Cambrian CC
Reg. No. 2001/031939/23

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Ms. Karabo Lenkoe-Magagula.
Kimopax.
546 16th Road.
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27th January 2019

Dear Karabo,

REVIEW OF THE POSSIBLE IMPACT OF BLASTING IN THE VICINITY OF A PROPOSED NEW MINE DEVELOPMENT.

1. Background.

When blasting takes place numerous disturbances occur that impact on people and infrastructure found in the vicinity of the blasting operation. When blasts are set off ground vibration and air blast disturbances occur, which diminish in intensity with increase in distance. In addition, fly rock, after blast fumes and dust may also occur. These disturbances occur unexpectedly, particularly where blasting occurs on surface such as in quarries or open pit mines, and for this reason they often attract unwelcome attention.

To help manage this situation a systematic approach to the drill and blast operation needs to be adopted. This approach should initially assess the potential impact of the drill and blast operation and then focus attention on the control and management of the day-to-day operations to ensure that these are managed such that the disturbance levels caused by blasting fall within accepted industry norms. The aim of this report is to assess the possible impact of the drill and blast operation and to provide guidelines to help ensure that the blasting process is correctly implemented.

2. Proposed Site.

The new mine development is located in the vicinity of the villages of Moruleng and Manamakgotheng. A view of the prospecting right area and the surrounding villages is shown in the attached Google image (Appendix 1). Manamakgotheng is on the south east side of the image and Moruleng is on the south side of the image.

3. Objective.

This report considers the possible impact of the blasting operations on the surrounding areas. It provides an assessment of the possible disturbance levels that may be experienced at various distances from the area of the blasting operations. It considers the preliminary work that should be carried out prior to the start of blasting and also the monitoring work that is recommended when drilling and blasting is underway.

The following aspects of the blasting operation are assessed:

3.1 Blast design and general safe blasting practice. It has been assumed that open pit mining will be carried out.
3.2 Ground vibration – predicted levels.
3.3 Airblast – predicted levels.
3.4 Side effects such as fly rock, after blast fumes and dust.

3.5 Disturbance monitoring. This may be an aspect to consider prior to the start of the drill and blast operation as a precautionary measure. The equipment required, placing of the equipment and the standards against which the disturbance levels measured are compared for review.
3.6 Mitigation measures. A number of suggestions are made. These generally affect all aspects of the operation so the points have been grouped together.

3.1 Blast Design.
Prior to the start of blasting a proposed blast design should be modelled to determine the firing sequence and the number of holes firing together and the combined charge mass per delay. Based on these figures the peak particle velocities should be calculated at the points of concern. These predictions should be compared to recognised standards to ensure compliance. When acceptable results are obtained, the design should be fixed for use.

The final blast design should be marked and drilled off. After the blast is drilled off and charging commences then the process should be audited to ensure that all stages of the operation are proceeding as per the design. The blast pattern, blasthole depths, charge mass per hole and final stemming lengths should all be checked. Any unusual occurrences should be noted and where possible, immediately corrected.

3.2 Ground Vibration.
Ground vibration may attract comment from people in the vicinity of a blast. Ground vibration disturbances will need to be quantified to ensure compliance with recognised and accepted industry standards such as the United States Bureau of Mines Standard (USBM RI 8507) or the Deutsches Institut für Normung (DIN) Standard. See Appendix 2 for a summary of these standards.

Factors Affecting Ground Vibration and Prediction of Ground Vibration Levels.
Ground vibrations occur as a consequence of blasting activity. The intensity of the vibrations depends on a number of factors some of which can be managed and controlled to help reduce the impact.

The two principal factors that control vibration levels are distance and charge weight. Vibration energy is attenuated by the rock mass so normally lower amplitudes are experienced further from a blast. Vibration levels will increase as the charge weight increases. The larger the charge mass the higher the amplitude of the vibration. The charge weight can be controlled by reducing the blasthole diameter or limiting the number of holes that fire at an instant in time.

Vibration Control.
Effective vibration control can be exercised by making use of a propagation law developed by the United States Bureau of Mines, which relates peak particle velocity (vibration), charge weight and distance. This is referred to as the “Scaled Distance Relationship” which takes the following form:

$$Sd = D/\sqrt{E}$$

and

$$PPV = a(Sd)^{-n}$$

Where

Sd = Scaled distance. Sd should be greater than or equal to 31 where no monitoring is carried out.

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PPV	=	Peak Particle Velocity (mm/sec).
D	=	Distance to point of concern (m).
E	=	Mass of explosive per delay (kg).
a	=	Site specific constant, which is a function of the rock mass.
n	=	Site specific constant, which is a function of the rock mass.

This method should initially be used as an estimate only, since it assumes site-specific constants, which differ from site to site depending on the rock types. In the absence of site-specific information, a value of 1143 for "a" and a value of –1.6 for "n" can be used. Calculated values using these constants are usually conservative but provide a useful starting point.

The maximum allowable ground vibration amplitudes are frequency dependant with higher frequencies allowing higher peak amplitudes (Graph 1, Appendix 2). In general, at lower frequencies, the ground vibration should not exceed 12.7 mm/sec at houses, but at higher frequencies, the limit can increase to 50 mm/sec. Suggested maximum levels for peak particle velocity are summarized in the table below.

Nature of structure	**PPV in mm/sec**
Heavily reinforced concrete structures.	120
Property owned by concern performing blasting (minor plaster cracks acceptable). This could include the mine's offices, workshops etc.	84
Private property where maximum level of public concern is taken into account. This would include privately owned houses, schools, churches etc.	12
National roads / Tar roads	150
Steel pipelines	50
Green Concrete i.e. aged for less than 3 days	5
Concrete > 10 days	20

Human Response.

Human beings are easily disturbed at low levels of vibration. Levels of 0.76 to 2.54 mm/sec are quite perceptible, but the probability of damage is almost nonexistent. Levels between 2.54 and 7.62 can be disturbing and levels above 7.62 can be very unpleasant depending on the sensitivity of individuals.

