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Application of radar monitoring at Savage River Mine, Tasmania

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Abstract

Grange Resources Ltd have been utilising radar monitoring since 2007 at their Savage River mining operation in Tasmania, Australia. Radar has provided prior warning of several large wall failures in the brittle amphibolite of the North Pit's east wall, and these experiences have increased the confidence in the radar's capability to provide reliable prior warning of large wall failures. With the increased confidence in the radar attention has focused on the remaining sources of risk in the forms of human error through mistakes in the application of the radar and human error in the form of 'slips and trips', particularly within software settings. These potential sources of human error are mitigated with the use of Standard Operating Procedures, Trigger Action Response Plans, training and checklists.

Radar monitoring of the east wall of North Pit has been found to have limited capability in providing prior warning of small wall failures. In order to mitigate the risk posed by small wall failures, remote controlled mining capabilities (including remote drilling, dozing, excavating, and blasthole loading) have been adopted for routine use within specified zones at the toe of the pit wall.

This paper describes how through applying appropriate radar alert thresholds across the entire pit wall, whilst ensuring the integrity of the radar monitoring system, and mitigating the risk posed by small wall failures, the risks of operating beneath a hazardous pit wall can be significantly reduced.

1 Introduction

The east wall of North Pit at the Savage River Mine is approximately 1.5 km in length and up to 330 m high. The design parameters in fresh rock comprise 30 m vertical batters with 12 m berms, with some older areas in the central region of the pit wall comprising 20 m vertical batters with 10 m berms. It is comprised of strong and brittle calcite chlorite schist which contains unfavourably orientated joints dipping approximately 47° to the west (into the pit). In recent years these joints have combined with steeper westerly dipping structures to produce several large wall failures. Radar monitoring has been successfully utilised to provide alerts prior to the large east wall failures, allowing personnel to safely evacuate prior to pit wall failure. However, a correlation between decreasing failure size and a decrease in the performance of the radar in providing an alert prior to failure has been observed. Due to the high incidence of failures on the east wall a thorough approach to the risk management of east wall failures has been required which focusses on ensuring the integrity of the radar monitoring system and mitigating the risk posed by small wall failures for which the radar does not provide alerts for.

2 Radar settings

Since 2009 radar monitoring of the east wall of North Pit has been carried out with Reutech Movement and Surveying Radars (MSR). Radar monitoring is carried out from the west wall at locations approximately 450 to 650 m away from the east wall with scan cycle times varying between seven and 12 minutes.

The approach to radar monitoring at Savage River is to regard all areas of the east wall as potentially unstable. For this reason rather than attempting to identify potentially unstable areas and strategically placing radar alerts, radar alerts are placed over the entire east wall of North Pit. The radar alert settings used for the east wall of North Pit are given in Table 1.

Table 1 Radar settings for the east wall of North Pit

	Area Threshold[1]	Movement Threshold[2]	Time Window[3]
Geotechnical Alert[4]	2 × 2 points	1.5 mm/hour	2 hours
Critical Alert[5]	2 × 2 points	2.0 mm/hour	2 hours

The following points pertain to the above table.

1. Each point is separated by an arc of 0.25° from the radar. With the range to the east wall being 450 to 650 m, a 2 × 2 point spacing means a minimum of four points spaced 2.0 to 2.8 m must exceed the velocity threshold for an alert to be generated.
2. Movement threshold is the pit wall velocity above which an alert is triggered.
3. The time window is used to calculate the velocity, so that the velocity is calculated as being the pit wall displacement over the specified time window.
4. The Geotechnical Alert is received by Savage River Mine Control who then refer the alert to the onsite Geotechnical Engineer for assessment.
5. The Critical Alert is received by the Savage River Mine Control who evacuate the affected area of pit before referring the alert to the onsite Geotechnical Engineer for assessment.

3 Radar alert performance

The performance of the radars in providing alerts prior to east wall failures using the settings given in the previous section is shown in Figure 1. It can be seen that for all east wall failures greater than 250 tonne there have been radar alerts prior to each failure. For east wall failures between 70 and 250 tonne some failures have occurred without a radar alert. For east wall failures smaller than 70 tonne there has not been any radar alerts.

