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Noise and Vibration Impact Assessment,
Wabush 3 Pit, West Labrador

Prepared For:

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EXECUTIVE SUMMARY

HGC Engineering was retained by Iron Ore Company of Canada ("IOC") to undertake a noise and vibration impact feasibility study of the proposed Wabush 3 Pit near West Labrador, Labrador. This assessment addresses three related emissions from the proposed project: The environmental noise associated with the operation of equipment within the boundaries of the new pit, the airblast, or overpressure created during rock blasting in the new pit, and ground borne vibration caused by blasting.

Sound power emission levels for each item of equipment proposed for use in Wabush 3 were obtained either from sound level measurements of existing IOC operations or from manufacturer's published sound levels. These source levels were used along with geometrical and topographical information about the site and surrounding area to develop a predictive acoustical computer model, in order to compute the offsite sound levels at the noise sensitive receptors (Hospital, college, dwellings in town, Menihek Ski Lodge, Smokey Mountain Ski Lodge, etc).

The results of the analysis indicate that the predicted operational sound levels will be within the limits of Health Canada and the International Finance Corporation (of the World Bank) guidelines. In regards to blast vibration and airblasts we were not able to make accurate predictions based on the available data. The predictions based on typical formulae indicate significant vibration and sound level excesses could occur. Once more blast monitoring data is collected it will be possible to make predictions which are more attuned to the circumstances at IOC. At that time, it will also be possible to begin considering particulars of the blast design, or meteorological restrictions on blasting times, in order to restrict impacts to acceptable levels.

Details of the measurement and analysis methods, results and recommendations are detailed in the main body of the report.

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1 INTRODUCTION

As requested, Howe Gastmeier Chapnik Limited ("HGC Engineering") has undertaken an assessment of the projected noise and vibration emissions of the proposed Wabush 3 pit at the Iron Ore Company of Canada ("IOC") mine in Labrador City, Labrador. Three related emissions are addressed: The environmental noise associated with the operation of equipment within the boundaries of the new pit, the airblast, or overpressure created during rock blasting in the new pit, and ground borne vibration caused by blasting.

The environmental noise component of the study is based on source sound levels obtained from our files for similar equipment, and on measurements made at the existing IOC operation. The predictions and assessment of blasting noise and vibration are based on established engineering prediction methods, and on a limited amount of noise and vibration monitoring data provided by IOC. This assessment focuses solely on the proposed Wabush 3 pit operations and does not include an assessment of existing IOC operations.

Several other Noise and Vibration studies have been completed in the past by others, including a *Baseline Noise Survey for the Proposed Wabush 3 Mine Site* in November 2012 [1], *Prediction of Blasting Noise/Vibration Levels at the Existing and Proposed Hospital and College Sites* in April 2008 [2], and *Noise and Ground-Borne Vibration Monitoring*, November 2007 [3].

2 SITE DESCRIPTION

The IOC mine at Labrador City has been in operation since the 1950s, and several pit areas have been mined since that time. The mine is located north of Labrador City in West Labrador. Figure 1 illustrates the mine in relation to the surrounding land uses.

As shown in Figure 1, the existing Luce pit is the pit area which is closest to the town, and also to the nearby Smokey Mountain Alpine Ski Club and the Menihek Nordic Ski Club. For the most part, blasts in the Luce pit have occurred at least 5000 metres from the closest parts of the town. The new Labrador City hospital, now under construction, will be one of the closest in-town buildings to the mine area, and will be located about 4900 metres from the Luce pit. The blasts closest to the two ski lodges which have occurred in the Luce pit have been about 2560 metres away. Because of the orientation of the Smokey Mountain ski area, the top of the lift equipment is located about 2000 metres from the edge of the Luce pit.

The new Wabush 3 pit will be closer both to the town and to the ski clubs. Figure 2 shows the identified points of reception while Table 1 summarizes the estimated minimum distances from past blasting operations at the Luce pit and proposed blasting at the Wabush 3 pit to the various receptor locations.

Table 1: Distances from Existing and Future Pits to Offsite Receptor Locations

Location	Receptor ID	Estimated Distance from Closest Blasts to Receptor [m]	
		Existing Luce Pit	Proposed Wabush 3 Pit
New Hospital and College	R1 / R2	4920	2400
Centre of Labrador City	R3	6250	3920
Harry Lake Subdivision	R4	6210	3590
Smokey Mountain Ski Lodge	R5	2560	880
Dumbbell Lake Residence	R6	2600	940
Menihek Ski Lodge	R7	2800	1110
Menihek Ski Trails*	R8	780	370
Menihek Ski Trail - Summit	R9	3030	1430
Smokey Mountain – Top of Lifts	R10	1990	240

*Note – closest trail to mine (a portion of the Koch trails forming a loop) is to be removed since it directly conflicts with the new pit. Different trails are therefore used for the existing and proposed cases throughout this report.

3 CRITERIA FOR ENVIRONMENTAL NOISE

There are no specific technical guidelines for assessing the acoustic impact of the mining facility on residential properties published by the province of Newfoundland / Labrador. The guidelines of Health Canada and the World Bank / World Health Organization are described herein.

3.1 Health Canada

Health Canada has recently prepared and is in the process of publishing the *Useful Information for Environmental Assessments* [4] which provides guidance for stakeholders with respect to human health and effects related to noise in environmental assessments (EA). Health Canada does not enforce these noise limits. The responsibility of enforcing noise limits is left to the Department of Environment and Conservation of Newfoundland and Labrador.

Specific criteria and assessment methodology are provided under Section 6 of the above noted document. For long term construction (more than one year) and for operations with noise levels between 45 and 75 dB, Health Canada recommends the health impact of a project be evaluated on the change in the percentage of the population who become highly annoyed (“%HA”). Where the predicted change in %HA at a specific receptor is greater than 6.5% between the project and baseline noise environments or when the project sound level exceeds 75 dB when measured on a linear or un-weighted scale, Health Canada suggests mitigation be proposed.

A relationship between the percentage of a population expressing high annoyance to aircraft, road traffic, and railway noise and the corresponding A-weighted day/night sound level is determined from *ISO 1996-1:2003 Acoustics – Description, measurement and assessment of environmental noise* [5]. For industrial noise the determination of %HA is as follows:

$$HA = \frac{100}{1+e^{(10.4-0.132L_{dn})}}\% \qquad \text{Equation 1}$$

The day/night sound level (L_{dn}) is a whole-day rating level determined by calculating a weighted energy average of the daytime (07:00-22:00) sound level (L_d) and the nighttime (22:00 – 07:00) sound level (L_n) including any adjustments for sound sources or characters. The nighttime level is weighted upwards by 10 dB to account for the increased annoyance during typical sleeping hours. Health Canada also suggests an adjustment of +10 dB to the project sound level where the project is undertaken in a quiet rural area. For this particular site, considering IOC has been in operation for nearly 60 years in the area the latter adjustment for quiet rural areas has not been included.

Useful Information for Environmental Assessments indicates that the limits apply at “all potential noise-sensitive receptors”, which “may include residences, daycares, schools, hospitals, places of worship, nursing homes, and First Nations and Inuit communities”. While outdoor areas such as campgrounds, where people would be expected to sleep, are often considered to be noise-sensitive, areas for active outdoor recreation such as skiing would not normally be considered to be noise-sensitive receptors. However, the acoustic impact of IOC on these areas remains of interest and is included in this document for reference purposes.

3.2 World Bank

The environmental noise guidelines from the International Finance Corporation (“IFC”) of the World Bank [6] are also applicable to this site. This document uses the term “stationary source” to refer to an industrial site, or equipment within the fixed boundaries of such a site, that can emit sound to the surrounding environment. As well, the document uses the term “background sound” to denote the total of all sound *excluding* that produced by the stationary source(s) under assessment. The IFC guideline stipulates that short-duration intrusive noises, such as aircraft flyovers and passing trains, should be excluded when establishing background sound levels.

The noise limits in the IFC guideline are site-specific, and vary depending on the characteristic background sound at any neighbouring, sound-sensitive points of reception. Typically, a sound-sensitive point of reception is considered to be a residential area, school, church, hospital, etc. In areas where the background sound can be low, the applicable limits for a stationary source are 55 dBA during daytime hours (07:00 to 22:00) and 45 dBA at night (22:00 to 07:00). In areas where the background sound is characteristically greater than 55/45 dBA, day/night, the sound of the stationary source should result in an increase in total sound level of no more than 3 dBA, relative to the background sound level. (In this latter case, the limit varies according to the minimum background sound during the day/night periods.) A 45 dBA nighttime limit is consistent with the guidelines of the World Health Organization for sleep disturbance [7].

The IFC guideline stipulates that, in order to establish the characteristic background sound levels in a sound sensitive area, monitoring should be conducted for at least 48 hours continuously, with results compiled on an hourly basis (one-hour L_{EQ}).

3.3 Applicable Sound Level Criteria

Health Canada and the IFC guidelines include criteria dependent on the existing background sound at the receptor locations. Therefore a sound level monitoring campaign was undertaken by HGC Engineering between April 8 and April 14, 2014 to determine the existing background sound levels.

In this regard, automated sound level monitors were deployed to continuously record the L_{EQ} and L_{90} sound levels, in A-weighted decibels, over periods of 10-minutes at the surrounding receptors. Data was collected at nine monitoring locations through two, three day campaigns. Figures 3 to 11 show the monitored sound level data. Sound levels at receptor locations within or close to town were dominated by road traffic, snow mobile traffic and the typical urban hum. The monitoring locations around Smokey Mountain Ski Hill and Menihek Nordic Ski Club were dominated by natural sources, the operation of the ski hill and by existing IOC operations. The attended sound levels and site observations are summarized in Appendix A. Table 2 summarizes the automated sound level data.

Table 2: Summary of Automated Sound Level Data and Applicable Criteria [dBA]

Location	Receptor ID	Health Canada		World Bank		
		Day/Night L_{DN}	%HA	Minimum L_{EQ} (1hr)		Criteria (1hr)
				Day	Night	
New Hospital	R1 / M1	44	1.7	39	35	45
College	R2 / M1	44	1.7	39	35	45
Indian Point	R2 / M2	47	1.5	37	23	45
Harry Lake Subdivision	R4 / M3	47	1.5	37	23	45
Smokey Mountain Ski Lodge	R5 / M4	55	4.1	38	35	45
Dumbbell Lake Residence	R6 / M4	55	4.1	38	35	45
Menihek Ski Lodge	R7 / M5	35	0.3	28	30	45
Menihek Ski Trails*	R8 / M6	45	1.1	34	32	NA
Menihek Ski Trail – Summit*	R9 / M7	50	2.2	40	32	NA
Smokey Mountain – Top of Lifts*	R10 / M8	50	2.2	34	28	NA

*Points of Interest

The automated sound level data indicates that during quiet daytime and nighttime hours the hourly sound levels can be as low as 23 dBA. Day/Night sound levels can be as low as 35 dBA in the more remote locations (ski hill area) and approximately 45 dBA at the in-town locations. Observations indicated that at Smokey Mountain Ski Lodge and the Dumbbell Lake Residence the operation of the ski hill significantly affected the sound level data.

4 CRITERIA FOR BLASTING NOISE AND VIBRATION

4.1 Blasting Vibration

Criteria for Cosmetic Structural Damage

Vibration is typically measured in terms of oscillatory displacement, velocity or acceleration. For blast vibration, most references refer to vibration velocity in units of in/s or mm/s peak. In addition to considerations of the level or amplitude of vibration, another important vibration quantity is the frequency of vibration (the rate of oscillation), generally discussed in units of Hertz (Hz).

Most guidelines for allowable levels of blast vibration which are used in North America are based on criteria developed by the US Federal Office of Surface Mining Reclamation and Enforcement (“OSM”) or reports of the former US Bureau of Mines (“USBM”).

The OSM provides three different methods for assessing blast vibration, two of which (OSM Method 1 and OSM Method 2) make no consideration of vibration frequency, and so are easier to implement, but tend to be more conservative. Method 1 requires vibration monitoring and provides a maximum allowable vibration for receptors at various distances from a blast operation. Method 2 provides a minimum scaled distance factor (a combination of explosive weight and distance). These are summarized in Table 3. The limits apply at any offsite dwelling, school, church, or public, community, or institutional building.

Table 3: OSM Criteria (Methods 1 and 2)

Distance from Blast Site	Maximum Allowable Particle Velocity	Minimum Required Scaled Distance Factor
0 to 91 m (0 to 300 ft)	32 mm/s (1.25 in/s)	50
92 to 1524 m (301 to 5000 ft)	25 mm/s (1.00 in/s)	55
> 1524 m (> 5001 ft)	19 mm/s (0.75 in/s)	65

Many standards make reference to USBM report RI8507 [8]. That report cited a limit for modern homes with drywall interiors of 19 mm/s (0.75 in/s), although the limit is relaxed at higher frequencies (greater than 40 Hz). Other standards, such as the Ontario Ministry of the Environment publication NPC-119 [9] use a more conservative limit of 12.5 mm/s (0.5 in/s) when routine monitoring of the vibration is conducted.

Both the OSM and USBM guidelines have a more complex criterion option which is frequency dependant. These criteria are the least conservative of the typical assessment methods since they allow for a more rigorous assessment of the measured vibration. These are summarized in Figure 12.

Criteria for Sensitive Uses

The above limits are intended to guard against cosmetic damage to structures. The new hospital and college are located relatively near to the Wabush 3 site. These types of buildings can present an additional complication, since many types of equipment used in hospitals and research settings are far more sensitive to vibration than are building constructions. The 1989 version of ISO standard 2631-2, *Evaluation of human exposure to whole-body vibration – Part 2: continuous and shock-induced vibration in buildings (1 to 80 Hz)* [10], as well as the current (2007) version of ISO standard 10137, *Bases for design of structures – Serviceability of buildings and walkways against vibrations* [11] provide a limit for critical working areas such as some hospital operating-theatres and precision laboratories, which is shown in Figure 12, and compared to the more typical blasting criteria.

Criteria for sensitive instruments such as microscopes are even more stringent. Generic spectral vibration criteria for different classes of sensitive equipment are generally based on the “VC” curves, variously referred to as the BBN criteria or the IEST criteria. The curves are identified as VC-A (the least restrictive, typically applied to low power optical microscopes and other minimally sensitive equipment) to VC-E (very restrictive: long path, laser based, small target systems and other highly sensitive systems). A common standard defining these criteria is the 2007 guide IEST-RP-CC012.2, *Considerations of Cleanroom Design* [12], published by the Institute of Environmental Sciences and Technology (IEST). The VC-A criterion is also shown in Figure 12.