Human perception is also affected by frequency. The approximate human response curves are combined with the USBM limiting curve for damage (Graph 2, Appendix 2). These curves slope in the opposite direction. In other words, humans are more tolerant to low frequency vibrations.

To avoid damage to buildings the USBM limiting curve should be applied. To avoid constant complaints from residents, the vibration should be kept below the unpleasant curve and definitely below the intolerable curve.

Vibration Levels – Predictions.

Information relating to the blast parameters was not provided. I therefore based this modelling exercise on designs that I know are used in hard rock opencast platinum mines. Based on this, the model was setup to assess blast design layouts drilled off using 165mm

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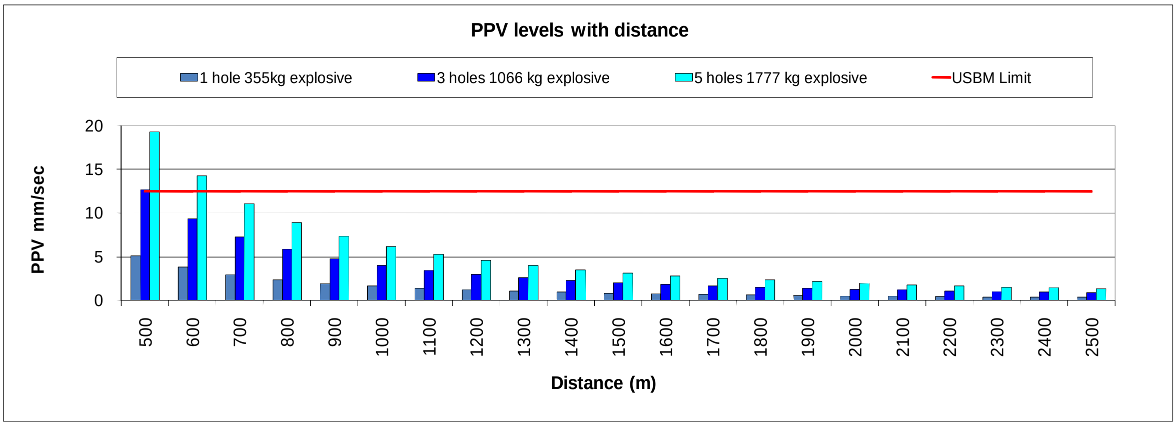
diameter blastholes on a 4.5m by 5.0m pattern. The blastholes were drilled to a depth of 16.5m with 0.5m of sub-drill added i.e. a final hole depth of 17m. A bulk explosive with an average in hole density of 1.2g/cc was used.

The number of holes firing together (and hence the charge mass per delay) was progressively increased from 1 to 6 holes to determine the effect on the peak particle velocity (PPV) levels at various distances. The following predicted PPV levels calculated at distances ranging from 500m to 2500m and for an increasing charge mass per delay, are tabled.

VIBRATION	Kimopax	Kimopax	Kimopax	Kimopax	Kimopax	Kimopax
Holes Detonated Per Delay	1	2	3	4	5	6
Combined charge mass firing	355	711	1066	1422	1777	2133
Distance increment in metres						
100	Production	Production	Production	Production	Production	Production
Distance (m)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)	PPV (mm/s)
500	5.12	9.07	12.67	16.07	19.31	22.45
600	3.79	6.71	9.38	11.89	14.30	16.62
700	2.94	5.21	7.27	9.22	11.08	12.88
800	2.36	4.18	5.83	7.40	8.89	10.34
900	1.94	3.44	4.80	6.09	7.32	8.51
1000	1.63	2.89	4.04	5.12	6.15	7.15
1100	1.39	2.47	3.45	4.37	5.26	6.11
1200	1.21	2.14	2.99	3.79	4.56	5.29
1300	1.06	1.87	2.62	3.32	3.99	4.64
1400	0.94	1.66	2.32	2.94	3.53	4.11
1500	0.84	1.48	2.07	2.62	3.15	3.66
1600	0.75	1.33	1.86	2.36	2.83	3.29
1700	0.68	1.20	1.68	2.13	2.56	2.98
1800	0.62	1.10	1.53	1.94	2.33	2.71
1900	0.57	1.00	1.40	1.78	2.13	2.48
2000	0.52	0.92	1.29	1.63	1.96	2.28
2100	0.48	0.85	1.19	1.50	1.81	2.10
2200	0.44	0.79	1.10	1.39	1.68	1.95
2300	0.41	0.73	1.02	1.30	1.56	1.81
2400	0.38	0.68	0.95	1.21	1.45	1.69
2500	0.36	0.64	0.89	1.13	1.36	1.58

The data tabulated above also shows how the PPV levels for a given charge mass attenuate rapidly with increase in distance. This can be seen more clearly when the data is graphed (below).



In the above table the vibration levels that correspond closely to the USBM threshold limit for private property (12.75mm/s at low frequency) occur at distances of 500m from the blast and when three or more holes fire together. At distances of up to 500 meters the disturbance levels will be noticeable but are below damage threshold levels when up to two holes fire together. At distances in excess of 800m the PPV levels are compliant even when six holes are fired together.

The ground vibration disturbance levels attenuate with increase in distance and at distances in excess of 800m the levels are within the USBM recommended limit even when six holes fire together.

3.3 Airblast.
Airblast is usually the main cause of blasting related complaints. Airblast is an atmospheric pressure wave consisting of high frequency sound that is audible and low frequency sound or concussion that is sub-audible and cannot be heard. Either or both of the sound waves can cause damage if the sound pressure is high enough (Konya).

Airblast results from explosive gasses being vented to the atmosphere that results in an air pressure pulse. This occurs as a consequence of stemming ejections or hole blowouts, direct rock displacement through face ruptures or surface cratering, the use of high Velocity of Detonation (VOD) accessories that are left unconfined and / or uncovered (e.g. detonating cord on surface), by ground vibration or by various combinations of the above.