Figure 1 also shows a comparison of failure size with run-out distance from the toe of the east wall. As would be expected larger wall failures generally come to rest further from the toe of the pit wall than for smaller failures. However there are incidences with smaller wall failures or rockfalls where individual blocks bounce off inclined slope surfaces and are projected further away from the toe, as noted in the figure.

The variation of failure size with time to failure from the Geotechnical Alert is shown in Figure 2. The plot shows a trend of increasing warning time with increasing size of failure.

It is noted that if tighter alert thresholds were used (for example a smaller area threshold, a smaller time window or a lower velocity threshold), then radar alerts would probably be received for smaller failures and there would be an increase in time to failure from Geotechnical Alert. Unfortunately this would also result in unacceptably high incidences of false radar alerts which are due to variations in atmospheric conditions and surface water flowing over the pit wall during rainfall.

The data shown in Figure 1 and Figure 2 has been used to develop two distinct approaches to the risk mitigation of pit wall failure:

1. Although large wall failures run-out the furthest from the toe of the pit wall, they also reliably trigger radar alerts which give ample warning time for evacuation. Risk mitigation for large wall failures involves ensuring the integrity of the radar monitoring system.
2. Small wall failures may occur without receiving a radar alert, but they are likely to come to rest closer to the toe of the pit wall. Risk mitigation for small failures involves restricting work activities near the toe of the highwall and utilising remote controlled mining equipment.

The application of these two approaches to risk mitigation of pit wall failure is the subject of the following sections.