Ski Lift Equipment

Ski lift equipment is naturally subject to vibration as part of its routine operation, and some form of elevated criteria is likely appropriate. A series of vibration velocity measurements were conducted on one of the yellow lift ski poles at Smokey Mountain during operation of the equipment to capture information related to background vibration on one of the poles, and the results are shown in Appendix B. The measurements indicate that at the measurement location, a height of about 2.6 metres on pole number 7, horizontal direction vibration velocity in the range of about 12 to 14 mm/s is regularly experienced during operation of the lift.

Regardless of current vibration experienced by the lift equipment due to its operation, it is reasonable to restrict blast-induced vibration below the acceleration of gravity (9810 mm/s^2) to avoid the potential for the ski lift cable to jump off the guide wheels. Because there will be resonant frequencies of the structure which will amplify ground vibration at specific frequencies, ground vibration should be less than this value.

To describe a vibration acceleration in terms of vibration velocity, it is necessary to know which frequencies of vibration are most relevant. As an example, the vibration data provided by IOC shows a strong frequency component at about 14 Hz for many of the blasts. A vibration acceleration of 9810 mm/s^2 is equivalent to 112 mm/s at 14 Hz. If any of the poles have resonances involving vertical-direction vibration which are in this frequency range, amplification could occur, and therefore ground vibration would need to be restricted to below this level.

In any case, the degree of amplification and the exact frequencies of structural resonances in the lift equipment will of course depend on the particulars of each individual pole. Although a detailed assessment of allowable vibration on the equipment has not been undertaken at this time, it is clear that careful consideration will need to be given to the design of blasts near to the lift equipment, and to the design of any future lift equipment which may be considered for the area.

Avalanche

There may also be some risk of vibration (or airblast) inducing avalanches on the steeper portions of the alpine ski trails. We are not aware of any criteria governing safe levels of vibration mitigating avalanche risk.

4.2 Airblast

For assessment of air blast amplitudes, both OSM and USBM documents make reference to criteria which are dependent on the ability of the monitoring instrumentation to detect low frequency sound. For large scale blasts, the airblast tends to be characterized by very low frequency pressure waves. Since the sensitivity of monitoring equipment to low frequency sound varies, the criteria summarized in Table 4 are more conservative for instruments with less sensitivity to low frequencies (i.e., for instruments with higher high-pass cutoff frequencies). Criteria in units of both dB and psi are included in Table 4, although this report utilizes units of dB herein.

Table 4: OSM and USBM Criteria for Airblast

Highpass Cut-off Frequency of Measurement Instrumentation [Hz]	Maximum Allowable Airblast [dB]	Maximum Allowable Airblast [psi]
0.1 Hz	134	0.015
2 Hz	133	0.013
6 Hz	129	0.0082
C-weighted slow response of a sound level meter	105	0.00052

These criteria are somewhat conservative, as many references indicate 140 dB as a safe level, with some breakage of window glass expected near 150 dB, and general breakage near 170 dB.

The Ontario Ministry of the Environment uses a standard limit of 128 dB, reduced to 120 dB if routine monitoring is not undertaken.

5 DESCRIPTION OF OPERATIONS

Operational plans for the pit have been developed by IOC which were used to evaluate sound emissions from mine operations. Rock drills will be used to drill the blast pattern; following blasting, material will be loaded in haul trucks by rope shovels which will transport the material to the waste rock area, the PODS crusher or to the #2, #3 or #4 Pockets. Sound emissions from equipment operating outside of the Wabush 3 Pit area have not been included herein.

IOC has indicated the mine will operate 24 hours per day. Extraction will occur in a number of benches with depths of approximately 13.7 meters (45’) per bench.

Equipment considered for the purposes of this study include: up to three rock drills, two rope shovels, 10 haul trucks, a rubber tired dozer, two tracked dozers, a water/sand truck and two graders. Table 5 provides the make and model numbers of the equipment.

Table 5: Proposed Equipment for Wabush 3

Description	Make	Model	Quantity
Electric Blasthole Drills	P&H	320XPC	3
Electric Rope Shovel	P&H	2800XPC	2
Haul Trucks	Komatsu	930E	10
Rubber Tired Dozer	CAT	844	1
Tracked Dozer	CAT	D10	2
Water / Sand Truck	Komatsu	830	1
Grader	CAT	16M	2

6 ANALYSIS

6.1 Operational Noise

In order to predict the worst-case impact of the facility as a whole (Wabush 3), the acoustically significant sources listed above were identified through discussions with personnel from the mine. A 3-dimensional acoustical computer model of the facility was developed using digital terrain information provided by IOC (2018 Pit Plan), satellite imagery, site drawings, and sound power emission levels of all of the equipment and activities on site. The model was developed using *Cadna/A* software (version 4.4.145), which is a computer implementation of ISO Standard 9613-2, "Acoustics – Attenuation of Sound during Propagation Outdoors – Part 2: General Method of Calculation" [13].

Vehicle routes for Haul trucks, graders and the water/sand truck were modeled as line sources whereas the stationary sources (drills, shovels, etc.) were modeled as point sources.

Source sound power levels for the proposed equipment were based on sound level measurements of existing IOC operations. HGC Engineering completed sound level measurements on April 12, 2014 utilizing a Norsonic model N140 Precision Sound Level Analyzer. The resulting sound power levels are provided in Table 6.

Table 6: Equipment Sound Power Levels [dB re 10^{-12} W]

Source				**Octave Band Centre Frequency [Hz]**						
	31	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**	**dBA**
Electric Blasthole Drill	114	110	111	115	118	115	116	113	111	122
Electric Rope Shovel	-	128	119	116	116	115	111	103	99	119
Haul Trucks	125	131	127	124	124	118	119	116	110	126
Rubber Tired Dozer	117	114	122	114	109	109	111	103	97	116
Tracked Dozer	118	119	122	119	117	109	115	106	98	120
Water / Sand Truck	126	131	126	126	124	117	117	113	110	125
Grader	110	107	117	106	106	107	103	101	93	111

The data presented above is consistent with past measurements of similar equipment by HGC Engineering at other sites and other publicly available information.

The sound power emission levels of each source were input to the model, which was used to compute the off-site sound pressure levels according to the ISO 9613-2 Standard. Tables 7 and 8 show the predicted sound levels at the receptor locations.

Table 7: Predicted Sound Levels [dBA] – Health Canada

Location	Receptor ID	L_{DN} [dBA]	%HA	L_{EQ} [dB]	Criteria	
					%HA*	dB
New Hospital	R1	41	0.7	56	7.5	75
College	R2	30	0.2	49	7.5	75
Centre of Labrador City	R3	40	0.6	56	8.0	75
Harry Lake Subdivision	R4	41	0.7	56	8.0	75
Smokey Mountain Ski Lodge	R5	51	2.5	62	10.6	75
Dumbbell Lake Residence	R6	51	2.5	62	10.6	75
Menihek Ski Lodge	R7	51	2.5	63	6.8	75
Menihek Ski Trails**	R8	57	5.3	68	NA	NA
Menihek Ski Trail – Summit**	R9	53	3.2	64	NA	NA
Smokey Mountain – Top of Lifts**	R10	51	2.5	63	NA	NA

*includes the allowable 6.5% increase from Health Canada
**Points of Interest

Table 8: Predicted Sound Levels [dBA] – World Bank / World Health

Location	Receptor ID	L_{EQ} (1 hour)	Criteria
New Hospital	R1	35	45
College	R2	23	45
Centre of Labrador City	R3	34	45
Harry Lake Subdivision	R4	34	45
Smokey Mountain Ski Lodge	R5	44	45
Dumbbell Lake Residence	R6	44	45
Menihek Ski Lodge	R7	45	45
Menihek Ski Trails*	R8	51	NA
Menihek Ski Trail – Summit*	R9	47	NA
Smokey Mountain – Top of Lifts*	R10	45	NA

* Point of interest.

The sound level predictions indicate that in terms of the Health Canada guidelines the project will increase the percentage of highly annoyed by at most 4.2%, which is within the allowable increase of 6.5%. Additionally, the linear weighted sound level predictions (31.5Hz to 8000 Hz) indicate sound levels will be less than the maximum level of 75 dB.

With regard to the World Bank and World Health sound level limits, the predictions indicate that sound levels exceeding the 45 dBA criteria are anticipated at the two locations on the Menihek Ski Trails. However, these locations would not normally be considered noise-sensitive receptors and have been included for reference purposes only. Figure 13 shows the predicted sound level contours (L_{EQ}, [dBA]) from the steady operations within the proposed Wabush 3 pit.

6.2 Blast Vibration

In order to make predictions regarding blast vibration at various distances, various simplified formula are used. Most predications of vibration from down-hole bench blasting make use of a square root scaling equation:

$$V = H\left(\frac{D}{\sqrt{W}}\right)^{-b} \qquad \text{Equation 2}$$

Where D is the distance from the blast to a receptor location, and W is the maximum total weight of explosive per delay. The factor H, sometimes termed the ground factor, is dependent on many things including geological factors, and can vary greatly. Both the exponent b and the H factor are determined experimentally. Different references cite different H and b factors based on different sets of experimental data.

Data from a series of blasts conducted in 2013 at the existing Labrador City operation was provided by IOC (Appendix C). This data shows a range in total blast sizes from about 30,000 kg to 940,000 kg, with an average of about 480,000 kg. The weight of explosives per delay ranged from about 20,000 kg to 65,000 kg, with an average of about 42,000 kg. Data from two additional blasts has been provided subsequently.

It is clear from these figures that the blasts at IOC are at the upper limit or beyond most published references for blast vibration prediction. It should also be realized that at the best of times, scaling methods do not represent a technically accurate model of ground vibration, and should be understood to only represent a preliminary estimate of vibration. It is necessary to collect vibration data in place to gain a better understanding of vibration generation and propagation at a specific site.

Nevertheless, to undertake a simple preliminary prediction, the form of scaling formula described by Oriard [14] is used, where b is taken to be -1.6, and the H factor varies between 24.2 to 242, where D and W are provided in imperial units of feet and pounds. This is equivalent to a range of 173 to 1729 in metric units. Taking the upper bound of the past total weight of explosives per delay (65,000 kg), the typical range in the H factor, the distances from Table 1, and equation 2 yields the following predicted peak partial velocities:

Table 9: Simple Preliminary Prediction of Peak Vibration Velocities Due to Blasting for Discussion. Calculation based on an Assumed 65,000 kg Explosive Weight per Delay, and Typical (Generic) Predictions [mm/s]

Location	Receptor ID	Predicted Peak Vibration Velocity [mm/s]	
		Existing Luce Pit	Proposed Wabush 3 Pit
New Hospital and College	R1/R2	1.5 to 15	4.8 to 48
Centre of Labrador City	R3	1.0 to 10	2.2 to 22
Harry Lake Subdivision	R4	1.1 to 11	2.5 to 25
Smokey Mountain Ski Lodge	R5	4.3 to 43	24 to 240
Dumbbell Lake Residence	R6	4.2 to 42	21 to 210
Menihek Ski Lodge	R7	3.7 to 37	16 to 160
Menihek Ski Trails	R8	29 to 290	95 to 950
Smokey Mountain – Top of Lifts	R10	6.5 to 65	190 to 1900

A few issues emerge from the calculation. Firstly, this calculation predicts very severe ground movement at the closer distances (i.e., at the ski trails), even at the lower range of the typical range of H factor. At the upper end, absurdly high ground velocities are predicted at these distances, and damaging vibration is predicted at all the buildings near the ski lodges.

Secondly, the calculations clearly indicate that the selected scaling function, including the value of the H factor has a profound effect on the conclusions that would be drawn from the prediction. In this case, since the blasts at IOC involve large boreholes, very large weights of explosive and very large blast areas, it is probable that these generic predictions are of limited use and do not accurately reflect ground-borne vibration from the blasts. It is therefore critically important that a body of actual vibration measurements is collected during blasts at the mine for a realistic discussion of likely vibration impact, and to allow realistic predictions of vibration from future blasts.

Unfortunately, some of the vibration data from past blasts which has been provided by IOC cannot be used either because the instrument did not capture the necessary vibration data, because the distance between the monitor and the blasts is not known, or because the complexity of the blast means that it is not possible to identify which blast components were captured by the monitor. Additionally, the calibration of the blast monitors utilized at the site has not been kept up-to-date, further complicating the assessment of the provided data. Appendix C summarizes the data which has been provided by IOC. As a result, at this time there are only seven monitored vibration records provided for which blast design information is available and which can be correlated to a specific blast profile. This is little data on which to base future predictions, but it is relevant since an analysis of the existing data suggests that, using the same simplified scaling formula described above, equation 2, the actual achieved H factor has been close to 84 in metric units. To put this into context, Figure 14 illustrates predicted vibration velocities and the measured data. This is considerably lower than the lower bound of typical data cited by Oriard, and at this time we do not have sufficient information to explain this large discrepancy. Broadly applying this unusually low H factor value for future predictions at a variety of locations must occur only tentatively since it may be a result of local shielding effects, localized geological factors, or other factors which may not apply to measurements conducted at other locations. Nevertheless, for discussion purposes, Table 10 contains predictions based on this value, in addition to the data from Table 9.

Table 10: Simple Preliminary Prediction of Peak Vibration Velocities Due to Blasting for Discussion. Calculation based on an Assumed 65,000 kg Explosive Weight per Delay, and Past Blast Data Supplied by IOC [mm/s]

Location	Receptor ID	Predicted Peak Vibration Velocity [mm/s]	
		Typical Generic Predictions	Predictions Based on Past Blast Data
New Hospital and College	R1/R2	4.8 to 48	2.3
Centre of Labrador City	R3	2.2 to 22	1.1
Harry Lake Subdivision	R4	2.5 to 25	1.2
Smokey Mountain Ski Lodge	R5	24 to 240	12
Dumbbell Lake Residence	R6	21 to 210	11
Menihek Ski Lodge	R7	16 to 160	8
Menihek Ski Trails	R8	95 to 950	46
Smokey Mountain – Top of Lifts	R10	190 to 1900	93

The predictions based on the past blast data are dramatically lower than the values predicted by more typical prediction formula, and would tend to indicate that blast vibration may not be a significant problem in most cases. However, even this calculation suggests that vibration velocities at the top of the upper Smokey Mountain lift equipment will be well above typical blast vibration criteria.

It is clear the actual vibration propagation in the area will dramatically alter the feasibility of the current mining practices, once work at Wabush 3 begins. It is therefore critical that additional monitoring of blast noise and vibration be undertaken at various locations, including in the town and at the ski areas before a confident prediction of blast vibration can be made.