It is difficult to predict air blast levels with certainty due to unknown blast conditions as well as varying atmospheric conditions. However, it should be possible to control airblast below 130dB by precise control of the charging operation. Airblast amplitudes up to 135dB should not cause damage to structures but it is recommended that the airblast be kept below the 130dB level. (Overcharged holes can generate amplitudes that exceed 142dB). Suggested threshold limits for air blast have been proposed by Personn (below) et.al. 1994. Chiappetta (personal communication) recommends that a threshold level of 125dB should be used to prevent damage and to avoid all complaints.

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.

Airblast Prediction.
Given the variables associated with airblast any attempt to predict air blast levels <u>can only be regarded as subjective</u>. There are a number of equations that can be used to try and predict airblast. Airblast is scaled according to the cube root of the charge weight:

$$K = D/W^{0.33}$$

The following equation can be used for the calculation of air blast:

$$L = 165 - 24 \, \text{Log}_{10} \, (D/W^{0.33})$$

Where

- K = Scaled distance value.
- L = Airblast level (dB)
- D = Distance from source (m)
- W = Charge mass per delay (kg)

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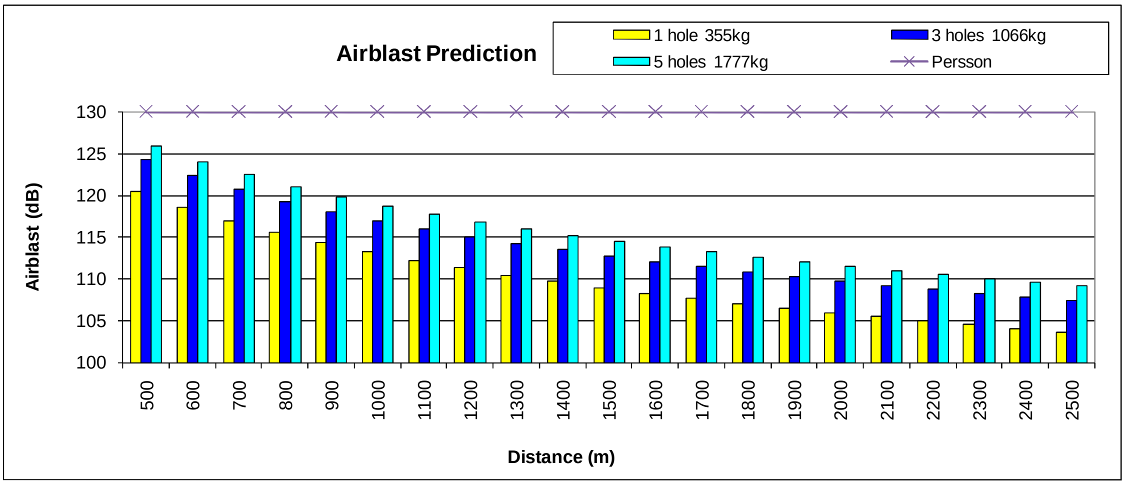
The air blast levels have been calculated using the same charge masses used for the prediction of ground vibrations. The calculated airblast levels are given in the table below. The data is graphed against the Persson recommended limit.

AIRBLAST						
Holes Detonated Per Delay	1	2	3	4	5	6
Combined charge mass firing	355	711	1066	1422	1777	2133
Distance increment in metres						
100	Production	Production	Production	Production	Production	Production
Distance (m)	**dB**	**dB**	**dB**	**dB**	**dB**	**dB**
500	120	123	124	125	126	127
600	119	121	122	123	124	125
700	117	119	121	122	122	123
800	116	118	119	120	121	122
900	114	117	118	119	120	120
1000	113	116	117	118	119	119
1100	112	115	116	117	118	118
1200	111	114	115	116	117	117
1300	110	113	114	115	116	117
1400	110	112	113	114	115	116
1500	109	111	113	114	115	115
1600	108	111	112	113	114	114
1700	108	110	111	112	113	114
1800	107	109	111	112	113	113
1900	107	109	110	111	112	113
2000	106	108	110	111	112	112
2100	105	108	109	110	111	112
2200	105	107	109	110	111	111
2300	105	107	108	109	110	111
2400	104	106	108	109	110	110
2500	104	106	107	108	109	110



The airblast levels at distances in excess of 500m from the blast were within the recommended Persson threshold limit of 130dB. As the distance from the blast increases further, the airblast levels attenuate even more and will therefore be less than the levels required to cause damage to structures.

3.4 Fly Rock.

Side effects such as fly rock are undesirable and usually occur unexpectedly, sometimes for unknown reasons. Fly rock typically originates either from the breaking face or the surface of the blast. The main causes are under burdened holes, geological discontinuities,

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poor blast timing leading to over confinement of holes and overcharged blast holes that result in hole blow outs. Secondary blasting can also produce fly rock.

Post Blast Fumes and Dust.
Explosives are formulated to be oxygen balanced to minimize fumes and optimize the energy output. Fumes such as carbon monoxide and oxides of nitrogen can be produced in the detonation process. Dust on the other hand is an inevitable consequence of blasting.

A number of factors can contribute to the creation of fumes. A number of these are mentioned below:

- Poor quality control and incorrect formulation;
- Excessively long sleep times;
- Damage to the explosive;
- Inadequate water resistance;
- Poor ground conditions;
- Premature loss of confinement;
- Inadequate priming; and
- Insufficient charge diameter.

It is difficult to ensure that post blast fumes never occur because some of the factors above are outside the blasters control. The best tools here are to ensure that strict quality control standards are in place and to exercise ongoing care and control during all stages of the charging up side of the operation.

3.5 Disturbance Monitoring – Ground Vibration and Airblast.
It is recommended that the initial blasts are monitored to record blast vibration and airblast levels. The measurements made can be used to ensure that the predicted and recommended vibration amplitudes and air blast levels are not being exceeded. The disturbance levels recorded should be compared to the predictions as well as accepted industry norms to ensure compliance with design and standard. The records give a clear indication of whether or not changes to the blast design need to be considered. The records can also be used to demonstrate compliance.

