ANNEXURE N5:
GROUND VIBRATION AND AIR BLAST STUDY BY BLAST MANAGEMENT & CONSULTING

Blast Management & Consulting

Report:
Phase 2 Social And Environmental Impact Assessment: Ground Vibration and Air Blast Study
For Rio Tinto, Rössing Uranium Mine Expansion Project, Namibia
Dated 31 January 2009

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Quality Service on Time

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Signed:
Name: JD Zeeman

CK 97 31139 / 23
Cell.: 082 854 2725
Tel.: +27 (0)12 662 1945 Fax.: +27 (0)12 662 3141
PO Box 61538 Pierre van Ryneveld Centurion 0045
54 Van Ryneveld Avenue Pierre van Ryneveld Centurion 0157

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List of acronyms used in this report:

Air pressure pulse	APP
Air blast	dB
Blasted Tonnage	T
East	E
Explosives (Trinitrotoluene)	TNT
Gas release pulse	GRP
North	N
North East	NE
North West	NW
Noxious Fumes	NOx’s
Rio Tinto	RT
Rock pressure pulse	RPP
Rössing Uranium Mine	RUM
South	S
South East	SE
South West	SW
United States Bureau of Mine	USBM
West	W

List of units used in this report:

Charge Density	kg/m
Charge Height	m
Cup Density	gr/cm^3
Ground Vibration	mm/s
Kilometre	km
mass	kg
Meter	M
Peak acceleration	mm/s^2
Peak Displacement	mm
Peak Particle Velocity	mm/s
Powder Factor	kg/T

1. Executive Summary

Rio Tinto, Rössing Uranium Mine (RUM), Namibia is considering an expansion of current opencast mining operations. Blast Management & Consulting was contracted, as part of a Social and Environmental Impact Assessment (SEIA), to perform a review of possible impacts with regards to blasting operations in the proposed expansion of opencast mining operations and to evaluate results from current blast operations. The aspects of blasting operations such as ground vibration, air blast, fly rock and fumes were evaluated.

The evaluation of effects yielded by blasting operations were considered for interested and affected parties located at various sides of Rössing Uranium Mine and ranged to distances in excess of 12km. Significant is the location of Arandis town and the Arandis Airport which were private structure locations closest to the mine.

The expected ground vibration and air blast levels from blasting operations were calculated and considered in relation to the surrounding structures and installations. No specific concerns were identified from the review of the expected ground vibration and air blast levels. The expected levels of ground vibration and air blast from detonating the maximum charge considered are within the allowed guidelines, but levels are such that it could be perceptible. This in turn may lead to complaints and subsequent investigations. The distances between the pit and private installations are significant and ranged between 5.6km and in excess of 12km.

Ground vibration levels of 3.2mm/s calculated from a worst case scenario at the closest point of interest – the Arandis Airport – were well within the minimum requirements even at very low frequencies. A level of 4.3 mm/s is allowed at 1 Hz. Air blast for the same situation was 110.2 dBL. Considering a reduced charge, which is more likely to occur at Rössing Uranium Mine, the levels observed were 0.8 mm/s and 105dBL. These levels are well below the lower recommended level specified. All other structures / installations were well within limits with no significant effect.

Specific consideration was also given to people’s perception and indicated that there is limited chance that people will be affected by blasting operations at Rössing Uranium Mine. A possibility exists that blasts could be noticed in very low ground vibration levels or possibly heard, but with no real concern that structures could be damaged.

The blasts monitored for ground vibration and / or air blast on the 21st October 2008 showed proper characteristics of ground vibration and air blast at points where data was registered. No results were obtained at Mr. Meyer’s farm that indicate actual ground vibration or air blast due to blasting operations done at Rössing Uranium Mine. Ground vibration and air blast from blasting operations are considered to be well within the recommended criteria at Mr. Meyer’s farm.

The current blasting operations may be changed for optimisation of the actual blast process and blast results, but changes are not necessarily required to facilitate specific reduction of ground vibration or air blast. Typical changes that can be incorporated are the option of changing the initiation system in order to facilitate possible better fragmentation, better loading conditions, better movement of blasts, and all factors that can be done through proper consideration of the various aspects of the mining process.

Probably the most effective way forward is setting up a monitoring program in order to collect data that will help determine specific effects that are unknown at this stage. Some of these effects are the levels generated and peoples experience due to location of the blast, size of the blast, orientation of the blast and initiation sequence, all factors that are bound to have an influence. The intensity of these influences is site specific and its outcome only known through detailed monitoring processes.

The levels observed from modelling done in this report are low and well within accepted norms and standards. Increased frequency of blasting to be done due to the proposed expansion will not have a cumulative effect on the ground vibration or air blast from one blast to another. Increased frequency is not expected to be problematic. The only aspect of the increase in blasting frequency due to the expansion may be a nuisance factor, if blasts are heard.

This report summarises the evaluation of recorded and expected effects from current blasting operations and the proposed future expansion at Rössing Uranium Mine. It is concluded that current blasting practices should have no significant influence towards current neighbours.

2. Introduction

The Rössing deposit was discovered in 1928, but only actively investigated after 1956. When Rio Tinto became involved in 1966, an intensive programme commenced, delineating a large, low grade uranium deposit that could be mined by means of an open pit. Operations at Rössing commenced in 1976 and have continued unabated for more than 30 years. Employment at Rössing is considerably lower today than at its peak, but the mine currently employs nearly 1100 people, 96% of whom are Namibians, and is an important contributor to the Namibian economy. In addition to the open pit, Rössing operates a mill and sulphuric acid leach plant which enables the mine to produce uranium oxide (U3O8) for export via Walvis Bay. The mine is a significant consumer of water and power. Presently water efficiency gains have enabled the mine to use less than half of its original water volume of the late 1970s. Rössing's power consumption represents about 5% of Namibia's total usage.

Rössing Uranium is majority owned by Rio Tinto (69%) and the Government of Namibia is a minority shareholder (3%) but has the majority (51%) in voting rights.

Through the Rössing Foundation, the company contributes to community development in the north-central regions of Namibia as well as locally in the Erongo Region.

In December 2005 the mine's operational life was extended to 2016, with potential to extend to 2021. With a growing nuclear power industry recognised worldwide as an efficient carbon-free source of power, and with an increase in the demand for uranium resulting in notable long-term market price increases, Rössing is favourably positioned to capture opportunities to increase its market share and to achieve production growth and expansion options for the mine. In 2006, the mine produced 3,617 tonnes of uranium oxide. With the expansion project, the plan is to increase production over the next few years to full capacity of 4,500 tonnes. This increase will be targeted through technical innovations, opening of new mining pits, establishing new processing facilities with associated waste storage facilities. The expansion includes a new sulphur burning acid plant on site and sulphur storage in the Walvis Bay harbour. The recruitment of additional fulltime employees and further training and development of current employees will continue.

Rio Tinto, Rössing Uranium Mine is now considering expansion of current opencast mining operations. Rössing Uranium Mine (RUM) is located approximately 6km south of the B2 highway opposite the Arandis town in Namibia. Latitude and Longitude: S22 27 54.4 E15 02 42.4.

Blast Management & Consulting (BM&C) was contracted as part of a Social and Environmental Impact Assessment (SEIA) to perform a review of possible impacts with regards to blasting operations due to the planned expansion and development of the mine. The possible impacts from current operations and the proposed expansion were reviewed. Ground vibration, air blast, fly rock and fumes are some of the aspects that can result from blasting operations. This study reviews possible influences on the surrounding area in respect of these aspects. The report, which concentrates on the ground vibration and air blast, intends to provide information, calculations, predictions, possible influences and mitigations of blasting operations for this project.

3. Protocols and Objectives

The protocols applied in this document are based on the author's experience, guidelines from literature research, client requirements and general indicators from the various Acts of South Africa and Namibia. There no current Namibian standard as far as could be established for ground vibration and air blast allowable limits or levels. There are guidelines on ground vibration and air blast under the Rio Tinto standards. This document however refers to standard that is currently applied in South Africa.

The guidelines and safe blasting criteria are according internationally accepted standards and specifically applied in this document is the United States Bureau of Mines (USBM) criteria for safe blasting for ground vibration and recommendations on air blast. However it is sure that the protocols and objectives will fall within the broader spectrum as required by the various Acts.

Comparison will be made between the standards and guidelines in section 12.2 in more detail.

The objective of this document is to outline the expected environmental effects that blasting operations could have on the surrounding environment. This study investigates the effect of blasting operations and the related influences with regard to expected ground vibration, air blast, fly rock, and noxious fumes. These effects are investigated in relation to the surroundings of the blast site and possible influence on the neighbouring houses and owners or occupants.

Objectives can be summarized according to the following steps taken as part of the SEIA Phase 2 study with specific regard to ground vibration and air blast due to blasting operations.

1 Visualisation of the Proposed Site
2 Blasting Requirements
3 Ground Vibration and Prediction
4 Limitations on Structures
5 Limitations with regards to Human perceptions
6 Air blast and Prediction
7 Fly Rock
8 Noxious Fumes
9 Site Specific Recommendations: Specific attention is then given to the site and discussed in particular to the following aspects:
   9.1 Ground vibration and Human Perception
   9.2 Air blast
   9.3 Fly-Rock
   9.4 Noxious Fumes
   9.5 Monitoring
   9.6 Risk Assessment

4. Visualisation of the Proposed Site

The Rio Tinto, Rössing Uranium Mine (RUM) is located approximately 6km south of the B2 highway opposite the Arandis town in Namibia. Latitude and Longitude: S22 27 54.4 E15 02 42.4. Figure 1 shows a geographical view of the planned project area with surroundings. Figure 2 shows an aerial view of the current opencast operations, followed by figure 3 showing the current opencast operations with the proposed expansion. Figure 4 shows a plan provided with current opencast area and proposed expansion with surroundings.

The site was reviewed and is presented hereafter. The site was reviewed / scanned using Google earth imagery and information provided by RUM. Information sought from the review was to identify which surface structures present around the mine boundary will require consideration during the modelling of blasting operations. This could consist of non mine owned houses, general structures, power lines, pipe lines, reservoirs, mining activities, roads, shops, schools, gathering places, possible historical sites etc. A list was prepared for the type of surface structures, direction from the mine operation and position. This is required for determining the allowable ground vibration limits, air blast limits and possible wind direction constraints that might be applicable. The surface structure concerns are provided in table 1 & 2 below. Graphical Visualisation of the mining operation and the expected ground vibration and air blast levels is presented on figures and is supplied in the discussion section.

Figure 1: Geographical View of Project Area.

Figure 2: Aerial view current opencast operations

Figure 3: Aerial view of current opencast operations with proposed expansion

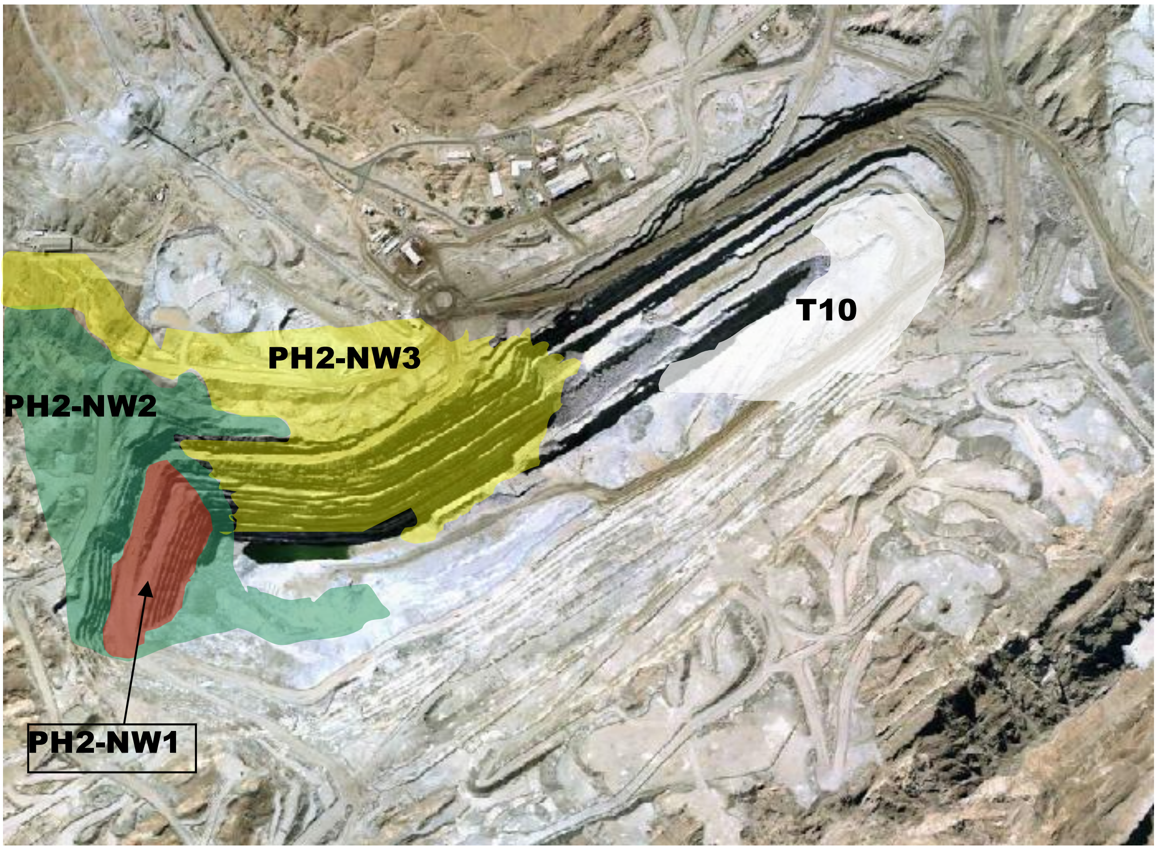

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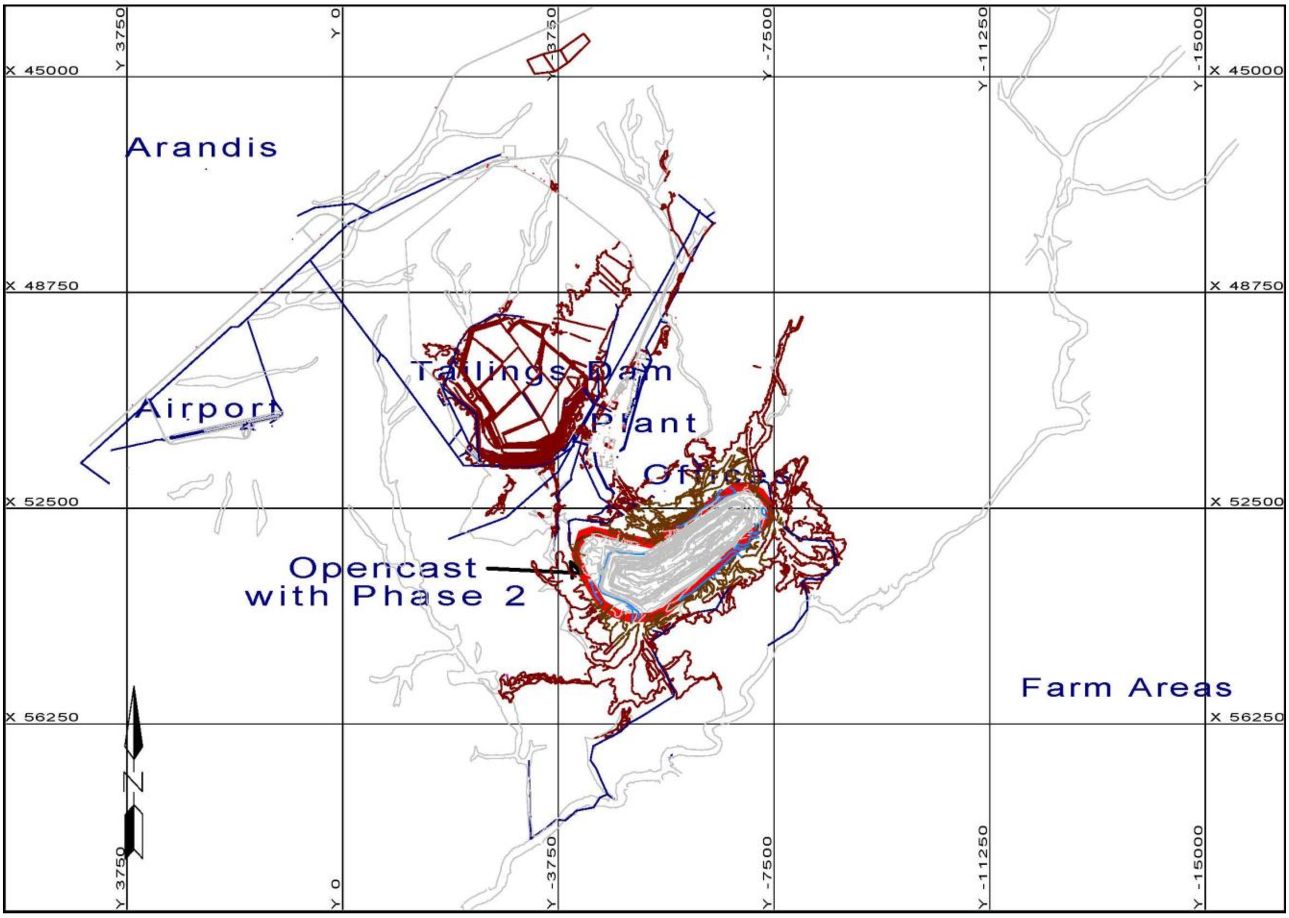
Figure 4: Surface Plan of the project area – Current Opencast and proposed expansion



4.1 Visualisation of the Proposed Sites

The mining operation location was reviewed and a list of surface structures was identified surrounding the mine area. Table 1 below is a list of all the structures / installations / concerned Interested and Affected Parties (I&APs) surrounding the mining.

Table 1: Structures / Farmsteads identified for consideration.

No.	Structure	Direction from Pit Position	Shortest Distance (km)
1	Arandis Town	NW	9.1 km
2	Arandis Airport	W	5.6 km
3	Farms	SE	>12 km
4	Mining Institute	NW	7.6 km

5. Blasting Operations

Mining operations at RUM are conducted on a regular basis. A detailed mine plan exists with specific blasting practices being conducted. The blasting operations currently done at the mine were considered in this document as a starting point for review of possible impacts and influences. Part of this document includes the monitoring and review of results report on blasts monitored. The current estimates of ore to be mined and expected blasting required is provided in table 2 below. The table shows the current expected tonnages for the current and expected expansion operations.

Table 2: Expected tonnages to be mined currently and for the proposed expansion.

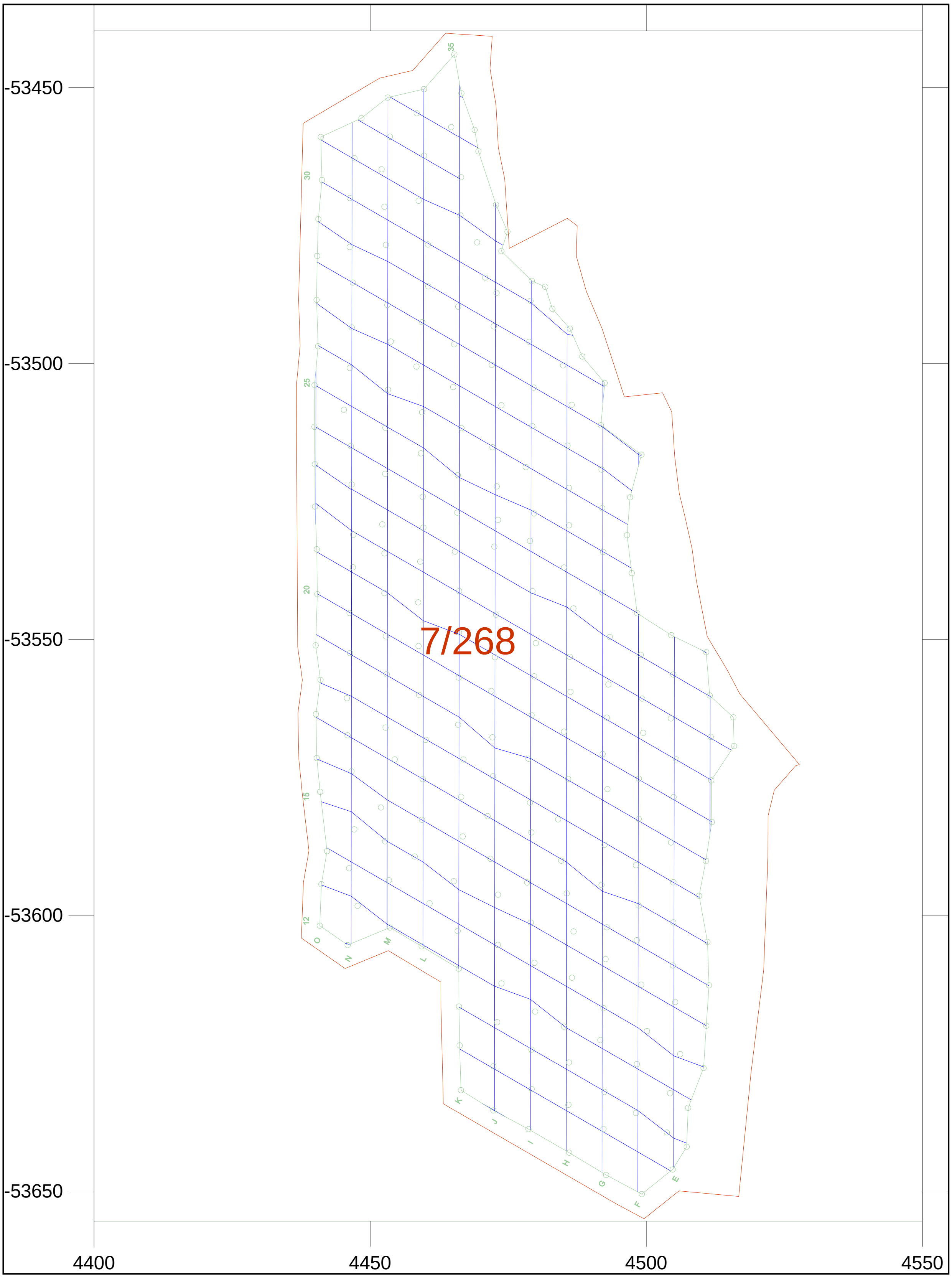
Description	Totals	Units
Current Operations Planning		
Total Mined from T10 (Waste+LG+Crush)	13,706,757	Tonnes
Blast Frequency	52	Times per annum
Average Blast	263,591	Tonnes
Proposed Expansion Planning		
Total Mined from Expansion (Waste+LG+Crush)	12,150,548	Tonnes
Blast Frequency	52	Times per annum
Average Blast	233,664	Tonnes

In order to understand current operations and the related possible influences, actual blasting operations were monitored and input data taken into account for this report. A typical block layout as found in the pit area is provided in Figure 5 below. Blast planning and layout is according to a specific schedule and information captured. Blasting is done using a standardised methodology. Blast information as typically found at RUM is provided in Table 3 below.

Table 3: Applicable Blast Information.

Blast Reference	07/268	05/265 & 05/267	04/243	04/246
Blast Type	Production	Production	Production	Trim
Bench Elevation	480m	510m	525m	525m
Blast Hole Depth (m)	17.8m min & 18.6m max	17.5m min & 19.8m max	11.0m min & 15.2m max	15.6m min & 16.9m max
Sub drill (m)	2.0m front & 2.5m rest	2.0m front & 2.5m rest	2.0m front & 2.5m rest	1.5m
Burden & Spacing (m)	6.5m x 7.5m	6.5m x 7.5m	6.5m x 7.5m	4.0m x 4.5m (Buffer 3.0 x 4.5)
Pattern Type	Staggered	Staggered	Staggered	Staggered
Holes	225	199	46	106
Cup Density (gr/cm^3)	1.1	1.1	1.1	1.1
Charge Density (kg/m)	100kg/meter	100kg/meter	100kg/meter	28kg/meter
Charge Height	11m	11m	9.5m	10m
Total Amount Of Expl. (kg)	270,310	233,230	58,600	58,210
Blasted Tonnage (T)	538,590	423,070	113,520	89,880
Powder Factor (kg/T)	0.502	0.551	0.516	0.648
Stemming Height & Type	6.0m/19mm Aggregate.	6.0m/19mm Aggregate.	6.0m/19mm Aggregate.	B-row open, C-row 5m, D&E 6.0m
Tie-Up	Closed Chevron	Closed Chevron	Open Chevron	Open Chevron
Accessories:	350g Trojan Booster	350g Trojan Booster	350g Trojan Booster	350g Trojan Booster
	500ms Down Hole Nonel	500ms Down Hole Nonel	500ms Down Hole Nonel	500ms Down Hole Nonel
	3.5g/m Deta Cord	3.5g/m Deta Cord	3.5g/m Deta Cord	3.5g/m Deta Cord
	84ms Inter row	84ms Inter row	84ms Inter row	42ms Inter row

Figure 5: Block 7/268 layout



Blast information provided is used for determining the expected charge mass per delay for ground vibration and air blast modelling. Calculations used in this document are based on the typical designs provided above.

RUM uses a relatively simplistic blasting methodology. Timing of the blast holes, apart from the blast holes size and charge mass, will have a significant influence on the ground vibrations and air blast. Detonating cord is mainly used between blast holes and rows are independently timed using specific relays / delays. This results in that the most blast holes that will detonate on one delay will be in the longest row of blast holes in a blast. The blast layout provided above shows a maximum of 25 blast holes in a row. This will prescribe the typical maximum charge that can be expected to detonate at once, and will be applied in the modelling of ground vibration and air blast as well.

Three basic models considered during the evaluation process are based on the blast design and possible mitigation, if required. Currently the initiation system is fixed – only one type of initiation system is used - and has been used as basis for calculations. Based on this, the three charge masses considered are: 1. 1003kg (single blast hole detonating), 2. 5014kg (5 blast holes detonating) and 3. 25068 kg (25 blast holes detonating).

6. Ground Vibration and Prediction

Explosives are used to break rock through the shock waves and gases yielded from the explosion. Ground vibration is a natural result from blasting activities. The far field vibrations are inevitable, but un-desirable by-products of blasting operations. The shock wave energy that travels beyond the zone of rock breakage is wasted and could cause damage and annoyance. The effect of these shock waves is very similar to that of the ripples created when a stone is dropped in water. The level or intensity of these far field vibrations is however dependant on various factors. Some of these factors can be controlled to yield desired levels of ground vibration and still produce enough rock breakage energy. Ground vibration is referred to as “The peak particle velocity” and normally quoted in velocity – mm/s. Ground vibration can also be presented in acceleration or displacement with units of mm/s^2 and mm. This report refers to ground vibration as “The levels and limits of ground vibration” or “Peak particle velocity”.

Factors influencing ground vibration are the charge mass per delay, distance from the blast, the delay period and the geometry of the blast. These factors are controlled by planned design and proper blast preparation.

The larger the charge mass per delay, not the total mass of the blast, the greater the vibration energy yielded. Blasts are timed to produce effective relief and rock movement for successful breakage of the rock. A certain quantity of holes will detonate within the same time frame or delay and it is the maximum total explosive mass per such delay that will have the greatest influence. All calculations are based on the maximum charge detonating on a specific delay.

Second is the distance between the blast and the point of interest. Ground vibrations attenuate over distance at a rate determined by the mass per delay, timing and geology. Each geological interface a shock wave encounters will reduce the vibration energy due to reflections of the shock wave. Closer to the blast will yield higher levels, and further from the blast will yield lower levels of ground vibration.

Thirdly, the geology of the blast medium and surroundings has influences as well. High density materials have high shock wave transferability where low density materials have low transferability of the shock waves. Solid rock, i.e. norite, will yield higher levels of ground vibration than sand for the same distance and charge mass. The precise geology in the path of a shock wave cannot be observed easily, but can be tested for, if necessary, in typical signature trace studies – which are discussed shortly below.

Normally, in order to determine effective control measures, it will be required to do a signature hole trace study. This process consists of charging and blasting test holes that are measured for ground vibration and air blast at various distances. Signature trace data can then be used to determine site specific constants for prediction of ground vibration and assist in determining timing of blasts in order to minimize the effect of vibration.

6.1 Prediction of Ground Vibration

When predicting ground vibration and possible decay, a standard accepted mathematical process of scaled distance is used. The equation applied (Equation 1) uses the charge mass and distance with two site constants. The site constants are specific to a site where blasting is to be done. In new opencast operations a process of testing for the constants is normally done using a signature trace study in order to predict ground vibrations accurately and safely. This is done by firing single holes at the site in question and monitoring the ground vibrations at various distances. The peak particle velocity (PPV) or ground vibration in mm/s is plotted against the scaled distance (D/√E) on a log/log graph. From this graph the slope and y-intercept for the trend line through the points are determined. The site constants *a* and *b* are the y-intercept and slope of the trend line respectively. The utilization of this formula is standard practice. The analysis of the data will also give an indication of frequency decay over distance.

In the absence of a signature trace study there are however constants used, prior to actual tests, which will take most of the factors into account. The signature trace process can be applied and will be useful in long term mining on surface and in sensitive blasting areas.

Equation 1:
$y = a(D/\sqrt{E})^b$
Where:
y = Predicted ground vibration
a = Site constant
b = Site constant
D = Distance
E = Explosive Mass

In the absence of tested values for *a* & *b*, the following factors are normally used and applied for the prediction of ground vibration. These factors were also applied for predicting expected ground vibrations in the area for the blasting to be done at the mining area.