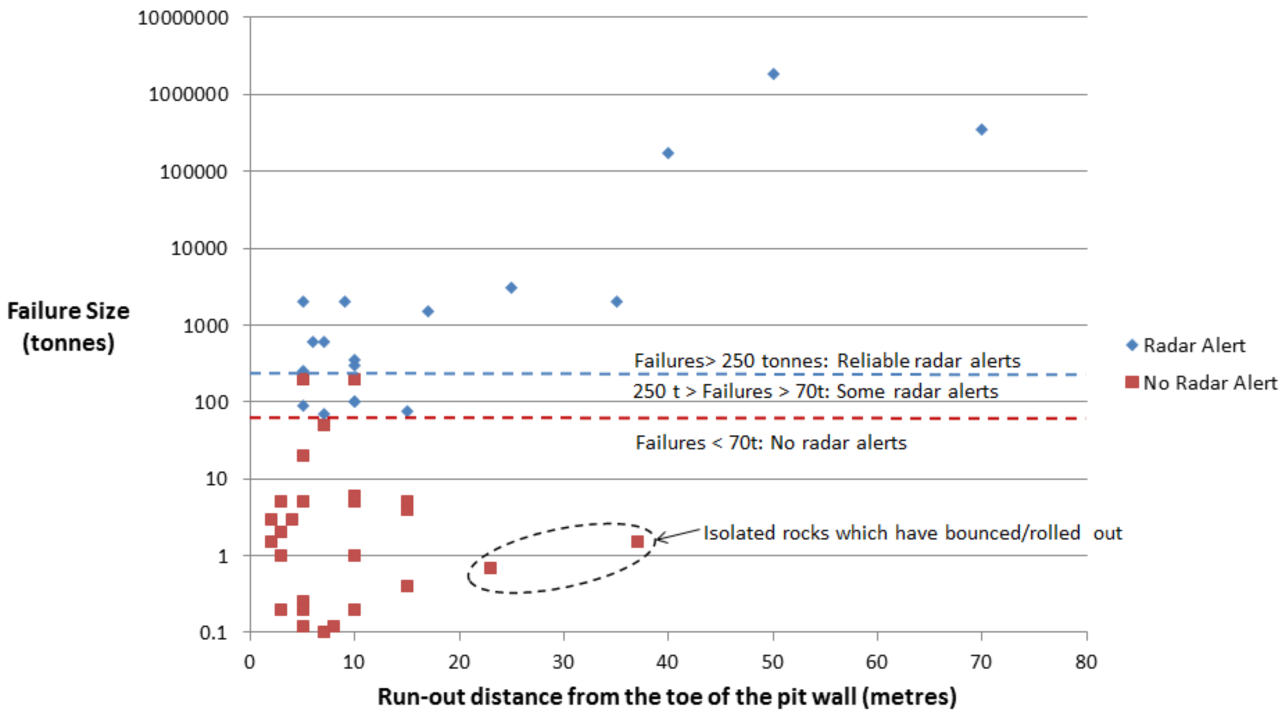

Figure 1 Radar performance in providing alerts prior to pit wall failures

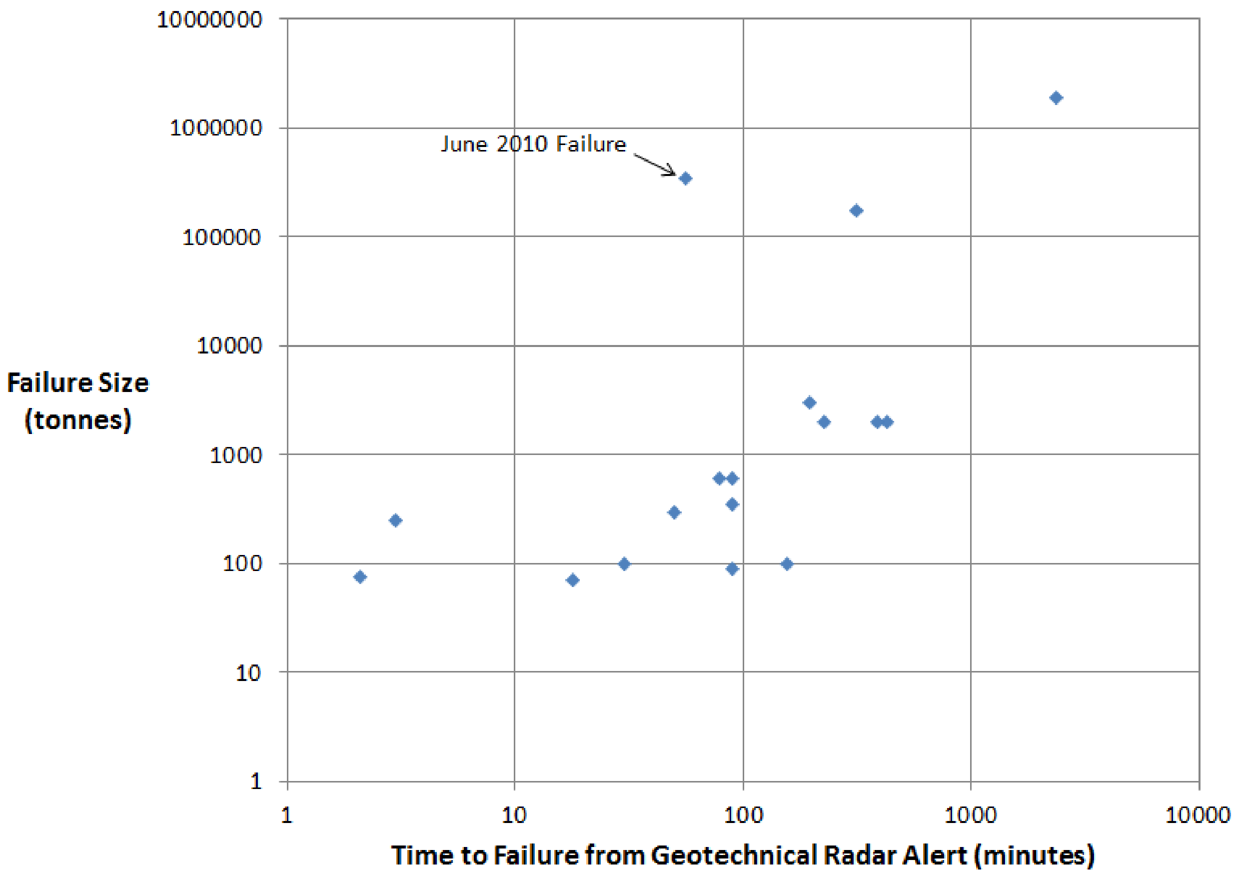

Figure 2 Variation of failure size with time to failure from the Geotechnical Alert

4 Radar monitoring system

With confidence in the capability of radar to provide prior warning before large wall failures, efforts to mitigate the risk of large wall failures have centred on ensuring the integrity of the radar monitoring system. The process steps in the radar monitoring system are shown graphically in Figure 3, which illustrates how an omission or error in radar set-up, the software settings, or the alert response has the potential to result in a failure to evacuate work areas prior to a pit wall failure.