Disturbance monitoring should be carried out using industry standard seismographs. Each seismograph is equipped with a triaxial geophone and a separate microphone. This allows ground vibrations and air blast to be measured simultaneously. The ground vibrations are measured in three directions. The three primary measurements can be plotted directly against an accepted standard, the two most common being the United States Bureau of Mines (USBM) and Deutsches Institut für Normung (DIN) standards. The USBM is most commonly used in South Africa. The DIN standard is more stringent as it restricts vibration levels to lower limits than the USBM standard. Attached are two printouts of measurements taken of a blast event (Appendix 3). The first shows the data measured at a specific monitoring station plotted against the USBM standard and the second shows the same data plotted against the frequency spectrum.

Air blast can be measured at levels in excess of 100dB with the seismographs. The peak air blast level as well as the associated frequency spectrum is measured.

Seismographs can initially be positioned at potentially sensitive locations on a blast-by-blast basis. Once ongoing production blasting is underway (and if it is required), then it

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will be simpler to establish a number of permanent monitoring stations. These stations remain in place for as long as necessary and can be moved to different locations as and when required. This is useful as it shows the level of local disturbance (caused for example by storms) that goes unnoticed. A reference database should be established and all data saved here. An independent third party should carry out the ground vibration and air blast monitoring.

3.6 Mitigation Measures.

A number of measures are suggested to ensure that the drill and blast operation proceeds smoothly. Some of the measures (e.g. quality acceptance) apply to specific areas of the operation. Others apply to a number of aspects of the operation to varying degrees.

- Exercise ongoing care and control during all stages of the drilling and blasting operation. Check, check and check again.
- Prior to charging up the blast, the holes drilled should be inspected and all ‘problem’ holes identified for corrective action. Examples of ‘problem’ holes could include holes that are under burdened, holes that are short drilled, holes surrounded by badly cracked ground and off pattern holes that could potentially lead to problems.
- Production QC checks must be implemented as part of the Standard Operating Procedures. This is particularly important if bulk explosives are being used. During charging up of the holes the bulk explosive product should be sampled on an ongoing basis to ensure acceptable quality. The explosive’s supplier should have standard operating procedures in place to address this issue. These procedures should be shared with the end user.
- After charging up is complete and prior to stemming the holes closed, the holes should be taped to determine the explosive column rise to ensure that the required stemming length is obtained. Any errors must be corrected before the hole is stemmed closed.
- The tie up should be carried out according to the blast plan to ensure that the timing and sequencing of the blast proceeds as planned.
- Avoid prolonged sleeping of blasts particularly in wet ground conditions. It is preferable to charge and blast in the shortest possible time frame.
- If fumes occur after a blast then the area must be kept clear until these have dissipated. The stipulated re-entry times must be enforced.

Keep accurate and comprehensive blast records. All of the blast parameters as well as the timing and sequencing used to delay the blast should be recorded, as the individual seismograph measurements made need to be linked to the blasts. The blast information can be referenced and used to assist with future blast designs. To facilitate this, the drill and blast contractor should keep accurate records of the following, which are essential inputs to the blast vibration report:

- Blast type (e.g. reef, parting, pre-split, overburden etc.);
- Hole diameter drilled;
- Final drilled hole depths;
- Blast pattern – burden and spacing dimensions, number of rows and number of holes per row, position of the cut and the cut design;
- Total number of holes per blast – design and actual;
- Position of any additional or relieving holes;
- Any irregularities in the blast such as under burdened or overburdened holes;
- Explosive type used to charge the blast;

- Explosive charge mass per individual hole and the total amount of explosive used per blast;
- The explosive column rise and the final stemming length achieved;
- Details of the final blast tie up with a schematic showing the position and value of the time delays used as well as the number of holes per delay;
- The date and time of firing the blast.
- The weather conditions and the wind direction at the time of the blast,

4. Knowledge Gaps.
The prediction of the possible disturbance levels at various distances is based on reasonable assumptions regarding the blast patterns to be drilled and blasted. Generally accepted equations and modeling methods were used to perform the calculations on which the predictions are based. However, prior to the start of the drill and blast operation these figures must be reviewed to correct for any variances between ‘actual’ versus ‘modeled’.

5. General Information.
The scope of this report was to assess the potential impact of blasting activity on areas surrounding the proposed mine development and focused on:

- Prediction of ground vibration for increasing charge mass at various distances;
- Prediction of air blast as above; and
- Assessment of unwanted side effects such as fly rock, post blast fumes and dust.

The report was compiled to provide input to assist with information required to assess proposed management measures as well as possible alternatives. It addresses routine ongoing drill and blast applications.

My (alphabetical) customer base includes the following companies: African Coal Trading, Afridex (DRC), Anglo Platinum at various operations, Aquarius Platinum Marikana Mine, Bombela Consortium, Bulk Mining Explosives, Enviro Blast, Exxaro, Gecamines (DRC), imPafa Technologies, Impala Platinum, Izimbiwa Coal, Lonmin, Lyttelton Dolomite, Mashala Resources, MCC, Moolman Mining, Mubiji Mayi (DRC), Murray and Roberts, NuCoal, Pretoria University, Shanduka Colliery, Tharisa Minerals, Total Coal, Tselentis Mining and Xstrata Coal and alloys.

This report was prepared by Erik Kohler, B.Sc. Geology (UCT). I operate independently and with associates on an as and when required basis. This allows the services and expertise of other professionals who offer specialised services and/or equipment for a specific need to be accessed. I have no vested interest in the projects that I am involved in other than to be compensated for the services that I render, which is a normal requirement.

6. Consultation with interested and affected parties (IAPs).
No specific consultation was undertaken or deemed necessary as part of this study. Comments made by IAPs were not forwarded to me for inclusion in this study.

7. NEMA Regs (2014).
This vibration impact assessment has been compiled in accordance with requirements of the National Environmental Management Act, 107 of 1998 (NEMA) and Appendix 6 of the Environmental Impact Assessment Regulations (GN R982), which outline the specific requirements for specialist reports. The table below indicates the location of each requirement in this report.