Factors:
a = 1143
b = -1.65

Utilizing the abovementioned equation, charge mass and applicable limits for an installation of concern, the expected ground vibration levels can be calculated for various distances.

Review of the type of structures observed around the mine operation and the limitations that may be typically applicable indicated that three different levels of ground vibration are necessary to consider. These are the 10 mm/s, 25 mm/s and 75 mm/s levels. The blast design considered showed that the maximum charge per delay expected on a worst case scenario could be 25068 kg.

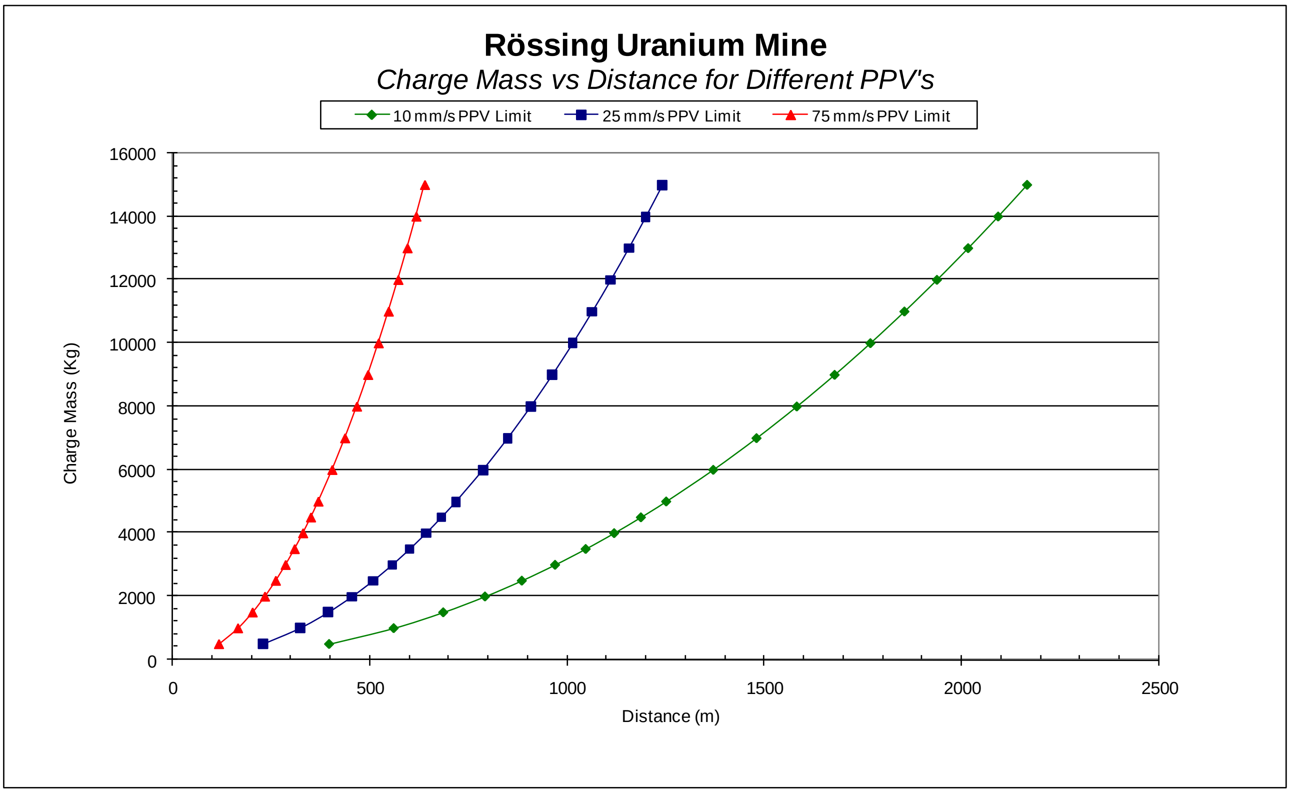
Considering the parameters, ground vibration and charge mass, the following calculations were done for consideration in this report:

Firstly the maximum charge mass that will yield specific ground vibration levels at various distances from the blast. The vibration levels considered are 10mm/s, 25 mm/s and 75 mm/s over the range of distances applied in the modelling phase as well. Data calculated is presented in Table 4 below. Figure 6 shows the graphic representation of data provided in Table 4.

Table 4: Distances required for maintaining specific vibration levels at specific charge masses.

No.	Charge Mass (kg)	Distance (m) 10mm/s PPV Limit	Distance (m) 25mm/s PPV Limit	Distance (m) 75mm/s PPV Limit
1	500.0	395	227	117
2	1000.0	559	321	165
3	1500.0	684	393	202
4	2000.0	790	454	233
5	2500.0	884	507	261
6	3000.0	968	556	285
7	3500.0	1046	600	308
8	4000.0	1118	641	330
9	4500.0	1186	680	350
10	5000.0	1250	717	369
11	6000.0	1369	786	404
12	7000.0	1479	849	436
13	8000.0	1581	907	466
14	9000.0	1677	962	494
15	10000.0	1767	1014	521
16	11000.0	1854	1064	547
17	12000.0	1936	1111	571
18	13000.0	2015	1156	594
19	14000.0	2091	1200	617
20	15000.0	2164	1242	638

Figure 6: Distance versus charge mass for limiting vibration levels.



Secondly, the charge masses required to yield different vibration levels (10mm/s, 25 mm/s and 75 mm/s) at various distances was calculated and presented in Table 5 below. This is used to consider what maximum charge mass can be allowed for a specific distance of interest.

Table 5: Limiting charge masses at specific distances for maintaining specific ground vibration levels

Distance (m)	Charge Mass (kg) 10mm/s PPV Limit	Charge Mass (kg) 25mm/s PPV Limit	Charge Mass (kg) 75mm/s PPV Limit
200.0	128	389	1473
400.0	512	1556	5891
600.0	1153	3500	13255
800.0	2049	6222	23565
1000.0	3202	9722	36820
1500.0	7204	21874	82844
2000.0	12807	38888	147278
2500.0	20011	60762	230122
3000.0	28816	87497	331376
3500.0	39222	119093	451040
4000.0	51229	155550	589113
4500.0	64837	196868	745596
5000.0	80046	243047	920489
6000.0	115266	349988	1325505
7000.0	156890	476372	1804159
8000.0	204917	622200	2356453
9000.0	259348	787472	2982386
10000.0	320183	972188	3681958
11000.0	387422	1176347	4455169
12000.0	461064	1399950	5302019

Based on the expected drilling and charging design, Table 6 (following) shows expected ground vibration levels (PPV) for various distances calculated at three different charge masses. A single blast hole, 5 blast holes detonating and the expected maximum charge mass per delay – 25 blast holes per delay. The maximum charge mass is as a worst case scenario. The charge masses used are representative of minimum and maximum charges that can be expected in a typical blast.

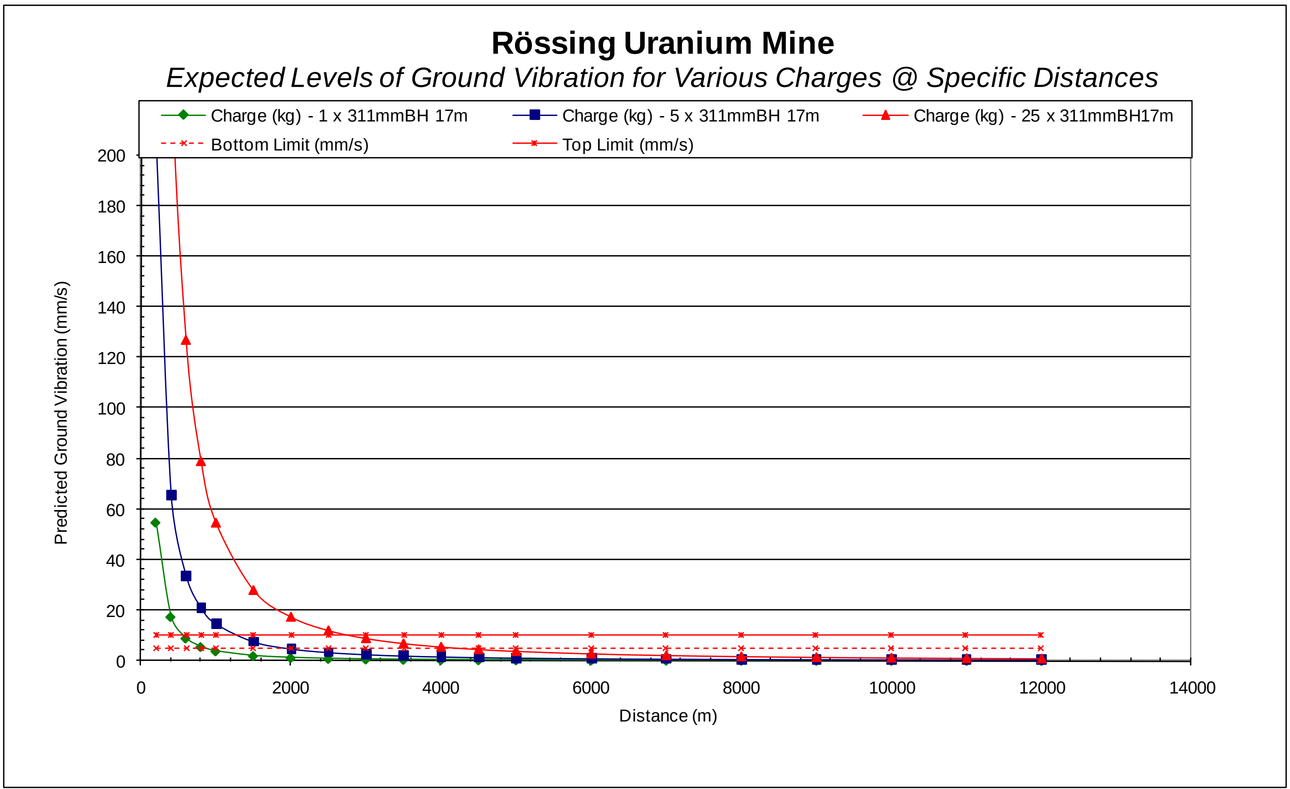
Table 6: Expected ground vibration at various distances from charges applied in this study.

Distance (m)	Expected PPV (mm/s) for Charge (kg) - 1 x 311mmBH 17m	Expected PPV (mm/s) for Charge (kg) - 5 x 311mmBH 17m	Expected PPV (mm/s) for Charge (kg) - 25 x 311mmBH 17m
200.0	54.6	206.1	777.4
400.0	17.4	65.7	247.7
600.0	8.9	33.6	126.9
800.0	5.5	20.9	78.9
1000.0	3.8	14.5	54.6
1500.0	2.0	7.4	28.0
2000.0	1.2	4.6	17.4
2500.0	0.8	3.2	12.0
3000.0	0.6	2.4	8.9
3500.0	0.5	1.8	6.9
4000.0	0.4	1.5	5.5
4500.0	0.3	1.2	4.6
5000.0	0.3	1.0	3.8
6000.0	0.2	0.8	2.8

7000.0	0.2	0.6	2.2
8000.0	0.1	0.5	1.8
9000.0	0.1	0.4	1.5
10000.0	0.1	0.3	1.2
11000.0	0.1	0.3	1.0
12000.0	0.1	0.2	0.9

Figure 7 below shows the relationship of ground vibration over distance for the three charges considered as given in table 6 above. The attenuation of ground vibration over distance is clearly seen from the graph. Ground vibration attenuation follows a logarithmic trend and the graph indicates this trend. The graph can be used to scale expected ground vibration at specific distances for the same maximum charges as used in this report. The expected vibration level at a specific distance can be read from the graph, provided the same maximum charges are applicable, or by rough estimate if the charge per delay should be between the charge masses applied for this case.

Figure 7: Ground vibration over distance for maximum charge mass.



6.2 Limitations on Structures

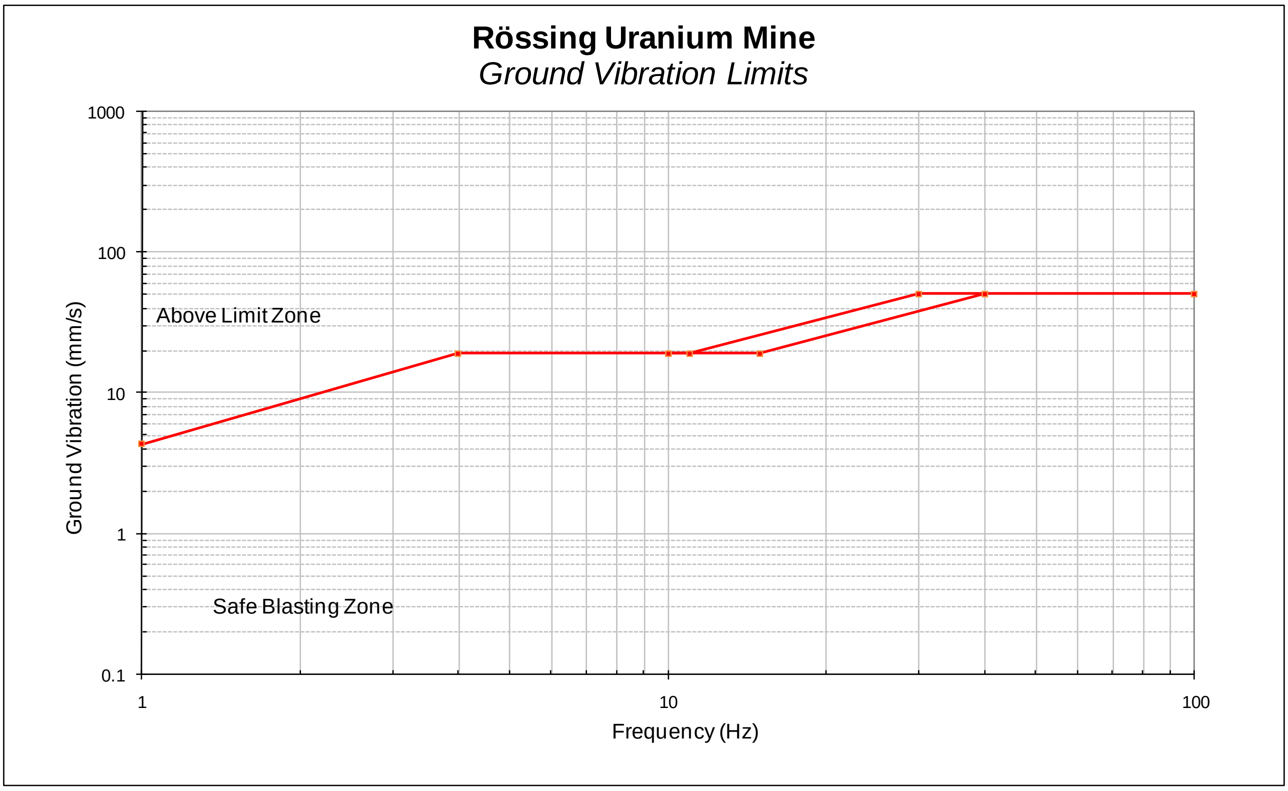
Limitations on ground vibration are in the form of maximum allowable levels for different installations and structures. These levels are normally quoted in millimetres per second, i.e. velocity of the particles. Early recommendations were as follows: 25 mm/s maximum at private structures, if frequency of ground vibration is greater than 10 Hz and 12.5 mm/s, where frequency of ground vibration is less than 10 Hz.

The South African standard currently applied is that of the United States Bureau of Mines (USBM) criterion for safe blasting, which is applied where private structures are of concern. This is a process of evaluating the vibration amplitudes and frequency of the vibrations according to set rules for preventing damage. The vibration amplitudes and frequency are then plotted on a graph. The graph indicates two main areas:

a) The Safe Blasting Criteria Area
b) The Unsafe Blasting Criteria Area

When ground vibration is recorded and the amplitude in velocity (mm/s) is analysed for frequency, it plots this relationship on the USBM graph. If data falls in the lower part of the graph then the blast was done safely. If the data falls in the upper part of the graph then the probability of inducing damage to mortar and brick structures increases significantly. There is a relationship between amplitude and frequency due to the natural frequencies of structures. This is normally low - below 10 Hz - and thus the lower the frequency, the lower the allowable amplitude. Higher frequencies allow for higher amplitudes. The extra lines on the graph are more detailed for specific types of wall and structure configurations. Locally we are only concerned with the lowest line on the graph. This is a pre blast analysis, but predictions help us determine expected amplitudes and experience has taught us what frequencies could be expected. The USBM graph for safe blasting was developed by the United States Bureau of Mines through research and data accumulated from sources other than their own research. Figure 8 shows an example of a USBM analysis graph.

Figure 8: USBM Analysis Graph



Additional limitations that should be considered are as follows, these were determined through research and various institutions:

a) National Roads/Tar Roads: 150 mm/s
b) Steel pipelines: 50 mm/s
c) Electrical Lines: 75 mm/s
d) Railway: 150 mm/s
e) Concrete aged less than 3 days: 5mm/s
f) Concrete after 10 days: 200 mm/s

g) Sensitive Plant equipment: 12 or 25 mm/s depending on type – some switches could trip at levels less than 25 mm/s.

Considering the above limitations, BM&C work is based on the following:

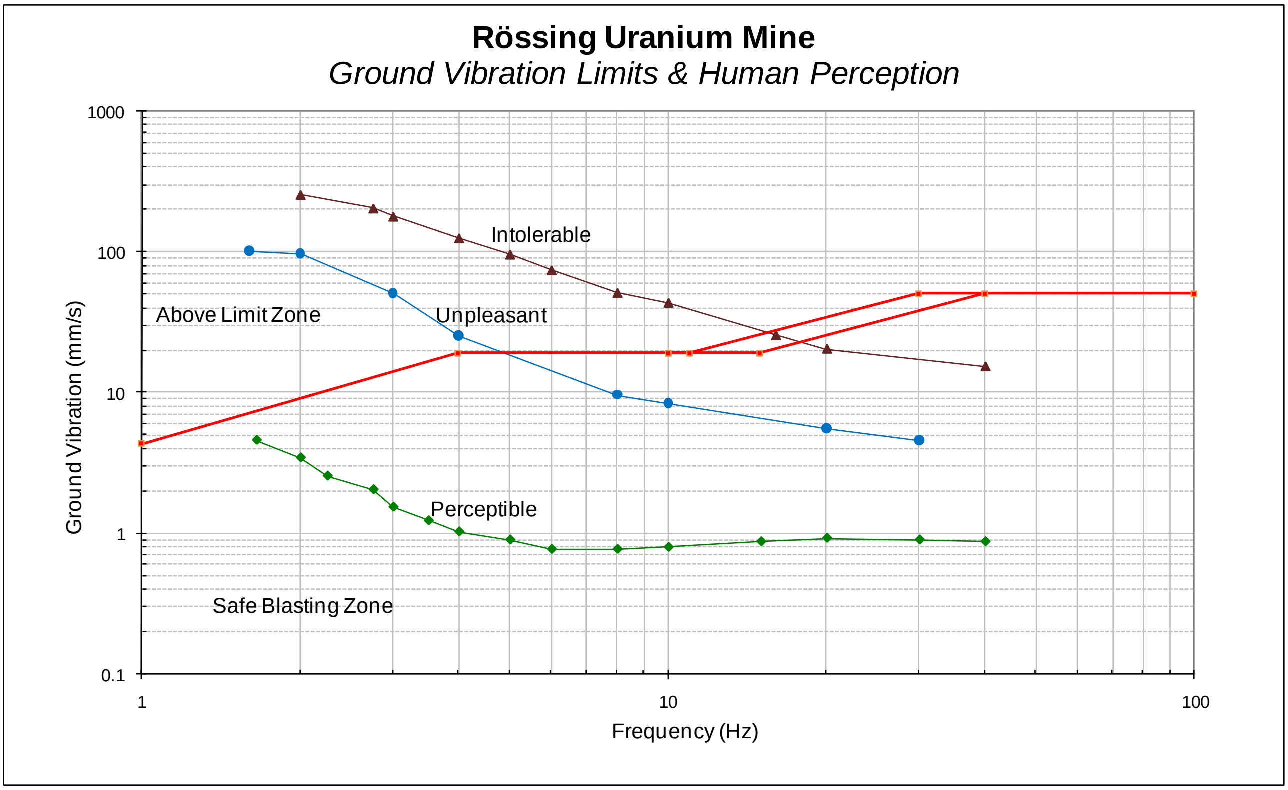
a) USBM criteria for safe blasting.
b) The additional limitations provided.
c) Consideration of private structures.
d) Should these structures be in poor condition is the basic limit of 25 mm/s reduced to 12.5 mm/s or even when structures are in very poor condition limits will be restricted to 6mm/s.
e) We also consider the input from other consultants in the field locally and internationally.

6.3 Limitations with regard to Human perceptions

A further aspect of ground vibration and frequency of vibration is the Human perception. It should be realized that the legal limit for structures is greater than the comfort zones for people. Humans and animals are more sensitive to ground vibration and vibration than structures. Research has shown that humans will respond to different levels of ground vibration and at different frequencies. Ground vibration is experienced as “Perceptible”, “Unpleasant” and “Intolerable” (only to name three of the five levels tested) at different vibration levels for different frequencies. This is indicative of the human’s perceptions on ground vibration and clearly indicates that humans are sensitive to ground vibration. This “tool” is only a guideline and helps with managing ground vibration and the respective complaints that people could have due to blast induced ground vibrations. Humans already perceive ground vibration levels of 4.5 mm/s as unpleasant.

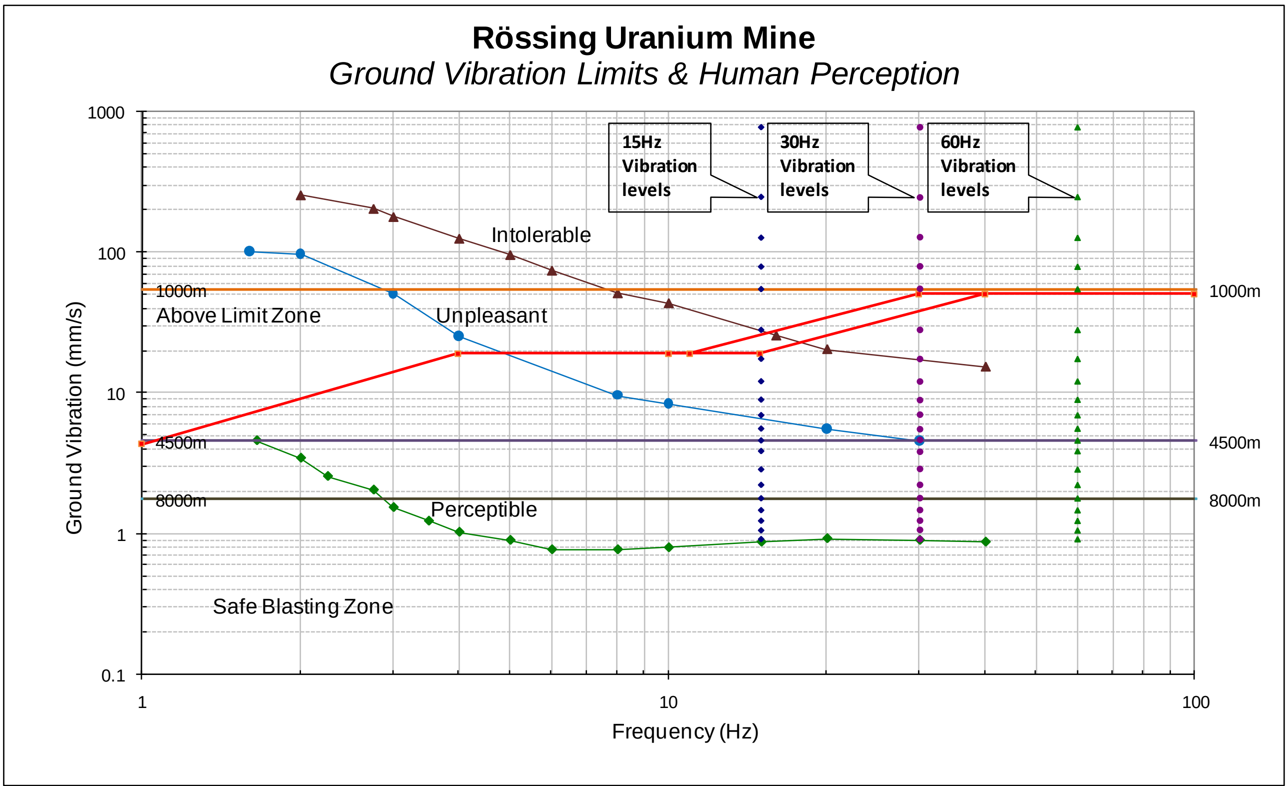
Generally people also assume that any vibrations of the structure – windows or roofs rattling – will cause damage to the structure. Air blast also induces vibration of the structure and is the cause of nine out of ten complaints. (See Figure 9)

Figure 9: Analysis with human perception



Considering the effect of ground vibration with regard to human perception, vibration levels calculated were applied to various frequencies and plotted with expected human perceptions on the USBM safe blasting criteria graph (See Figure 10 below). On the graph are indicators of the effect of vibration amplitude at various distances for three specific frequencies 15, 30 and 60 Hz. The frequency range selected is the expected range for frequencies that could be measured for ground vibration. Considering the maximum charge per delay of 25068kg, there is indication that though levels of ground vibration are well within the specified limit at 4500m, it will be strongly perceptible, verging onto being unpleasant for people. At 3500m the people's perception would have changed from perceptible to unpleasant whilst the levels of ground vibration are still within the specified limit. Ground vibration expected is still below the 10 mm/s level. Damage to structures (normal brick and mortar) is still not expected to be induced. Figure 10 below shows this effect of ground vibration with regard to human perception.

Figure 10: The effect of ground vibration with regard to human perception plotted with the Rio Tinto Standard. Highest charge mass applied.



7. Air blast and Prediction

Sound pressure is the general term used for changes in air pressure caused by sound waves. Peak sound pressure levels can be given in either Pascal (Pa) or Decibels (dB). When sound recordings are to be used to either assess human annoyance or hearing damage, it is normal for the raw sound wave to be processed via an 'A' weighting filter, thus giving peak levels with units of dB(A). The 'A' weighting process effectively filters out much of the low frequency, sub-audible, energy in the recording. However, when recording sound pressure levels from concussive or explosive events much of the energy is sub-audible and it is normal to use unweighted signals giving peak values in dB (Linear). Such low frequency recordings are often referred to as air overpressure recordings and are normally taken as applying to frequencies above 2.Hz. Although there is no clear guidance on the levels of air overpressure likely to cause damage to the human ear, it is widely recognised that the levels of air overpressure required to cause structural damage is higher than 170.dB(Linear), with even weak windows surviving levels of 150.dB(Linear).

Air blast or air-overpressure is the air pressure wave generated by a detonation. Air blast is normally associated with frequency levels less than 20 Hz, which is the threshold for hearing. Air blast is the direct result from the blast process, although meteorological conditions, the final blast layout, timing, stemming, accessories used, covered or not covered etc., all have an influence on the outcome of the result.

The three main causes of air blasts can be observed as:

1. Direct rock displacement at the blast; the air pressure pulse (APP),
2. Vibrating ground some distance away from the blast; rock pressure pulse (RPP),
3. Venting of blast holes or blowouts; the gas release pulse (GRP).

7.1 Limitations with regards to Air blast

The recommended limit for air blast currently applied is 134 dB. This is specifically pertaining to air blast or otherwise known as air-overpressure. This takes into consideration where the public is of concern. Air-overpressure is pressure acting and should not be confused with sound that is within audible range (detected by the human ear). However, all attempts should be made to keep air blast levels generated from blasting operations below 120 dB toward critical areas where public is of concern. This will ensure that the minimum amount of disturbance is generated towards the critical areas surrounding the mining area.

Based on work carried out by Siskind *et.al.* (1980)[1], monitored air blast amplitudes up to 135 dB are safe for structures, provided the monitoring instrument is sensitive to low frequencies (down to 1 Hz). Persson *et.al.* (1994)[2] have published the following estimates of damage thresholds based on empirical data (Table 7).

Table 7: Damage limits for air blast.

Level	Description
120 dB	Threshold of pain for continuous sound
>130 dB	Resonant response of large surfaces (roofs, ceilings). Complaints start.
150 dB	Some windows break
170 dB	Most windows break
180 dB	Structural Damage

Levels given in Table 7 are at the point of measurement.

7.2 Air blast Prediction

An aspect that is not normally considered as pre-operation definable is the effect of air blast. This is mainly due to the fact that air blast is an aspect that can be controlled to a great degree by applying basic rules. Standards do exist and predictions can be made, but it must be taken into account that predictions of air blast are most effective only when used in conjunction with charges on the surface, and are normally referred to detonation of TNT as a reference. Blasts that are normally covered show the least effect on air blast. However even covered blasts with the use of detonating cord can yield high air blast levels when pieces of the detonation cord that are used for indicators are not covered. Covered blasting is normally used in the blasting of trenches etc., in close proximity of structures.

The following equation is associated with predictions of air blast, but is considered by the author as subjective. The only real fact is that air blast does decrease over distance and nominally at a rate of -6dB for each doubling of the distance from the source. However, applying equation 2 gives some indication of the expected levels of air blast and attenuation over distance.