6.3 Airblast

In order to make predictions regarding airblast (peak overpressure), various simple expressions of airblast level vs. scaled distance are used. Unlike the formula for blast vibration (Equation 2), these equations make use of a cubed root scaling function, and take the form:

$$Overpressure = A\left(\frac{D}{\sqrt[3]{W}}\right)^{-c} \qquad \text{Equation 3}$$

Where D is the distance from the blast to a receptor location, and W is the maximum total weight of explosive per delay. The factor A and the exponent c are empirically derived. A few such relationships are summarized in Figure 15, including those drawn from USBM publication RI 8485 [15] and Oriard.

The monitor data provided by IOC is shown on Figure 16, overlaid on the various relationships described in Figure 15. As shown, the measured data exceeds most of the relationships.

Because of the variation in the various equations summarized in Figure 5, and because the small quantity of existing measurement data suggests that the airblast is stronger than many prediction formulae would estimate, future predictions should also be informed by the actual measured data.

As an initial prediction, two formulae have been used, one is taken from Oriard [14] for “average burial” and one is based on the formula for “metal mines” described in RI 8485 [15], but scaled upward to the average of the measured data. It should be emphasized that because of the small amount of data, this later prediction is a tentative initial estimate until more data is available. The predictions assume the same total weight of explosives per delay (65,000 kg) discussed above.

Table 11: Preliminary Prediction of Overpressure Levels Due to Blasting. Effects of Topographic Shielding and Meterology are Not Included

Location	Predicted Peak Overpressure [dB]			
	Existing Luce Pit		Proposed Wabush 3 Pit	
	Oriard "Average Burial"	Scaled "Metal Mines"	Oriard "Average Burial"	Scaled "Metal Mines"
Centre of Labrador City	114	131	118	134
New Hospital and College	116	133	123	137
Harry Lake Subdivision	114	131	119	135
Menihek Ski Lodge	121	136	130	142
Menihek Ski Trails*	134	144	141	149
Smokey Mountain Ski Lodge	122	137	132	143
Smokey Mountain – Top of Lifts	125	138	145	151
Dumbbell Lake Residence	122	137	132	143

As shown in Table 11, the various prediction formulae result in large variations of predicted peak overpressure. The preliminary measurement data suggest that, without consideration of topographic shielding effects or atmospheric effects, it should be expected that typical criteria for airblast overpressure will be exceeded at the ski areas, at the hospital, and possibly at portions of Labrador City itself, once blasting begins at the Wabush 3 pit. Blast designs would need to be significantly altered in order to bring these predictions below the criteria discussed in this report.

Blasts near the bottom of the existing pits are well shielded by the existing topography, and so it is likely that the predictions shown in Table 11 for the existing Luce pit, which do not take into account shielding, are higher than would be measured in practice. However, there will initially be little topographic shielding between the new hospital and the college and the closest blasts in the proposed Wabush 3 pit, which will occur near the existing grade. Other areas such as the ski lodges will benefit from some shielding initially. As the pit becomes established, and blasts occur further below the existing grade, the shielding effect will become more significant. However, it should be noted that airblast overpressure contains principally low frequency energy, and acoustic barrier effects are reduced at low frequencies, so the shielding effect will not be as pronounced for the airblast as it will be for day-to-day noise from vehicles and equipment in the pit.

Meteorological conditions can dramatically alter the propagation of noise and airblast overpressure, particularly over large distances such as between the pits and surrounding receptor locations. The two main variables are the wind distribution and the vertical temperature gradient. Temperature related effects can be strong, such as when an inversion condition exists (temperature increases with altitude), which has the effect of bending upward-propagating sound back down to the ground. Increasing wind speed with altitude has a similar effect when wind is blowing from a sound source toward a receptor location. Thus, accurate prediction of meteorological effects can be difficult to achieve in practice since a detailed picture of wind speed and temperature gradients is required.

To provide an order-of-magnitude picture of the importance of these effects, standard engineering references such as Bies and Hansen [16] indicate that for distances in the range of 1000 metres, meteorological effects can be expected to increase sound levels by up to about 8 dB over a neutral condition, or decrease them by about 2 dB. An increase of 8 dB can be expected to largely negate modest topographic shielding, such as may be present in the initial stages of the pit.

7 CONCLUSIONS

7.1 Operational Noise

The acoustical measurements and analysis indicate that the sound levels of the proposed construction and ongoing operations of the Wabush 3 Pit will meet Health Canada and the IFC sound level limits at all existing noise sensitive receptors.

7.2 Blast Vibration and Airblast Overpressure

Blasts at the proposed Wabush 3 pit will be closer to both receptor locations in Wabush City, and to locations in the ski trails. Noise and vibration from blasting should therefore be expected to increase, all else being equal. Predictions of blast vibration and airblast overpressure which are based on standard prediction methods vary widely, and knowledge of the specific site conditions, in the form of a collection of monitored vibration and noise data is necessary for meaningful predictions. In this case, a significant body of such information has not yet been collected, and no information which can directly be applied to considerations of the effects of future blasts at Wabush 3 on the existing sensitive receptor locations is available. HGC Engineering has not been in Labrador City during a blast, so no additional measurements have been undertaken by HGC personnel. The preliminary information which has been made available suggests that the ground vibration is weaker than would normally be expected for the very large total weights of explosives per delay which are in use, but conversely the airblast overpressure is greater than would normally be expected. This could be due to the fact that the prediction equations are not well suited for blasts of this size, the use of a potentially inefficient blast design, questionable calibration of blast monitors, etc.

While standard predictions would tend to indicate that the blast vibration will be dramatically in excess of typical vibration criteria at many receptor locations, but the airblast may be acceptable in most cases, predictions based on the preliminary measured data suggest that the opposite may be true: vibration may be acceptable in most cases, but air blast may exceed the criterion values to a large degree. It is therefore critical that more measurement data be collected. Ideally, test blasts will be undertaken in the Wabush 3 area with low explosive weights, while measurements are conducted at the various actual receptor locations. Data should also be collected at key receptor locations such as the hospital or college, and at the top of the lift equipment, and at intervening distances during blasts at the existing pits. This information can then be used to make more realistic predictions of blast noise and vibration from the proposed pit.

To maximize the utility of these blasts, given the complex nature of many of the blasts currently in use, monitoring equipment should be configured to trigger on ground vibration (although triggering also on airblast is appropriate as a backup measure), since ground vibration will generally arrive at a receptor location considerably in advance of the airblast. The recording time should be long enough to capture the entire blast sequence, which can be quite long at IOC. Detailed records of the location of blasts and the location of monitoring equipment must be kept. Additionally, records of the blast design must be kept for both blasts utilizing electronic detonators and also those that do not. Without all this information, the monitor data cannot be accurately assessed.

The preliminary calculations which are based on the initial existing monitor data suggest that vibration at the upper ski lift equipment will be beyond typical blast vibration criteria. A detailed assessment of allowable vibration on the equipment has not been undertaken, but it is clear that careful consideration will need to be given to the design of blasts near to the lift equipment, and to the design of any future lift equipment which may be considered for the area.

Calculation methods for scaling airblast data to different distances vary, and it will be necessary to obtain monitor data at different locations and at different distances from the very large blasts which occur at IOC. However, the preliminary calculations suggest that airblast amplitudes exceeding the typical criteria may occur regularly.

In summary, at this time it is not possible to make accurate and reliable predictions of blast vibration and airblast at the IOC site, but preliminary calculations indicate that there could be cause for concern regarding both phenomena. Once more blast monitoring data is collected it will be possible to make predictions which are more attuned to the circumstances at IOC. At that time, it will also be possible to begin considering particulars of the blast design, or meteorological restrictions on blasting times, in order to restrict impacts to acceptable levels.

8 REFERENCES

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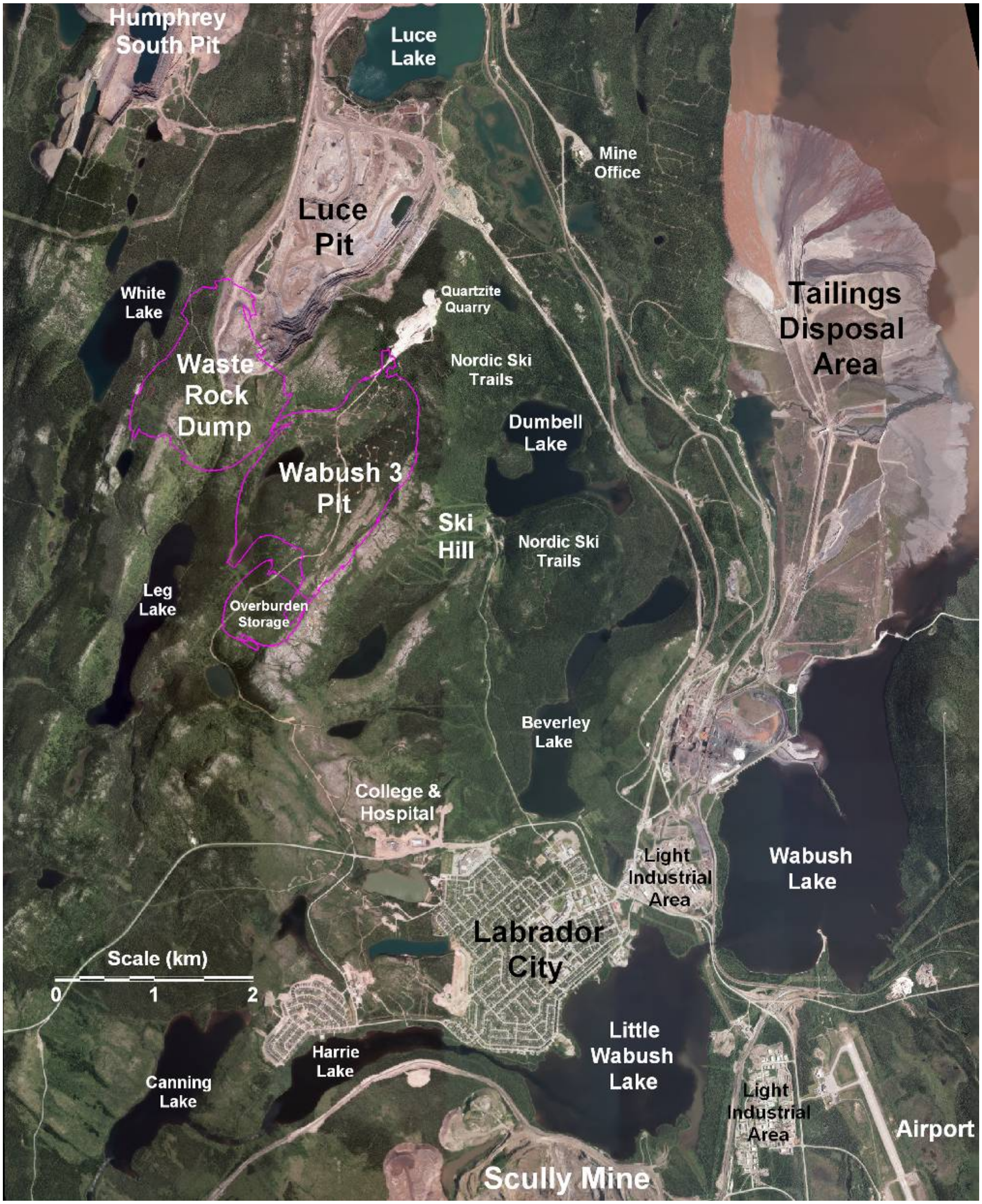

Figure 1: Key Plan

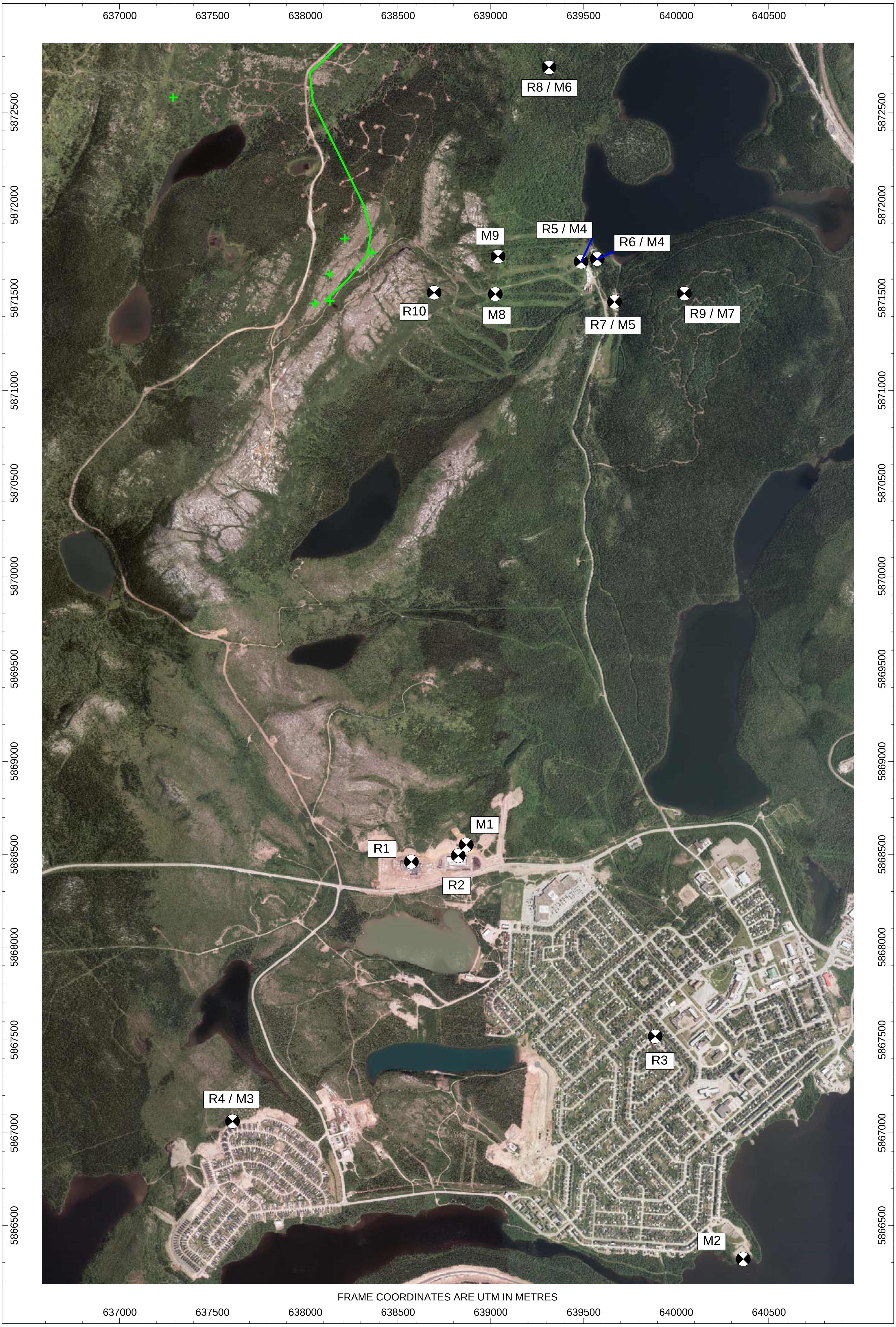

Figure 2: Receptor and Baseline Sound Level Monitoring Locations
IOC, Proposed Wabush 3 Pit