NEMA Regs (2014) - Appendix 6	Reference to section of specialist report or justification for not meeting requirement.
A specialist report or a report on a specialised process prepared in terms of these Regulations must contain -	
Details of the specialist who prepared the report.	Section 5.
The expertise of that person to compile a specialist report including curriculum vitae.	Section 5.
A declaration that the person is independent in a form as may be specified by the competent authority.	Section 5.
An indication of the scope of, and the purpose for which, the report was prepared.	Section 5.
The date and season of the site investigation and the relevance of the season to the outcome of the assessment.	N / A
A description of the methodology adopted in preparing the report or carrying out the specialised process.	Section 4.
The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure.	Section 2.
An identification of any areas to be avoided, including buffers.	Sections 3.2 and 3.3
A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers.	Appendix 1.
A description of any assumptions made and any uncertainties or gaps in knowledge.	Section 4.
A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment.	Sections 3.2 and 3.3
Any mitigation measures for inclusion in the EMPr.	Section 3.6
Any conditions for inclusion in the environmental authorisation.	Section 8
Any monitoring requirements for inclusion in the EMPr or environmental authorisation.	Section 3.5
A reasoned opinion as to whether the proposed activity or portions thereof should be authorised; and	Section 8
If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan.	Section 8
A description of any consultation process that was undertaken during the course of carrying out the study.	Section 6
A summary and copies if any comments that were received during any consultation process.	Section 6
Any other information requested by the competent authority.	Section 5

8. Recommendations.

- The modelling results indicate that the disturbance levels that could be experienced at various locations around the planned mine will not cause damage to surface infrastructure when a single hole is fired. Individual hole firing is therefore required. This can be achieved through the use of electronic detonators.
- The first blasts should be audited. Aspects such as pattern layout, hole depths, method of charging holes, explosive column rise, stemming length and finally the timing and sequencing of the blast must be checked and verified to ensure that these comply with the design criteria.
- The charging operation must be accurately controlled. Overcharged holes can result in excessive airblast and flyrock and are therefore unacceptable. It is

therefore essential that the correct control measures are put into place from day one to help control and minimise the disturbance levels.

- The blasts should be monitored at a number of pre-selected locations around the mining operation. This will allow the disturbance levels to be measured. Industry approved seismographs capable of recording ground vibration and airblast simultaneously should be used for this. The monitoring locations will need to be decided on prior to the first blast being set off.
- After the first blast the actual measurements made must be compared to the predictions. The design can then be remodelled if required.

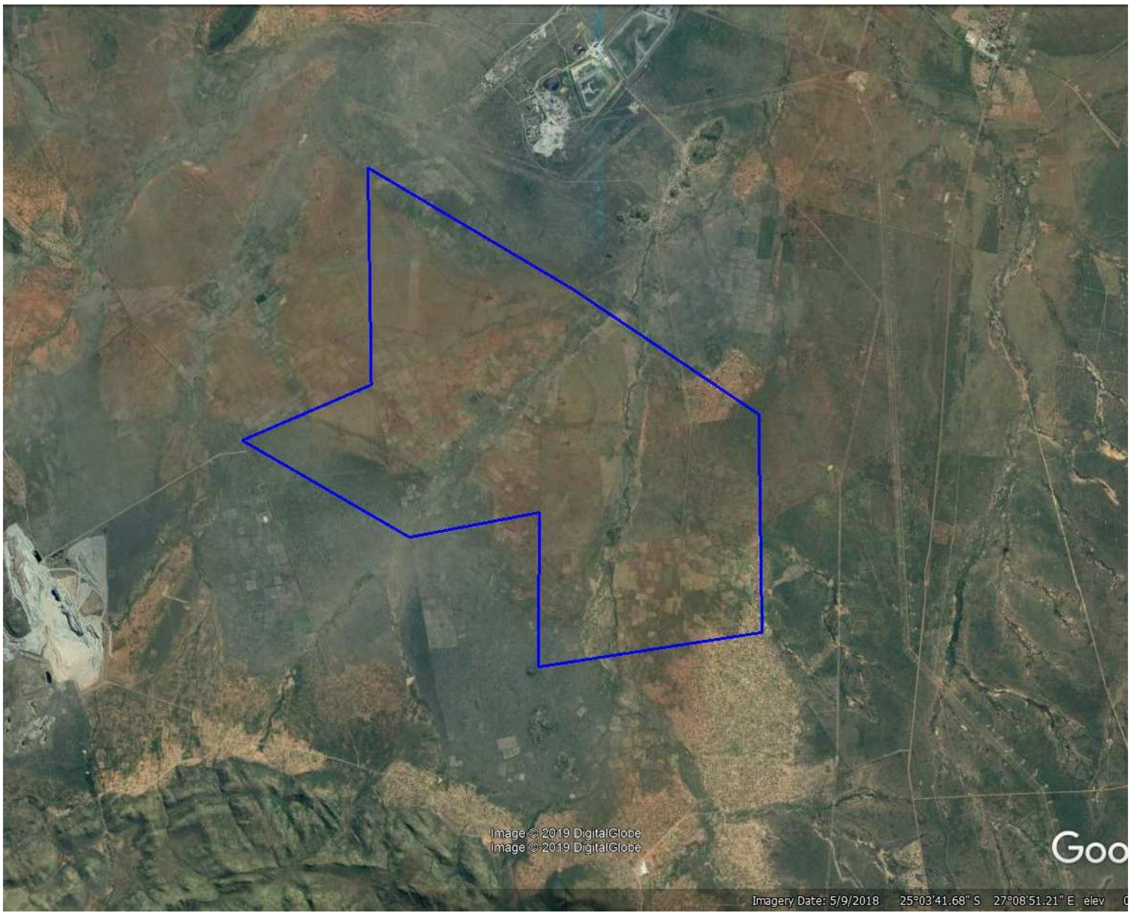
If the drill and blast procedures are well controlled and executed then there is no reason why this activity should not be authorised and carried out. It follows that the mitigation measures/recommendations and monitoring requirements as outlined in this report should form part of the conditions of the environmental authorisation.