Equation 2:
$L = 165 - 24 \text{ Log10 } (D/ E^{1/3})$
Where:
L = Air blast level (dB)
D = Distance from source (m)
E = Maximum charge mass per delay (kg)

Although the above equation was applied for prediction of air blast levels, additional measures can also be recommended in order to ensure that air blast and associated fly-rock possibilities are minimized completely.

As discussed earlier the prediction of air blast is very subjective. Following in Table 8 below is a summary of values predicted according to equation 2.

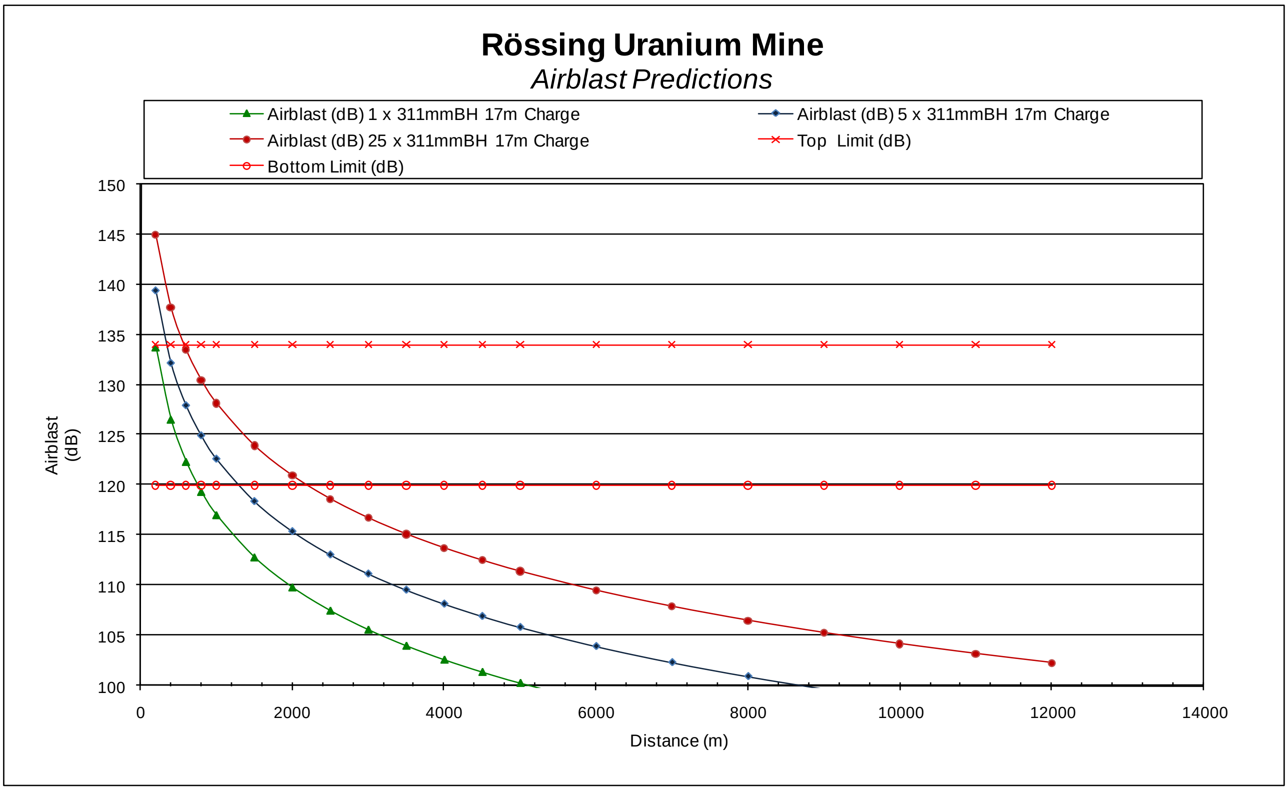
Table 8: Air blast predicted values at the point of measurement.

Distance (m)	Air blast (dB) - 1 x 311mmBH 17m Charge (kg)	Air blast (dB) 5 x 311mmBH 17m Charge (kg)	Air blast (dB) 25 x 311mmBH 17m Charge (kg)
200.0	134	139	145
400.0	127	132	138
600.0	122	128	134
800.0	119	125	131
1000.0	117	123	128
1500.0	113	118	124
2000.0	110	115	121
2500.0	107	113	119
3000.0	106	111	117
3500.0	104	110	115
4000.0	103	108	114
4500.0	101	107	113
5000.0	100	106	111
6000.0	98	104	110
7000.0	97	102	108
8000.0	95	101	107
9000.0	94	100	105
10000.0	93	99	104
11000.0	92	98	103
12000.0	91	97	102

Figure 11 below shows the predicted values for air blast as given in Table 8 with values for air blast predicted.

(Intentionally left open)

Figure 11: Predicted air blast.



8. Fly Rock

Blasting practices require some movement of rock to facilitate the excavation process. The extent of movement is dependent on the scale and type of operation. For example, blasting activities within large coal mines are designed to cast the blasted material much greater distances than practices in a quarrying or hard rock operation. This movement should be in the direction of the free face, and therefore the orientation of the blasting is important. Material or elements travelling outside of this expected range may be considered to be fly rock.

Fly rock from blasting can result from three mechanisms due to the lack of confinement of the energy in the explosive column. Fly rock can occur if there is insufficient burden for the hole diameter or a zone of weak rock occurs in the face, the main mechanisms are:

a. Face burst – burden conditions usually control fly rock distances in front of the face,
b. Cratering: If the stemming height to hole diameter ratio is too small or the collar rock is weak, and
c. Rifling: if the stemming material is ejected with insufficient stemming height or inappropriate stemming material is used.

It is possible to blast without any fly rock, with proper confinement of the explosive charges within blast holes, using proper stemming procedures and materials. Stemming is further required to ensure that explosive energy is efficiently used to its maximum. Free blasting with no control over stemming cannot be allowed, as this will result in poor blast results and possible damage to any nearby structures.

Strict control of blast loading practices should include the following:

1. minimum confinement of explosives with respect to both stemming heights (minimum height of 30 times the blast hole diameter) and front row burdens, are to be maintained at all times;
2. downloading of front row blast holes if minimum burden requirements are not met;
3. free faces should be checked to ensure there are no areas which are under burdened;
4. accurate loading of charge weights ensuring holes are not overloaded;
5. depth to the top of the explosive column to be checked, with explosive product to be removed from overloaded holes prior to adding stemming material; and
6. appropriate stemming material (10% of blast hole diameter aggregate size) to be used.

The processes which control air overpressure levels and fly rock are the same. Therefore, the restrictions imposed to blasting activities based on regulatory compliance requirements will, in turn, act as a safety control, restricting the extent of rock displacement.

There are more intensive predictions for fly-rock but generally the best way to control fly-rock is to charge in such a way that the possibility of fly-rock is minimized to the absolute minimum, according to the following: Stemming length must be a minimum of 30 hole diameters and stemming material size must be in the order of 10% of the hole diameter.

9. Noxious Fumes

Explosives currently used are required to be oxygen balanced. Oxygen balance refers to the stoichiometry of the chemical reaction and the nature of gases produced from the detonation of the explosives. The creation of poisonous fumes such as nitrous oxides and carbon monoxide are particularly undesirable. The carbon monoxide and oxides of nitrogen are emitted at different levels depending on the characteristics of the explosion. Factors contributing to undesirable fumes are typically: poor quality control on explosive manufacture, damage to explosive, lack of confinement, insufficient charge diameter, excessive sleep time, soil moisture, level of additives/enhancers, and specific types of ground.

10. Discussion of Possible Effects due to Blasting Operations

Possible effects of blasting operations are presented here. Firstly, consideration is given to modelling the expected blast levels based actual blast information and typical designs, and secondly the review of actual results recorded from blasts monitored. Section 5 provides detail on the typical information, as provided by Rössing mine, and which is applied in the modelling of the ground vibration and air blast analysis.

Modelling is based on a blast which has a set quantity of blast holes, specific charging configuration (typically as that given in section 5), and specific surface and down the hole timing arrangement. The size of the blast in volume or in quantity of blast holes does not primarily define the outcome of the modelling. It is the charge mass per delay in a specific layout and configuration that defines the yielded ground vibration or air blast levels. The quantity of blasts will not have an influence on the ground vibration or air blast levels expected or generated. Each blast occurring is an entity on its own when separated from the next blast by at least five times the time length of the blast. The quantity of blasts might have an influence on people’s perception and if levels are high enough it could have an influence on structures. But then one blast with significant damaging levels will also have an influence on structures. The quantity of blasts is significant when neighbours are in close proximity and ground vibrations or air blast is causing disturbances. In such cases larger but less blasting may relieve the situation.

10.1 Modelling of the various expected levels of blasting operations

10.1.1 Ground vibration and Human Perception

Review of the area surrounding the Rössing Uranium Mine showed various structures and farms that were identified and taken into consideration. Expected ground vibration levels were calculated for each of these structure locations surrounding the mining area. Evaluation is given for each structure with regard to human perception and structural concern. Evaluation is done in the form of the criteria of what humans experience and whereby structures could be damaged. This is according to accepted criteria for the prevention of damage to structures and when levels are low enough to not have significant influence. Tables are provided for each of the different charge models which provides information with regards to **No., Structure, Direction from Pit Position, Shortest Distance (m), Max Charge, Predicted PPV (mm/s), Possible Concern.** The No." is only number order. "Structure" is a description of the structure. "Direction from the Pit position" is an indication of the direction of the structure as a help for orientation. The "Shortest Distance" is the distance between the structure and edge of the pit area. The "Max Charge" is the charge size in kg used for the specific modelling or calculations. The "Predicted PPV (mm/s)" is the calculated ground vibration for the structure and the "Possible Concern" indicates if there is any concern for structural damage or human perception. Indicators used are "perceptible", "unpleasant", "intolerable" which stem from human perception information given. Indicators such as "high" or "low" are given where there is a possibility of damage to a structure or if no significant influence is expected and concern is low. Levels below 0.91mm/s could be considered to be low or a negligible possibility of influence. Table 9 below summarises the limits applied in the evaluation of the data for human response and structural response.

Table 9: Classification of ground vibration levels

Human Response and Structural Acceptance Classification	Ground Vibration Level (mm/s)
Too high	Greater than Limit for Structure (> 25 for houses)
Intolerable	> 20.3
Unpleasant	> 5.6
Perceptible	> 0.91
Low	<0.91

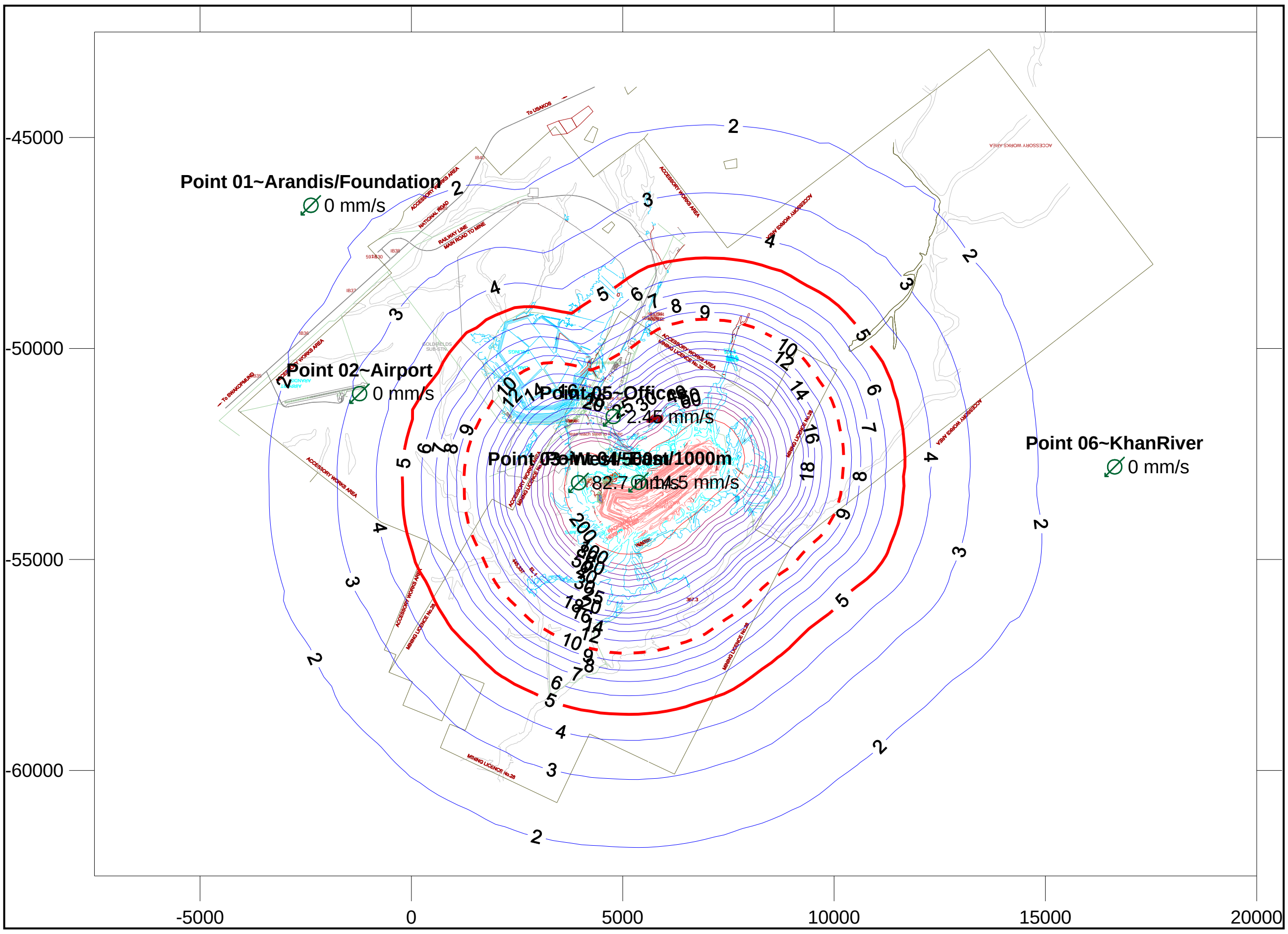
Ground vibration was calculated from the boundary of the mining area for the proposed expansion. This means that vibration is taken from the edge – the most outer point of the pit area on plan, as if it is the closest place where drilling and blasting will be done to the various structures.

Firstly, a worst case scenario was calculated and simulated. In this case 25 times the expected charge mass for a 311mm diameter blast hole was used at 17 m blast hole depths. Ground vibration is calculated and modelled for maximum charge mass at specific distances from the opencast mining area. These levels are then plotted and overlaid with current mining plans to observe possible influences at structures identified. Structures for consideration are also plotted in this model. Ground vibration predictions considered distances ranging from 400 to 9520m around the opencast mining area. The expected level for each of the identified structures and possible influences or concerns are also considered and presented in Table 10 below. The outcome of the simulation is presented in Figure 12 below. Provided with the simulation are indicators of the 5mm/s and 10mm/s levels for reference. These are indicated as a red and red-dotted line for 5 mm/s and 10mm/s respectively. This enables immediate review of possible concerns that may be applicable to any of the privately owned structures or installations. Consideration can then be given to influences on sensitive installations within the mine boundary.

Table 10: Expected ground vibration levels for the various structures.

No.	Structure	Direction from Pit Position	Shortest Distance (m)	Max Charge	Predicted PPV (mm/s)	Possible Concern
1	Arandis Town	NW	9100	25068	1.4	Perceptible
2	Arandis Airport	W	5600	25068	3.2	Perceptible
3	Farms	SE	12000	25068	0.9	Low
4	Mining Institute	NW	7600	25068	1.9	Perceptible

Figure 12: Ground vibration influence from maximum charge.



Note: Red dotted line is the 10mm/s level and Solid Red line is the 5mm/s level.

Review of the modelling shows the expected levels from the maximum charge mass per delay of 25 blast holes will yield levels less than the prescribed limits at the Arandis Airport, the Arandis Town, point 6 (as indicated in figure 12) and thus at farms further away than point 6. Specific levels expected at the Arandis airport are 3.2 mm/s and at Arandis town 1.4 mm/s. The position of point 6 showed an expected level of 0.9 mm/s. These levels are well below any damage inducing possibility but on a par with levels where people will experience ground vibration as perceptible. This will have the implication that blasting at the maximum charge considered here could lead to

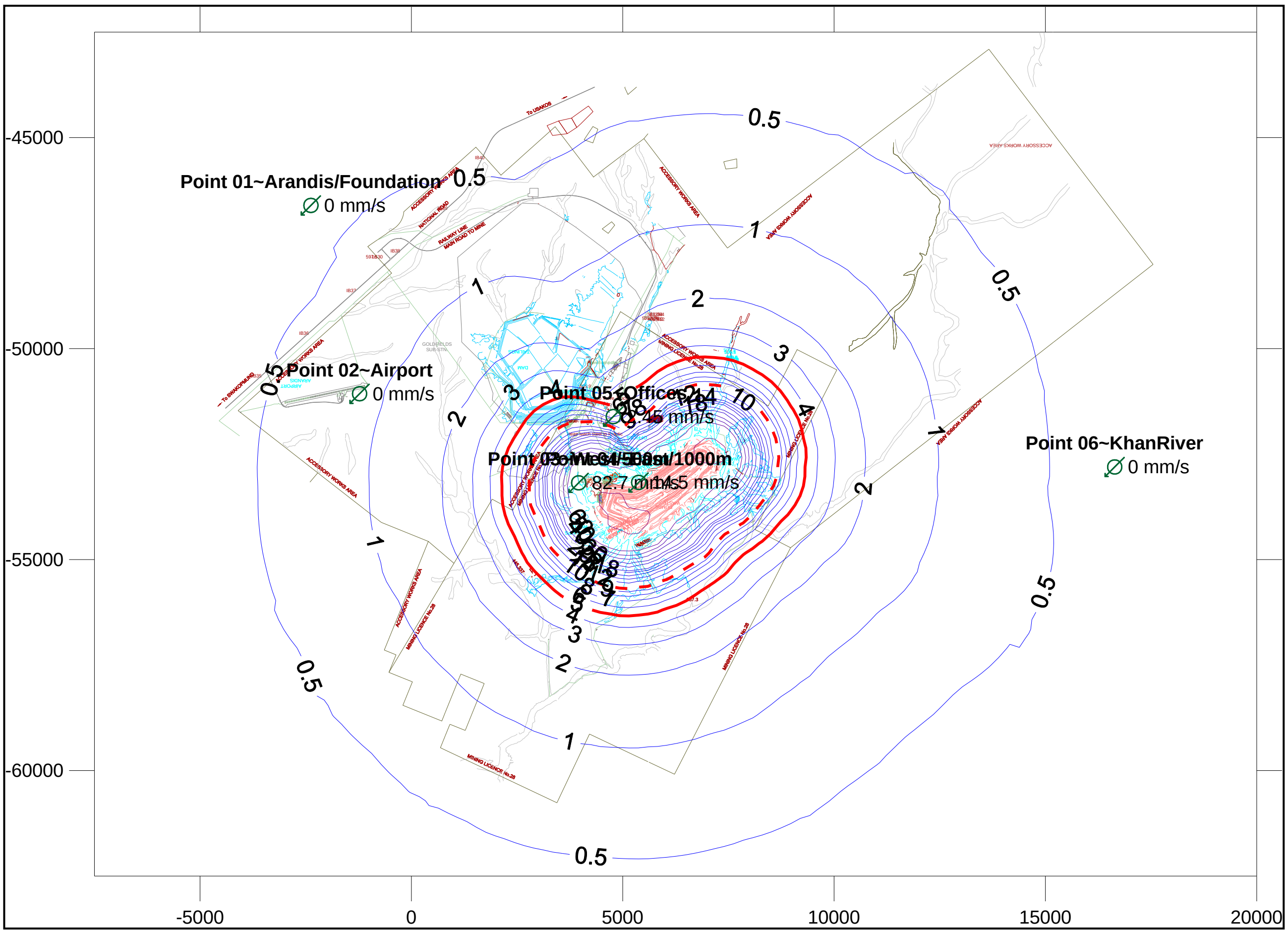
complaints from people, especially when sensitive to the ground vibration due to blasting operations and related issues.
Reconsidering of the outcome of the modelling for a maximum charge mass, two smaller charge masses were also modelled. Firstly, a maximum of 5 blast holes are detonating and secondly, a single blast hole charge is detonating. This resulted in charge masses of 5014kg and 1003kg respectively.

Modelling of the 5014 kg charge is presented here. The expected levels were significantly less and showed a great reduction at the various points considered. Specific levels calculated are presented in Table 11 below for each of the points. Figure 13, below, shows the outcome of the modelling for the same area with the same points of interest indicated.

Table 11: Expected ground vibration levels for the various structures at 5014kg charge mass.

No.	Structure	Direction from Pit Position	Shortest Distance (m)	Max Charge	Predicted PPV (mm/s)	Possible Concern
1	Arandis Town	NW	9100	5014	0.4	Low
2	Arandis Airport	W	5600	5014	0.8	Low
3	Farms	SE	12000	5014	0.2	Low
4	Mining Institute	NW	7600	5014	0.5	Low

Figure 13: Modelling of the 5014kg charge mass.



Note: Red dotted line is the 10mm/s level and Solid Red line is the 5mm/s level.

Modelling of the lower charge mass per delay clearly indicates a significant reduction of ground vibration levels. Simulations and specific levels are less than 1mm/s at all the positions considered. Concern for actual damage to structures is low. This clearly indicates that a reduction of blast holes timed together and the resulting reduction of charge mass will have a significant reduction in the expected levels of ground vibration.

Modelling of the 1003 kg charge is presented here. The expected levels are even less with a great possibility that blasting will not even be felt or realised. Specific levels calculated are presented in Table 12 below for each of the points.

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Figure 14 below shows the outcome of the modelling for the same area with the same points of interest indicated.

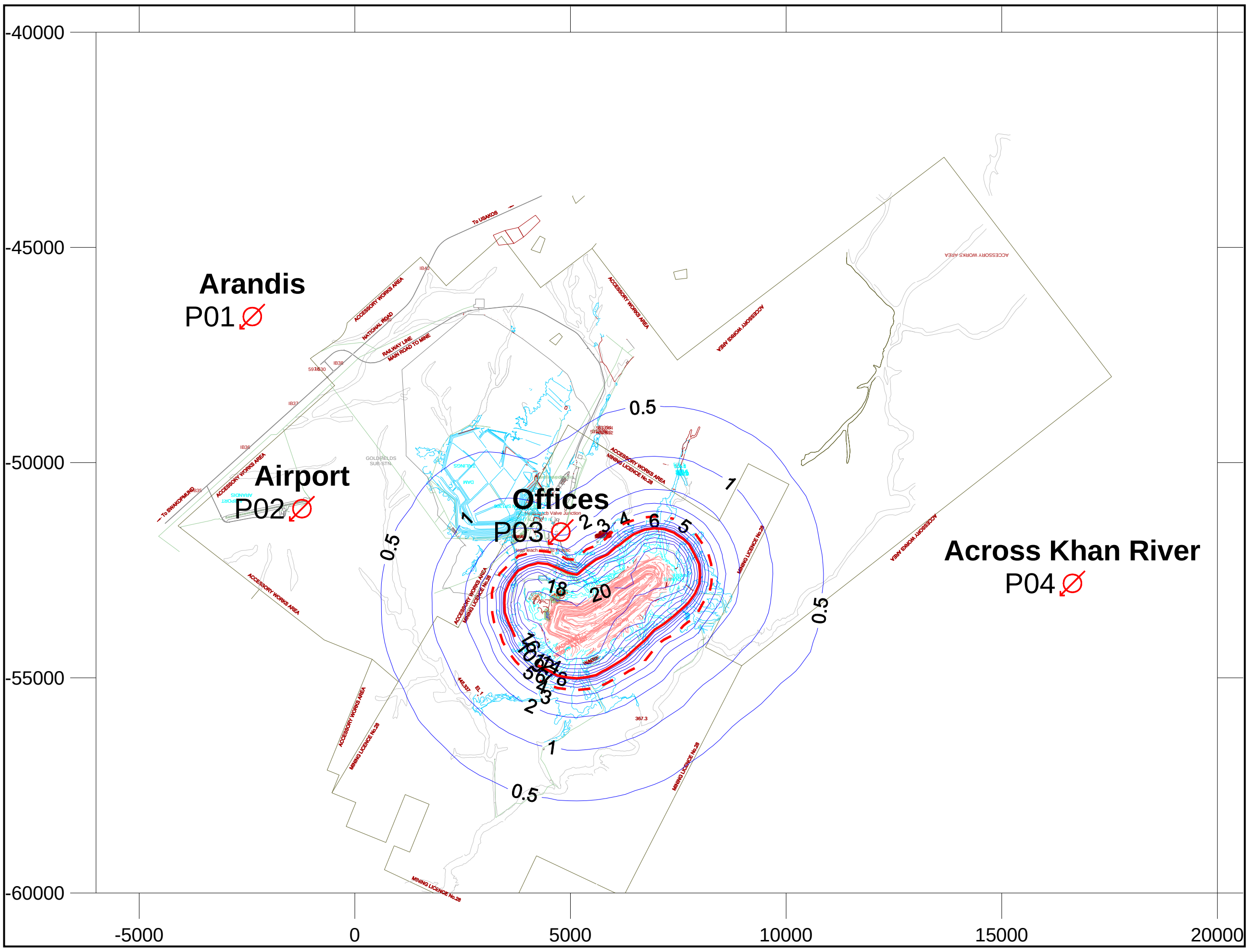
Table 12: Expected ground vibration levels for the various structures at 1003kg charge mass.

No.	Structure	Direction from Pit Position	Shortest Distance (m)	Max Charge	Predicted PPV (mm/s)	Possible Concern
1	Arandis Town	NW	9100	1003	0.1	Low
2	Arandis Airport	W	5600	1003	0.2	Low
3	Farms	SE	12000	1003	0.1	Low

4	Mining Institute	NW	7600	1003	0.1	Low

(Intentionally Left Open)

Figure 14: Modelling of the 1003kg charge mass.



Note: Red dotted line is the 10mm/s level and Solid Red line is the 5mm/s level.

Modelling of the lowest charge mass per delay clearly indicates a significant reduction of ground vibration levels. Simulations and specific levels are far less than 1mm/s at all the positions considered. Levels are very low and will even be difficult to measure at the respective positions.

10.1.2 Air blast

The effect of air blast, if not controlled properly, is in my opinion a factor that could be problematic. Maybe not in the sense of damage being induced but rather having an impact – even at low levels of roofs and windows that could result in complaints from people. In more than one case this effect is misunderstood where people consider this effect as being ground vibration and thus damaging to their house structures. Review of expected data for the three charges evaluated is given in Table 13 below. Section 5 gives detail on the selection of the charges sizes applied.

As with ground vibration, evaluation is given for each structure with regard to the calculated levels of air blast and concerns, if applicable. Evaluation is done in the form of criteria of what humans experience and where-by structures could be damaged. This is according to accepted criteria for the prevention of damage to structures and when levels are low enough to not have a significant influence. Tables are provided for each of different charge models, which provide information with regard to **No., Structure, Direction from Pit Position, Shortest Distance (m), Max Charge, Air blast (dB), and Possible Concern.** The No." is only number order. "Structure" is description of the structure. "Direction from the Pit position" is indication of the direction of the structure as a help for orientation. The "Shortest Distance" is the distance between the structure and edge of the pit area. The "Max Charge" is the charge size in kg used for the specific modelling or calculations. The "Air

Blast (dB)" is the calculated air blast level at the structure and the "possible concern" indicates if there is any concern for structure damage or not or human perception. Indicators used are "Problematic" where there is real concern for possible damage, "Complaint" where people will be complaining due to the experienced effect on structures – not necessarily damaging, "Acceptable" is if levels are less than 120 dB and low where there is very limited possibility that the levels will give rise to any influence on people or structures. Levels below 115dB could be considered as to be low or negligible possibility of influence.

Table 13 below summarises the limits applied in the evaluation of the data for human response and structural response with regard to air blast.

Table 13: Classification of air blast levels

Human Response and Structural Acceptance Classification	Air Blast Levels (dB)
Problematic	>134
Complaint	<130 – approx. 120
Acceptable	<120
Low / Negligible	<115

Table 14 shows that the applied limits may be exceeded at distances 2500m to 3500m for the maximum charge applied. This distance is reduced to 1500m and 2000m for the second charge and further reduced to 800m and 1500m for the smallest charge. Table 15 below shows the specific expected levels for the points considered.

The levels observed for the maximum charge and the specific positions of the concerned installations were modelled and presented in
Figure 15 below. Levels predicted indicate that the levels will be below any level of possible structural damage and are within the specified limits at the points of interest.

