slag remnants

The lancing of the pin was not planned at the start of the shift. The crew boilermaker and spotter completed a personal risk assessment SLAM prior to undertaking the lancing operation. The site has two recognised SLAM booklets. One for general use and one for engineering maintenance activities. The crew boilermaker and spotter completed the SLAM using the general use booklet, identifying the task as routine. Given that lancing of pins had been completed by the boilermaker many times before this is understandable. Had they used the engineering maintenance booklet, it may have led the workers to complete a job safety analysis (JSA) specific to the task. Furthermore, the hot work permit required a Level 2 risk assessment approach or JSA/SWMS to be prepared.

The causal investigation team unanimously agreed a JSA would not have reasonably considered ‘rapid steam expansion from water quenching’ based on the workers’ industry knowledge, training and experience. As the boilermaker had carried out this task many times without seeing this outcome, it was less likely to predict the pin ejection scenario.

Following the site assessment, a prohibition order was issued by the Regulator due to the uncertainty of the cause of the incident at that time. The prohibition order prevented the activity of lancing and quenching of pins on mobile plant. The mine extended this across the site for all lancing activities.

At this stage of the investigation, possible causes were considered to be:

- a steam expansion event
- a combustion event involving water to gas constituent (H_2 and O_2)
- a combustion event involving grease or hydrocarbon.

It was the consideration of the potential severity, the frequency of lancing operations at mines and the unusual nature of the incident that prompted the recommendation for a causal investigation.

4. Post incident actions

The mine responded to the incident with the following actions:

- The incident was communicated to all boilermaker teams across the site.
- The mine accepted an invitation to assist the Regulator to conduct a causal investigation.
- Mine engineers conducted analysis through calculations, considering mechanical sources of energy as a potential cause.
- Metallurgical engineers were engaged to conduct an analysis of the remnants collected, including the pin, inner collet and slag, to determine the mechanism of the ejection.
- An incident cause analysis method (ICAM) investigation was conducted including a 5 whys analysis.

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4.1. Engineering assessment

4.1.1. Mechanical energy

From reviewing the video, the pin was ejected at an estimated 22 kilometres per hour. Further analysis confirmed any residual energy stored in the pin was orders of magnitude lower than that necessary to eject the pin as it did in the incident.

4.1.2. Metallurgical review

The metallurgical engineering report included an examination of various components including the pin, the inner collet and slag. The examination included visual inspection, low power microscope and analysis of the scrapings from the pin bore and scanning electron microscope. An extract from the report:

'Examination of the various components and samples associated with incident involving ejection of a front dogbone connection pin from a 797F dump truck indicated that the ejection was likely to have occurred upon pressure build up, high energy created by wet steam evaporation and/or combustion. Although the evidence supporting these hypotheses was not conclusive.

Based on the process of elimination, it was understood the majority of the mechanical means of potential stored energy could be ruled out. The likely scenario would be thermal induced pressure build up, high internal energy created by second heating of the initial saturated steam producing dry steam, and/or combustion.'[1]

4.1.3. Ejection mechanisms

As well as the metallurgical report, an independent review by other causal investigation members was commissioned to investigate the possible causes for the incident considering:

- the possibility of hydrogen production from water and extreme temperatures
- carbon monoxide combustion event

[1] Dogbone Connection Pin Ejection Incident, 21 July 2019. Bureau Veritas Report No. 19-2888654-1, Cindy Liu, Senior Consultant Metallurgist

- steam expansion event

Thermolysis of water is the thermal decomposition of water into its constituent parts.

$H_2O \rightleftharpoons \frac{1}{2}O_2 + H_2$

This reaction is a reversible process and requires temperatures over 2000°C to produce any appreciable amount of hydrogen. Achieving combustion would require a very high temperature, sufficient hydrogen produced to get a combustible atmosphere, followed by quenching to retain the hydrogen, then an ignition source. This is considered highly unlikely.

'Water-gas' shift reactions also produce hydrogen and can be described as follows:

$CO + H_2O \rightleftharpoons CO_2 + H_2$

$C + H_2O \rightleftharpoons CO + H_2$

The only source of carbon was from the steel pin or the oxygen lance steel. Free carbon would be unlikely, though there would be some carbon monoxide from the combustion of the steels present.

Both of the above reactions are also considered highly unlikely given that:

- there was very little carbon present to react with
- they both required atmospheres with little or no oxygen present (reducing atmosphere)
- the water in these reactions was in the form of steam (more on this below).

The mechanism that produces carbon monoxide includes reactions between carbon present in steels (about 0.1%) consumed/melted in lancing process. This can be described as:

$C + \frac{1}{2}O_2 \rightleftharpoons CO$

It is likely that some carbon monoxide would be created during the lancing process. Given that pure oxygen was being used, it is considered unlikely that the concentration of carbon monoxide would exceed the lower explosive limit of 12.5%.