If you have any queries regarding the above, please contact me at 083 488 1392.

Yours sincerely

E. Kohler

Erik Kohler.



<u>Appendix 1</u>. Google Earth view of the general area in the vicinity of the proposed mine development.

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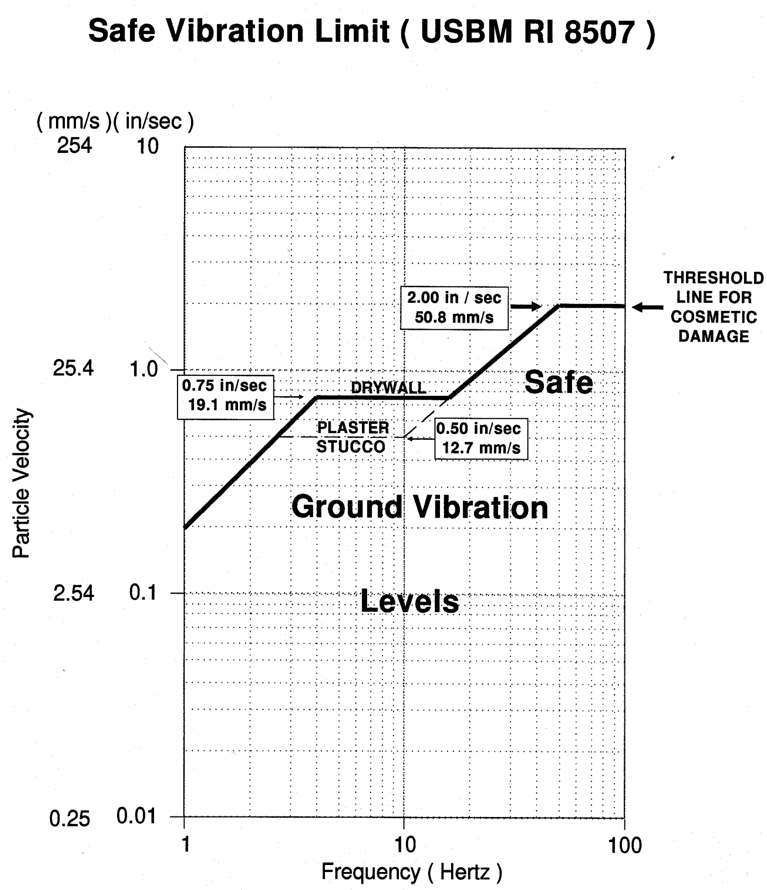
Vibration and Air Blast Limits.

Ground Vibration - Building response to ground vibration.
Although there are no legislated limits to vibration, the United States Bureau of Mines (USBM) limits are commonly applied in South Africa. The limiting curve is shown in Graph 1 and has been developed from empirical studies (Siskind *et.al.* 1980).



Graph 1. USBM curve that is generally used in South Africa. (After Chiappetta, March 2000)

The limiting curve in Graph 1 represents the limit for cosmetic damage to a house. The maximum ground vibration amplitudes are frequency dependent with higher frequencies allowing higher peak amplitudes. Most modern blasting seismographs will display the vibration data in terms of the USBM limiting criterion. In general, at lower frequencies, the ground vibration should not exceed 12.7 mm/s, but at higher frequencies, the limit can increase to 50 mm/s.

Appendix 2: Vibration and Airblast Limits.

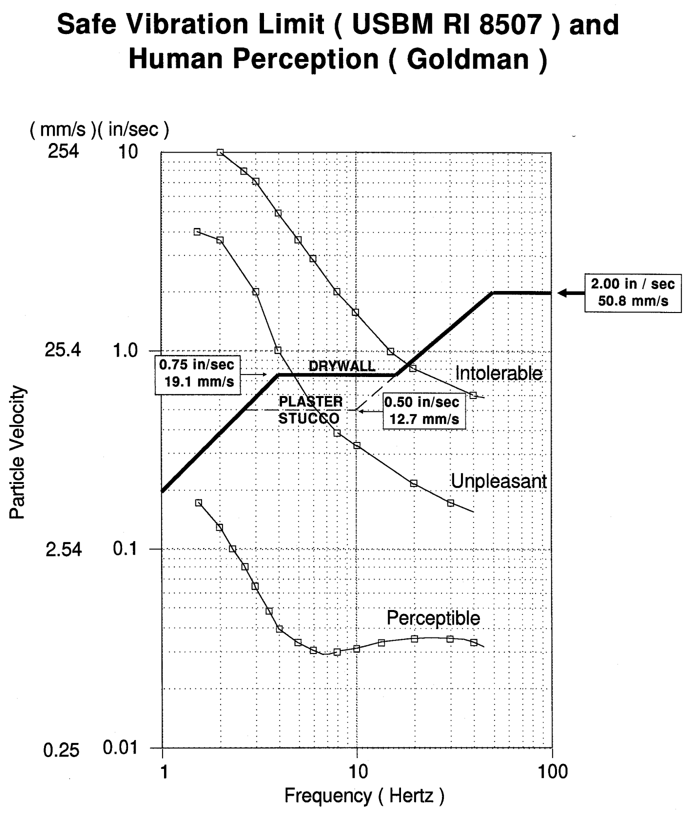
Human response to ground vibration.

Although buildings can withstand ground vibration amplitudes of 12.7 mm/s or more, depending on the frequency, human beings are easily disturbed at lower levels. The typical human response to ground vibration is illustrated in the table below.

Effects on Humans	Ground Vibration Level mm/s
Imperceptible	0.025 – 0.076
Barely perceptible	0.076 – 0.254
Distinctly perceptible	0.254 – 0.762
Strongly perceptible	0.762 – 2.540
Disturbing	2.540 – 7.620
Very disturbing	7.620 – 25.400

Human response to vibration (Chiappetta, 2000)

Ground vibration levels of 0.76 to 2.54 mm/s received at a structure are quite perceptible, but the probability of damage is almost nonexistent. Levels in the 2.54 to 7.6 mm/s can be disturbing and levels above 7.6 mm/s can be very unpleasant, although permanent damage is unlikely.