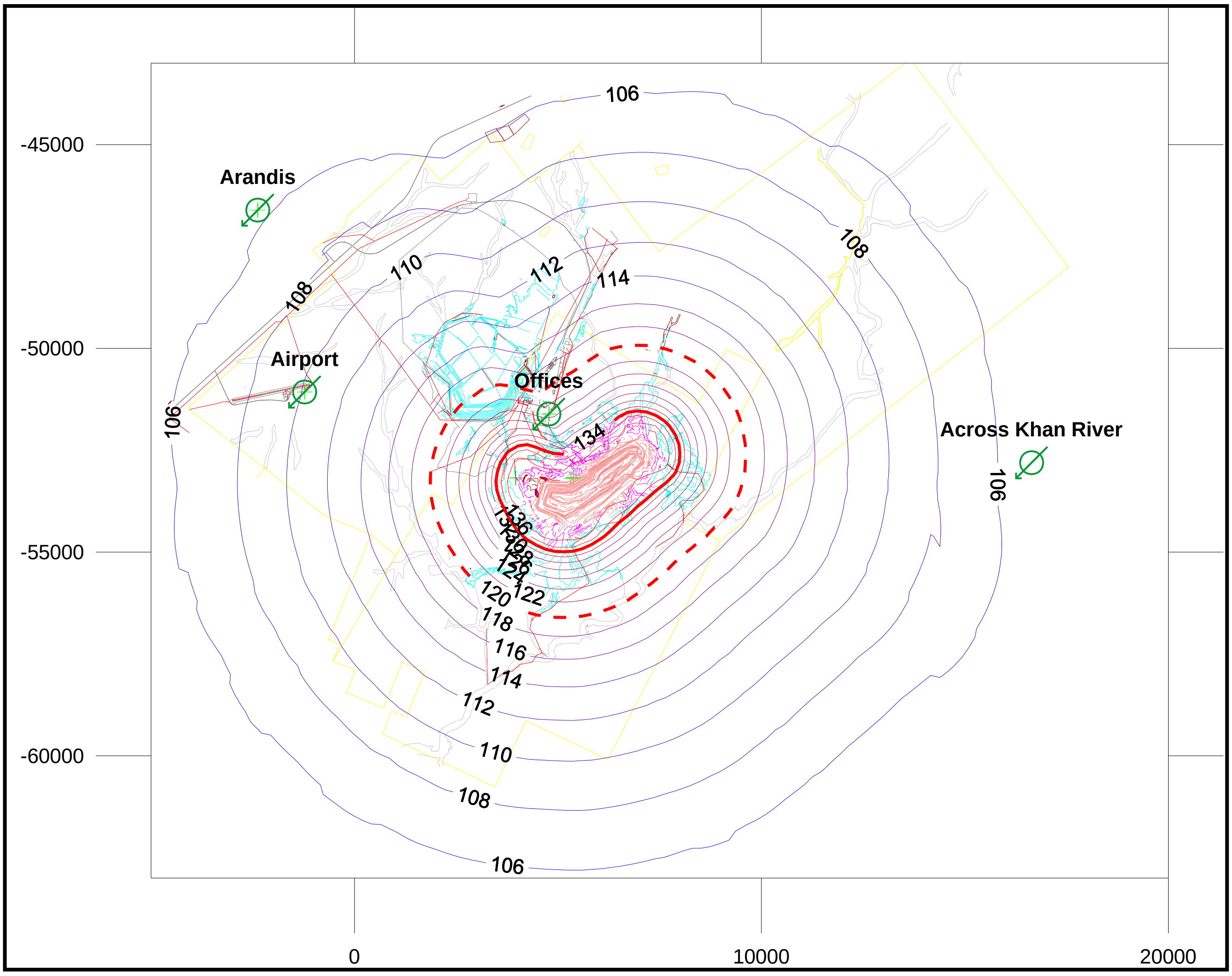
Table 14: Expected air blast levels.

Distance (m)	Air blast (dB) - 1 x 311mmBH 17m Charge (kg)	Air blast (dB) 5 x 311mmBH 17m Charge (kg)	Air blast (dB) 25 x 311mmBH 17m Charge (kg)
200.0	134	139	145
400.0	127	132	138
600.0	122	128	134
800.0	119	125	131
1000.0	117	123	128
1500.0	113	118	124
2000.0	110	115	121
2500.0	107	113	119
3000.0	106	111	117
3500.0	104	110	115
4000.0	103	108	114
4500.0	101	107	113
5000.0	100	106	111
6000.0	98	104	110
7000.0	97	102	108
8000.0	95	101	107
9000.0	94	100	105
10000.0	93	99	104
11000.0	92	98	103
12000.0	91	97	102

Table 15: Expected levels of air blast at the identified structures.

No.	Structure	Direction from Pit Position	Shortest Distance (m)	Max Charge	Air blast (dB)	Possible Concern
1	Arandis Town	NW	9100	25068	105.2	Low
2	Arandis Airport	W	5600	25068	110.2	Low
3	Farms	SE	12000	25068	102.3	Low
4	Mining Institute	NW	7600	25068	107.1	Low

Figure 15: Simulation of air blast levels for the areas of concern using 25068kg charge.



Note: Red dotted line is the 120dbL level and Solid Red line is the 134dBL level.

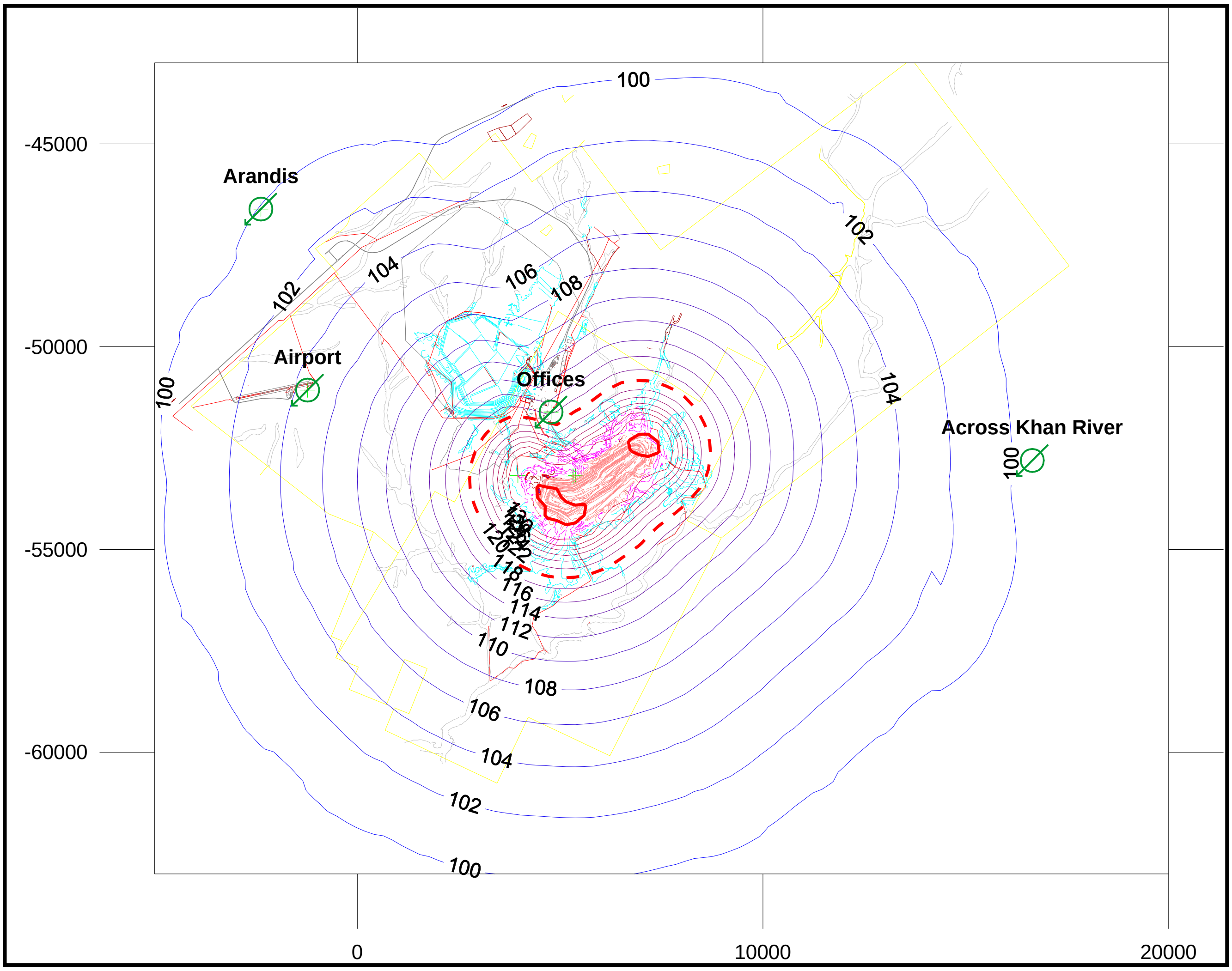
Air blast normally generates rattling of roofs and windows which could be easily misjudged by house owners as ground vibration. These levels do not need to be excessively high in order to upset the owners. Levels of air blast required to induce damage are in the order of 145 dB and greater. In some areas the levels could be perceptible but possible damage to the nearest structures is low and is not expected to be problematic. However, considering human perception the air blast was remodelled using a charge mass of 5014kg per delay and is presented here.

Table 16 shows the expected levels for the identified structures with this reduced charge. Review of the results shows a decrease from 110.2 dB to 105dB at the Arandis Airport and a decrease from 105.2 to 100dB at Arandis Town. Figure 16 shows the simulation for the 5014kg charge as used in calculations. This is a significant reduction and may result in less influence on human perceptions.

Table 16: Expected air blast levels from the smallest charge designed.

No.	Structure	Direction from Pit Position	Shortest Distance (m)	Max Charge	Air blast (dB)	Possible Concern
1	Arandis Town	NW	9100	5014	100	Low
2	Arandis Airport	W	5600	5014	105	Low
3	Farms	SE	12000	5014	97	Low
4	Mining Institute	NW	7600	5014	101	Low

Figure 16: Simulation of air blast levels for the areas of concern using 5014 kg charge.



Note: Red dotted line is the 120dbL level and Solid Red line is the 134dBL level.

10.1.3 Fly-Rock

Blasting operations in general will yield fly rock if blasts are not properly prepared. This will include consideration of stemming lengths, stemming material, first row burdens, timing etc. A review of the area around the Rössing Mine revealed no direct concern for public installations. All privately owned installations are relatively far and not considered to the threatened by fly rock.

The critical surface structures are, however, that of the mine and obviously consideration should be given to the mine structures, equipment and personnel. Rössing Uranium Mine has a standard procedure that is followed with regards to personnel and location of equipment. This will however not exclude that fact that stemming should be controlled with correct stemming length and material. The final blast result will also be influenced by poor stemming control, which could be costly if material is not blasted to expected muck pile and fragmentation. Fly rock on own equipment could also be costly and damages will certainly have a negative effect on efficiencies.

Following is a series of pictures extracted from the video films that were taken. Discussion of each picture is provided. These pictures do show some fly rock that occurred on a blast on 21st October 2008.

	Circles show pieces of rock elements that are propelled from the blast.

	Circles show pieces of rock elements that are propelled from the blast. Some of which are the same as the previous photo and some others.

	Circles show pieces of rock elements that were propelled from the blast and on the downward trajectory.

	Circles show the same pieces of rock elements from the previous photo that has landed in the vicinity of the drill rigs.

Generally there do not seem to be major fly rock concerns, as observed from the blast monitored. There were limited elements from the blast, but all were located relatively close to the blast.

10.1.4 Noxious Fumes

Dust and Noxious fumes should be controlled as best as possible. Fumes are generated by all explosives. Emulsion explosives that have been standing for a while and where water or certain geology factors are present, could generate fumes when blasting is done. Consideration should also be given to the prevailing wind direction when blasting is done.

Typical controls that can be used are:
10.1.4.1 Proper stemming and stemming material.
10.1.4.2 Blasts can be delayed when prevailing wind is blowing towards the area of concern.
10.1.4.3 Do not leave blasts standing for long periods of time.

The following pictures were taken from video material of the blast on 21st October 2008. The series shows the start of the blast and as it progressed over some time. There are indications that NOx's are present. The air quality study will address the levels and quantities of this. The blast done does not, however, show major reddish/orange clouds that could indicate a severe case of NOx's, which will require immediate action to determine the causes.

(Intentionally Left Open)

	Blast operation well into detonation.

	Blue circle shows slight orange colouring that could possibly indicate some NOx fumes.

(Intentionally Left Open)

	Blue circle shows slight orange colouring that could possibly indicate some NOx fumes.

10.2 Review of actual results recorded from blast monitored

The objective of this section is to provide the results recorded to date from a blast on 21st October 2008, and the continuous monitoring conducted at Mr. Meyer's farm.

10.2.1 Blast & Monitor Information

During the specific blast monitoring six Instantel seismographs were used to monitor the blasting operations. Ground vibration is measured on a tri-axial arrangement of velocity transducers and air blast by means of an air blast microphone. Standard analysis software is used for analysis with the inclusion of USBM analysis of vibration levels and vibration frequency. The continuous monitoring uses the same type of equipment and is a semi permanent setup. The monitor is operational each day during day time and in sleep mode at night. Results recorded are stored onboard and downloaded in the office for analysis.

The blast was drilled, charged, timed, tied up and blasted by Rössing Uranium Mine.

10.2.2 Ground Vibration and Air Blast Instrumentation Set-up

Setup information and locations for each monitor position are given in Table 17 below. The Monitor Locations are the positions where monitoring was done with reference to the blast area. "Trig. PV (mm/s)" indicates the ground vibration trigger level for the instrument. It is the threshold where data recording will begin. This level is normally, by choice of experience, set to 1.2 mm/s. Levels below 1.0 are so small that they can almost not be analysed and have little significance in the blasting industry. Lower levels could have the system falsely triggered by people, animals, vehicles etc. As a start of defining what the current levels are, monitoring is done at 1.2mm/s. "Trig. Air Blast (dB)" is the threshold level for air blast / overpressure when monitoring blasting operations. Again this is an acceptable level and a lower threshold could see false triggers occurring that would fill system memory with false data. "Rec. Time (Sec.)" is the length of the record that is recorded once the system is triggered. Blasting does not normally occur longer than 5 seconds. "Graph Id." is the identification of the specific event for the specific monitor as it is displayed on the graphs. Table 18 shows blast dates for the period of continuous monitoring.

Table 17: Seismograph set-up information

Seismograph Position Indicators	Monitor Location	Trig. PV (mm/s)	Trig. Air Blast (dB)	Rec. Time (sec.)	Graph Id.
Point 1	Arandis Town	1.20	120	5	081021P01
Point 2	Airport	1.20	120	5	081021P02
Point 3	West/500m	1.20	120	5	081021P03
Point 4	East/1000m	1.20	120	5	081021P04
Point 5	Offices	1.20	120	5	081021P05
Point 6	Khan River	1.20	120	5	081021P06
Continuous Monitoring					
Point 1	Mr Meyer Farm	1.20	120	5	N/A

Table 18: Blast dates for November 2008 and December 2008

Date	Time
21-Nov-08	15h10
28-Nov-08	14h30
03-Dec-08	14h13
05-Dec-08	16h14
09-Dec-08	14h13
11-Dec-08	17h07
22-Dec-08	15h13

10.2.3 Results recorded

Presented here are all results recorded for the blast monitored, as well all the events registered on the monitor at Mr. Meyer's farm. The ground vibration and air blast results recorded for the blast are summarized in Table 19 below and all events registered at Mr. Meyer are presented in Table 19 below. Further to this the following graphs and figures are also included for more detail.

Figure 17: Graph for ground vibration and air blast recorded for blast on 21 October 2008.

(Intentionally Left Open)

Figure 18: Graph for ground vibration and air blast recorded at Mr. Meyer.
Figure 19: Monitor positions used for the blast (Google Earth)

Table 19: Results obtained for blast on 21 October 2008.

Date	Time	Seis. Location	L-PPV	T-PPV	V-PPV	L-Freq	T-Freq	V-Freq	R - PPV	dB

2008/10/21	15:28:25	Point 01	Unit did not Trigger “No Trigger”							
2008/10/21	15:28:25	Point 02	Unit did not Trigger “No Trigger”							
2008/10/21	15:28:25	Point 03	40.0	73.2	57.3	36.60	56.90	28.40	82.7	141
2008/10/21	15:28:24	Point 04	13.5	7.87	11.8	22.30	18.30	20.50	14.5	133
2008/10/21	15:28:26	Point 05	2.16	2.03	2.03	19.00	22.30	14.60	2.45	123
2008/10/21	15:28:25	Point 06	Unit did not Trigger “No Trigger”							

Figure 17: Graph for ground vibration and air blast recorded for blast on 21 October 2008.

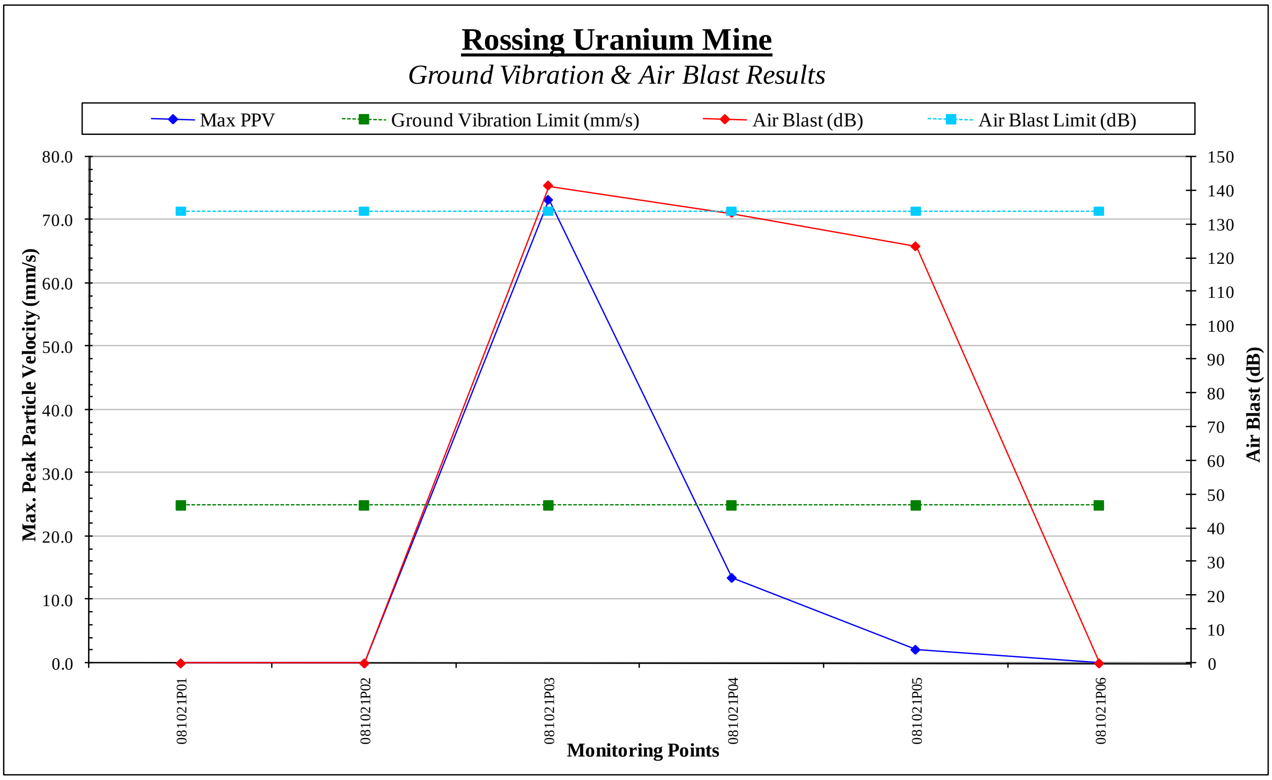


Table 20: Results obtained from Mr. Meyer’s Farm

Date	Time	Seis. Location	L-PPV	T-PPV	V-PPV	L-Freq	T-Freq	V-Freq	R - PPV	dB
2008/11/20	12:55:40	Point 01~ Mr Meyer 's Farm	3.44	4.60	0.87	>100	>100	>100	5.80	108
2008/11/20	12:56:01	Point 01~ Mr Meyer 's Farm	7.52	8.79	2.91	39.40	>100	>100	11.7	104
2008/11/20	12:56:24	Point 01~ Mr Meyer 's Farm	11.5	6.14	3.67	9.48	85.30	85.30	13.1	112
2008/11/20	12:57:17	Point 01~ Mr Meyer 's Farm	2.05	2.02	3.65	>100	>100	>100	4.08	119
2008/11/22	17:05:28	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.07	125
2008/11/26	13:57:02	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	>100	>100	>100	0.07	121
2008/11/26	13:58:27	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.05	85.30	>100	>100	0.09	121
2008/11/26	13:59:04	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.07	121
2008/11/26	14:00:50	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.09	121
2008/12/02	14:07:47	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	>100	>100	>100	0.07	120
2008/12/02	14:27:33	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.06	73.10	>100	>100	0.07	121
2008/12/02	14:27:52	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.06	>100	>100	>100	0.09	123
2008/12/02	14:28:18	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.08	>100	>100	>100	0.10	128
2008/12/02	14:28:45	Point 01~ Mr Meyer 's Farm	0.13	0.08	0.08	>100	>100	>100	0.13	133
2008/12/02	14:29:05	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.08	>100	>100	>100	0.10	124
2008/12/02	14:29:24	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.06	>100	>100	>100	0.09	121
2008/12/02	14:29:45	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.06	>100	>100	>100	0.09	123
2008/12/02	14:30:03	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.06	>100	>100	>100	0.09	120
2008/12/02	14:30:27	Point 01~ Mr Meyer 's Farm	0.06	0.08	0.06	>100	>100	>100	0.09	121
2008/12/02	14:31:17	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.06	85.30	>100	>100	0.08	122

2008/12/02	14:31:58	Point 01~ Mr Meyer 's Farm	0.08	0.11	0.06	>100	>100	>100	0.14	123
2008/12/02	14:35:15	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.06	>100	>100	>100	0.08	121
2008/12/02	14:35:40	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.06	>100	>100	>100	0.07	122
2008/12/02	14:36:30	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.06	>100	>100	>100	0.08	120
2008/12/02	14:37:26	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.06	>100	>100	>100	0.07	123
2008/12/02	14:38:30	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.07	121
2008/12/02	14:40:44	Point 01~ Mr Meyer 's Farm	0.06	0.08	0.06	>100	>100	56.90	0.08	122
2008/12/02	14:41:48	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.06	85.30	>100	>100	0.07	121
2008/12/02	14:42:44	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.06	>100	>100	>100	0.09	121
2008/12/02	14:46:05	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	>100	>100	>100	0.07	120
2008/12/08	18:26:27	Point 01~ Mr Meyer 's Farm	0.08	0.05	0.06	56.90	>100	>100	0.09	121
2008/12/12	16:02:51	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	85.30	>100	>100	0.07	123
2008/12/12	16:07:13	Point 01~ Mr Meyer 's Farm	0.08	0.08	0.06	>100	>100	>100	0.09	120
2008/12/16	15:45:16	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	51.20	>100	>100	0.07	123
2008/12/16	15:47:22	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.07	122
2008/12/16	15:50:22	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	>100	>100	>100	0.07	124
2008/11/20	12:55:40	Point 01~ Mr Meyer 's Farm	3.44	4.60	0.87	>100	>100	>100	5.80	108
2008/11/20	12:56:01	Point 01~ Mr Meyer 's Farm	7.52	8.79	2.91	39.40	>100	>100	11.7	104
2008/11/20	12:56:24	Point 01~ Mr Meyer 's Farm	11.5	6.14	3.67	9.48	85.30	85.30	13.1	112
2008/11/20	12:57:17	Point 01~ Mr Meyer 's Farm	2.05	2.02	3.65	>100	>100	>100	4.08	119
2008/11/22	17:05:28	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.07	125
2008/11/26	13:57:02	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	>100	>100	>100	0.07	121
2008/11/26	13:58:27	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.05	85.30	>100	>100	0.09	121
2008/11/26	13:59:04	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.07	121
2008/11/26	14:00:50	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.09	121
2008/12/02	14:07:47	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	>100	>100	>100	0.07	120
2008/12/02	14:27:33	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.06	73.10	>100	>100	0.07	121
2008/12/02	14:27:52	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.06	>100	>100	>100	0.09	123
2008/12/02	14:28:18	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.08	>100	>100	>100	0.10	128
2008/12/02	14:28:45	Point 01~ Mr Meyer 's Farm	0.13	0.08	0.08	>100	>100	>100	0.13	133
2008/12/02	14:29:05	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.08	>100	>100	>100	0.10	124
2008/12/02	14:29:24	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.06	>100	>100	>100	0.09	121
2008/12/02	14:29:45	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.06	>100	>100	>100	0.09	123
2008/12/02	14:30:03	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.06	>100	>100	>100	0.09	120
2008/12/02	14:30:27	Point 01~ Mr Meyer 's Farm	0.06	0.08	0.06	>100	>100	>100	0.09	121
2008/12/02	14:31:17	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.06	85.30	>100	>100	0.08	122
2008/12/02	14:31:58	Point 01~ Mr Meyer 's Farm	0.08	0.11	0.06	>100	>100	>100	0.14	123
2008/12/02	14:35:15	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.06	>100	>100	>100	0.08	121
2008/12/02	14:35:40	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.06	>100	>100	>100	0.07	122
2008/12/02	14:36:30	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.06	>100	>100	>100	0.08	120
2008/12/02	14:37:26	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.06	>100	>100	>100	0.07	123
2008/12/02	14:38:30	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.07	121
2008/12/02	14:40:44	Point 01~ Mr Meyer 's Farm	0.06	0.08	0.06	>100	>100	56.90	0.08	122
2008/12/02	14:41:48	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.06	85.30	>100	>100	0.07	121
2008/12/02	14:42:44	Point 01~ Mr Meyer 's Farm	0.08	0.06	0.06	>100	>100	>100	0.09	121
2008/12/02	14:46:05	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	>100	>100	>100	0.07	120
2008/12/08	18:26:27	Point 01~ Mr Meyer 's Farm	0.08	0.05	0.06	56.90	>100	>100	0.09	121
2008/12/12	16:02:51	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	85.30	>100	>100	0.07	123
2008/12/12	16:07:13	Point 01~ Mr Meyer 's Farm	0.08	0.08	0.06	>100	>100	>100	0.09	120
2008/12/16	15:45:16	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	51.20	>100	>100	0.07	123
2008/12/16	15:47:22	Point 01~ Mr Meyer 's Farm	0.06	0.06	0.05	>100	>100	>100	0.07	122
2008/12/16	15:50:22	Point 01~ Mr Meyer 's Farm	0.06	0.05	0.05	>100	>100	>100	0.07	124

Explanation of column headings:

Date: Date event recorded
Time: Time event recorded
Seis. Location: Seismograph position where placed
L, T & V-PPV: Longitudinal, Transverse & Vertical peak particle velocities (mm/s)
L, T & V-Freq: Longitudinal, Transverse & Vertical dominate frequencies (Hz)
R-PPV: Resultant Peak Particle velocity (mm/s)
dB: Peak Air blast Recorded (dB)
*** Too low to analyse

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Figure 18: Graph for ground vibration and air blast recorded at Mr. Meyer.