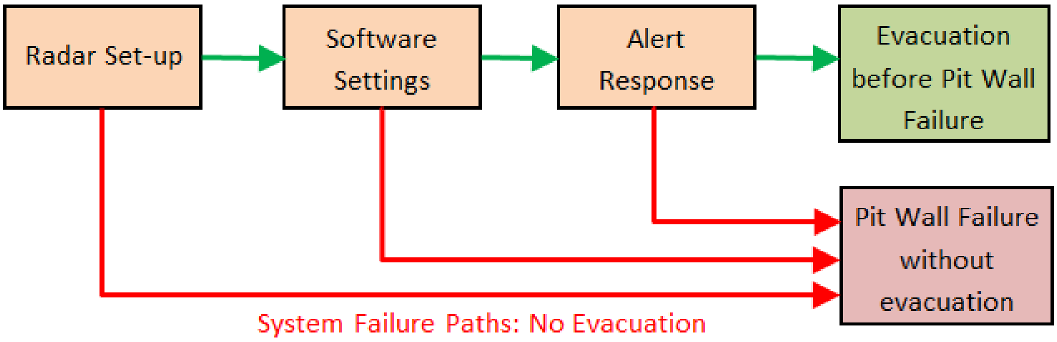

Figure 3 Simplified radar monitoring system diagram

Potential failure paths of the radar monitoring system have been identified through risk assessment and also through past experience. The documents controlling the operation of the radar monitoring system are designed to eliminate the potential for failure of the system through these causes. Table 2 lists the documents used in controlling the operation of the radars.

Table 2 Documents controlling the radar monitoring system

Document	Purpose
Radar Monitoring Training Manual	Provides training and reference material for new and existing geotechnical personnel
Radar Monitoring SOP (Safe Operating Procedure)	Specifies procedures to geotechnical personnel
Monitoring of Radar Communications by Mine Control SOP (Safe Operating Procedure)	Specifies procedures to Savage River Mine control personnel
Radar Monitoring TARP (Trigger Action Response Plan)	Specifies actions to be carried out by key personnel in the event of a radar alert
Radar Checklist	Daily checklist carried out by geotechnical personnel to ensure all radar settings are correct

The following sections describe some potential mistakes and errors that could compromise the integrity of the radar monitoring system.

4.1 Radar set-up – June 2010 wall failure

In June 2010 a 350,000 tonne wall failure occurred on an east wall 'bullnose' (see Figure 4). The 'Known Stable Region' (a scanning area which is used by the radar to enable corrections to atmospheric variations) was placed near the bullnose, and the area of concern which was being scanned by the radar was further to the south (see Figure 5). The bullnose had been in place for approximately four years without any indication of potential failure. Radar alerts were received a short time prior to the failure but they were not in the area of the actual wall failure, this being due to the Known Stable Region partially covering the failure area.

Figure 4 June 2010 east wall failure

Several lessons were learnt from this failure, which are now encompassed in Savage Rivers' radar monitoring procedures. These are listed below:

- All areas of wall should be considered potentially unstable. However, the Known Stable Region needs to be placed somewhere on the wall where stability is assumed. If a wall failure develops in the location of the 'Known Stable Region' then the radar will show an improbable scale of movement in the other scanning areas. For the onsite Engineer interpreting this data there are three possibilities; that the stable region is moving, that the radar is moving, or that a very large (and seemingly improbable) area of wall is moving. It is important that the first response to this confusing situation is to evacuate the pit. Interpretation of the radar data should be done once evacuation is in progress. The interpretation of this data is greatly assisted by having survey prisms installed at the radar location, on the Known Stable Region, as well as within the main scanning area on the pit wall.
- There was only seven minutes from the first radar alert to the commencement of the wall failure. The radar data was re-processed by Reutech Mining to show that if the scanning areas were swapped around so that alerts were set over the area of the wall failure and the stable region was located away from the wall failure; there would have been 56 minutes from the radar alert to the wall failure. The June 2010 wall failure is identified in Figure 2, with 56 minutes used as the time to failure from Geotechnical Radar Alert. It can be seen that in comparison to other large wall failures on the east wall, 56 minutes is a very short time. This is due to there being only a small component of the pre-failure wall movement in the direction of the radar (see Figure 5). The strategy to prevent this situation occurring has involved utilising a second radar which can be situated at a more appropriate location relative to the section of wall being scanned. When the situation does not necessitate a second radar for this purpose, then it is often used to scan a small particular area of concern above an active work area. This greatly reduces the scan cycle time, increasing the chance that radar alerts will be received before a small wall failure occurs.