Graph 2. Human response curves compared with potential damaging limits. (After Chiappetta, 2000).

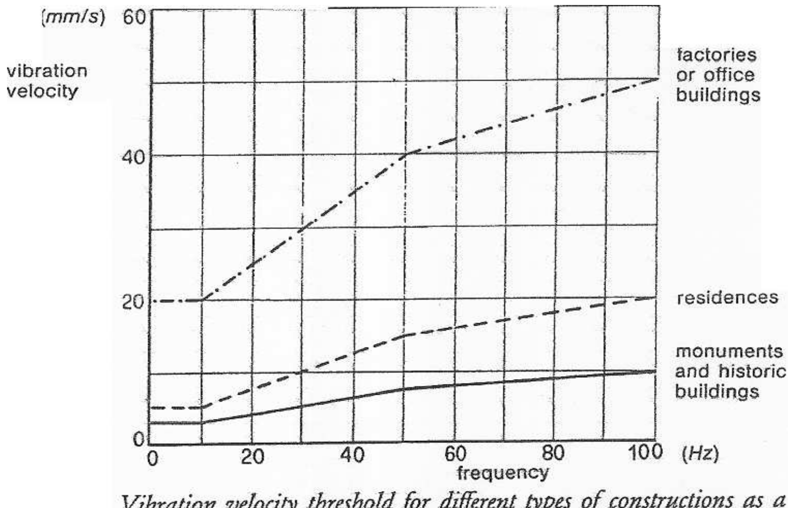
Appendix 2 (cont): Vibration and Airblast Limits.

Human perception is also affected by frequency. The approximate human response curves are combined with the USBM limiting curve for damage in Graph 2. These curves slope in the opposite direction. In other words, humans are more tolerant to low frequency vibrations.

To avoid damaging buildings, the USBM limiting curve should be applied. However, to avoid constant complaints from neighbours, the vibration should preferably be kept beneath the *unpleasant* curve and definitely be kept beneath the *intolerable* curve.

<u>Deutsches Institut für Normung - DIN STANDARD 4150 (Western Germany, 1983)</u>. Limit values of vibration are expressed in mm/sec.

Recording spots / Type of structure	Foundations			Floor of the highest storey of the building
	< 10 *Hz*	10 – 50 *Hz*	50 – 100 *Hz*	Any frequency
1. Office or factory building	20	20 – 40	40 – 50	40
2. Residential building with plastered walls	5	5 – 15	15 – 20	15
3. Historic and other buildings to be treated with care	3	3 – 8	8 – 10	8
With frequencies > 100 Hz higher levels may be accepted				



Vibration velocity threshold for different types of constructions as a function of frequency, as defined by DIN STANDARD 4150 (West Germany)

It may be prudent to apply the DIN standard where 3rd world housing is encountered, as these buildings are often poorly constructed.

<u>Appendix 2 (cont)</u>: Vibration and Airblast Limits.

Air Blast Limits.

As with ground vibration, there are no legislated limits to air blast amplitudes caused by blasting activity.

Siskind *et.al.* (1980), indicate that 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) have published the following estimates of damage thresholds based on empirical data.

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.

Damage thresholds for air blast.

References.

Siskind, D.E., Stagg, M.S., Kopp, J.W. & Dowding, C.H., 1980. *Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting,* U.S. Bureau of Mines RI 8507.

Chiappetta, R.F., 2000, *Vibration/airblast controls, Damage criteria, record keeping and dealing with complaints*. The Institute of Quarrying, Southern Africa, Symposium, Durban

Persson, P-A, Holmberg, R and Lee, J, 1994, *Rock Blasting and Explosives Engineering*. CRC Press, USA.

Siskind, D.E., Stachura, V.J., Stagg, M.S. & Kopp, J.W., 1980. *Structure Response and Damage Produced by Airblast from Surface Mining,* U.S. Bureau of Mines RI 8485