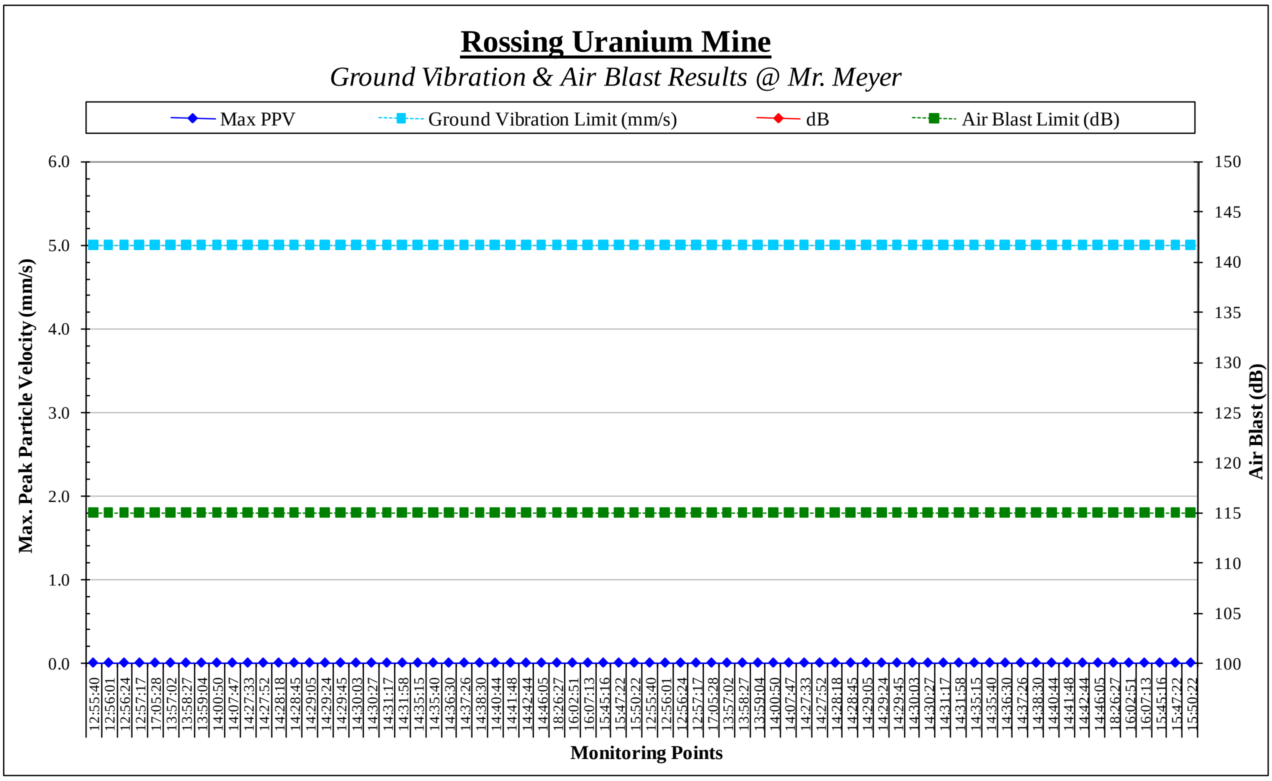
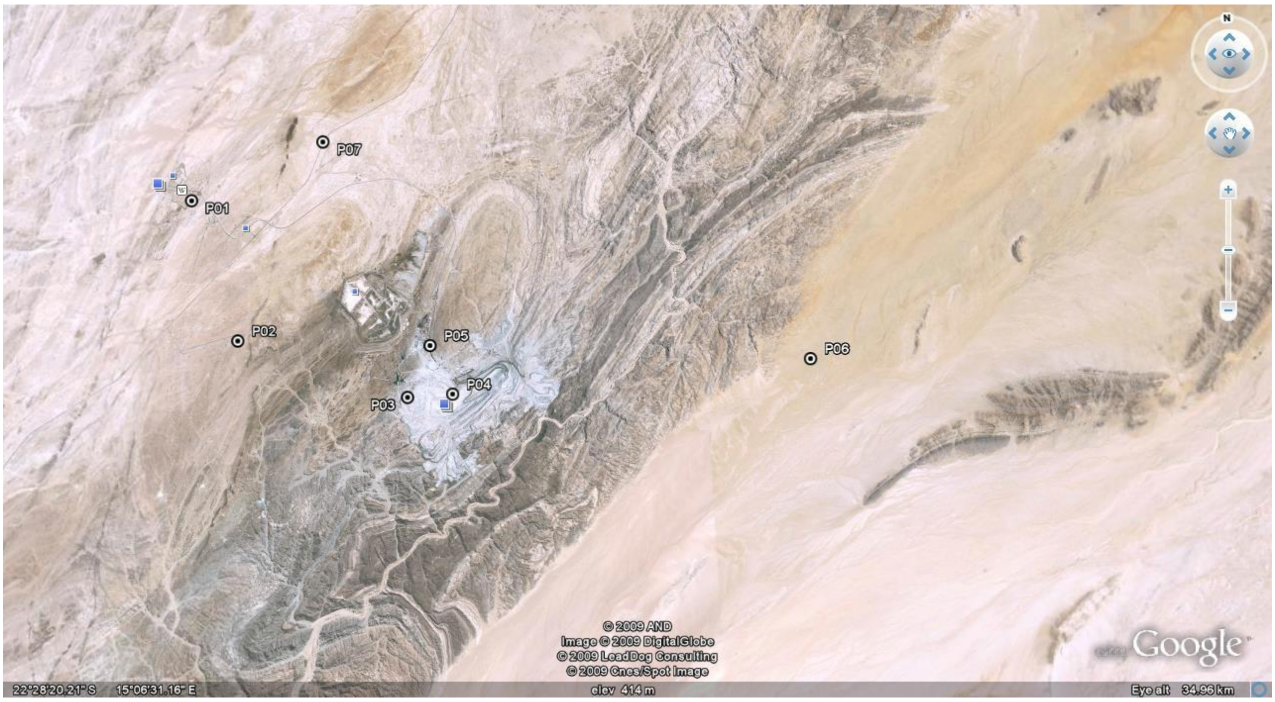


Figure 19: Monitor positions used for the blast (Google Earth)



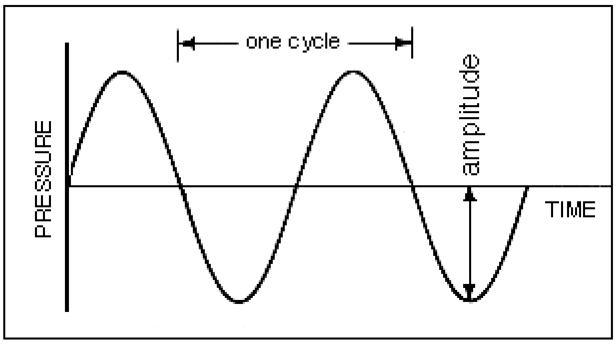
10.2.4 Ground Vibration and air blast characteristics and results discussion.

10.2.4.1 Ground Vibration and air blast characteristics.

Ground vibration and air blast traces recorded from typical blast operations have specific signatures.

Ground vibration is typically sinusoidal, meaning a format of movement in simple harmonic motion. Figure 20 below shows this typical format.

Figure 20: Sine wave format



The results from ground vibration will also show levels on all three tri-axial axes used for monitoring ground vibration. The traces will all start relative to the same position on the graph. The length of recording will also be at least the same length as the blast length in detonation time. Air blast occurs after the shockwave from ground vibration. Thus the trace recorded for air blast will not be located at the same time start as for ground vibration. The traces from air blast are some times more difficult to analyse than ground vibration. Some pointers used are: What is the expected air blast level? Is the data concentrated in a span than less than one second and not continuous activity for the full length of the recording time? Air blast follows after the ground vibration and the trace shows levels returning to zero. Continuous activity on the trace indicates a multiple of reasons other than blasting related. The following figures show various qualities from events that were observed. Each is discussed shortly.

(Intentionally Left Open)

Figure 21 below shows a proper ground vibration and air blast recorded trace from the blast recorded at one of the monitoring points. Figure 22 shows a false trigger on the ground vibration. Figure 23 shows false triggers on the ground vibration and air blast sensors.

(Intentionally Left Open)

Figure 24 shows a trace recorded at Mr. Meyer that relates closely to typical air blast results.

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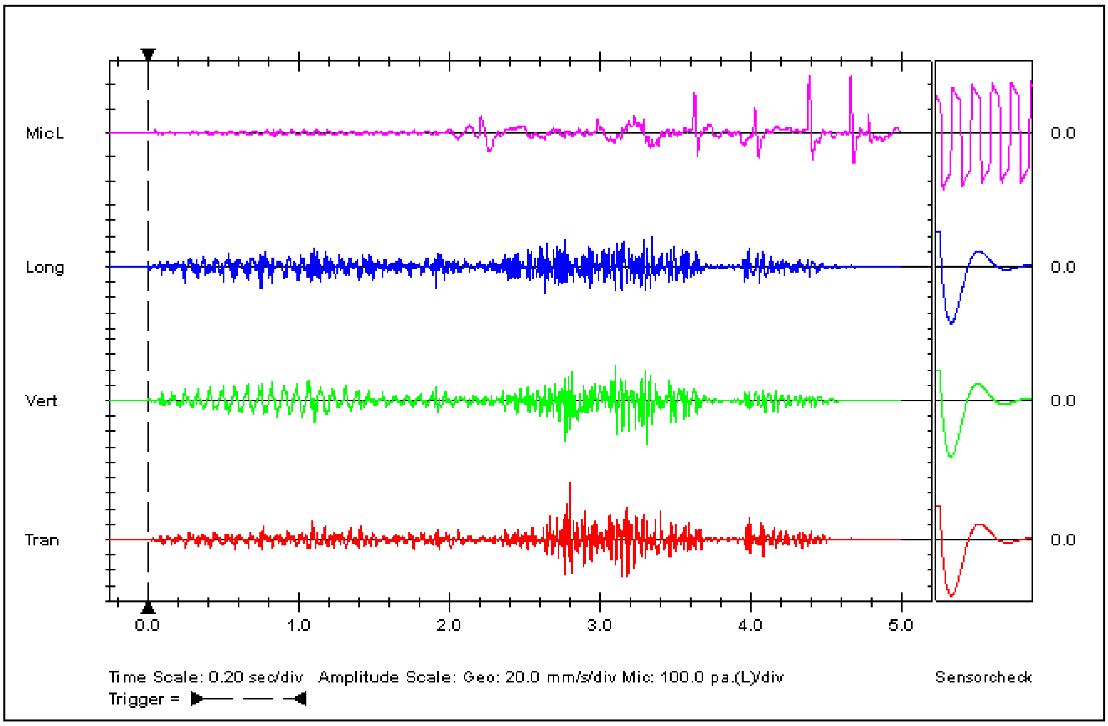
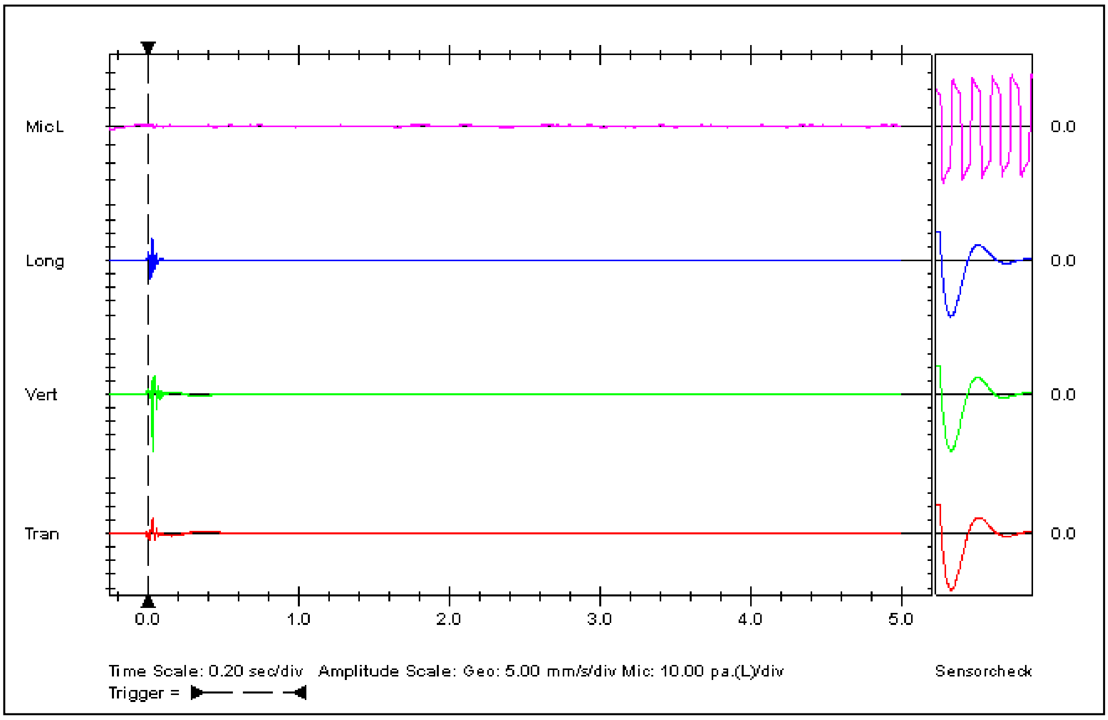
Figure 21: Recorded trace at Rössing Uranium Mine



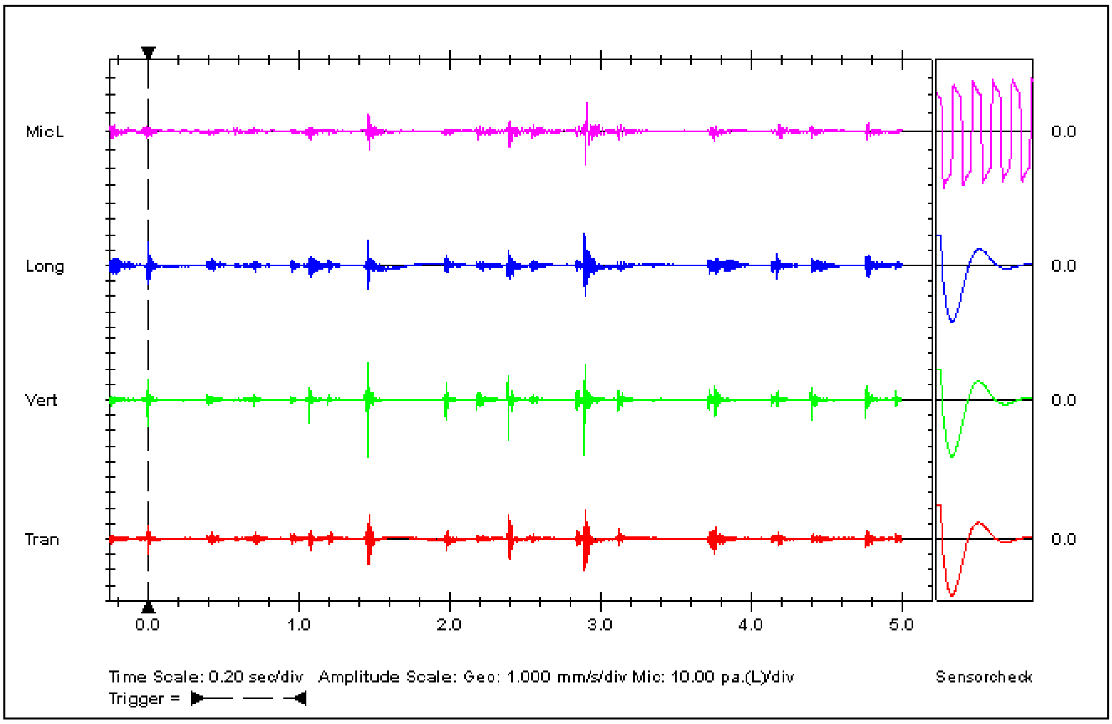
Trace shows proper ground vibration and air blast as recorded from the blast.

Figure 22 shows a false trigger on the ground vibration



Trace shows a false trigger on the ground vibration. It is suspected that something has dropped onto or moved the sensors.

Figure 23 shows false triggers on the ground vibration and air blast sensors



Trace shows false triggers on all the sensors. Note that all activities occur at the same time. This could have been movement or bumping against the box in which the seismograph is housed.

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Figure 24: Trace recorded at Mr. Meyer that relates closely to typical air blast results

Blast Management & Consulting

Date/Time	MicL at 17:05:28 November 22, 2008
Trigger Source	Geo: 1.20 mm/s, Mic: 120 dB(L)
Range	Geo : 31.7 mm/s
Record Time	5.0 sec at 1024 sps
Notes	
Location:	Point 01~ Mr Meyer's Farm
Client:	Rossing Uranium Ltd
Operation:	Rossing Pit
User Name:	Aina Kadhila Amoomo

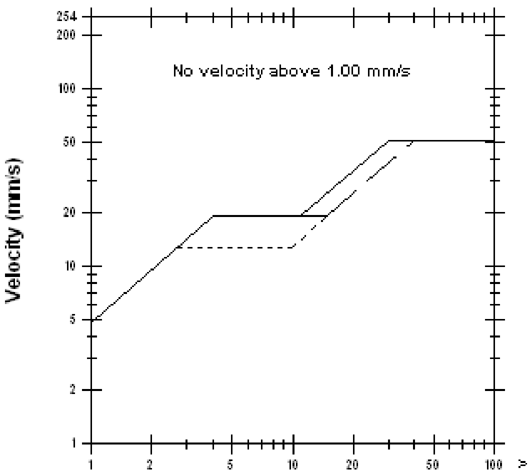
Serial Number	BE12490 V 8.12-8.0 MiniMate Plus
Battery Level	6.7 Volts
Unit Calibration	October 18, 2008 by Blast Man. & Cons
File Name	N490CGWK.T40

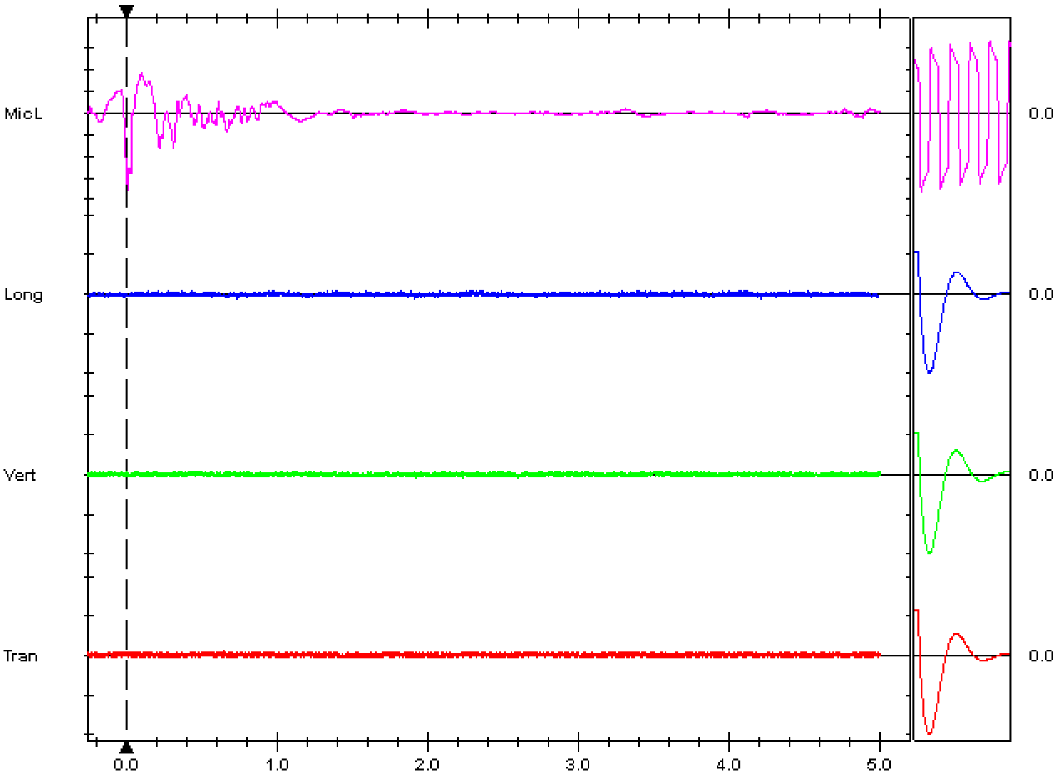
Microphone	Linear Weighting
PSPL	125.0 dB(L) 35.5 pa.(L) at 0.013 sec
ZC Freq	9.0 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 508 mv)

	Tran	Vert	Long	
PPV	0.0635	0.0476	0.0635	mm/s
ZC Freq	>100	>100	>100	Hz
Time (Rel. to Trig)	0.652	0.440	0.741	sec
Peak Acceleration	0.00663	0.00663	0.00663	g
Peak Displacement	0.00007	0.00005	0.00011	mm
Sensorcheck	Passed	Passed	Passed	
Frequency	7.5	7.6	7.3	Hz
Overswing Ratio	3.7	3.4	3.7	

Peak Vector Sum 0.0710 mm/s at 0.741 sec

USBM RI8507 And OSMRE





Time Scale: 0.20 sec/div Amplitude Scale: Geo: 0.500 mm/s/div Mic: 10.00 pa.(L)/div Sensorcheck

Printed: March 8, 2010 (V 10.06 - 10.06) Format Copyrighted 1996-2004 Instantel Inc.

This event was recorded at Mr. Meyer's farm. The event showed clearly no ground vibration but the air blast almost seemed to be that from blasting operations. Analysis of the event showed that the date was on a Saturday 22nd November 2008 at 17:05. No blasting was done on this day. Further there is activity beyond the original activity indicating something other than a blasting air blast pulse creating the trace. Air blast will arrive at the sensor and past the sensor. The shock will not continue to excite the sensor for more than a 1sec. With these conclusions it is sure that this event is non-blasting related.

Considering the above the following summaries and conclusions regarding levels of ground vibration and air blast can be put forward, as discussed in section 10.2.4.2 below.

10.2.4.2 Blast Monitoring on 21 October 2008

General:
The monitors placed at Points 01, 02 & 06 did not register any events for the blast due to the fact that the levels generated by the blast were lower than the set trigger levels of the seismograph of 1.2 mm/s and 120 dB. This resulted in a “No Trigger”.

Ground Vibration Results:
The highest level of ground vibration was recorded at Point 03. Point 03 was closest to the three blasts. The blasts were located at 192m, 557m and 593m from this monitor. The results recorded for these events can be summarized as follows:

Peak particle velocity levels recorded ranged between “No Trigger” and 73.2 mm/s. The resultant peak particle velocity levels ranged between “No Trigger” and 82.7 mm/s. The frequencies recorded for these levels ranged between 18.3 and 56.9 Hz.

The Rio Tinto Standard for safe blasting for buildings and where people are of concern was applied and the data analysed accordingly. The data analysed showed no activity on the analysis graphs for the monitors placed at the private installations. The outcome of analysis indicates blast results at these points were well below the 5mm/s limit. Levels recorded at the office did show activity but also well within the 5mm/s limit.

Air Blast Results:
The air blast levels recorded on the monitors ranged between “No Trigger” and 141 dB. The highest level recorded was at the monitor placed at Point 03. None of the monitors placed at the private installations registered any air blast of significance. Monitors close to the blast did show high levels but there is no concern of damage to private structures.

10.2.4.3 Continuous Blast Monitoring at Mr. Meyer’s Farm

General:
The monitor at Mr. Meyer’s farm registered 72 events for the specific period. The data was analysed and reviewed for conformance to firstly, if data was actual ground vibration or air blast data, and secondly, to the dates of the blasts.

The review showed that none of the events showed typical blast related characteristics, nor did the results viewed correspond to the dates that blasts took place at Rössing Uranium Mine. The data observed showed typical false triggers that could be due to various factors. All triggers that resulted in the events recorded originated from the triggers on the air blast microphone. None occurred on the ground vibration sensors.

No specific data can be identified at this stage that could be problematic with regard to blasting operations done at Rössing Uranium Mine and the specific position at Mr. Meyer’s farm.

11. Comparison of Results and Operations

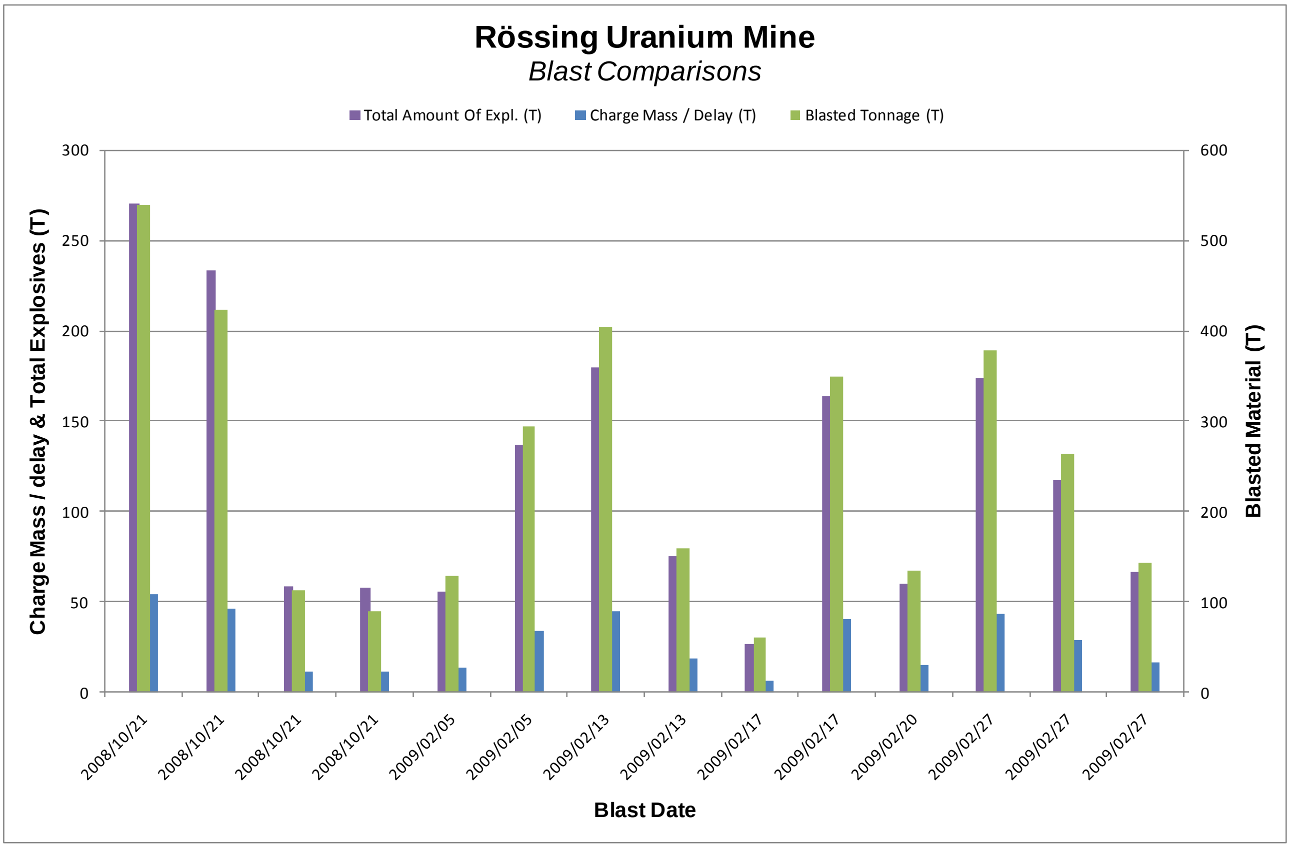
11.1 Results Comparison

Results obtained from actual blasting monitored and results from modelling are compared to ensure that the process applied is portraying a realistic view on the expected levels for ground vibration and air blast.

Comparison is made between the actual ground vibration and air blast results and those predicted. Further, the blast sizes and expected charge per delay between actual blasts monitored and typical blasts taking place at Rössing Uranium Mine are compared. It must be noted that data can be refined more with more actual measurements. The proposed monitoring program and active management of equipment setups will make it possible to record a more defined lower level of data. The blast monitored was recorded with equipment setups which considered levels where false events would not influence data recording capability. Equipment was setup as well to ensure that the levels observed are the actual events resulting from blasting. Meaning that where a 0 "zero" level is indicated, that a "no trigger" was observed and thus no level greater than this trigger level was observed.

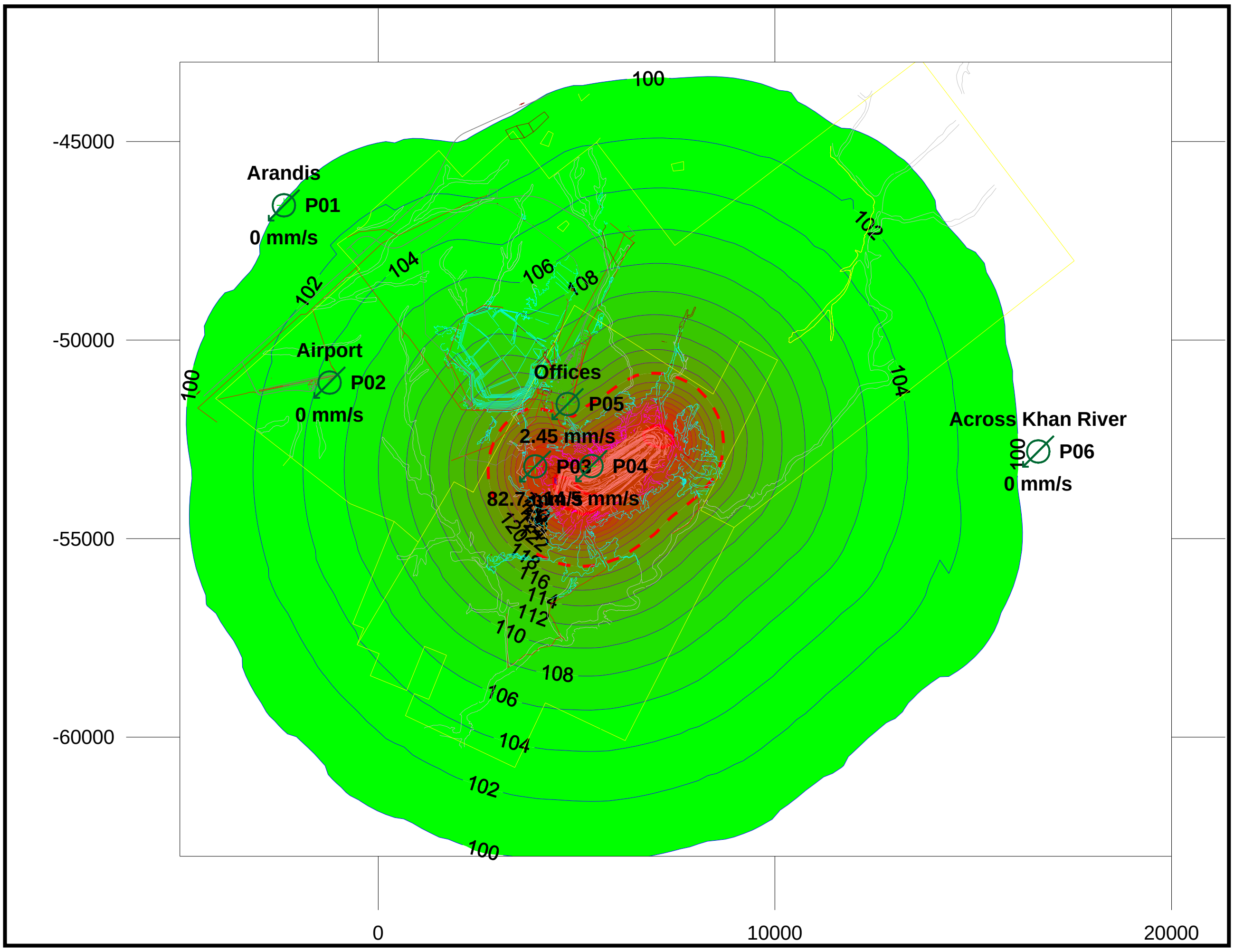
First compared are the actual operations at Rössing Uranium Mine. The blast monitored was similar to any other blast at the mine. The specific blast monitored was on the 21 October 2008. Figure 25 below shows a comparison of the total explosives used, tonnage of material blasted and the expected charge mass per delay for the specific blast. The blast information data was provided by Rössing Uranium Mine. Expected charge mass per delay considered was 5 blast holes per delay.