Steam flashes, also known as rapid phase transitions, occur when water contacts very hot materials. The water can flash to steam, which increases its volume by 1700:1 or greater. This appears to be most likely explanation of what occurred as it matches the sequence of events.

Important indicators to the rapid expansion were the creation of the void behind the pin, the deposit of very hot slag into that void, and the addition of water into the void. This rapid expansion, coupled with the limited passage for the steam to exit, would have resulted in a build-up of pressure behind the pin. Coupled with a weakened bond between the pin and bearing, the build-up of pressure overcame the frictional resistance to expel the pin.

Steam flashes are a well know hazard in steelworks and foundries where they may occur if liquid metal is dropped into water, or if scrap material containing water comes into contact with liquid metal.

4.2. ICAM

An ICAM investigation was held at Ravensworth Mine on 16 July. Fifteen people were involved, including welding specialists, site safety representatives, boiler makers, fitters, mechanical engineers, asset managers and maintenance managers.

The ICAM concluded the pin ejection was caused by the rapid expansion of steam over other possibilities, acknowledging that the existence of grease in the pin bearing may have produced a similar outcome in other circumstances. It was believed that the initial lancing attempt, which lasted around 20 minutes, would have input enough heat energy to cause a hydrocarbon explosion, if it were going to occur. Additionally, the quantity of slag located behind the pin would have been considerably less on the first attempt. Given witness statements indicating that the incident occurred very quickly after applying water to the front of the pin, this further supported the steam expansion theory.

The ICAM recognised a number of contributing factors, which are summarised:

Hazard identification – There was a lack of awareness and identification of the hazard from a mass of molten slag and contact with water within a confined volume to cause a build-up of pressure. The reaction of water and molten or near-molten metal appears to be well known in smelting industries but not well recognised in mining or repair industries.

Mechanical removal (procedures and tooling) – The OEM procedure for pin removal does not consider the event of the pin becoming seized. There was no guidance available for the staged escalation of methods using the application of force through to thermal lancing.

Industry training – Thermal lancing is not supported by a nationally recognised unit of competence. Trade qualifications briefly address thermal lancing as a technique, but competence appears to be mostly due to on-the-job training or at best, training provided by the supplier of thermal lancing products.

Safe standing zones – Could have been used if the potential for stored energy was identified. However as mentioned above, general industry knowledge, training, experience and procedures did not equip workers with sufficient knowledge to initially identify the hazard and therefore implement controls.

It was generally accepted that it is necessary to stand in line with the pin to perform lancing. This is for accurate control of the lance and avoid unnecessary damage. While quenching it would be possible to stand clear of the line of fire.

Restricted access – Because of space restrictions, the inner collet was not removed before the lancing task. Specialist tooling to remove the inner collet or oxy-cutting a large opening in it would have significantly reduced the risk posed by the pressure build-up from the steam during water quenching.

Thermal lancing procedures – While the thermal lancing procedure did acknowledge the risk of the exploding nature of concrete and moisture when contacting slag, it did not recognise how this could manifest in the case of removing a seized pin.

Pin design – The best way to avoid the risks of thermal lancing is not to perform lancing at all. Having a pin and collet design to give the best opportunity for removal by mechanical means following years of operational service is very important. This includes removal of the collets and puller-to-pin connections (size of thread or through pin provision).

Risk management – Prompts to manage risks during the pin lancing did not clearly identify the potential for steam expansion while quenching.

5. Further actions

The ICAM investigation resulted in a corrective action plan. Actions undertaken to date include:

- Review of the risk assessment for hot work to include the potential for steam expansion events, fires and explosions from combustible substances and explosive gas mixtures, projectile releases and exposure to pure oxygen.
- Revision of the thermal lancing procedure including, but not limited to, an escalation process from the mechanical removal of pins to thermal lancing, control measures for identifying voids and cavities, quenching and safe positioning.
- Training and assessment of workers in the lancing procedure for relevant workers held in a training-needs-analysis employee record.
- The escalation of the incident through the Caterpillar organisation via Westrac. This has resulted in a design change to the collet to aid removal and detail changes to reduce the likelihood of breakage of collet ‘fingers’. It has also resulted in a planned design review of the pin centre-tapped hole to assist mechanical removal and adaptation of tooling.

A review was conducted by third party consultants to investigate viable alternatives to lancing seized pins. However, this did not yield any viable alternatives.

- Revision of the hot work permit to include references to the lancing procedure.

- Engagement of a third party to begin development of hydraulic-powered tooling specific for common pin extraction tasks at the mine.

The mine also plans to investigate alternatives to existing lance handle oxygen control valves to include a latch to open a valve to prevent unintended oxygen release.

The contractor to the mine for boilermaker services has:

- included hazards associated with rapid steam expansion in its induction material
- developed a standard operating procedure for thermal lancing
- trained workers in the lancing procedure.