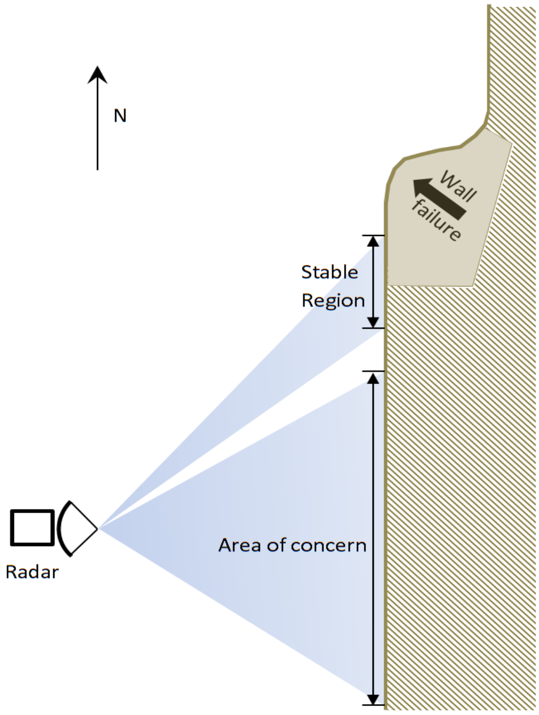

Figure 5 Diagram of the radar set-up prior to the June 2010 wall failure

4.2 Software setting errors

The importance of ensuring correct software settings was highlighted during a risk assessment prior to a 1,900,000 tonne failure in July 2012 (see Figure 6). Following the identification of the potential for a large wall failure, operations continued beneath the east wall for three months until the pit was evacuated 60 hours before the wall failed. During the period between the identification of a potential wall failure and the evacuation, it was identified as crucial to ensure that the correct software settings were maintained to ensure that a radar alert would be received prior to failure. As it eventuated the pit was evacuated before the first radar alerts were received that indicated the large wall failure.

Figure 6 July 2012 east wall failure

A checklist was developed to ensure that the radar was operational and there were no errors or omissions in the radar set-up or software settings. Geotechnical personnel carry out this checklist daily, and after any changes (such as modifying the scanning area or creating a new database) are made to the system. The checklist includes the following checks (note that this is not the full checklist):

- All radars are operating.
- The alert settings are correct (velocity threshold, area threshold, time window).
- All software settings that need to be set to ensure a radar alert is received are correctly set.
- The radar alerts cover all possible areas of pit wall above working areas.

The checklist also includes a check of Savage River's Mine Control office which involves the following:

- Generating a test alert to check the alert response for each operating radar.
- The onsite Geotechnical Engineer visits the Mine Control Office to ensure that all active radars are logged on, that the person attending the office has been trained in the Monitoring of Radar Communications by Mine Control SOP and that they have no issues or questions.

The importance of this checklist has been reinforced on several occasions since it was instigated. There have been several occasions where errors and omissions in the software settings have been identified during the checks. Typically the errors are found when the checklist is carried out after changes are made to the system. The errors found tend to be relatively simple errors (such as entering 12 hours for the time window instead of two hours) that greatly compromise the radar monitoring system.

4.3 Alert response

The radar alerts are received by the Savage River Mine Control. For a Geotechnical Alert the Mine Control personnel call the onsite Geotechnical Engineer who investigates the alert before advising on a course of action. For a Critical Alert the Mine Control personnel initiate evacuation of the affected area of the pit before calling the onsite Geotechnical Engineer. The full alert response procedure is detailed in a Trigger Action Response Plan which specifies actions for key personnel in the event of a radar alert.

Whether the radar alert is Geotechnical or Critical, the Geotechnical Engineer is required to make an assessment of the alert before advising on a course of action. Potential judgement errors by the Geotechnical Engineer have been identified both through risk assessments and through experience. Some important examples are given in the sub-sections below.

To prevent these judgement errors from occurring (or reoccurring) a Training Manual has been created for Geotechnical Personnel which provides guidelines to the interpretation of radar data and includes radar monitoring case studies. A Radar Monitoring Standard Operating Procedure (SOP) is also in place which provides procedures for the operation of the radars and overarching principles for the interpretation of data.