Figure 25: Comparison of production blasts



The second comparison is between the levels of ground vibration recorded and modelled levels. The levels recorded are produced on the modelling graphs. Levels show a 0mm/s at points outside mine boundaries and the modelling shows levels below the set trigger levels of the systems. The recorded levels could well be between the 1.2 mm/s and 0mm/s. The modelling shows expected levels as less than 0.5 mm/s for points 01 and 06 and less than 1 mm/s for point 02. The recorded levels were less than the set 1.2 mm/s trigger level. Levels this low have little or no influence on structures and thus lower trigger levels were not considered. In my opinion the 1.2 mm/s trigger level used is defendable in court, and working at lower levels for conformance, if damage is induced, will have no significant benefit. Figure 26 below shows the predictive modelling of ground vibration with the positions of actual blasts monitored. Specifically the positions of Points 01, 02 & 06 are indicated on the figure, as well as the set trigger level of 1.2 mm/s.

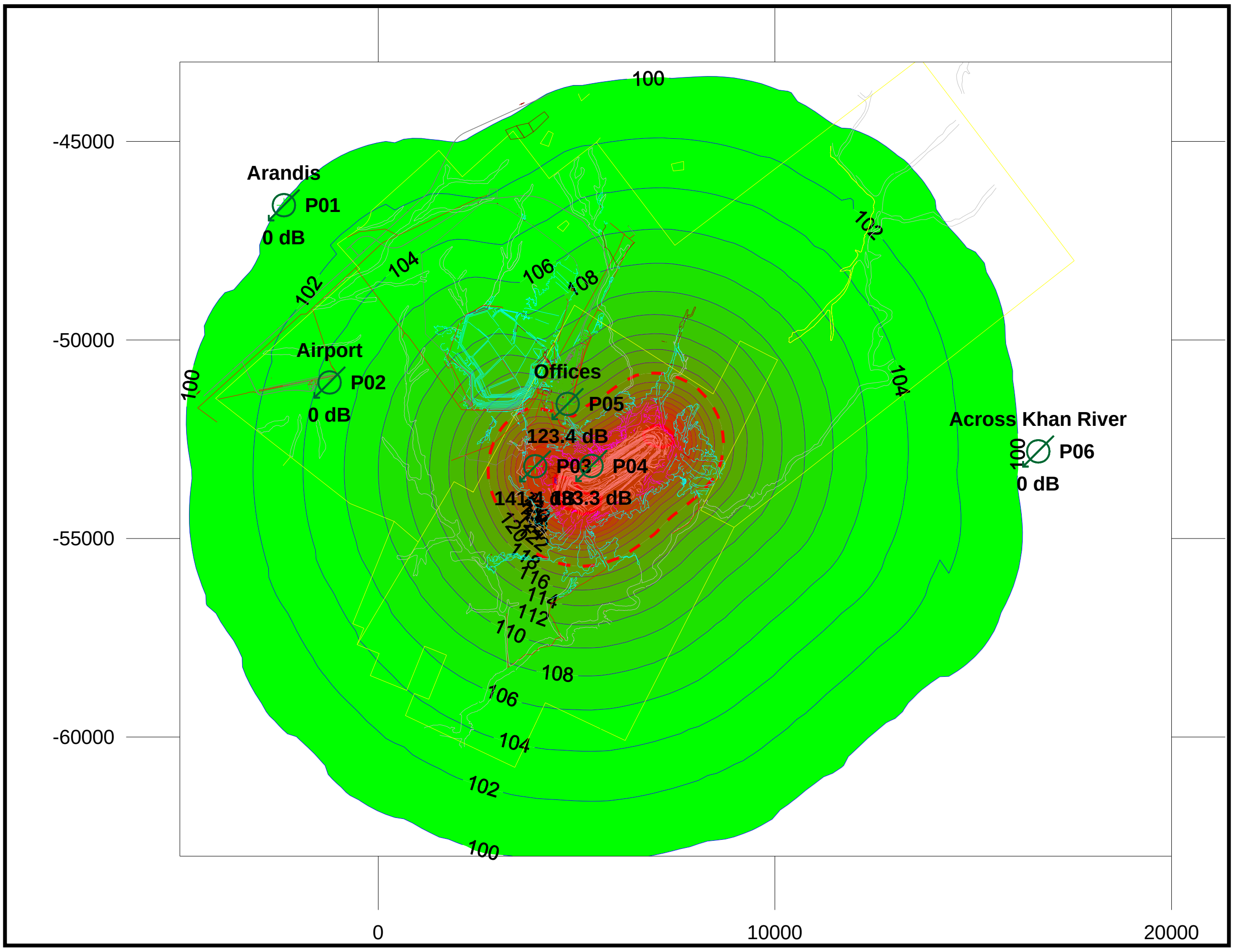
Figure 26: Ground vibration levels – actual and modelled



Note: Red dotted line is the 10mm/s level and Solid Red line is the 5mm/s level.

Similarly in comparing the levels of air blast recorded and modelled levels. The levels recorded are produced on the modelling graphs. Levels show 0dB at points outside the mine boundaries and the modelling shows levels below the set trigger levels of the systems. The recorded levels could well be between 120 dB and 0 dB. The modelling shows expected levels at points 01, 02 & 06 as about 100dB for point 01, less than 106 dB for point 02 and less than 100dB for point 06. The recorded levels were less than the set 120dB trigger level. Levels this low have little influence on structures and thus lower trigger levels were not considered. In my opinion the 120 dB trigger level was used and is defendable in court. Figure 27 below shows the predictive modelling of air blast with the positions of the actual blasts monitored. Specifically, the positions of points 01, 02 & 06 are indicated on the figure as well as the limit levels of 120db and 134 dB.

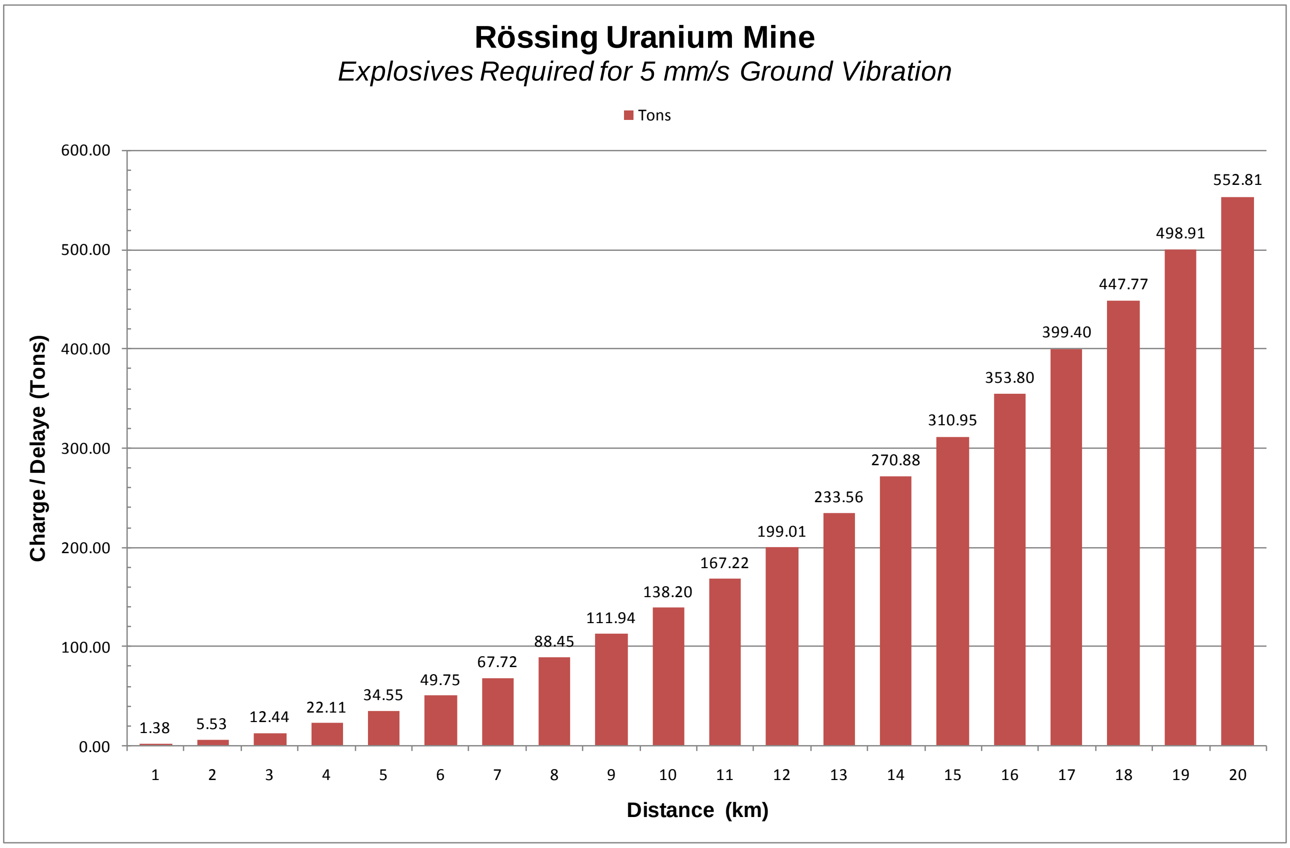
Figure 27: Air blast levels – actual and modelled.



Considering the actual and predicted levels for ground vibration, a further aspect that needs to be addressed is at which stage the minimum limit levels will be reached. The maximum charge mass required producing at least 5mm/s ground vibration was calculated and is shown in the Figure 28 below.

(Intentionally Left Open)

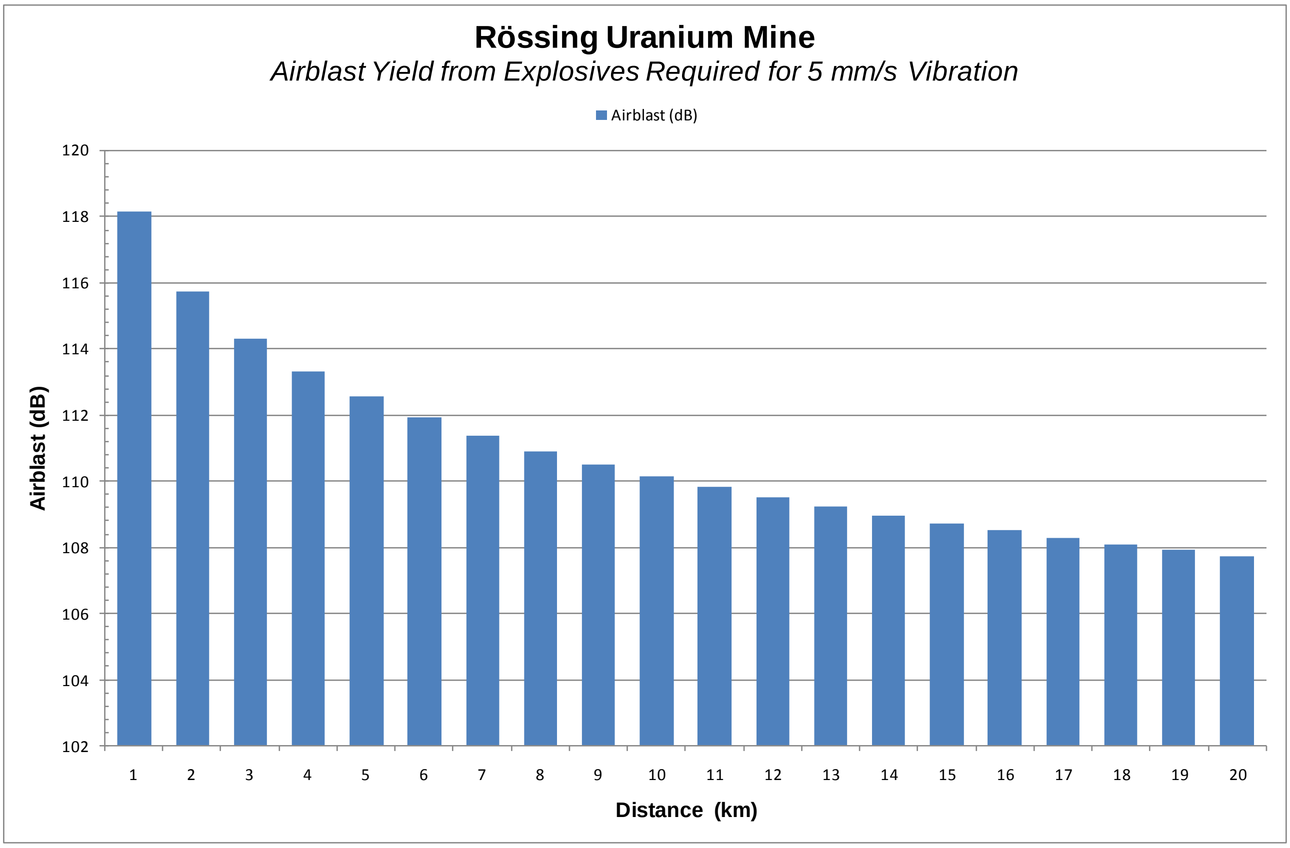
Figure 28: Charge required inducing 5mm/s Ground Vibration



Similarly the same required charge mass used to induce 5mm/s was applied to predicting the expected air blast over distance. Figure 29 shows the effect on air blast over distance. It is clear that at distances greater than 1km from the charge, levels are already below 120dB.

(Intentionally Left Open)

Figure 29: Air blast expected



The above indicates that levels expected and levels measured are comparable. There is some variance between the levels predicted and levels recorded. The levels recorded are less than predicted. This, in essence, is good as the safety margin built into the prediction ensures that levels will be less than expected. In order to define exact variances, more definition will be required in actual measurements to be done. The measurements gathered were put in relation with the prediction models used and Figure 30 shows the relationship for ground vibration. Actual levels are confirmed to be less than predicted. But this can, however, not be applied to the prediction model as only three measurement points are available for use. Similar analysis of the air blast measured and the predicted values show a closer resemblance. See Figure 31 below. Here the actual is slightly greater than the predicted. In both the cases for ground vibration and air blast the actual and predicted values are plotted on a scaled distance graph. In this way the data can be evaluated on the same basis. Scaled distance is a function of the distance and the charge mass. See section 6.1.

(Intentionally left open)

Figure 30: Ground Vibration prediction graph

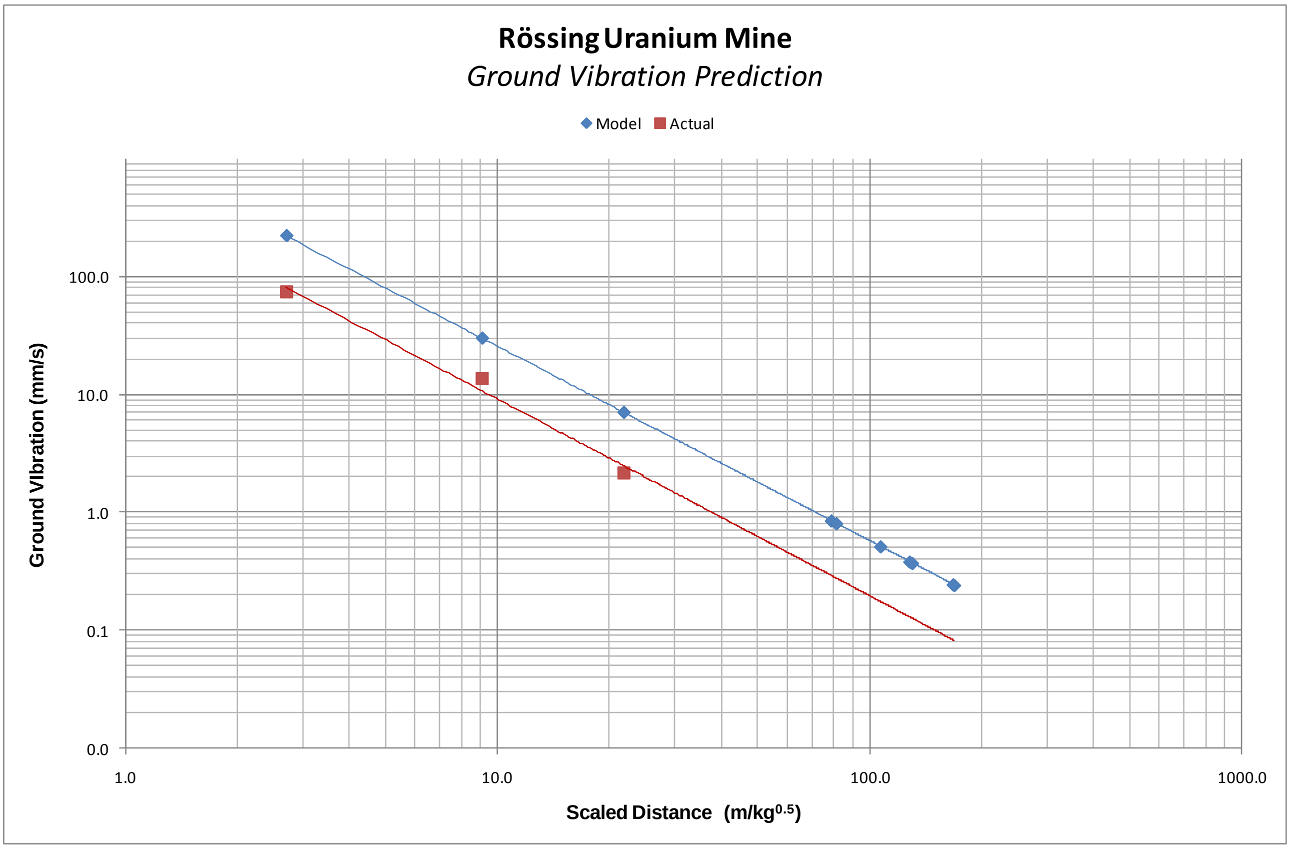
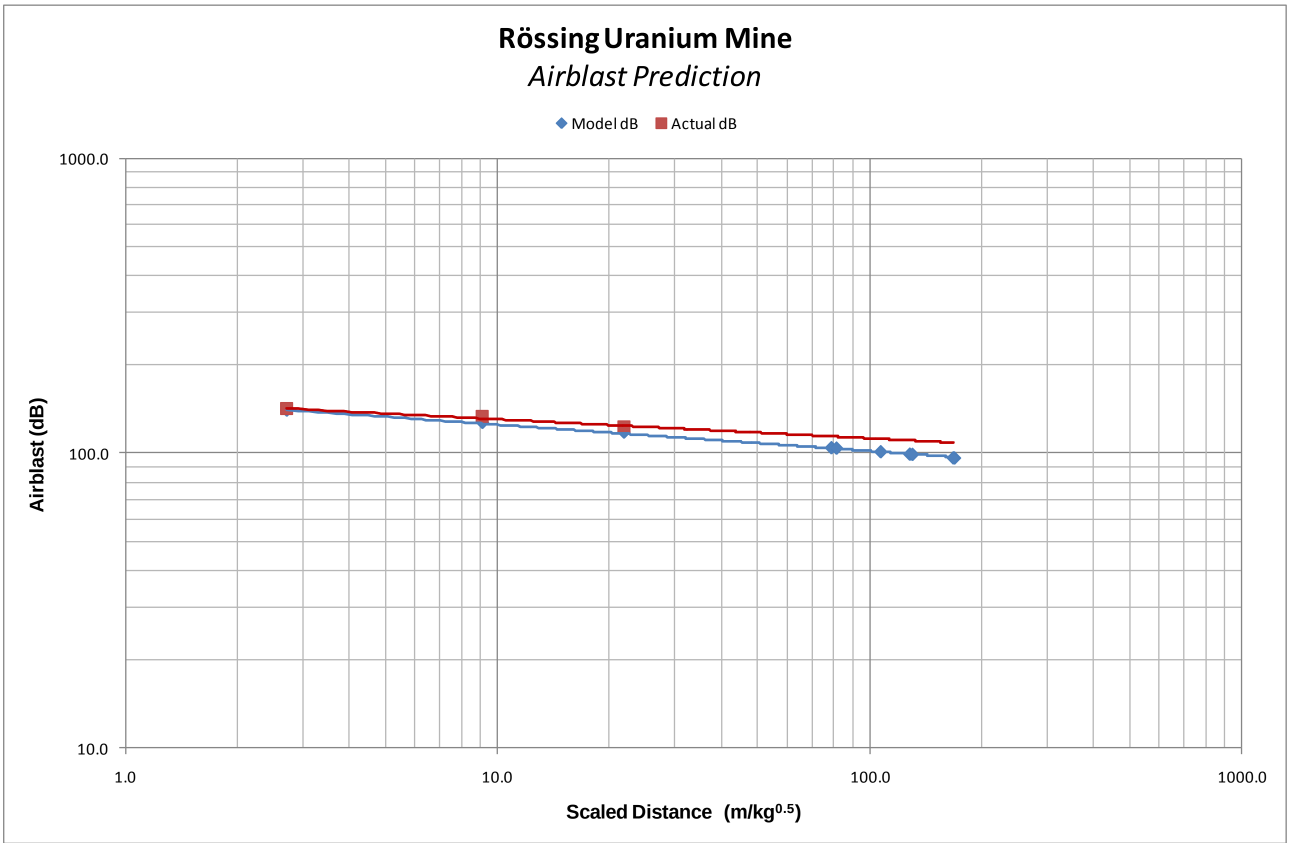


Figure 31: Air blast prediction graph



11.2 Operations Comparison

In reference to the expected mining tonnages for the current operations and the proposed expansion there are similarities on planned and actual values. The average blast tonnage required during the expansion is approximately 33000 T less than the current blast planning. The specific blast information provided showed blasted tonnages ranging between 89880 to 538590 Tons. See Table 21 below. The current pit blast planned tonnages are 263591T and the expansion planned is 233,664 T. See Table 22 below. The proposed expansion will bring about a doubling of the required blasting to be done. This will effectively mean that blasts will be done twice a week instead of the current once a week. There is no expected cumulative impact of ground vibration or air blast in the sense of increased levels due to the blasting twice a week instead of once a week. The impact may be rather one of nuisance, but any blast separated by the next with substantial time will not have an accumulative effect of the levels of ground vibration or air blast. Blasts greater than expected in tonnage that were done at the mine have not shown effects that could be considered problematic with regards to ground vibration or air blast either. For example, the blast that was monitored on 21 October 2008.

Table 21: Summary of blast tonnages done at RUM

Blast Reference	07/268	05/265 & 05/267	04/243	04/246
Blasted Tonnage (T)	538,590	423,070	113,520	89880
Powder Factor (Kg/T)	0.502	0.551	0.516	0.648

Table 22: Planned blast tonnages for RUM current and expansion

Description	**Totals**	**Units**
Current Operations Planning		
Total Mined from T10 (Waste+LG+Crush)	13,706,757	Tonnes
Blast Frequency	52	Times per annum
Average Blast	263,591	Tonnes
Proposed Expansion Planning		
Total Mined from P2 (Waste+LG+Crush)	12,150,548	Tonnes
Blast Frequency	52	Times per annum
Average Blast	233,664	Tonnes

11.3 Multiple Mines Blasting

The effect of multiple mines blasting at a specific date and time needs to be considered. Firstly these mines need to be close enough to each other to produce a significant level of influence. This is however unlikely as the mines are not really bordering each other. Secondly the geology, firing sequence and charge masses will vary. The exact time of blasting will vary. The possibility for an increased impact from typically ground vibration due to any form of super imposing of shock waves is highly improbable. This effect is mainly observed during the detonation within a single blast. The variables of influence from and between the different mines will more likely have a negative effect on the levels of ground vibration and air blast than cumulative effect. Thus again, the main problem for the area is rather the effect of nuisance. There is no increased effect on ground vibration or air blast predicted or expected.

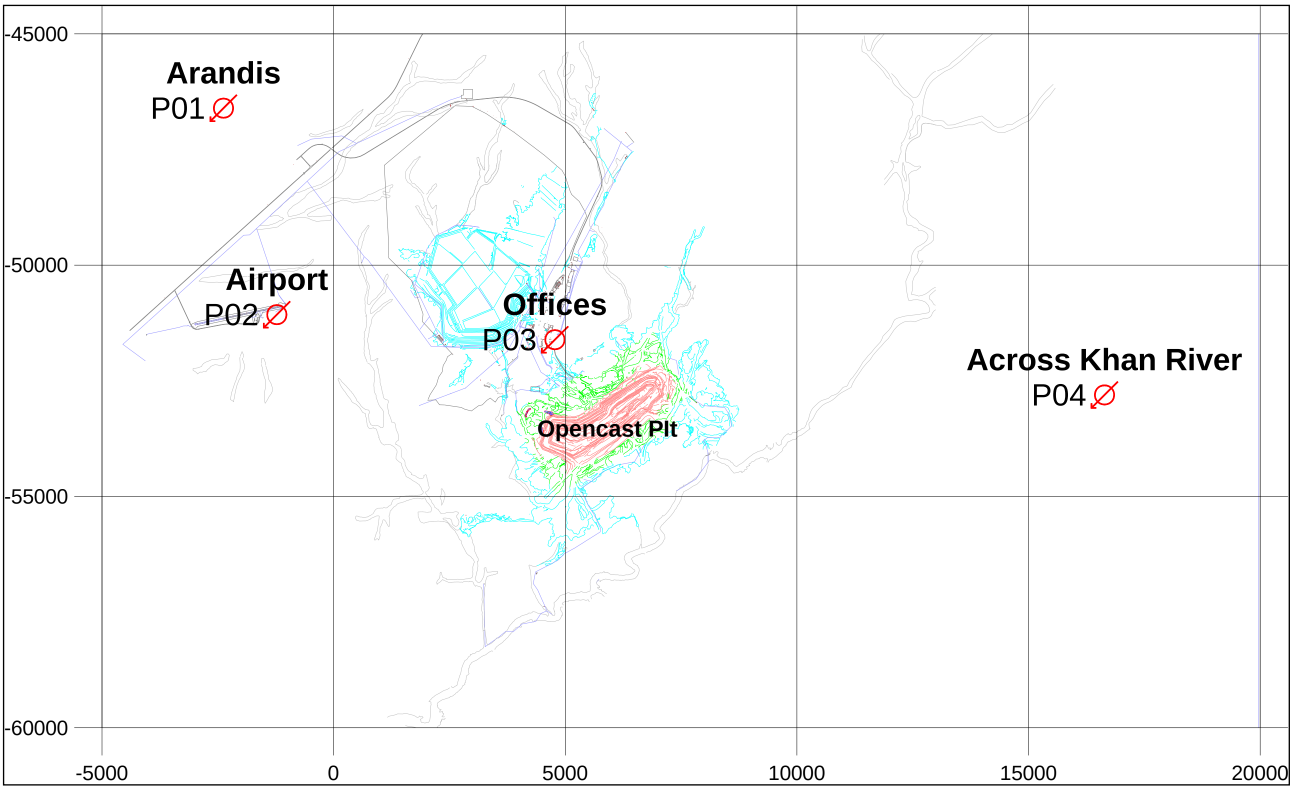
12. Ground Vibration and Air blast Monitoring Program

12.1 Monitoring Program

The monitoring of ground vibration and air blast should be compulsory when blasting operations have a possibility of impacting on the circumstances of a mine's neighbours. This could range from life threatening to possibly being a disturbance. Considering the situation at Rössing Uranium Mine the current trend is definitely not life threatening. The blasts could possibly be heard and seen from the dust clouds, but with no real effect on structures. Even with this low impact, the sensitivity of the situation as reflected through the interested and affected parties' meetings, does make it necessary to mitigate future actions. A monitoring program, will also add to maintaining good relationships with neighbours. For this reason the following monitoring program is proposed. Provided here are monitoring locations, equipment and setups that can be applied.

It is proposed that at least four seismographs be placed at the positions as indicated on the Figure 32 below.

Figure 32: Proposed monitoring Positions



Seismograph Position.

The four monitor positions will cover the private installations, i.e. the Arandis airport, Arandis town and the farmers across the Kahn river. The monitor at the office is a control point and can be used to verify results obtained at any of the other positions. This monitor is likely to be the only one triggering. Blasting in various areas of the pit will yield different results. The office monitor will help build a database for assessing the influence from blasts at different locations.

There are different methodologies that can be applied for monitoring. These are monitoring ad hoc at each of the positions suggested, fixed monitoring stations with downloads from the stations on a regular basis, or fixed stations with modem connectivity capability where automatic back-to-office dial-in (or dial the instrument) is possible. The modem capability will be dependent on cellular communication capability in the area.

In all cases it is recommended that fixed boxes are installed and used for the monitoring position. This will eliminate the variances in fixing the sensors to the ground. In fixed installations this is a requirement for the protection of the seismograph and also for stability in the connection over time.