Figure 3: Automated Sound Level Monitoring, M1
College (R2)
IOC Labrador City, Wabush Mine, April 7 - 14, 2014

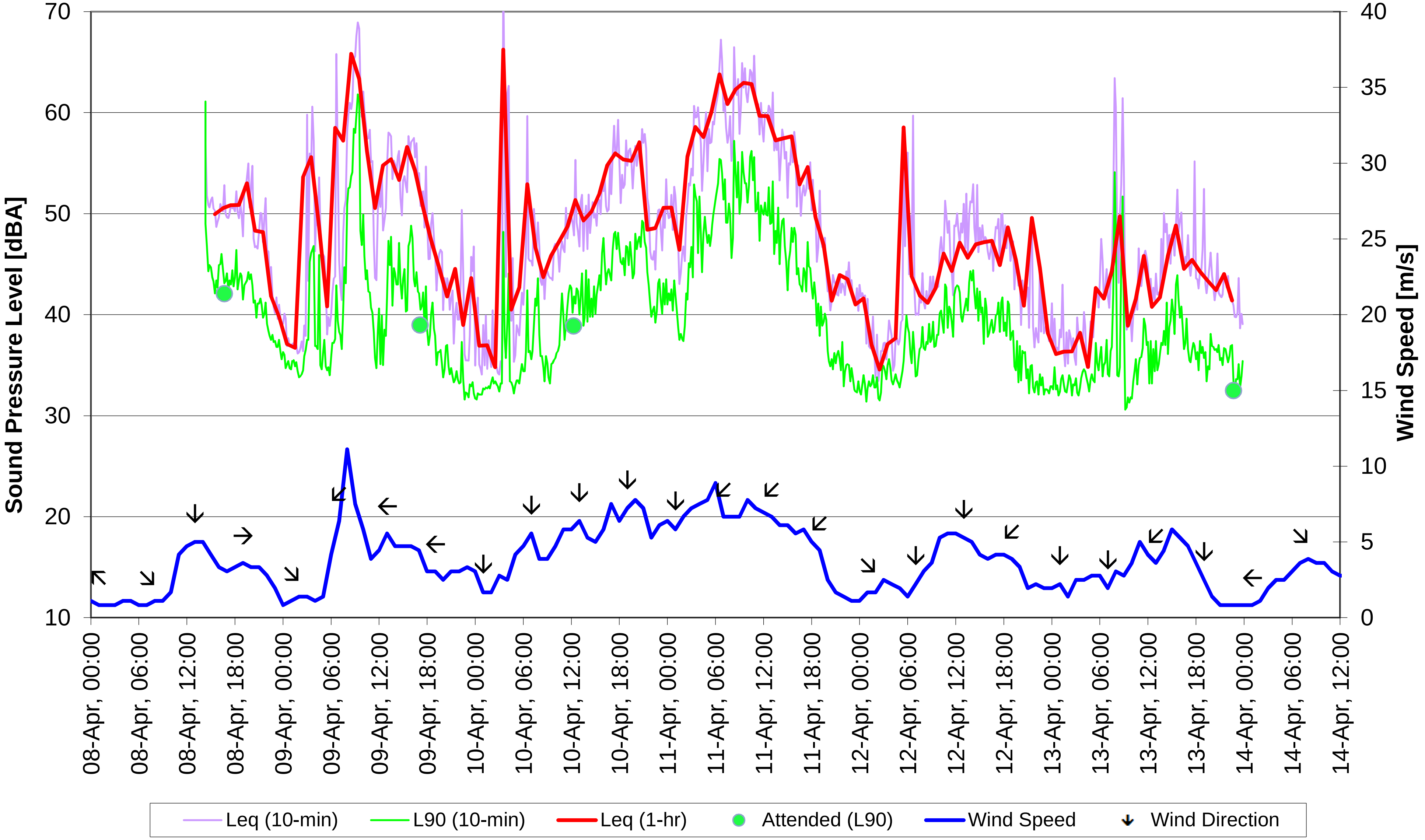

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Figure 4: Automated Sound Level Monitoring, M2
Indian Point
IOC Labrador City, Wabush Mine, April 7 - 11, 2014

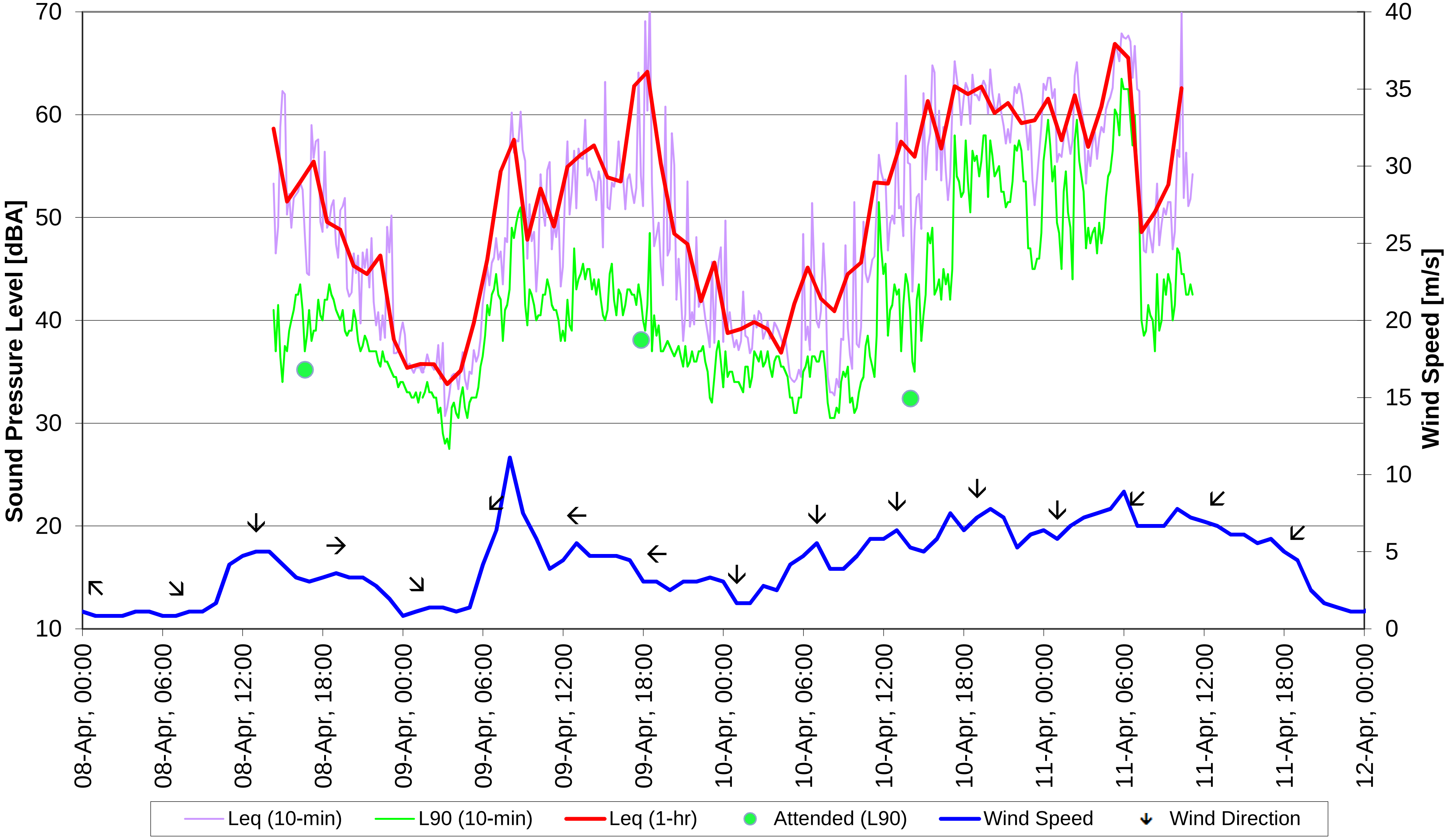

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Figure 5: Automated Sound Level Monitoring, M3
Harrie Lake Subdivision (R4)
IOC Labrador City, Wabush Mine, April 7 - 11, 2014

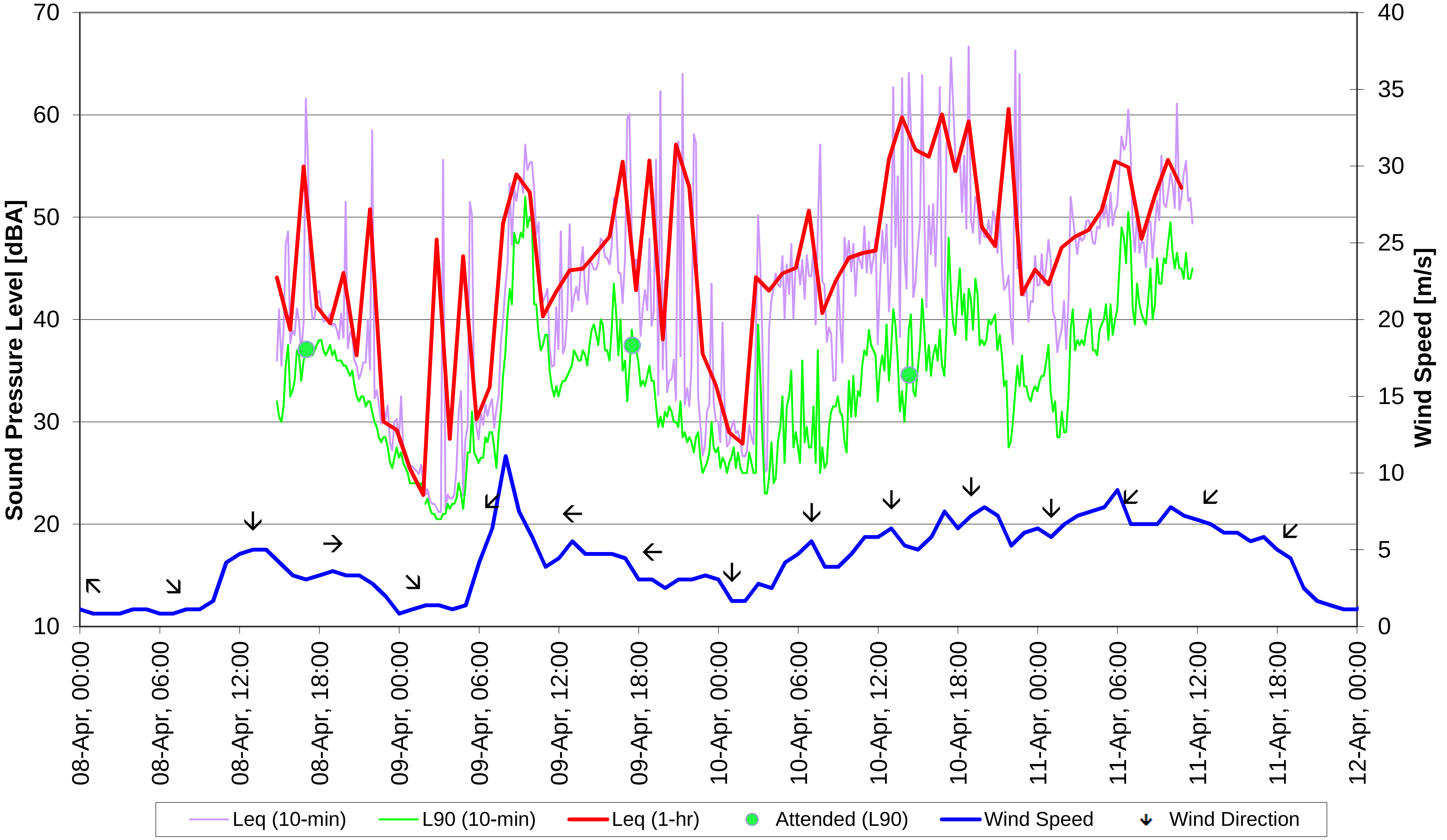

Figure 6: Automated Sound Level Monitoring, M4
Smokey Mountain Lodge (R5)
IOC Labrador City, Wabush Mine, April 11 - 14, 2014