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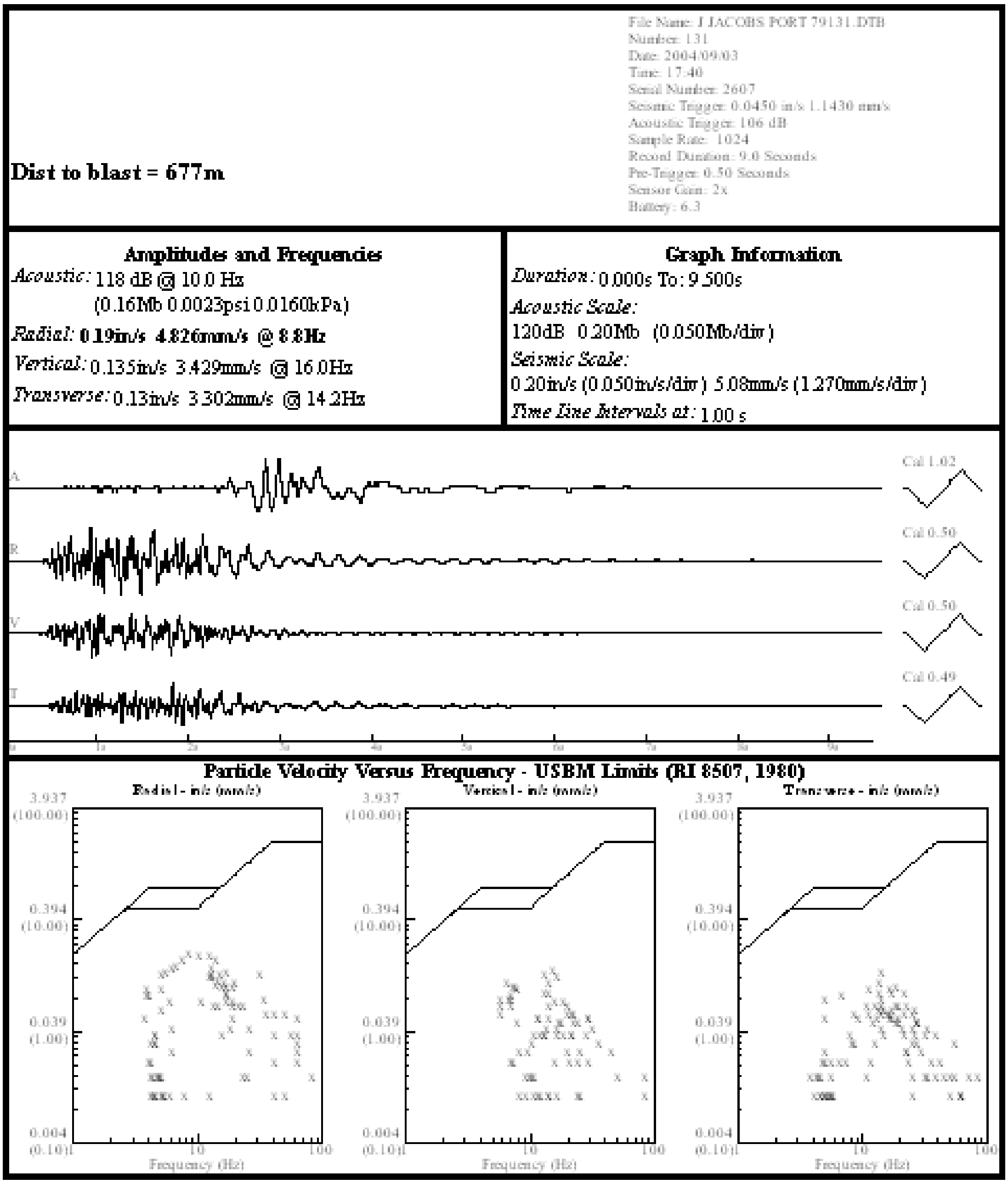
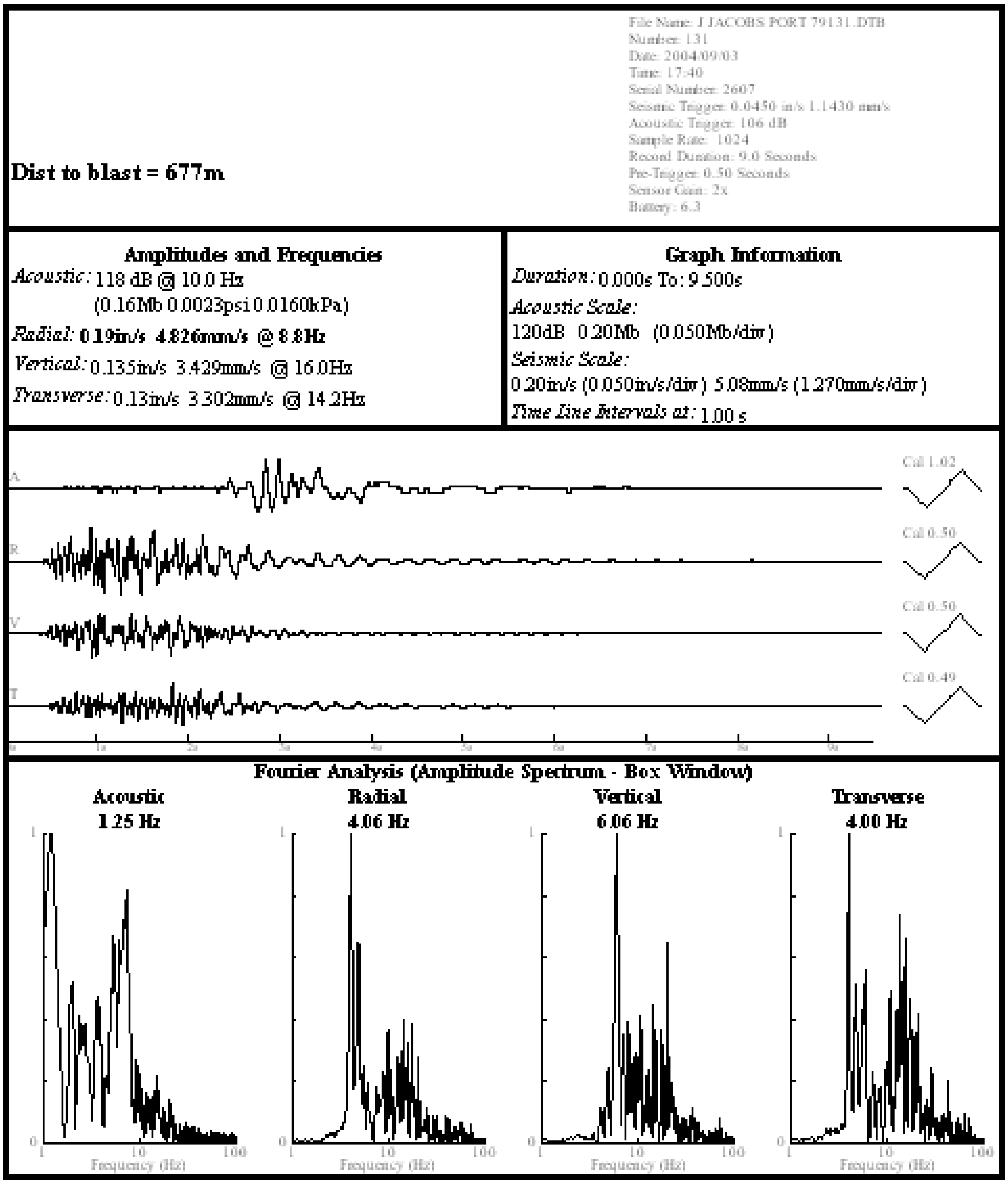


<u>Appendix 3</u>: Vibration and Airblast Data plotted against the USBM Standard.



<u>Appendix 3 (cont)</u>: Vibration and Airblast Data plotted against frequency.