Requirements in order to facilitate a fixed monitoring station are as follows:

1. Seismograph with modem capability (all seismographs currently available can communicate via modem);
2. A steel box of approximate dimensions 500x500x300mm with lockable lid;
3. Steel box must have a pipe extension of 35mm diameter for microphone placement;
4. Concrete slab with dimensions 550x550x50mm, with an 8mm pin cemented for fixture of the geophone assembly;
5. If modem route is selected the following will also be required: Modem and antennae, battery supply cable, data card from cellular supplier;
6. Batteries for field backup and solar panels (optional);
7. Battery chargers – batteries in the field are swapped out once a month;
8. Seismograph Software for general data download and communications; and
9. Office computer for download and data analysis.

Pictures below show a typical field setup that is currently used by BM&C.

The following equipment is used by BM&C and can be recommended for the monitoring of ground vibration and air blast. Instantel Seismographs, Minimate Blaster or Minimate Plus III. The Minimate plus has an optional function ability as well as an auto call home function. When setup it will dial the office and download data to the office computer. The Minimate Blaster has a similar storage capability but cannot auto call home. A modem can be connected and the unit dialled from the office and data downloaded.

Following are the basic specifications of the units:

(Intentionally left open)

Minimate™ Blaster

General Specifications	Minimate Blaster
Channels	Microphone and Triaxial Geophone
Vibration Monitoring	
Range	Up to 254 mm/s (10 in/s)
Resolution	0.127 mm/s (0.005 in/s) or 0.0159 mm/s (0.000625 in/s) with built-in preamp
Accuracy	+/- 5% or 0.5 mm/s (0.02 in/s), whichever is larger, between 4 and 125 Hz
Transducer Density	2.13 g/cc (133 lbs/ft³)
Frequency Range	2 to 250 Hz, within zero to -3 dB of an ideal flat response
Air Overpressure Monitoring	
Weighting Scale	Linear
Range	88 to 148 dB (500 Pa (0.072 PSI) Peak)
Resolution	0.25 Pa (0.0000363 PSI)
Accuracy	+/- 10% or +/- 1 dB, whichever is larger, between 4 and 125 Hz
Frequency Range	2 to 250 Hz between -3 dB roll off points

Waveform Recording

Record Modes	Manual and Continuous
Seismic Trigger	0.125 mm/s to 254 mm/s (0.005 to 10 in/s)
Acoustic Triggers	100 to 148 dB
Sample Rate	1024 Hz to 4096 Hz per channel (independent of record time)
Record Stop Mode	Fixed record time, **AutoRecord** record stop mode
Record Time	1 to 20 seconds (programmable in one-second steps) plus 0.25 second pre-trigger
AutoRecord™ Time	Quiet window programmable from 1 to 9 seconds, plus a 0.25 second pre-trigger. Event is recorded until activity remains below trigger level for duration of quiet window, or until available memory is filled.
Cycle Time	Recording uninterrupted by event processing - no dead time
Storage Capacity	
Full Waveform Events	300 one-second events at 1024 Hz sample rate
Event Summaries	1750

Physical Specifications

Dimensions	81 x 91 x 160 mm (3.2 x 3.6 x 6.3 in)
Weight (monitor and sensors)	2.6 kg (5.7 lbs)
Battery	Rechargeable 6 V sealed gel cell - capacity for 210 hours of continuous monitoring
User Interface	8-key keypad with domed tactile keys
Display	4-line x 20-character, high contrast, backlit LCD with on-line help
PC Interface	RS-232
Auxillary Inputs and Outputs	External Trigger, Remote Alarm
Environmental	
LCD Operating Temperature	-10 to 50°C (14 to 122°F)
Electronics Operating Temperature	-20 to 60°C (-4 to 140°F)
Remote Communications	Compatible with Telephone, GSM, Cellular, RF, Satellite and Short-haul modems.
Additional Feature	Monitor start/stop timer

Corporate Office:
309 Legget Drive,
Ottawa, Ontario K2K 3A3
Canada

US Office:
808 Commerce Park Drive,
Ogdensburg, New York 13669
USA

Toll Free: (800) 267 9111
Telephone: (613) 592 4642
Facsimile: (613) 592 4296
Email: sales@instantel.com

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On the Practical Edge of Technology

CERTIFIED TO THE ISO 9001 QUALITY STANDARD

Minimate® Plus

General Specifications	Minimate Plus
Channels	Microphone and Triaxial Geophone or 4 independent user-configurable channels (two Microphones and two Triaxial Geophones or 8 independent channels with optional 8-channel upgrade)
Vibration Monitoring (with Standard Triaxial Geophone)	
Range	Up to 254 mm/s (10 in/s)
Resolution	0.127 mm/s (0.005 in/s) or 0.0159 mm/s (0.000625 in/s) with built-in preamp
Accuracy (ISEE / DIN)	+/- 5% or 0.5 mm/s (0.02 in/s), whichever is larger, between 4 and 125 Hz / DIN 45669-1 standard
Transducer Density	2.13 g/cc (133 lbs/ft^3)
Frequency Range (ISEE / DIN)	2 to 250 Hz, within zero to -3 dB of an ideal flat response / 1 to 315 Hz
Maximum Cable Length (ISEE / DIN)	75 m (250 ft) / 1,000 m (3,280 ft)
Air Overpressure Monitoring	
Weighting Scales	Linear or A-weight
Linear Range	88 to 148 dB (500 Pa (0.072 PSI) Peak)
Linear Resolution	0.25 Pa (0.0000363 PSI)
Linear Accuracy	+/- 10% or +/- 1 dB, whichever is larger, between 4 and 125 Hz
Linear Frequency Response	2 to 250 Hz between -3 dB roll off points
A-weight Range	50 to 110 dBA
A-weight Resolution	0.1 dBA
Waveform Recording	
Record Modes	Manual, Single-shot, Continuous
Seismic Trigger	0.125 to 254 mm/s (0.005 to 10 in/s)
Acoustic Triggers	
Linear	100 to 148 dB
A-weight	55 to 110 dBA
Sample Rate	1,024 to 16,000 S/s per channel (independent of record time), up to 65,000 S/s in single-channel mode with advanced software (max 8,000 S/s per channel for 8 channels)
Record Stop Mode	Fixed record time, **Instantel® AutoRecord™** record stop mode
Record Time	1 to 100 seconds (programmable in one-second steps) or 500 seconds plus 0.25 seconds pre-trigger
AutoRecord Time	Auto window programmable from 1 to 9 seconds, plus a 0.25 second pre-trigger. Event is recorded until activity remains below trigger level for duration of auto window, or until available memory is filled.
Cycle Time	Recording uninterrupted by event processing - no dead time
Storage Capacity	
Full Waveform Events	300 one-second events at 1,024 S/s sample rate (1,500 event capacity with optional memory upgrade)
Event Summaries	1,750 (8,750 event capacity with optional memory upgrade)
Histogram Recording	
Record Modes	Histogram and **Instantel Histogram Combo™** (monitor captures triggered waveforms while recording in Histogram mode)
Recording Interval	2, 5 or 15 seconds; 1, 5 or 15 minutes
Storage Capacity	46,656 intervals - 3 days at 5-second intervals or 102 days at 15-minute intervals (with memory upgrade - 15 days at 5-second intervals or 540 days at 15-minute intervals)
Physical Specifications	
Dimensions	81 x 91 x 160 mm (3.2 x 3.6 x 6.3 in)
Weight	1.4 kg (3 lbs)
Battery	Rechargeable 6 V sealed gel cell - capacity for 210 hours of continuous monitoring
User Interface	8-key keypad with domed tactile keys
Display	4-line x 20-character, high-contrast, backlit LCD with on-line help
PC Interface	RS-232
Auxillary Inputs and Outputs	External Trigger, Remote Alarm, coordinate download from GPS
Environmental	
LCD Operating Temperature	-10 to 50^{0}C (14 to 122^{0}F)
Electronics Operating Temperature	-20 to 60^{0}C (-4 to 140^{0}F)
Remote Communications	Compatible with Telephone, GSM, Cellular, RF, Satellite, Short-haul modems and Ethernet® device servers. Automatically transfers events when they occur through the **Instantel Auto Call Home™** feature.
Additional Features	Monitor start/stop timer

Corporate Office:
309 Legget Drive,
Ottawa, Ontario K2K 3A3
Canada

US Office:
808 Commerce Park Drive,
Ogdensburg, New York 13669
USA

Toll Free: (800) 267 9111
Telephone: (613) 592 4642
Facsimile: (613) 592 4296
Email: sales@instantel.com

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Costing expected for the different components as given above are as follows:

Table 23: Commercial layout

Minimate Blaster Complete Standard	US$ 4,995.00
Minimate Plus III	US$ 5,995.00
A steel box of approximate dimensions 500x500x300mm with lockable lid, Steel box must have a pipe extension of 35mm diameter for microphone placement,	± R1500
Concrete slab with dimensions 550x550x50mm, with a 8mm pin cemented for fixture of the geophone assembly,	± R1500
If modem route is selected the following will also be required: Modem and antennae, battery supply cable,	± R2500
Batteries for field backup and solar panels (optional),	± R500 x 2
Battery chargers – batteries in the field are swapped out once a month,	± R400
Seismograph Software for general data download and communications,	± R0
Office computer for download and data analysis.	± R6000

Quotes should rather be obtained for exact costs when required. Prices given are an indication only.

Monitor setup should be finalised at the time of installation, but the following guidelines can be applied at Rössing Uranium Mine:

Table 24: Equipment setup

Seismograph Position Description:	**Trigger level for Ground vibration (mm/s)**	**Trigger Level for Air Blast (dB)**	**Recording Time (sec.)**
Point XX – Position description (Arandis Airport etc.)	1.20	110	5

Further assistance can be provided to finalise a monitoring program and the setting up of equipment.

12.2 Limits for Ground Vibration and air blast

Limits for ground vibration and air blast leaves some area open for discussion. Without the existence of a dedicated department or persons of mining, it is not easy to derive to an applicable standard where there is no standard. South Africa and Namibia found themselves in a similar situation. Therefore we must draw on standards that were developed by other countries and evaluate their relevance to this situation. In most cases, when referring to a United States methodology, there is rejection and objection against the use of such criteria. However, when considering the detail of the work that was conducted in order to produce such criteria, there is more than one aspect that makes it relevant. The following hopes to shed some light on the subject and BM&C's acceptance that the USBM Criteria for safe blasting is applicable.

12.2.1 Back ground and basis to the USBM standard:

Cracking from blasting occurs where excessive stresses and strains are produced within the planes of the walls or between walls at the corners. Vibration in the corners is assumed to indicate cracking potential, because it corresponds to whole-structure response. Midwall motions are primarily responsible for window sashes rattling, picture frames tilting, and dishes jiggling.

Three factors of Structural Response are important (Structural response is directly and linearly proportional to ground vibration amplitude): Amplitude, duration of blast and frequency of vibration.

Controlling Structural Response can be achieved by adjusting the three factors as follows:

- •Amplitude: Reduce vibration by ½,
  Reduce response by ½.
- •Frequency: Double the frequency,
  Reduce response by as much as 10 times.
- •Duration: Reduce duration,
  Reduce response.

(How much depends on both duration and frequency)

The above ground portion of each structure will respond more than the ground when excited at its natural frequency. Amplification is a comparative measure of the maximum structure response to ground velocity (GV), at the same point in time. Amplification occurs when the motion becomes larger than that at GV. Amplification varies for typical and atypical structures. When the ground vibration frequency is significantly higher than that of the structure the motion is equal to that of the ground.

Natural frequency and damping are the most important structure response characteristics. Ground vibrations below the fundamental frequency of the house will still cause the house to vibrate at least as much as the ground. If the frequency of the ground vibration is more than 40% greater than the fundamental frequency of the house however, the house will vibrate less than the ground.

The USBM also determined that while houses vibrate as a single-degree-of-freedom between 4 and 12 Hz, the natural frequency of the house's midwall tends to occur between 12 and 20 Hz. In order to control the response of a structure that has more than one fundamental frequency, the two lowest fundamental frequencies must be controlled. For residential structures, this means minimizing ground vibrations to between 4 and 20 Hz. Damage potentials for a low-frequency blast (<40 Hz) are considerably higher than those for high-frequency blasts (>40 Hz).

Most significant for blasting is that the principal frequencies of the ground motion almost always equal, or exceed, the gross structure natural frequency of 4 to 10 Hz. Little difference in natural frequencies is observed among 1- and 1 ½-story homes; those of 2-story homes are lower. The relatively higher frequencies in 1-story homes with natural frequencies nearer 10 Hz are more damage-prone than taller 2-story homes with natural frequencies near 5 Hz.

Conclusion to the use of the USBM

Considering the amplitude and frequency of blast induced ground vibration, the resulting effects on structures is dependent on the natural frequency of a structure. The research work that led to the USBM criteria for safe blasting was based on work from various researchers and a variety of structures were included. Work includes research on typical American built houses, but also that of brick and mortar, reinforced constructions and brick and concrete structures. Thus considering that similar structures to South African built structures were also considered in the making of the USBM criteria, it can be accepted as a standard in view of there being no formal South African standard. Typical South African structures are within the same range of natural frequencies as those described above. Thus the USBM standard will also be applicable.

12.2.2 Rio Tinto standard:

Rio Tinto provides guidelines with regards to ground vibration and air blast. These guidelines are provided with the notice that effective control of ground vibration and air blast must be done and that a proper set of levels may be developed by the mine in question. The author is not familiar with the detail of how and why these standards came about. The following is a summary of the standards according to the "*The Rio Tinto Environmental Standards, Noise and Vibration Control Guidance Note version 1:*"

The Rio Tinto Environmental Standards, Noise and Vibration Control Guidance Note version 1: September 2003 specifies under section 4.1 EPA and Corporate Requirements the following limits.
"overpressure shall not exceed 120dBL for any blast and shall not exceed 115dBL for more than 5% of blast during a year"
"Vibration shall not exceed 10mm/sec for any blast and shall not exceed 5mm/sec for more than 5% of blast during a year"

12.2.3 Standard and final decision:

A review of these guidelines showed that they are rather strict – significantly stricter than the USBM guidelines for the higher frequencies specifically. The Rio Tinto guidelines are a one level standard across the board for all frequencies. They are simple and easy to use. However, we know that ground vibration from blasting operations varies in frequency and needs to be taken into account as well. Different structures respond to ground vibration differently as well. It is, however, sure that conforming to these limits will curb the probability of neighbour's complaints. Alternatively, if these limits are applied by RUM, it is sure that damage will not be induced to neighbour's structures and installations.

This report and its contents will also act as a starting point to review the above mentioned guidelines. The report uses a worst case scenario for maximum charge mass per delay and, even within the expected and actual recorded results, levels for ground vibration and air blast were well within the levels given in the guideline. The option is to adopt the guidelines as a standard or to seek alternative standards that are applicable to RUM. There are various standards internationally i.e. The DIN Standard, Indian Standard, British Standard etc. The basis for each of these standards are too detailed to discuss here, but they all are probably done in good faith and supported by experience and research. The fact is that South Africa currently has no specific standard and uses the USBM because it is applicable. Damage to structures has not yet been observed by the author when applying the USBM standard. It is also a fact that researchers in India have proven that the current Indian standard is too tight and creates a situation where mining costs are increased due to the limitations placed on ground vibration and air blast.

The conclusion from this is that adopting the Rio Tinto guide as a standard may impose unnecessary restrictions that are not valid for structural damage criteria on RUM. Adopting the USBM standard or any other standard may allow excessive ground vibration and air blast levels that could be damaging, or even cause neighbours to react negatively. If neighbours are negatively influenced, it could impact on RUM's public image in the area.

The development of a set of criteria through testing and monitoring seems to be the one solution to be considered that could be seen by Namibian Mining authorities as ground breaking work, which could be applied as a formal standard for Namibia.

12.3 Good Practice and Corrective actions

The following will have to be taken into account and considered when monitoring blasting operations on a continuous basis.

1. A dedicated person or persons must be assigned the responsibility of operating and maintaining the equipment.
2. When fixed monitors are installed, data should be downloaded more frequently to observe correctness and activity recorded. This will assist in making sure that false triggers are kept

to a minimum. Analysis must be done as soon as possible and relevant information forwarded to the chain of command as defined by the Rio Tinto standards.

3. Ground vibration and air blast levels recorded greater than specified limits should be reported immediately to the necessary persons, who should be included the blasting operations team. The exact process from this point cannot be specified as the Rio Tinto standards will define exact course of actions. It is my view that blasting operations should be halted and cause of any exceeding of levels investigated immediately. Proper record keeping of blasting and seismograph data will ensure that investigations can be conducted speedily, and without major interference to the production process.
4. Seismographs are used to establish compliance with regulations and evaluate explosive performance. Laws and regulations have been established to prevent damage to property and injury to people. The disposition of the rules is strongly dependant on the reliability and accuracy of ground vibration and air blast data.
5. General Guidelines

5.1 Read the instruction manual. Every seismograph comes with an instruction manual. Users are responsible for reading the appropriate sections before monitoring a blast.

5.2 Seismograph calibration. Annual calibration of the seismograph is recommended.

5.3 Keep proper records. A seismograph user's log should note the user's name, date, time, place and other pertinent data.

5.4 Record the blast. When seismographs are deployed in the field, the time spent deploying the unit justifies recording an event. Set the trigger levels low as practical enough to record each blast.

5.5 Record the full waveform. It is not recommended that the continuous recording option available on many seismographs be used for monitoring blast generated vibrations.

5.6 Document the location of the seismograph. This includes the name of the structure and where the seismograph was placed on the property relative to the structure. Any person should be able to locate and identify the exact monitoring location at a future date.

5.7 Know and record the distance to the blast. The horizontal distance from the seismograph to the blast should be known to at least two significant digits. For example, a blast within 1000m would be measured to the nearest tens of meter and a blast within 10,000 m would be measured to the nearest hundreds of meters. Where elevation changes exceed 2.5h:1v, slant distances or true distance should be used.

5.8 Know the data processing time of the seismograph. Some units take up to 5 minutes to process and print data. If another blast occurs within this time the second blast may be missed.

5.9 Know the memory or record capacity of the seismograph. Enough memory must be available to store the event. The full waveform should be saved for future reference in either digital or analog form.

5.10 Know the nature of the report that is required. For example, provide a hard copy in the field, keep digital data as a permanent record or both. If an event is to be printed in the field, a printer with paper is needed.

5.11 Allow ample time for proper setup of the seismograph. Many errors occur when seismographs are hurriedly set-up. Generally, more than 15 minutes for set-up should be allowed from the time the user arrives at the monitoring location until the blast.

5.12 Know the temperature. Seismographs have varying manufacturer specified operating temperatures.

5.13 Secure cables. Suspended or freely moving cables blown by wind or other extraneous sources can produce false triggers due to micro phonic or electrical noise.

5.14 Obtain a copy of the blast information and file with the seismograph reports.

5.15 Maintain a database with all relevant seismograph event data and blast information; this will be useful when predictive studies are to be conducted.

In the event of ground vibration and air blast levels exceeding the limits, the following can be considered during the mitigation process. Following are two tables showing the various blast design parameters and extent of the influence they will have on ground vibration and air blast. Changing the parameters will certainly have an influence on the outcome of the final results.

Table 25: Blast Design Parameters influence on Ground vibration

Controllable Blast Design Parameters	Most Significant	Moderate Significance	Insignificant
Quantity of explosive per detonation	X		
Delay period	X		
Detonation Precision	X		
Confinement		X	
Stemming (quantity and & Type)			X
Charge Length and Diameter		X	
Charge decoupling		X	
Angle of borehole			X
Direction of Initiation		X	
Total Charge Weight per Blast			X
Total Shot Duration		X	
Charge Depth			X
Bare vs Covered Detonation			X
Electric vs Nonelectric Initiation			X
Uncontrollable Parameters	**Most Significant**	**Moderate Significance**	**Insignificant**
General surface terrain		X	
Overburden type and depth		X	
Ground Structure & orientation		X	
Atmospheric Conditions			X
Wind			X

Table 26: Blast Design Parameters influence on Air blast.

Controllable Blast Design Parameters	Most Significant	Moderate Significance	Insignificant
Quantity of explosive per detonation	X		
Delay period	X		
Detonation Precision	X		
Confinement	X		
Stemming (quantity and & Type)	X		
Charge Length and Diameter			X
Charge decoupling		X	
Angle of borehole			X
Direction of Initiation	X		
Total Charge Weight per Blast			X
Total Shot Duration	X		
Charge Depth	X		
Bare vs Covered Detonation	X		
Electric vs Nonelectric Initiation			X
Uncontrollable Parameters	**Most Significant**	**Moderate Significance**	**Insignificant**
General surface terrain		X	
Overburden type and depth			X
Ground Structure & orientation			X
Atmospheric Conditions	X		
Wind	X		

The guidelines must be considered in conjunction with the appropriate Rio Tinto standards and laws regulating the blasting and mining industry of Namibia. None of the above can be used in substitution of regulatory requirements. The above information is additional information to ensure that blasting operations are conducted in a safe and appropriate manner.

13. Additional Recommendations

The assessment of ground vibration and air blast for Rössing Uranium Mine has been conducted on the worst-case scenario and with a mitigated situation. This assessment showed minor concerns with regard to the probability that damage to structures could be induced or that life forms are threatened. There could be a case for slight disturbance but with no specific concerns that will require major recommendations or changes to the blasting operations. There are always factors to be considered by the mining department to optimise blasting operations in order to obtain optimal blast sizes, fragmentation, yield etc. It is an ongoing process. The blasts reviewed during this process are some of the worst cases that could happen. Only changes to the initiation system will bring about significant changes to the levels of ground vibration and air blast generated.

One aspect not dealt with in detail in this report, but which could be addressed with time, is the location of the blast in relation to actual complaints or people's perceptions. There is suspicion that the orientation of the blast could have contributed to people's negative perception. The following recommendations originating from this report are then applicable.

Consideration should be given to the following recommendations.

13.1 Resort to the use of non detonating cord as an initiation system, shock tube systems or electronic systems may be investigated,
13.2 Restrict the maximum quantity of blastholes tied into one row to a maximum of 10 blastholes when detonating,
13.3 Monitor the blast location in relation to complaints from neighbours,
13.4 Setup a ground vibration monitoring programme with at least three monitors, of which two are at least at opposite sides of the mine,
13.5 Create a database of ground vibration and air blast with information from blast operations, in order to assist in dealing with complaints effectively and working towards building an own set of ground vibration and air blast limiting levels.

14. Impact Assessments

Following is an impact assessment of the various concerns covered in this report. The matrix below in Table 27 shows outcomes before any mitigation is done and considers the worst case scenarios as a basis.

Table 27: Impact Assessment

CRITERIA	DESCRIPTION	Ground Vibration	Air Blast	Fumes	Fly rock
Extent or spatial influence of impact	Mine Licence Area and Mine Accessory Works Area	Local	Local	Regional	Local
* Magnitude of impact (at the indicated spatial scale)	Social and/or natural functions and/ or processes are *slightly* altered	Low	Low	Medium	Very Low
Duration of impact	More than 10 years	Long Term	Long Term	Long Term	Long Term

	after construction				
SIGNIFICANCE RATINGS					
Level Of Criteria Required		**Ground Vibration**	**Air Blast**	**Fumes**	**Fly rock**
High magnitude with a local extent and medium term duration or High magnitude with a regional extent and construction period or a site specific extent and long term duration or High magnitude with either a local extent and construction period duration or a site specific extent and medium term duration or Medium magnitude with any combination of extent and duration except site specific and construction period or regional and long term or Low magnitude with a regional extent and long term duration		Medium	Medium	Medium	Medium
PROBABILITY RATINGS	**CRITERIA**	**Ground Vibration**	**Air Blast**	**Fumes**	**Fly rock**
Probable	Estimated 5 to 95% chance of the impact occurring.	Probable	Probable	Probable	
Unlikely	Estimated less than 5% chance of the impact occurring.				Unlikely
CONFIDENCE RATINGS	**CRITERIA**	**Ground Vibration**	**Air Blast**	**Fumes**	**Fly rock**
	Reasonable amount of useful information on, and relatively sound understanding of, the environmental factors potentially influencing the impact.	Sure	Sure	Sure	Sure
REVERSIBILITY RATINGS	**CRITERIA**	**Ground Vibration**	**Air Blast**	**Fumes**	**Fly rock**
	The impact is reversible, within a period of 10 years.	Reversible	Reversible	Reversible	Reversible

The only mitigations that could be added are a reduction of the quantity of blastholes detonating simultaneously, ensure that blastholes are stemmed properly with crushed aggregate, and ensure that stemming lengths are not less than the minimum required.

15. Risk Assessment

Risk assessment was done based on the Rio Tinto standards, HSEQ Qualitative Risk Assessment (Level 2) 5 x 5 Risk Matrix and the Rio Tinto Risk analysis and Risk management process.

Following is a risk assessment of the various concerns covered in this report. The matrix in Table 28 below shows risk identification and evaluation. This is prior to any mitigation done and considers the current case scenario as a basis. This risk assessment is an indication of the current status. It is the opinion of the author that it could be further refined, especially with the input of various other role players at the mine.

Table 28: Risk Assessment: Evaluation of Risks as per RUM Risk Assessment Matrix

Risk Type	Category	Item	Threat Title	Causes (Triggers / Indicators)	Impacts /(Consequences)	Health	Personnel Safety	Environment	Community / Cultural	Compliance	Rio Tinto Reputation	Outcome (max from each)
T	H	1	Ground Vibration & Air blast	Blasting	Ground Vibration	Minor	Minor	Minor	Serious	Serious	Serious	Serious
T	H				Air blast	Medium	Minor	Minor	Serious	Serious	Serious	Serious
T	H				Flyrock	Minor	Minor	Minor	Minor	Minor	Minor	Minor
T	H				Fumes	Minor	Minor	Minor	Minor	Minor	Minor	Minor

Table 29: Evaluation of the risk and rating

Risk Rating						
Ground Vibration	**Rating**	**1 - Minor**	**2 - Medium**	**3 - Serious**	**4 - Major**	**5 - Catastrophic**
A – Almost Certain		Moderate	High	Critical	Critical	Critical
B – Likely		Moderate	High	High	Critical	Critical
C – Possible		Low	Moderate	High	Critical	Critical
D – Unlikely	X	Low	Low	**Moderate**	High	Critical
E - Rare		Low	Low	Moderate	High	High
Air blast		1 - Minor	2 - Medium	3 - Serious	4 - Major	5 – Catastrophic
A – Almost Certain		Moderate	High	Critical	Critical	Critical
B – Likely		Moderate	High	High	Critical	Critical
C – Possible		Low	Moderate	High	Critical	Critical
D – Unlikely	X	Low	Low	**Moderate**	High	Critical
E - Rare		Low	Low	Moderate	High	High
Flyrock		1 - Minor	2 - Medium	3 - Serious	4 - Major	5 – Catastrophic
A – Almost Certain		Moderate	High	Critical	Critical	Critical
B – Likely		Moderate	High	High	Critical	Critical
C – Possible		Low	Moderate	High	Critical	Critical
D – Unlikely		Low	Low	Moderate	High	Critical
E - Rare	X	**Low**	Low	Moderate	High	High
Fumes		1 - Minor	2 - Medium	3 - Serious	4 - Major	5 – Catastrophic
A – Almost Certain		Moderate	High	Critical	Critical	Critical
B – Likely		Moderate	High	High	Critical	Critical
C – Possible		Low	Moderate	High	Critical	Critical
D – Unlikely		Low	Low	Moderate	High	Critical
E - Rare	X	**Low**	Low	Moderate	High	High

Table 30: Risk Assessment with final outcome and Confidence Rating

Risk Rating		Outcome	Uncertainty / confidence Rating	
Ground Vibration	3 - Serious		**Certain**	**Highly Uncertain**
D – Unlikely	X	Moderate	Active Monitoring Needed	
Air blast	3 - Serious			
D – Unlikely	X	Moderate	Active Monitoring Needed	
Flyrock	1 - Minor			
E - Rare	X	Low		Information Gathering Needed
Fumes	1 - Minor			
E - Rare	X	Low		Information Gathering Needed

In view of the outcome above the risk management response is summarized in Table 31 below.

Table 31: Risk Management Response

Rating		***Risk management response[1] - RTRPS***	**Risk management response – HSEQ focus**
Moderate	***Class II***	*Risks that lie on the risk acceptance threshold and require active monitoring.*	Risks that lie on the risk acceptance threshold and require active monitoring. The implementation of additional measures could be used to reduce the risk further.
Low	***Class I***	*Risks that are below the risk acceptance threshold and do not require active management.*	Risks that are below the risk acceptance threshold and do not require active management. Certain risks could require additional monitoring.

Concluding on the risk assessment the following is applicable. The risk assessment was done for private installations at the current location of the mining and the proposed new areas. The current blasting operations are not yielding levels of ground vibration, air blast, fumes or fly rock that poses a direct threat to neighbours, with regard to personal damage or structural damage. The possibility of fly rock reaching any of the said structures is zero. Fumes are influenced by various factors but it is highly unlikely that these would reach any neighbours. Ground vibration and air blast are the factors that people could possibly experience but with no significant influence. Rather, these could be considered to be a nuisance, which could lead to outcomes described in Table 30, above, whereby Community / Cultural, Compliance and Rio Tinto Reputation were evaluated as Serious. This was based more on people's perception rather than actual damage or injury.

16. Knowledge Gaps

To the knowledge of the author there is no immediate concern with regard to a shortfall in the information provided. Considering the stage of the project, the data observed was sufficient to conduct an initial study. This report is based on data provided and internationally accepted methods and methodology used for calculations and predictions.