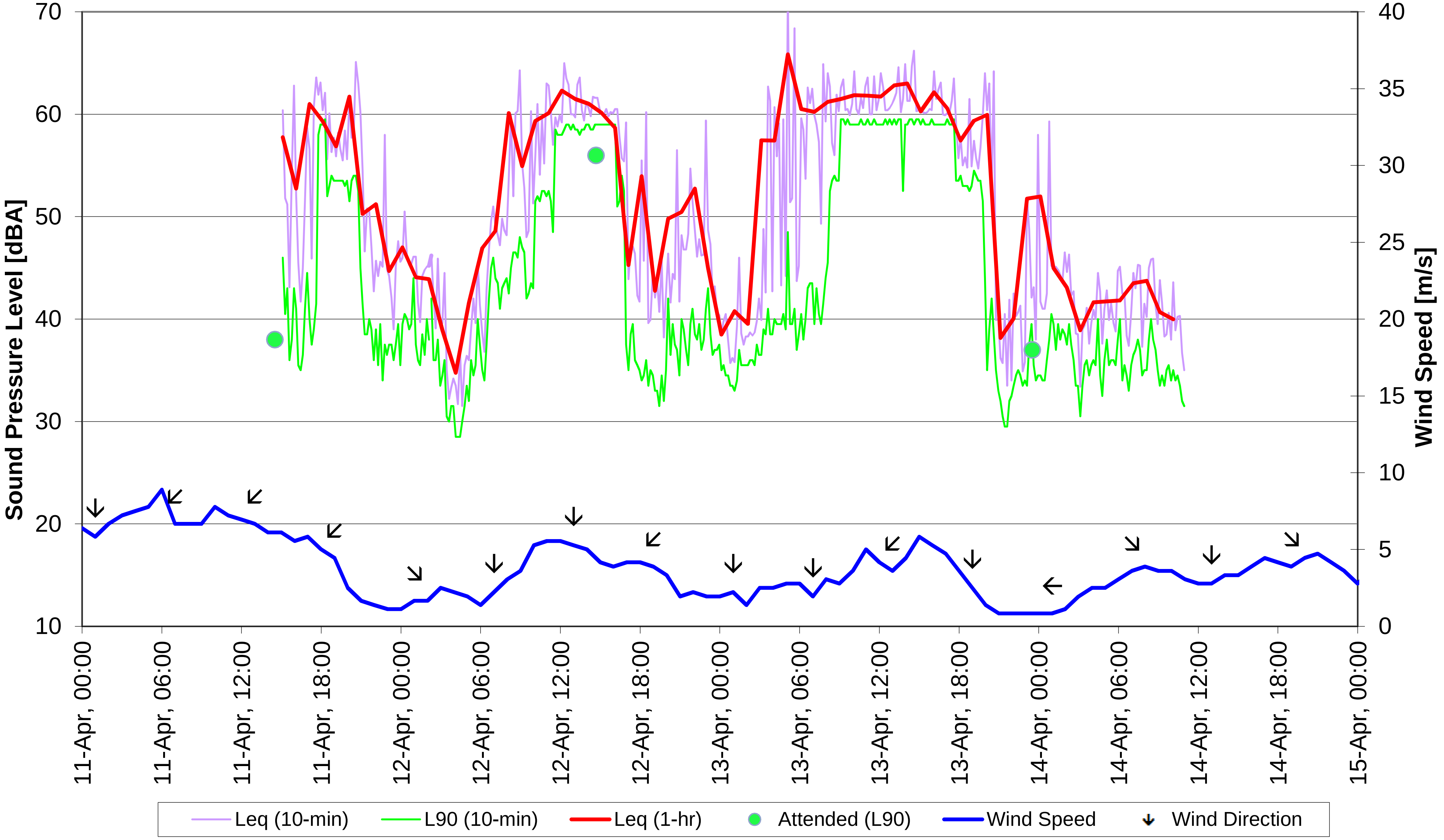

Figure 7: Automated Sound Level Monitoring, M5
Menihek Lodge (R7)
IOC Labrador City, Wabush Mine, April 11 - 14, 2014

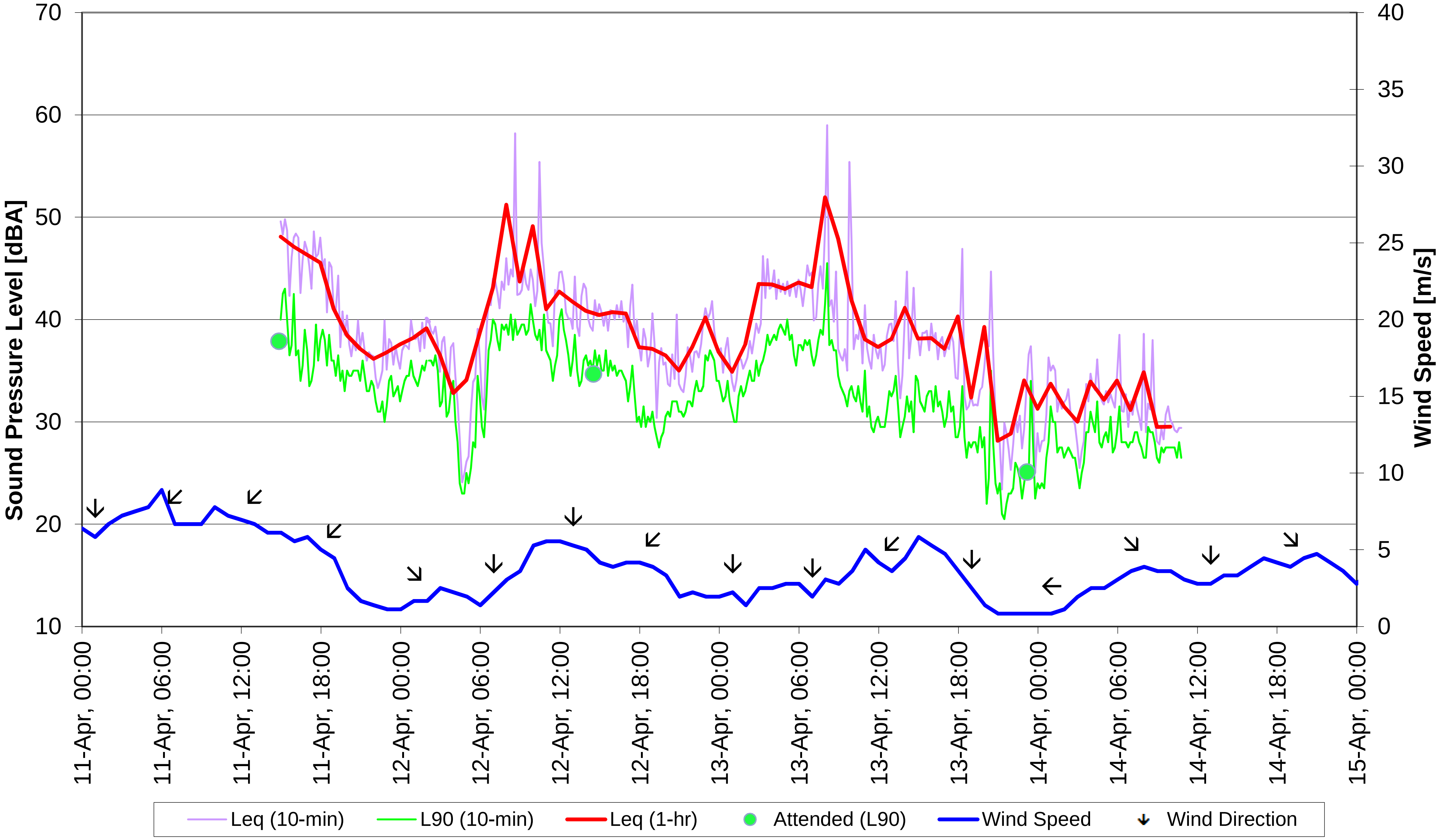

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Figure 8: Automated Sound Level Monitoring, M6
Koch Trail (R8)
IOC Labrador City, Wabush Mine, April 7 - 11, 2014

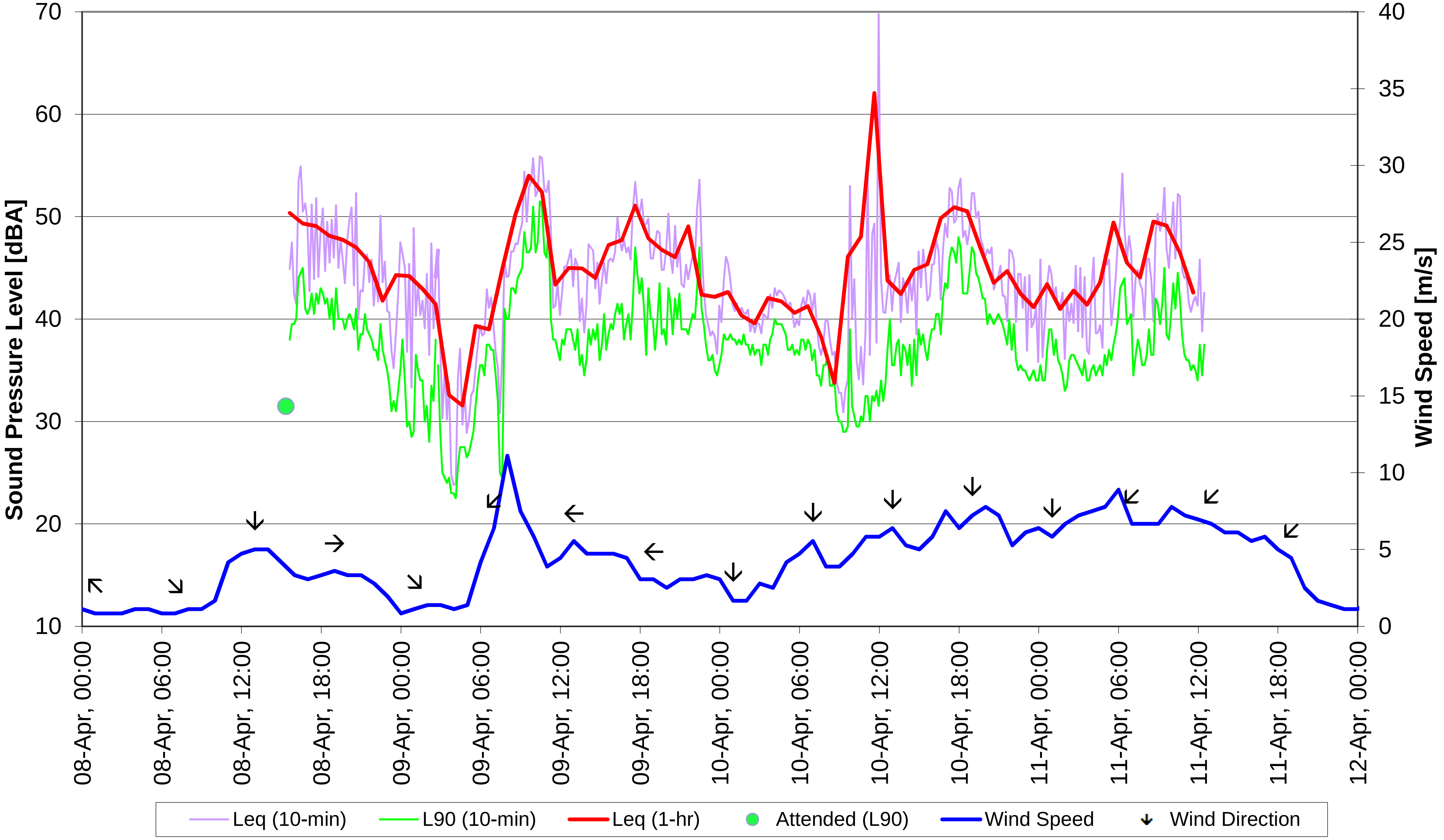


Figure 9: Automated Sound Level Monitoring, M7
Alf's Trail @ Summit (R9)
IOC Labrador City, Wabush Mine, April 7 - 11, 2014

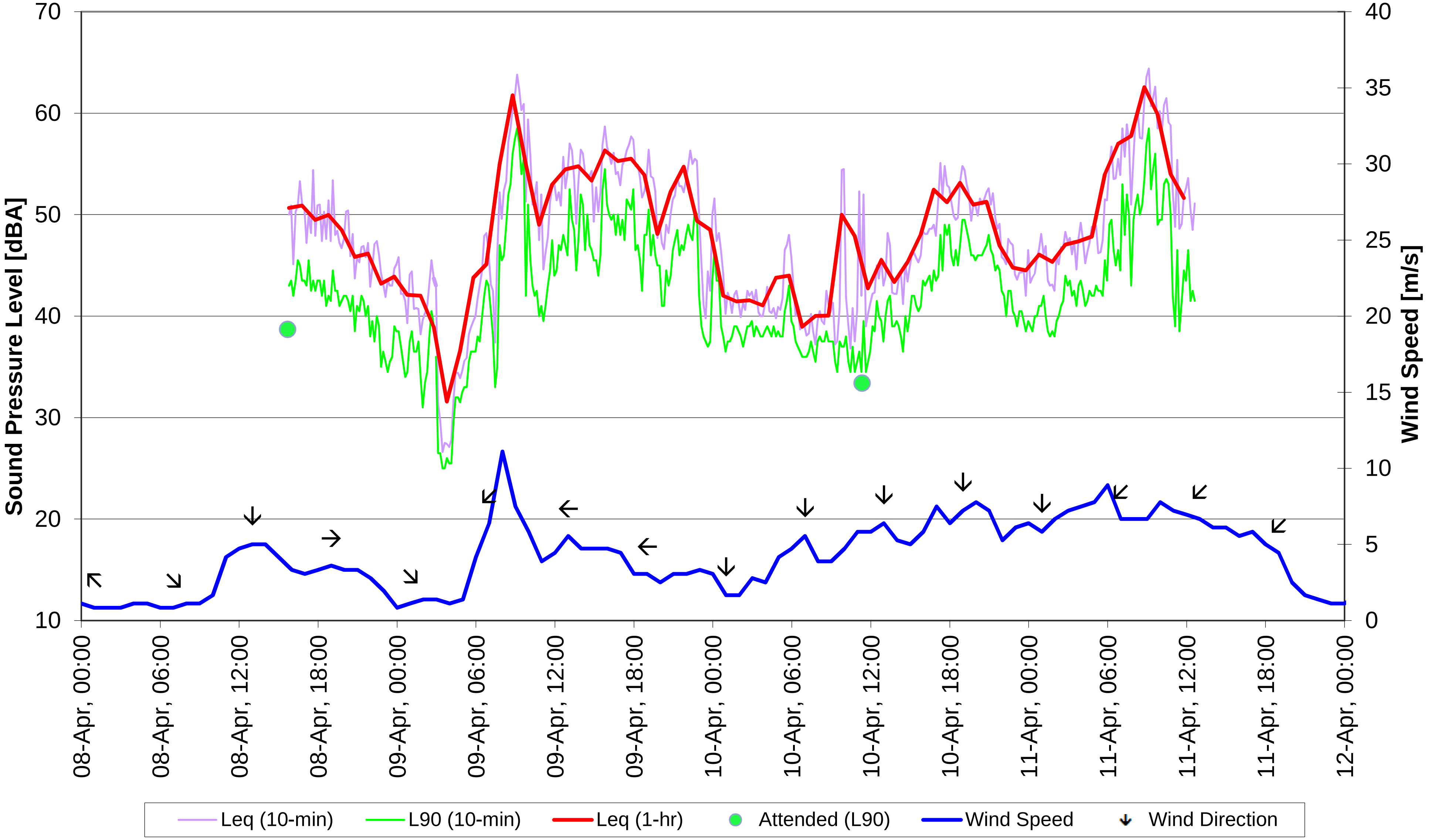
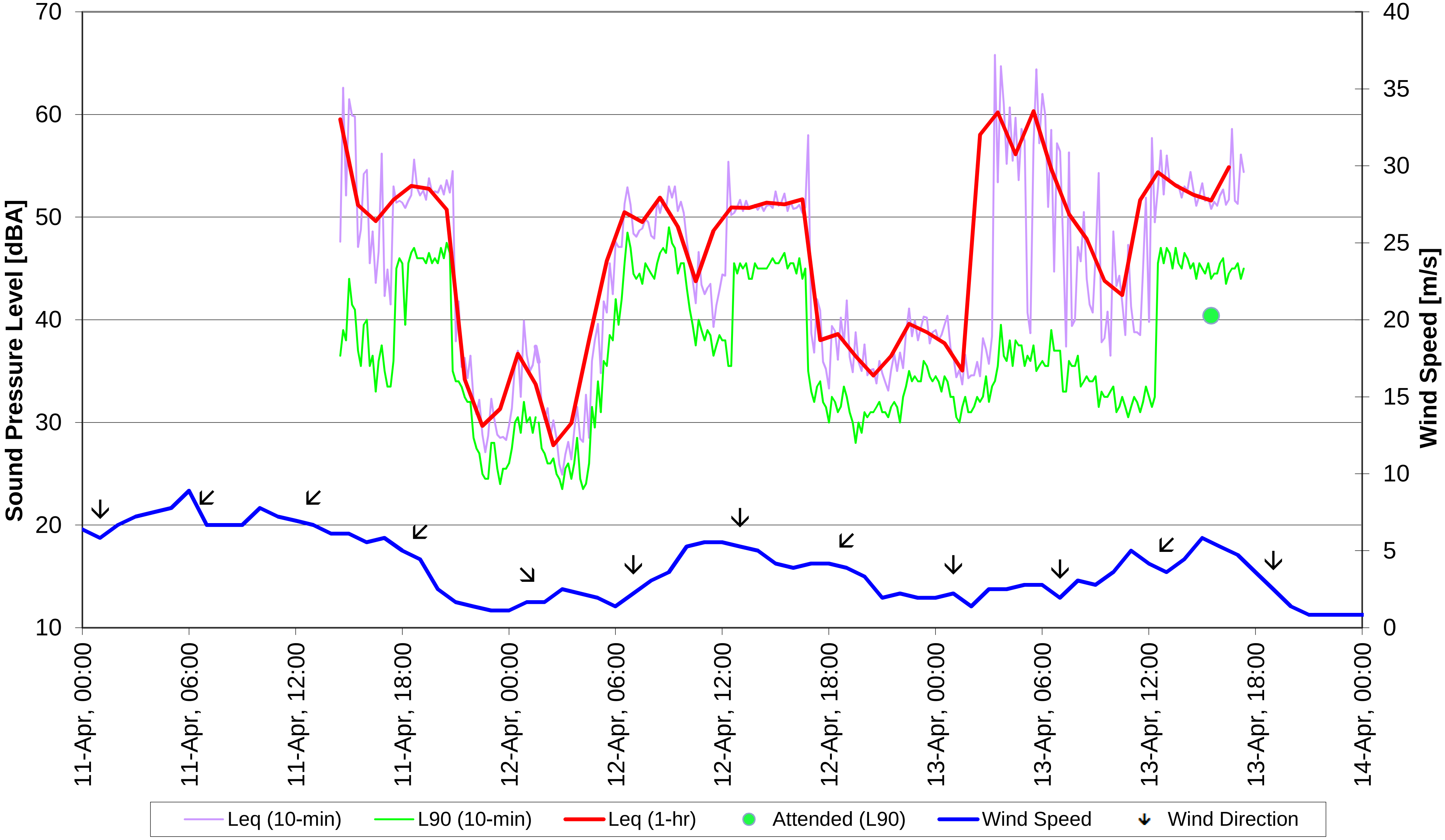