4.3.1 November 2012 wall failure

In November 2012 a 175,000 tonne wall failure occurred (see Figure 7) which resulted in a pump being destroyed. Based on the radar data and cracks observed on the wall prior to the failure the onsite Geotechnical Engineer interpreted the movement to be two distinct and separate potential failures. The affected area of the pit was evacuated but the pump was left in place under the assessment that it was probably outside the area that would be affected by the wall failure. As the wall accelerated towards failure it became obvious that the two separate areas of wall movement were part of the same large unstable block, and thus the size of the failure was much larger than expected. By this time it was not safe to allow personnel into the pit to remove the pump. The lessons learnt were to recognise that small and seemingly separate areas of wall movement can be precursors to a larger failure, and that after the initial evacuation there may be no further safe opportunity to retrieve machinery.

Figure 7 November 2012 east wall failure

4.3.2 June 2010 wall failure

As described in Section 2.1, there are occasions when confusing or improbable radar data is received. This can be due to the Known Stable Region moving, the ground beneath the radar moving, or occasionally malfunctioning within the radar unit. An important procedural step in the event of improbable or confusing radar data is that the evacuation of the affected area of the pit is commenced before the interpretation of the radar data to determine the precise reason for the confusing data.

4.3.3 False alerts due to atmospheric conditions or surface water on the pit wall

With Savage River's high rainfall (average annual rainfall is approximately 2 m) and variable atmospheric conditions, there are often occasions when radar alerts are triggered due to surface water flowing over the pit walls or due to changing atmospheric conditions. A radar alert due to these reasons is usually easily identifiable and work is often allowed to proceed. However, there are occasions when the effect of rainfall and/or atmospheric conditions on the radar data is so intense that real wall movements could be obscured by the surface water or atmospheric effects. On these occasions work under the affected area of wall is restricted or ceased until the data returns to normal.

The east wall of North Pit has a 15,000 m^2 drape mesh system in place that protected personnel and equipment when recovering from the June 2010 wall failure (Hutchison et al., 2013). It was found that in areas where the mesh bridged overhangs or hung free, radar alerts were triggered by small movements of the mesh in strong wind. The movement of the mesh obscured any real wall movement and triggered so many false alerts that eventually the radar alerts over problematic areas of mesh were deactivated.

5 Small failure risk mitigation

In Section 3 it was shown that radar monitoring of the east wall of North Pit was effective for failures greater than 250 tonnes. However, failures smaller than 250 tonnes still present a significant risk to work activities near the toe of the east wall, particularly to personnel on foot.

Figure 8 shows a histogram of 178 failures smaller than 250 tonnes which have been recorded on the east wall of North Pit since 2007. It can be seen that the majority of failures come to rest near the toe of the east wall. The failure in the 31 to 40 metre category was from one wall failure that resulted in a single 100 kg rock bouncing/rolling 37 m from the toe of the east wall.