17. Conclusion

Rio Tinto, Rössing Uranium Mine (RUM), Namibia is considering an expansion of current opencast mining operations. Blast Management & Consulting was contracted as part of Social and Environmental Impact Assessment (SEIA) to perform a review of possible impacts with regard to blasting operations in the proposed expansion of opencast mining operations, and the evaluation

[1] As in Rio Tinto Risk policy and standard

results from current blast operations. Aspects of blasting operations such as ground vibration, air blast, fly rock and fumes were evaluated.

The evaluation of effects yielded by blasting operations were considered for interested and affected parties located on various sides of Rössing Uranium Mine and ranged to distances in excess of 12km. Of significant are the locations of Arandis town and the Arandis Airport, which are private structure locations closest to the mine.

The expected ground vibration and air blast levels from blasting operations were calculated and considered in relation to the surrounding structures and installations. No specific concerns were identified from the review of the expected ground vibration and air blast levels. The expected levels of ground vibration and air blast from detonating the maximum charge considered are within the allowed guidelines, but levels are such that blasts could be perceptible. This in turn may lead to complaints and subsequent investigations. The distances between the pit and private installations are significant and ranged between 5.6km and in excess of 12km.

Ground vibration level of 3.2mm/s calculated from a worst case scenario at the closest point of interest – the Arandis Airport – were well within the minimum requirements, even at very low frequencies. A level of 4.3 mm/s is allowed at 1 Hz. Air blast for the same situation was 110.2 dBL. Considering a reduced charge, which is more likely to occur at Rössing Uranium Mine, the levels observed were 0.8 mm/s and 105dBL. These levels are well below the lower recommended level specified. All other structures / installations were well within limits with no significant effects.

Specific consideration was also given to people's perception, which indicated that there is limited chance that people will be affected by blasting operations at Rössing Uranium Mine. A possibility exists that blasts could be noticed in very low ground vibration levels, or possibly heard, but with no real concern that structures could be damaged.

The blasts monitored for ground vibration and / or air blast on the 21st October 2008 showed proper characteristics of ground vibration and air blast at points where data was registered. No results that indicate actual ground vibration or air blast due to blasting operations at Rössing Uranium Mine were obtained at Mr. Meyer's farm. Ground vibration and air blast from blasting operations are considered to be well within the recommended criteria at Mr. Meyer's farm.

The current blasting operations may be changed for optimisation of the actual blast process and blast results, but changes are not necessarily required to facilitate a specific reduction of ground vibration or air blast. Typical changes that can be incorporated are the option of changing the initiation system in order to facilitate possible better fragmentation, better loading conditions, better movement of blasts, and all factors influenced through the proper consideration of the various aspects of the mining process.

Probably the most effective way forward is to set up a monitoring program in order to collect data that will help determine specific effects that are unknown at this stage. Some of these effects are the levels generated and peoples experience due to location of the blast, size of the blast, orientation of the blast and initiation sequence, all factors that are bound to have an influence. The intensity of these influences is site specific and their outcome can only be determined through detailed monitoring processes.

The levels observed from modelling done in this report are low and well within accepted norms and standards. Increased frequency of blasting due to the proposed expansion will not have a cumulative effect on the ground vibration or air blast from one blast to another. Increased frequency is not expected to be problematic. The only aspect of an increased blasting frequency due to the expansion may be a nuisance factor, if blasts are heard.

This report summarises the evaluation of recorded and expected effects from current blasting operations and the proposed future expansion at Rössing Uranium Mine. It is concluded that current blasting practices should have no significant influence on current neighbours.

18. Curriculum Vitae of Author

Author joined Permanent Force at the SA Ammunition Core for period Jan 1983 - Jan 1990. During this period I was involved in testing at SANDF Ammunition Depots and Proofing ranges. Work entailed munitions maintenance, proofing and lot acceptance of ammunition. For the period Jul 1992 - Dec 1995 I worked at AECI Explosives Ltd. Initially I was involved in testing science on small scale laboratory work and large scale field work. Later on work entailed managing various testing facilities and testing projects. Due to the restructuring of the Technical Department I was retrenched but fortunately could take up an appointment with AECI Explosives Ltd's Pumpable Emulsion explosives group for underground applications. December 1995 to June 1997 I gave technical support to the Underground Bulk Systems Technology business unit and performed project management on new products. I started Blast Management & Consulting in June 1997. Main areas of concern were Pre-blast monitoring, *In situ* monitoring, Post blast monitoring and specialized projects. I have obtained the following Qualifications:

1985 - 1987	Diploma: Explosives Technology, Technikon Pretoria
1990 - 1992	BA Degree, University Of Pretoria
1994	National Higher Diploma: Explosives Technology, Technikon Pretoria
1997	Project Management Certificate: Damelin College
2000	Advanced Certificate in Blasting, Technikon SA

Member: International Society of Explosives Engineers

Blast Management & Consulting has been active in the mining industry since 1997 and work has been on various levels for all the major mining companies in South Africa. Some of the projects where BM&C has been involved are:

Iso-Seismic Surveys for Kriel Colliery in conjunction with Bauer & Crosby PTY Ltd, Iso-Seismic surveys for Impala Platinum Limited, Iso-Seismic surveys for Kromdraai Opencast Mine, Photographic Surveys for Kriel Colliery, Photographic Surveys for Goedehoop Colliery, Photographic Surveys for Aquarius Kroondal Platinum – Klipfontein Village, Photographic Surveys for Aquarius – Everest South Project, Photographic Surveys for Kromdraai Opencast Mine, Photographic Inspections for various other companies including Landau Colliery, Platinum Joint Venture – three mini pit areas, Continuous ground vibration and air blast monitoring for various Coal mines, Full auditing and control with consultation on blast preparation, blasting and resultant effects for clients e.g. Anglo Platinum Ltd, Kroondal Platinum Mine, Lonmin Platinum, Blast Monitoring Platinum Joint Venture – New Rustenburg N4 road, Monitoring of ground vibration induced on surface in Underground Mining environment, Monitoring and management of blasting in close relation to water pipelines in opencast mining environment, Specialized testing of explosives characteristics, Supply and service of seismographs and VOD measurement equipment and accessories, Assistance in protection of ancient mining works for Rhino Minerals (PTY) LTD, Planning, design, auditing and monitoring of blasting in new quarry on new road project, Sterkspruit, with Africon, B&E International and Group 5 Roads, Structure Inspections and Reporting for Lonmin Platinum Mine Limpopo Pandora Joint Venture 180 houses – whole village, Structure Inspections and Reporting for Lonmin Platinum Mine Limpopo Section : 1000 houses / structures.

BM&C is currently busy installing a World class calibration facility for seismographs, which will also be accredited by Instantel, Ontario Canada as an accredited Instantel facility. The projects described and discussed here are only part of the capability and professional work that is done by BM&C.

19. References

19.1 Siskind, D.E., V.J. Stachura, M.S. Stagg and J.W. Kopp, 1980a. Structure Response and Damage Produced by Air blast From Surface Mining. US Bureau of Mines RI 8485.

19.2 Persson, P. A., R. Holmberg and J. Lee, 1994, Rock Blasting and Explosives Engineering, Boca Raton, Florida: CRC Press.

19.3 Scott, A., Open Pit Blast Design, 1996, Julius Kruttschnitt Mineral Research Centre, The University of Queensland.

19.4 Client Report : Air Overpressure from Le Maitre Flash Report : Dr R. Farnfield, Technical Services Manager, Dated : 27 April 2007

19.5 Chiapetta, F., A Van Vreden, 2000. Vibration/Air blast Controls, Damage Criteria, Record Keeping and Dealing with Complaints. 9th Annual BME Conference on Explosives, Drilling and Blasting Technology, CSIR Conference Centre, Pretoria.

20. Appendixes

Appendix 1: Elements Causing Variances On Air blast Levels Expected, For Rio Tinto, Rössing Uranium Mine, Namibia, Dated 30 March 2009 (Addendum 01 to Phase 2 SEIA Noise and Vibration)
Appendix 2: Analog Crack Gauges

Appendix 2: Analog Crack Gauges

OZA strain gauges can be mounted on a crack on an inside or outside wall of a house. OZA gauges are visual and read to within 0.25 mm accuracy. The gauge consists of two plastic plates with calibrated markings on. The bottom plate has a grid with 1mm increments and the top plate a red crosshair. The plate is mounted across a crack using glue at the opposite ends of the gauge. An example of an installation is given in Figure 1. Measurements are taken by visually examining the gauge and recording the position of the red crosshair on the black grid. The position of the crosshair is then marked on the sheet provided. Figure 2 shows an example of a recording sheet for an installed gauge. The data from the sheet can then be transferred to plotting program such as Microsoft Excel for detail plotting options and calculations. Figure 3 shows an example of plotted data and the variation that occurred over time. Additional information such as, temperature, humidity, wind, blast dates and times, etc. should also be noted and plotted with the gauge data. Cost of units are in the order of US$550 per box of 10 units.

Figure 1: OZA Gauge

Figure 2: Recording Sheet example

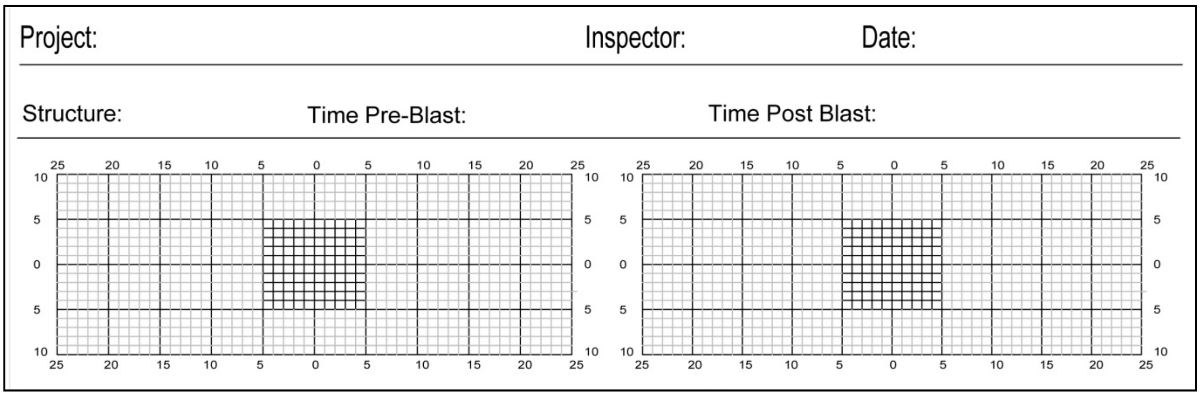
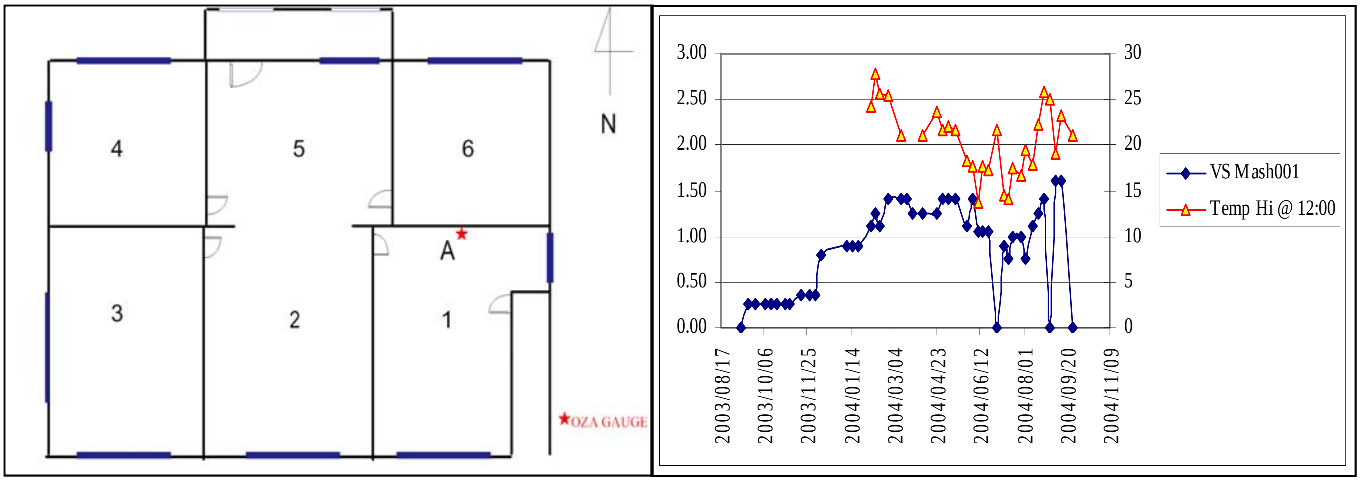


Figure 3: Example of gauge application



Blast Management & Consulting

Report:
Elements Causing Variances
On Airblast Levels Expected,
For Rio Tinto, Rössing Uranium Mine, Namibia
Dated 30 March 2009
(Addendum 01 to Phase 2 SEIA Noise and Vibration)

Ref. No. RUM~March2009EIAAdd01

Quality Service on Time

Date: 2009/03/30

Signed:

Name: JD Zeeman

CK 97 31139 / 23
Cell.: 082 854 2725
Tel.: +27 (0)12 662 1945 Fax.: +27 (0)12 662 3141
PO Box 61538 Pierre van Ryneveld Centurion 0045
54 Van Ryneveld Avenue Pierre van Ryneveld Centurion 0157

1. Introduction:

The effect of blasting operations in the mining industry on the surrounding environment has more than once been a contentious issue. The level or intensity of the concerns varies from mine to mine and environment to environment.
In order to address specific concerns of damage or disturbance with regards to Rio Tinto Rössing Uranium Mine a literature research was done on the subject of long distance influence of blasting operations. This report summarises the findings from said research.

It is important to note that this document is supplement to the SEIA Phase 2 Noise and Vibration study that was conducted for Rössing Uranium Mine. The main objective of the SEIA Phase 2 Noise and Vibration study was to determine, indicate and evaluate the effects of blasting operations with regards to possibility that damage can be induced to neighbouring installations or houses and to express with this peoples perception of blasting related effects. The main focus is on damage probability.

This report concentrates on specific elements that could have effect on the levels of airblast at distances from the source and the possible variance in levels between actual and expected.
Added at the end of this report is an abstract from actual events occurred from a fuel depot that exploded.

2. Background

Sound pressure is the general term used for changes in air pressure caused by sound waves. Peak sound pressure levels can be given in either Pascals (Pa) or Decibels (dB). When sound recordings are to be used to either assess human annoyance or hearing damage it is normal for the raw sound wave to be processed via an ‘A’ weighting filter thus giving peak levels with units of dB(A). The ‘A’ weighting process effectively filters out much of the low frequency, sub-audible, energy in the recording. However, when recording sound pressure levels from concussive or explosive events much of the energy is sub-audible and it is normal to use unweighted signals giving peak values in dB (Linear). Such low frequency recordings are often referred to as air overpressure recordings and are normally taken as applying to frequencies above 2.Hz. Although there is no clear guidance on the levels of air overpressure likely to cause damage to the human ear, it is widely recognised that the levels of air overpressure required to cause structural damage is higher than 170.dB(Linear) with even weak windows surviving levels of 150.dB(Linear). Air blast or air-overpressure is the air pressure wave generated by a detonation. Air blast is normally associated with frequency levels less than 20 Hz, which is the threshold for hearing. Air blast is the direct result from the blast process although influenced by meteorological conditions the final blast layout, timing, stemming, accessories used, covered or not covered etc. all has an influence on the outcome of the result.

The three main causes of air blasts can be observed as:

1. Direct rock displacement at the blast; the air pressure pulse (APP),
2. Vibrating ground some distance away from the blast; rock pressure pulse (RPP),
3. Venting of blast holes or blowouts; the gas release pulse (GRP).

There are mainly three factors of interest regarding air blasts.

1. By themselves or in combination with ground vibration, air blasts can produce structural motions that may lead to crack propagation in walls,
2. Air blasts may crack windows, however pressures would have to be very high,
3. Human response to air blast, human reaction is the most intriguing, yet the most difficult to analyze quantitatively.

Previous research has shown that noise within a structure is the source of many complaints. Even at very low levels of ground vibration. The rattle of loose objects due to structure and wall motions which are induced by air blasts or sonic booms startle the occupants. Human response is often more intense inside than outside the structure. This is mainly due to the sound produced inside the structure by the structure itself.

In all documentation reviewed it is clear that damage to structures is governed by extreme high air blast pressures. Windows will break prior to damage to structures. Levels of air blast required to break windows is in excess of a minimum specified safe level of 133dB.
Most of the documentation currently accessible on the effects off air blast or air over pressure is associated with nuclear related blast effects. There is little information of actual studies that was done on blast operation related air blast on distances typically of interest here of 25km and further away. Only one study was found that mentions long distance considerations.

3. Discussion

The following additional concepts were identified as aspects that need to be considered with the already provided information.

3.1 Importance of Confinement

As discussed in the SEIA Phase 2 study report, confinement of charges is of extreme importance. As with fly rock control is the control on airblast best achieved by control on confinement. Airblast will be controlled by confinement such as proper stemming lengths, stemming material and abstaining from detonation of explosives on surface. The effects from blasting / detonation of unconfined charges are far greater than that of confined charges. Control of stemming is the single most significant factor that will control airblast.

3.2 Weather Influences of Airblast

Many of the researchers that work in the field of airblast due to mining blasting operations are sure that weather has an influence on the propagation of airblast. This subject has been discussed in detail by some and also found that it is not always possible to define the exact influence as weather changes and the extent to test for all situations is nearly impossible. An aspect that was considered by various researchers was: humidity, wind and wind direction, temperature, atmospheric pressure. The consensus is that weather does have an influence. Two atmospheric conditions are most significant: Temperature inversions and wind (both direction and speed) and humidity less significant. Both these aspects can increase airblast levels above what would be expected. Additional airblast energy is not produced, only the distribution is affected.

In temperature inversions, warm air overlies cooler air. Under normal conditions the sound rays are bent away from the earth surface by process of acoustic refraction. When an inversion exists these rays are bent downwards towards the earth surface and can produce one or more focus point's at large distances from the blast. A focus point or location is an area where higher than expected levels of airblast is observed with lower intensity between this point and the source. Research done by Schomer has shown that for propagation distances of 3.2 to 64 km inversions can produce sound intensification zones of up to 3 times average values. This means that the attenuation of sound over distance will decrease slower than expected and higher than expected could be experienced.

The wind and direction is also influencing the expected levels of airblast. The wind changes the angle of the airblast wavefront. In downwind situations the wind is concentrating the wavefront near the ground and in upwind situation the wavefront is concentrated away from the ground in the absence of an inversion. Researchers showed that closed in measurements were between 10 and 15dB greater downwind than with cross winds or no wind conditions. The difference in down wind and upwind attenuation was investigated and results showed that down wind the attenuation could occur at -5.3dB per doubling of distance and upwind it could occur at -10.1dB per doubling of distance.

3.3 Structural Response to Airblast

Airblast can also produce structure rattling similarly than ground vibrations. In extreme cases cracking and other damage can be induced. Airblast influence of structures is most significant on the midwall responses. It is also highest here. Research has found also that the midwall response does not produce in-plane strains and are presumed not significant in the cracking potential of structure walls except for window breakage. Window breakage was found to be the first indication of airblast damage.

Midwall responses have been found to be the cause of much secondary rattling in house and other observed effects such as movements of pictures etc. Although the rattling effect is not significant to induce damage but the perception of home owners concerns is that something serious can happen to their homes.

With regards to window breakage it was found that an impulsive sound level of 140dB is a reasonable threshold for glass. Indicating that windows will not be broken by airblast levels less than the 140dB level.

3.4 Wind Pressure

Much research has also been done on the relationship between wind speed and the relation to pressure. In reference a 28.5 mph (46kph) wind will yield the same pressure as 134dB pressure or 100.2Pa. Or according to maximum allowed for airblast by Rio Tinto is 120dB or 20 Pa and resulting in 20 kph winds. There are slight differences in the way different researchers address the influence and correlation between airblast and wind towards structures. Some say that the effects of winds are noticeable due to the slow rate of pressure changes. Others do indicate that the pressure acts over a longer time, and thus the damage potential increased, along with the fact that gusts will increase the nominal wind pressure by 25 – 50 %. Moderate winds are not as noticeable to building occupants because they make less noise and do not begin suddenly. Fact is that the reactions of people due to airblast are more than normal governed by the perception. Table below shows correlation between wind speed and resulting equivalent of airblast applicable.

Table 1: Wind speed conversion

Wind Speed (km/h)	Over Pressure (dB)	Over Pressure (Pa)
5	95	1.2
10	107	4.7
15	115	10.7
20	120	18.9
25	123	29.6
50	135	118.4
75	142	266.3
100	147	473.5

Randall Noon in “Forensic Engineering Investigation” describes the process of wind force on structures and refers also to the damage mechanisms of wind on structures and in specific the order of damage induced, damage due to winds occurs in the following order with items 1 or 2 that can be in reverse order:

1. Lifting of shingles,
2. Damage to single pane, loose fitting glass windows,
3. Lifting of awnings and roof deck,
4. Damage to side walks.

This confirms that windows are the weakest point and should get damaged when the damage conditions are met.

3.5 Human response to Airblast

Humans are extremely sensitive to sound. The threshold of hearing is extremely low at $2.07x10^{-5}$ Pa and the threshold of pain at 20.6843 Pa. Audible frequency range between 20 Hz and 20,000 Hz. There are orders of magnitude range in the pressure level and frequency. The primary concern normally is the apprehension that damage could be occurring due to the structural response people notice. Most of the times people are also present inside the house. People respond to the structural motion that creates the rumbling and rattling noises. In most cases people does not experience the ground vibration but rather the influence of airblast which arrives at a specific point after ground vibration. A distant blast may produce noticeable airblast response even at low levels. The airblast will likely be of low frequency with little energy above 5Hz. The atmosphere selectively attenuates the higher frequency. Occupants may not hear the sound but the structure could be excited and therefore do people also misinterpreted the effect as ground vibration.

3.6 Terrain

Terrain, blast location, direction of blast also has influences on the result of air blast. In cases airblast may like the aspects discussed above enhance or decrease the levels more than expected. Work was done on ground vibration and airblast in Contour mine blasting. The outcome was that higher than expected levels of airblast was observed due to the mountainside geometry. Ground vibration levels were lower. It was concluded that the hilly effect caused channelling of airblast and resulted in enhanced propagation. The blast orientation and location also contributes to various effects of the airblast. It was found that increased effect is found with the face toward the receiver. Large weight per delay, effective delays between blastholes – too short or too long - could also contribute to anomalies. Difference in levels can be expected between the front of the face and the back of the blast. Higher levels are expected at the front of the face. The direction of initiation also plays a role. Airblast levels could be increased in the direction initiation is done. Less airblast is expected in the opposite direction. This is expected to be due to positive enhancement that occurs as the individual blasthole's initiates. This has not been researched in a great detail but due to previous work done there is corresponding evidence that blast design and orientation could contribute to airblast in a negative and positive way.

4. <u>Conclusion</u>

Concluding I believe it will be fair to admit that there could be reason for more research into the aspect of noise at larger distances than what would normally be considered for damage probability studies. If this is within the scope of this SEIA phase 2 project is however debatable.

Literature research showed that the effects of air blast at distances beyond the normally expected are certainly influenced by various factors. Confinement is certainly the most important. Not just for the effect over greater distances but also for the immediate surroundings that can be influenced severely and damage caused. Weather will not contribute in the generation of energy but only in distribution of the energy from air blasts. The sensitivity of the neighbours are not disputed as one can only imagine the level of noise (maybe the greatness of the quietness) with no influence and the changes in these levels that blasting operations or even mining operations per say could be producing. The human body being very sensitive to noise it can be understood that variances are observed by the neighbours. I do believe as well that there is enough evidence showing that the probability of the damage as indicated in the SEIA phase 2 noise and vibration study is still extremely low.

The research done has shown no additional information that is any indication that the blasting conducted at Rio Tinto Rössing Uranium Mine is inducing damage to neighbouring structures due to airblast.

5. References

5.1 Bollinger, G.A, 1980, Blast Vibration Analysis, Illinois, Southern Illinois University Press.

5.2 Dowding, C.H, 1996, Construction Vibrations, Upper Saddle River, NJ, Prentice-Hall.

5.3 Noon, R.K, 2001, Forensic Engineering Investigation. CRC Press.

5.4 Oriard, L.L, 1999, The Effects of Vibrations and Environmental Forces, Cleveland, OH, International Society of Explosives Engineers.

5.5 Persson, P. A., R. Holmberg and J. Lee, 1994, Rock Blasting and Explosives Engineering, Boca Raton, Florida: CRC Press.

5.6 Siskind, D.E, 2005, Vibrations from Blasting, Cleveland, OH, International Society of Explosives Engineers.

5.7 Siskind, D.E., V.J. Stachura, A.J Engler, 1981. Airblast Instrumentation and Measurement Techniques for Surface Mine Blasting. US Bureau of Mines RI 8508.

5.8 Siskind, D.E., V.J. Stachura, M.S. Stagg and J.W. Kopp, 1980a. Structure Response and Damage Produced by Air blast From Surface Mining. US Bureau of Mines RI 8485.

5.9 Siskind, D.E., V.J. Stachura, M.S. Stagg and J.W. Kopp, 1984. Airblast and Ground Vibration From Contour Mine Blasting. US Bureau of Mines RI 8892.

5.10 Scott, A., Open Pit Blast Design, 1996, Julius Kruttschnitt Mineral Research Centre, The University of Queensland.

5.11 Client Report : Air Overpressure from Le Maitre Flash Report : Dr R.Farnfield, Technical Services Manager, Dated : 27 April 2007

Appendix 1: Fuel Depot explosion.

Members of staff of the Institute of Acoustics had a very rude awakening at around 6.00 a.m. on Sunday, 11th December! Based in and around the Hemel Hempstead area, all felt the effects of the fuel depot explosion - some more than others. Thankfully there was no damage to any of the houses – or people - although most of the houses shook with the effect of the blast. We have been following developments closely, quite closely in fact as the fire and enormous plumes of smoke can be seen from the office.

The noise of the blast could be heard from miles away, and even as far away as Holland! As a follow up to this, local radio BBC Three Counties interviewed Geoff Kerry from the University of Salford, Immediate Past President of the IOA on Monday afternoon.

Below is a piece written by Geoff Kerry on sound propagation effects at the time of the explosion.

There have been a number of reports made to radio and television stations of the sound of the oil terminal explosion that occurred in Hemel Hempstead just before dawn on Sunday, 11 December being heard as far away as Holland and even the north of France. At the same time some people living nearer to the blast have reported hearing very little.

Meteorological changes can have a large effect on propagation as sound travels through the atmosphere and this has been demonstrated many times in the past especially with loud sources such as large explosions where the effects have been observed over long distances. However the longer the distance, the greater is the influence of the weather.

Without detailed meteorological observations and a lack of knowledge on the exact nature of the Hemel Hempstead explosion itself it is difficult to determine the extent of the area over which the sound would have been heard and especially the area over which the sound level would have been high enough to cause damage to buildings.

On Sunday morning, at the time of the explosion in Hemel Hempstead, the wind had a relatively light westerly component and coupled with the likely temperature inversion accompanying the clear skies and frosty ground, the sound speed gradient would have favoured propagation towards the east, resulting in some enhancement of the sound in that direction. The size of the blast, involving much sound energy in the low and almost sub audible frequencies, would result in the sound being heard at some distance from the source. However the area of audible sound would have been influenced by the exact nature of the temperature and wind profile above the ground and it is quite possible that sound shadows could have been created nearer to the explosion which would result in some people hearing very little especially if there were any masking sounds such as local traffic present.

Briefly and in general, noise propagation through the atmosphere is controlled by the rate of change of sound speed with altitude, which is mainly a function of the wind vector and temperature. Usually the wind vector has an influence of an order of magnitude greater than temperature. When the wind is very light there is usually a decrease of temperature (lapse) upward from the ground. This bends sound upward resulting in a sound shadow on the horizon. However as the wind speed increases, friction at the surface causes the wind nearer to the surface to have a lower velocity than that in the layer above creating a significant wind gradient up to several hundred metres altitude resulting in a sound speed increasing with height (positive gradient) downwind. This is easily sufficient to overcome the temperature lapse and produce an enhancement by bending the sound back to the ground. Upwind the effects of the temperature gradient are reinforced. In the presence of a low level temperature inversion, experienced on cold, windless, frosty mornings or at night when there is often a nocturnal temperature inversion of several hundred metres depth above the ground, sound is refracted back towards the ground giving sound enhancement in all directions. If any wind is present, it will result in there being a preferred direction for the enhancement. Above a few hundred metres' altitude, horizontal temperature gradients are the main cause of wind changes especially in the region near a weather front. Ahead of a warm front the winds increase and turn clockwise (veer) with height and to the rear of a cold front the winds increase and turn anti-clockwise (back) with height. This can result in a change in wind direction of up to 180deg between the surface and 3000m and significant changes in the sound speed gradient that can cause the sound to return to the ground at several kilometres from the source, often in a different direction to the surface wind. In addition, elevated inversions can also occur in the area of frontal systems and these can refract sound back to the ground.

Although there weren't any significant weather fronts to influence the situation on this occasion, on the basis of the information available it is not surprising that reports have been received from continental Europe about the explosion being quite audible.