Figure 10: Automated Sound Level Monitoring, M8
Pole 7 Smokey Mountain Ski Hill
IOC Labrador City, Wabush Mine, April 11 - 14, 2014



ACOUSTICS NOISE VIBRATION

Figure 11: Automated Sound Level Monitoring, M9
Centre of Smokey Mountain Ski Hill
IOC Labrador City, Wabush Mine, April 11 - 14, 2014

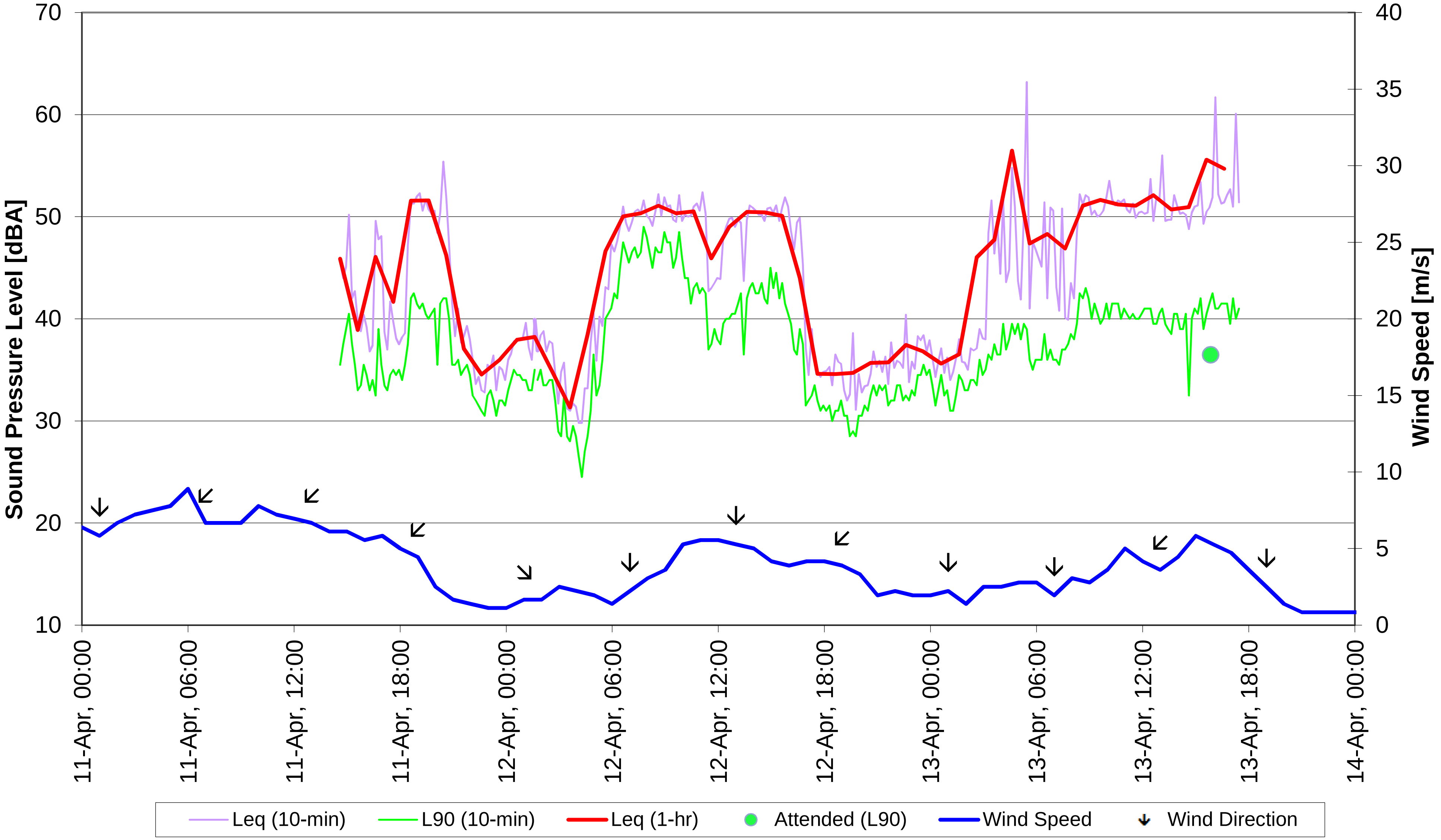


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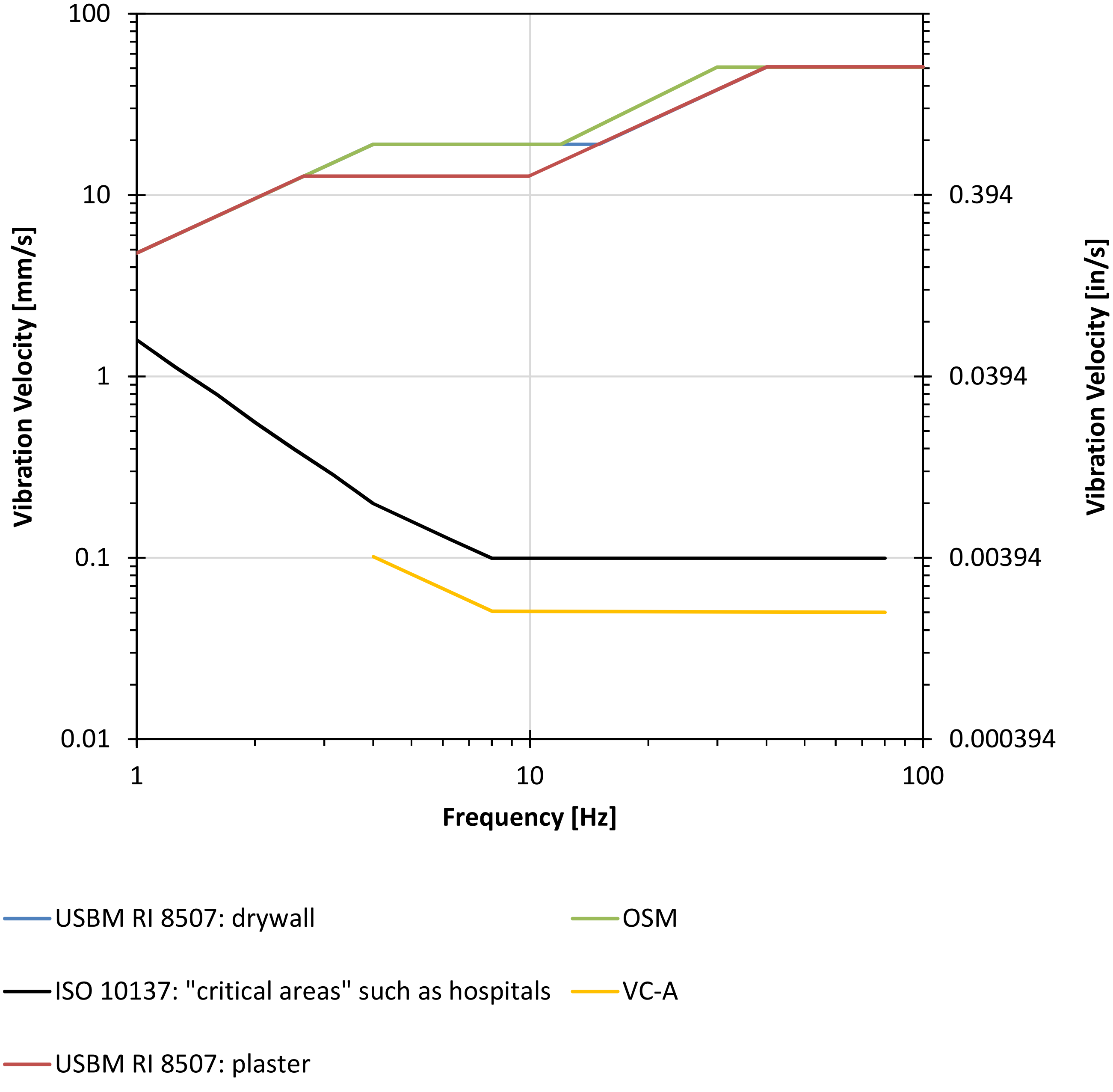
Figure 12: Various Vibration Velocity Criteria for Blasting Operations