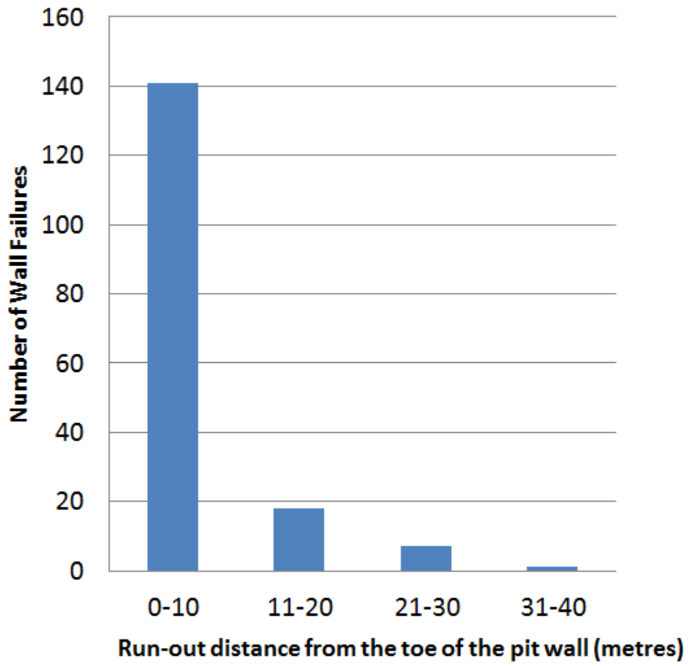

Figure 8 Histogram of east wall failures smaller than 250 tonnes

Savage River manages the risk of small failures by specifying a 'High Wall Toe Exclusion Zone' along the toe of the east wall. The High Wall Toe Exclusion Zone usually extends 20 m from the toe of the east wall, but this can be increased or decreased depending on particular instability concerns on the east wall. The risk controls used in the High Wall Toe Exclusion Zone include using spotters for personnel on foot, using excavation practices which keep machinery cabs away from the highwall, and restricting work during and after rainfall and blasting. Figure 9 shows a histogram relating the occurrence of east wall failures to blasting and rainfall. From this data it can be seen that the majority of wall failures are related to blasting and rainfall, and so an element of risk mitigation at Savage River is to restrict work activities, particularly for personnel on foot, during and soon after rainfall or blasting.

Where there is an area of pit wall for which there is a particular instability concern and further controls are required a Restricted Area is specified. A Restricted Area requires a Job Hazard Analysis (JHA) to be completed prior to any work activity. The risk controls used in Restricted Areas typically involve the same controls as for the High Wall Toe Exclusion Zone, but will also include additional controls such as restricting night time work activities and utilising remote controlled mining machinery.

The remote controlled machinery adopted at Savage River includes remote drills, excavators and bulldozers. Recently remote blast priming and loading has been made possible with the development of a Remote Explosive Blasting Unit (see Figure 10). This machine uses a Merlo telehandler base and the attachments and system were developed and patented by Grange Resources. It is used in areas where there is a high risk of small wall failures, and has enabled the complete exclusion of personnel on foot within 20 m from the toe of the highwall.

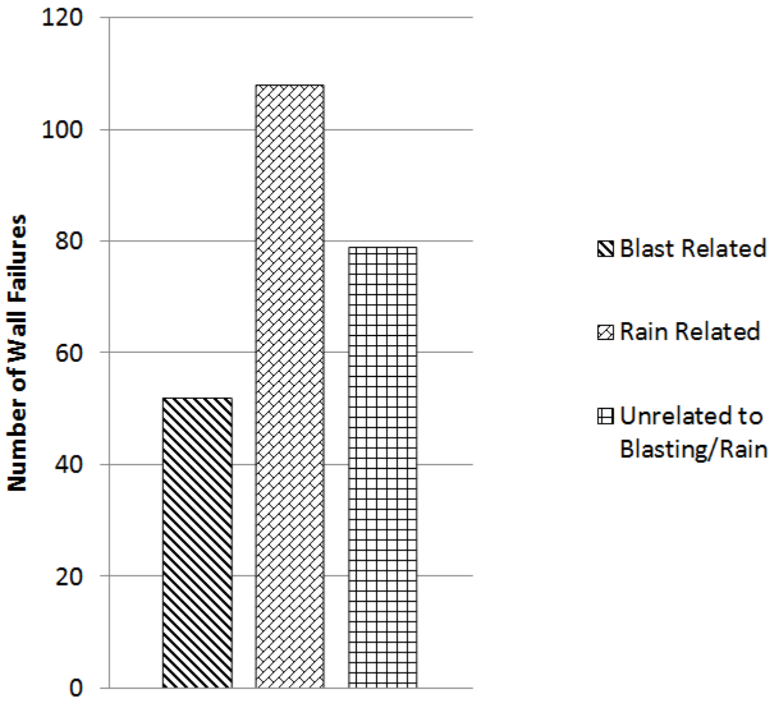

Figure 9 Histogram relating the occurrence of wall failures to blasting and rainfall

Figure 10 Grange Resource's patented Remote Explosive Blasting Unit

6 Conclusions

The high incidence of wall failures on the east wall of North Pit at the Savage River Mine has required a thorough approach to risk management of wall failures. Radar monitoring has been found to be successful in providing alerts prior to large (greater than 250 tonne) wall failures, but less successful in providing alerts prior to smaller wall failures. The risks posed by large east wall failures are mitigated through ensuring the integrity of the radar monitoring system. It was shown that small wall failures tend to come to rest close to the toe of the east wall, and for this reason the risk controls for small wall failures involve applying specified zones at the toe of the east wall where work activities are restricted and remote controlled mining equipment is heavily utilised.

References

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