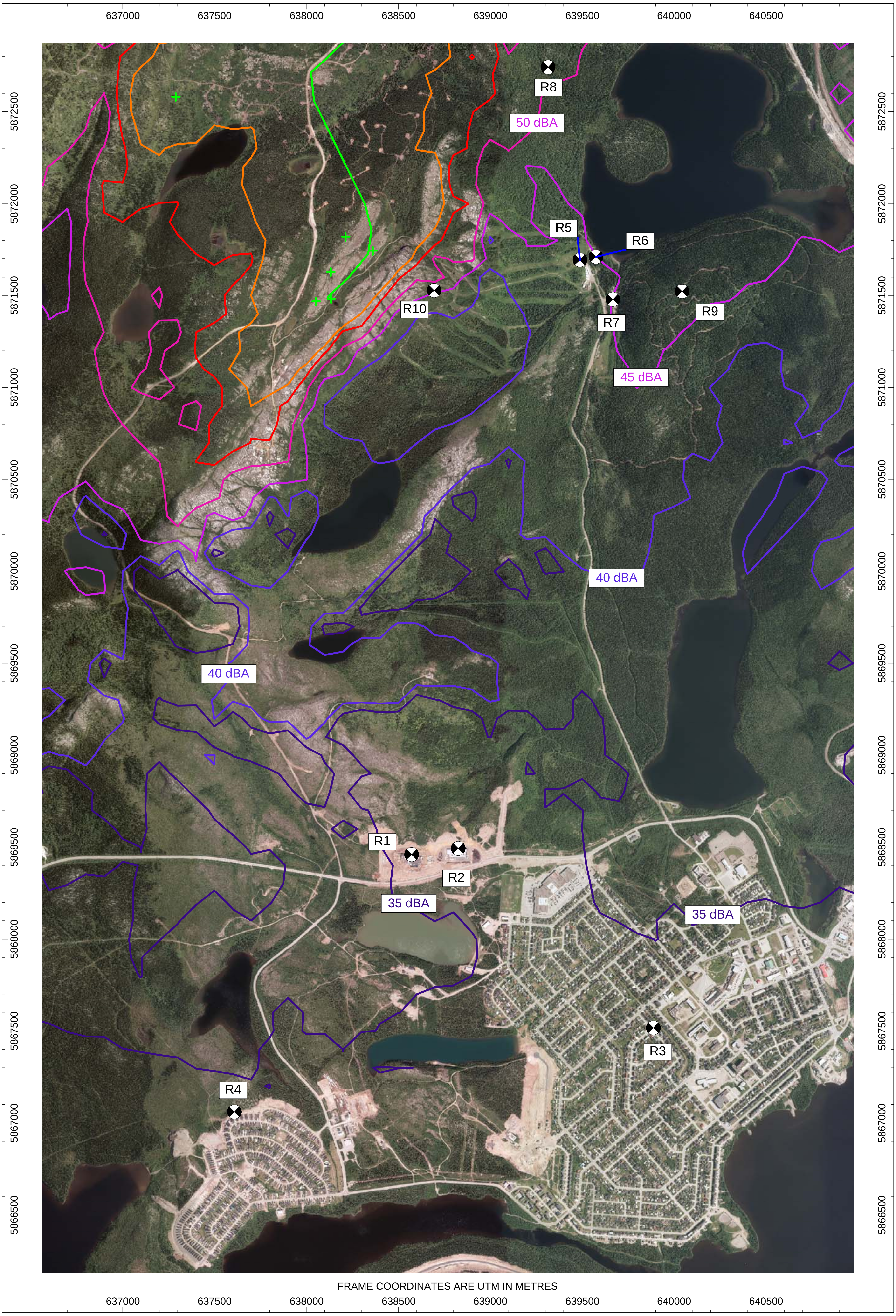
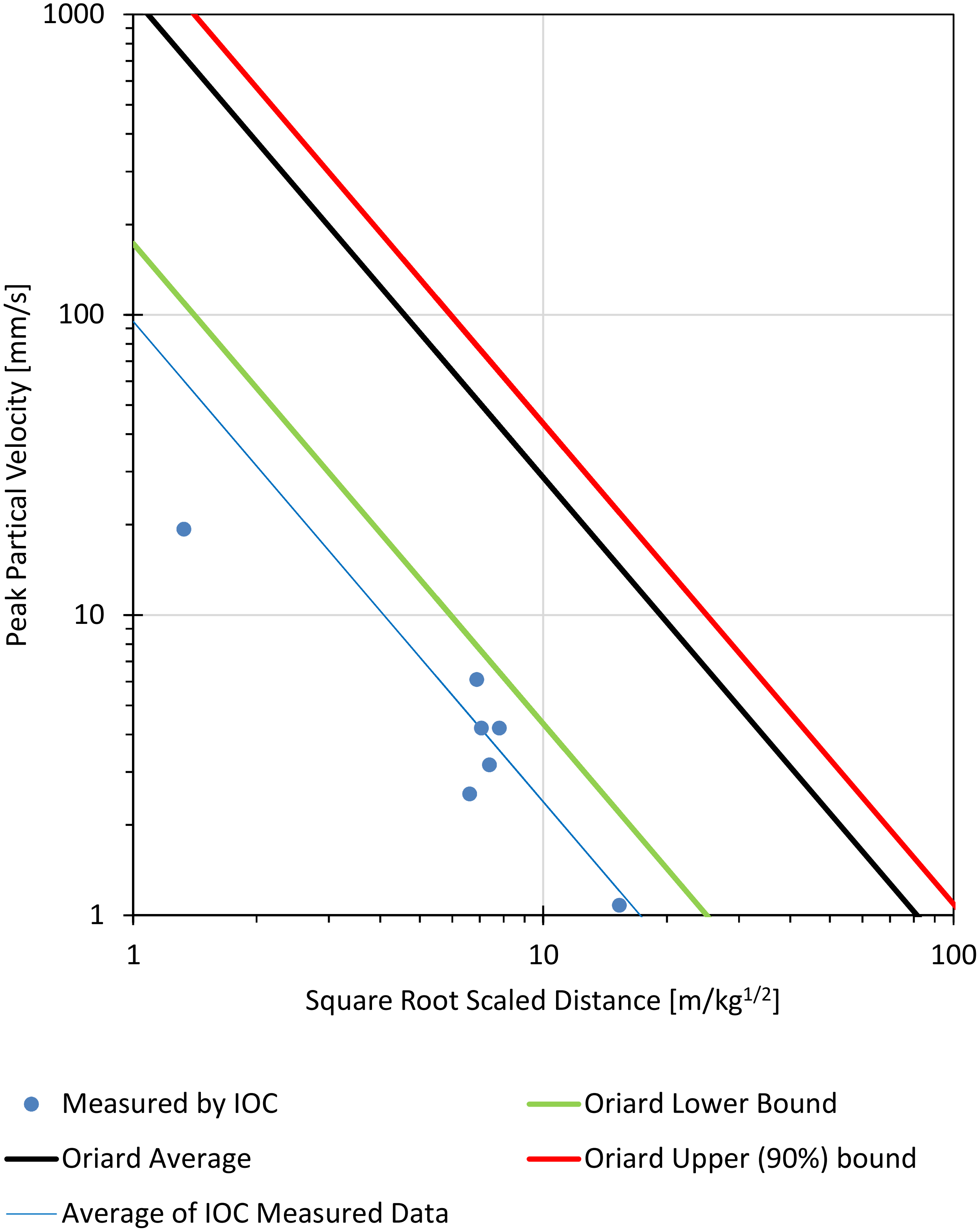


Figure 13: Predicted Sound Levels, Leq [dBA]
Iron Ore Company of Canada, Proposed Wabush 3 Pit, Labrador City
Sound Pressure Grid Calculated at 4.5m

Figure 14: Predicted and Measured Peak Partical Velocity Data



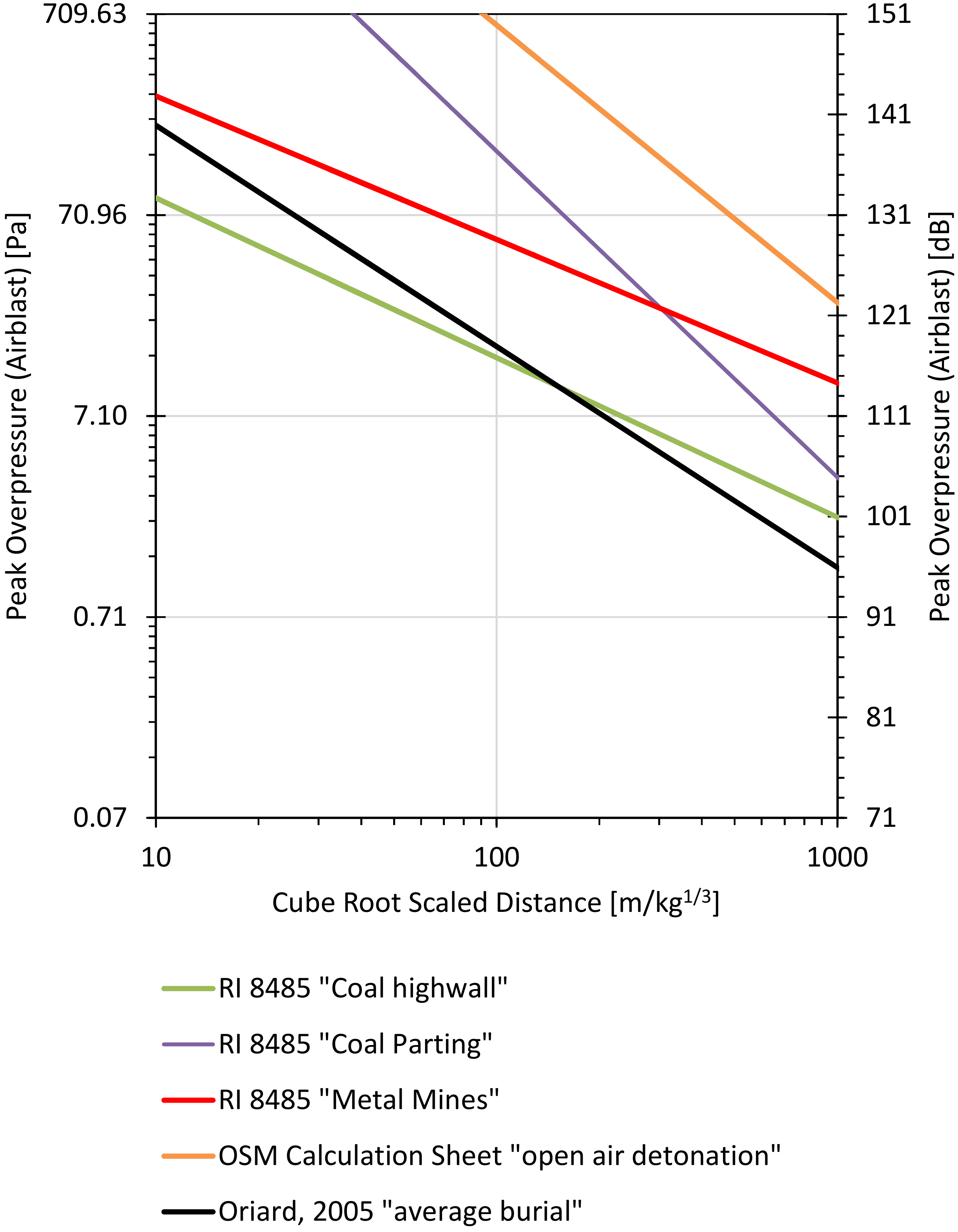
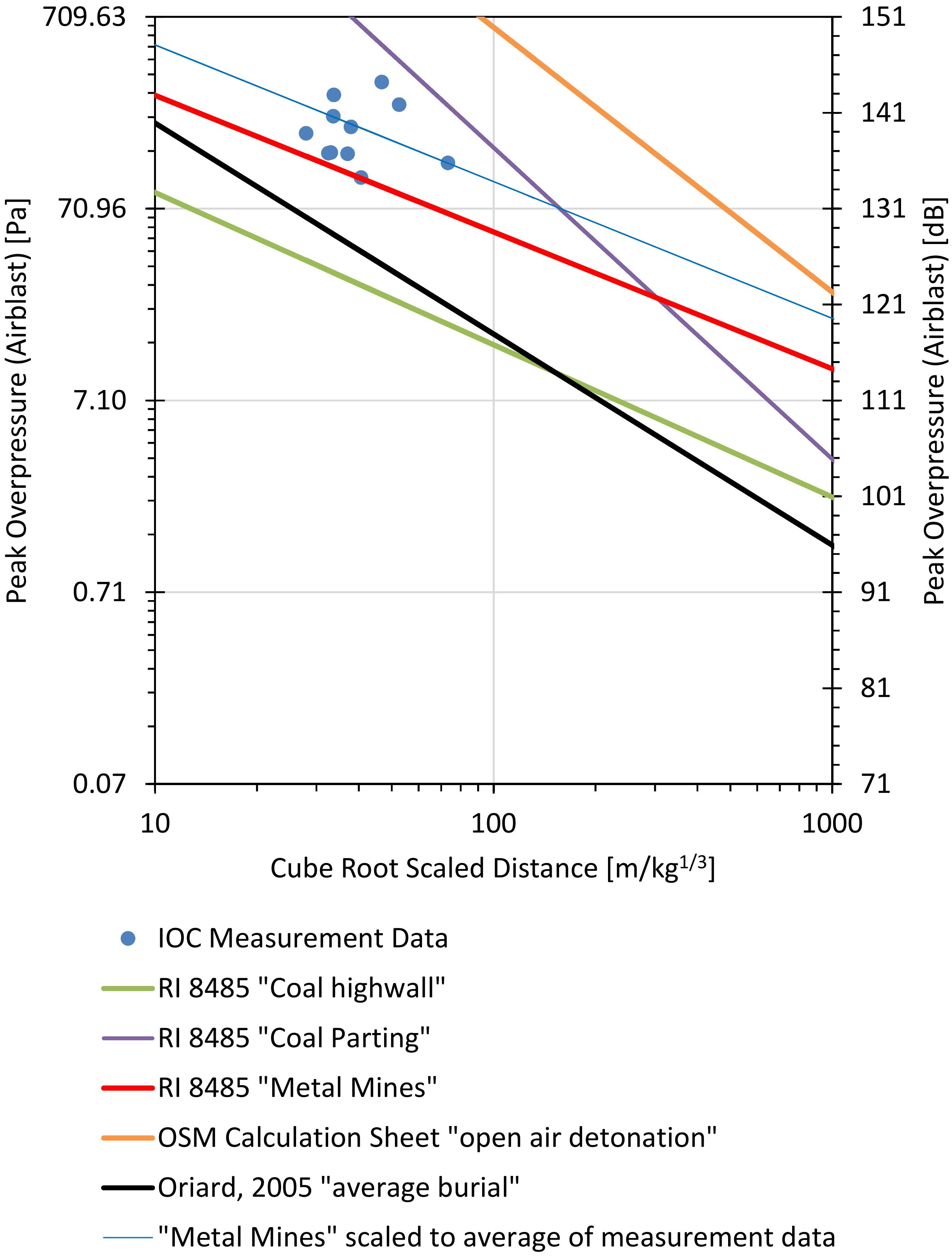


Figure 15: Various Predictions of Airblast Peak Overpressure

Figure 16: Predicted and Measured Airblast Data



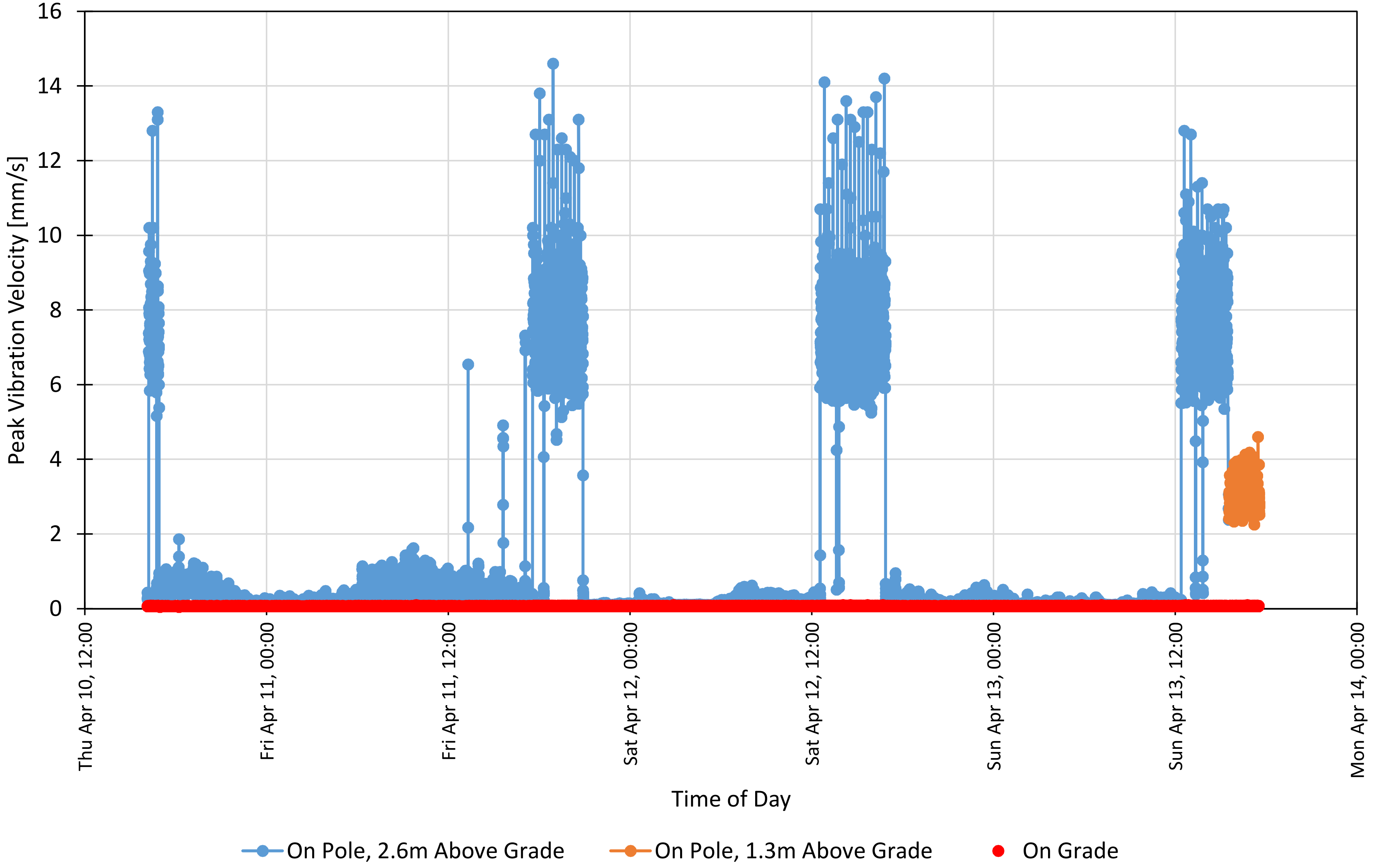
APPENDIX A: Summary of Attended Sound Level Measurements

Attended Sound Level Measurements, [dBA]

Monitor Location	Description	Time	L_{EQ}	L_{90}	Comments
M1	College	Apr 08, 16:20	49	42	Road traffic on hwy 500 and in town, heavy equip @ Wabush mine
M1	College	Apr 09, 17:00	51	39	Traffic hwy 500
M1	College	Apr 10, 12:20	48	39	Traffic hwy 500, some construction, couple wind gusts, some local traffic
M1	College	Apr 13, 22:40	34	33	Distant snowmobiles, occasional traffic, distant fan
M2	Indian Point	Apr 08, 16:40	42	35	Distant fans in Wabush, snowmobiles, distant trains
M2	Indian Point	Apr 09, 17:50	47	38	Wind gusts, wind in trees, distant fans, distant snowmobiles
M2	Indian Point	Apr 10, 14:00	50	32	Wind in trees, snowmobiles on lake, faint voices
M2	Indian Point	Apr 13, 22:00	32	27	Faint buzzing, distant fan and traffic, no wind
M3	Harrie Lake Subdivision	Apr 08, 17:00	42	37	Distant fans, snowmobiles, trucks local roads
M3	Harrie Lake Subdivision	Apr 09, 17:30	46	38	Wind gusts, wind in trees, distant plant activity, train and truck distant
M3	Harrie Lake Subdivision	Apr 10, 14:20	47	35	Dump truck with snow, tailgate slam, snowmobiles, wind gusts and in trees
M3	Harrie Lake Subdivision	Apr 13, 22:20	29	26	Distant traffic, brief radio noise from nearby house
M4	Smokey Mtn Lodge	Apr 09, 18:30	40	36	Wind in trees, distant fans and train, car movement, distant voices
M4	Smokey Mtn Lodge	Apr 11, 14:30	47	38	Light gusts of wind, snowmobiles, groomers, voices
M4	Smokey Mtn Lodge	Apr 12, 14:40	58	56	Lift noise dominant, voices
M4	Smokey Mtn Lodge	Apr 13, 23:30	40	37	Train horn dominant, faint voices
M5	Menihek Lodge	Apr 09, 18:20	45	38	Wind in trees, distant fans, wind in flags near lodge, distant snowmobiles
M5	Menihek Lodge	Apr 10, 08:30	40	34	Little or no wind noise, ski lift equipment noise, faint train horn
M5	Menihek Lodge	Apr 11, 14:50	47	38	Wind, voices, groomers
M5	Menihek Lodge	Apr 12, 14:30	38	35	Distant snowmobiles, lift noises, voices, flags
M5	Menihek Lodge	Apr 13, 23:10	30	25	Distant fan, train, snowmobiles at Smokey mountain
M6	Koch Trail	Apr 08, 15:20	43	32	Train horn up to 57 (sets Leq), distant fans
M6	Koch Trail	Apr 10, 09:50	36	31	Wind in trees, distant grooming machine and train horn, birds,
M7	Alf's Trail	Apr 08, 15:40	44	39	Train horn, distant fans
M7	Alf's Trail	Apr 10, 11:20	38	33	Wind in trees, distant grooming machine and train, occasional wind gusts
M8	Pole 7 Ski Hill	Apr 13, 15:30	48	40	Lift noise, skiers
M9	Ski Hill Centre	Apr 13, 15:50	48	37	Lifts, skiers, distant train

APPENDIX B: Vibration Data, Smokey Mountain Chair Lift

Figure B1: Vibration Velocity Measured on Ski Lift Pole, Maximum of 3 Orthagonal Axis.
Measurements Conducted at Pole 7, Yellow Lift.



APPENDIX C: Summary of IOC Blast Monitor Data

APPENDIX C: Summary of IOC Blast Vibration and Airblast Data

Blast Data					Blast Centroid UTM NAD 27			CALCULATIONS													IOC MEASUREMENT DATA					
Date	Blast Number	Total Explosive Weight [kg]	Maximum Explosive Weight Per Delay (W) [kg]	Comment	Easting	Northing	Elevation	Distance (D): Blast Centroid to Monitor [m]	Square root Scaled Dist. (m, kg)	Cube root Scaled Dist. (m, kg)	PPV Oriard Low [mm/s]	PPV Oriard Avg [mm/s]	PPV Oriard High [mm/s]	PPV PRELIM. Based on IOC Data [mm/s]	Airblast (Coal highwall RI8485) [dB]	Airblast (Coal parting RI8485) [dB]	Airblast (Metal Mine highwall RI8485) [dB]	Airblast (blast in air, OSM prediction) [dB]	Airblast (Average Burial - Oriard) [dB]	Airblast PRELIM. Based on IOC Data [dB]	Vector Sum PPV [mm/s]	Max Axis PPV [mm/s]	f1 of max Lv [Hz]	Airblast [Pa]	Airblast [dB]	Comments
April 25, 2013	LU-31-65	405,989	35,160		638,238.1	5,875,465.5	615.2	1101	5.9	33.6	10.2	67.3	101.9	4.9	124	153	135	163	128	141				215	141	No vibration data
April 25, 2013	LU-31-66	796,691	31,477		638,195.2	5,874,572.3	611.0	1173	6.6	37.2	8.4	55.6	84.1	4.1	124	151	135	162	127	140	3.42	2.54	13.5			No airblast data
May 18, 2013	LU-32-49	639,102	52,709		638,221.2	5,875,164.3	600.4	1046	4.6	27.9	15.3	101.0	152.7	7.4	126	155	136	165	130	142				175	139	No vibration data
May 26, 2013	LU-34-30	674,040	39,665		637,684.9	5,874,288.3	571.6	1757	8.8	51.5	5.3	35.1	53.0	2.6	121	147	133	158	124	138						No vibration or airblast data
June 11, 2013	LU-31-67	495,495	43,163		638,061.6	5,874,561.3	613.4	1300	6.3	37.1	9.2	60.8	91.9	4.5	124	151	135	162	127	140				137	137	No vibration data
June 11, 2013	LU-32-50	306,629	43,163		638,134.4	5,874,884.1	602.5	1142	5.5	32.5	11.3	74.8	113.2	5.5	125	153	136	163	129	141						No vibration data, no airblast data
July 22, 2013	LU-34-31	223,630	19,541		637,887.5	5,874,299.4	572.8	1573	11.3	58.4	3.6	23.8	36.0	1.7	121	145	132	156	123	137						No vibration data, no airblast data
July 22, 2013	LU-32-51	860,768	45,723		638,215.4	5,874,557.4	600.5	1162	5.4	32.5	11.5	76.2	115.2	5.6	125	153	136	163	129	141				138	137	No vibration data
August 8, 2013	LU-35-13	622,701	59,489		637,557.6	5,873,916.3	559.5	2055	8.4	52.6	5.7	37.8	57.1	2.8	121	146	133	158	124	138				247	142	No vibration data
August 8, 2013	LU-35-14	217,559	59,489		637,623.5	5,874,084.1	559.6	1909	7.8	48.9	6.4	42.5	64.3	3.1	122	147	133	158	125	138						Small blast component
August 8, 2013	LU-36-01	3,718	27,763		637,966.8	5,875,191.1	561.4	1304	7.8	43.1	6.4	42.5	64.3	3.1	123	149	134	160	126	139						Small blast component
August 8, 2013	LM-35-10	32,640	27,763		638,035.6	5,875,254.6	559.8	1244	7.5	41.1	6.9	45.8	69.3	3.4	123	150	134	161	126	139						Small blast component
August 8, 2013	LU-32-52	429,186	27,763		638,163.0	5,875,389.9	600.8	1147	6.9	37.9	7.9	52.2	78.9	3.8	123	151	135	162	127	140	6.19	6.1	14.1	189	140	
September 2, 2013	LU-32-53	936,227	45,736		638,039.6	5,874,412.2	599.7	1384	6.5	38.7	8.7	57.6	87.1	4.2	123	151	134	161	127	140						No vibration data, no airblast data
September 5, 2013	LU-33-40	906,710	50,600		638,138.6	5,874,960.9	580.1	1129	5.0	30.5	13.1	86.5	130.8	6.4	125	154	136	164	129	141						Uncertain vibration, airblast data
September 5, 2013	LU-29-64	769,709		Dexter Non-el	638,493.6	5,875,065.8	638.0	768																		Uncertain vibration, airblast data, no blast design data
September 10, 2013	SH-25-18	652,667	40,947		636,108.3	5,878,110.1	695.5	4387	21.7	127.3	1.3	8.3	12.6	0.6	115	134	127	147	116	132						No vibration data, no airblast data
September 10, 2013	SH-25-11	130,470	40,947		636,151.0	5,878,382.4	697.1	4551	22.5	132.1	1.2	7.8	11.9	0.6	115	133	127	147	115	132						No vibration data, no airblast data
September 10, 2013	SH-25-19	201,796	40,947		636,468.6	5,877,912.4	697.7	3992	19.7	115.8	1.5	9.7	14.6	0.7	116	135	128	148	117	133						No vibration data, no airblast data
September 19, 2013	LU-35-15	664,136	24,603		637,637.8	5,874,222.8	559.3	1830	11.7	62.9	3.4	22.4	33.9	1.6	120	144	131	155	122	137						No vibration data, no airblast data
September 28, 2013	LU-32-54	446,684	25,221		638,182.1	5,875,458.1	597.8	1151	7.2	39.2	7.3	48.1	72.7	3.5	123	151	134	161	127	140						No vibration data, no airblast data
September 28, 2013	LU-29-66	309,986		Dexter Non-el	638,439.0	5,875,173.2	637.9	830																		No vibration data, no airblast data, no blast design data
October 4, 2013	LU-32-55	591,076	31,398		638,047.2	5,874,571.7	601.3	1310	7.4	41.5	7.0	46.6	70.4	3.4	123	150	134	160	126	139	3.47	3.17	›px 14 & 27			No airblast data
October 4, 2013	LU-32-56	95,428	20,000		638,196.6	5,874,376.1	601.0	1267	9.0	46.7	5.2	34.2	51.8	2.5	122	148	133	159	125	139				324	144	No vibration data
October 4, 2013	LU-29-65	571,664		Dexter Non-el	638,330.7	5,874,812.4	642.8	963																		No measurement data, no blast design data
October 17, 2013	LU-35-17	321,763	64,615		637,558.8	5,874,214.9	558.8	1903	7.5	47.4	6.9	45.6	69.0	3.3	122	148	133	159	125	138						No vibration data, no airblast data
October 17, 2013	LU-36-03	65,911	64,615		637,563.7	5,873,846.4	544.4	2090	8.2	52.1	5.9	39.3	59.4	2.9	121	147	133	158	124	138						No vibration data, no airblast data
October 17, 2013	LU-35-18	213,737	64,615		637,694.7	5,874,375.9	559.0	1712	6.7	42.7	8.2	54.0	81.7	4.0	123	149	134	160	126	139						No vibration data, no airblast data
October 17, 2013	LU-35-16	561,460	64,615		637,764.6	5,874,222.3	559.1	1718	6.8	42.8	8.1	53.7	81.3	3.9	123	149	134	160	126	139						No vibration data, no airblast data
October 31, 2013	LU-36-04	6,151	51,021		637,928.6	5,875,323.3	545.8	1362	6.0	36.7	9.8	64.5	97.6	4.7	124	151	135	162	127	140						Uncertain vibration, airblast data
October 31, 2013	LU-33-41	748,680	51,021		638,144.3	5,875,332.2	587.0	1151	5.1	31.0	12.8	84.4	127.7	6.2	125	154	136	164	129	141						Uncertain vibration, airblast data
October 31, 2013	LU-29-67	768,430		Dexter Non-el	638,368.6	5,875,001.5	643.5	895																		Uncertain vibration, airblast data, no blast design data
November 11, 2013	LU-32-57	568,145	26,782		638,101.7	5,874,706.8	600.5	1213	7.4	40.6	7.0	46.3	70.1	3.4	123	150	134	161	127	139				103	134	No vibration data
November 21, 2013	LU-35-19	449,520	29,211		637,757.9	5,874,414.3	559.4	1639	9.6	53.2	4.6	30.7	46.4	2.3	121	146	132	157	124	138						No vibration data, no airblast data
November 21, 2013	LU-35-20	84,606	29,211		637,763.9	5,874,707.4	559.0	1541	9.0	50.0	5.1	33.9	51.2	2.5	122	147	133	158	125	138						No vibration data, no airblast data
March 31, 2014	LU-35-26		5700					590	7.8	33.0	6.4	42.6	64.4	3.1	124	153	135	163	129	141		4.2	13.6	139	137	
March 31, 2014	LU-35-32		11900					770	7.1	33.7	7.6	50.1	75.8	3.7	124	153	135	163	128	141		4.2	13.6	278	143	
March 31, 2014	LU-35-32		11900					1672	15.3	73.2	2.2	14.5	21.9	1.1	119	142	130	154	121	136		1.08	14.0	123	136	
April 5, 2014	LU-36-07		22681					200	1.3	7.1	109.8	726.0	1098.1	53.3	135	175	145	182	143	150		19.3	13.5			No airblast data