

Decontamination of the SmartDet Manufacturing Facility (RL26)

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1. Abstract

The RL 26 facility, at AECI Mining Explosives' Research and Development department, had been previously used for the manufacture of the SMARTDET Electronic Delay Detonators. A section of ground surrounding the facility has over many years been regularly contaminated with lead styphnate. Lead styphnate is a primary explosive that is highly susceptible to initiation, even when wet.

The exact amount of lead styphnate that has been washed into the ground is unknown but evidence suggests that both liquid and solid effluent from the production facility went directly into the soil. This contamination may not only have created a significant explosion hazard, but may seriously affect the future use and thus the asset value of the whole site.

This paper deals with the methodology used to decontaminate the facility for the purpose of a change of licence of the explosive facility.

2. Introduction

Since 1993, RL26 was used for the manufacture of electronic detonator products (SmartDet). Manufacturing activities in this facility ceased in October 2011. This facility is situated within the Research and Development Danger area, which is situated within the Pinelands office park in Modderfontein. As a result of the manufacturing, the facility and the surrounding area was potentially contaminated with lead styphnate. The majority of the contamination that occurred appears to be mainly from the discharge of washing through pipe and drain connected to a sink within the building.

The explosives contaminant of concern in the interior and exterior of the facility was believed to be mainly lead styphnate, although some lead azide and delay powders may also be present. During production and past decontamination activities, wastewater containing lead styphnate was channelled into a ditch and subsequently through a PVC pipe that discharged into an uncharacterized subsurface structure or drain feature in the open area behind the facility. When manufacturing activities ceased, the facility was decontaminated to some extent and decommissioned. The extent of the contamination was not known, however it was believed that up to 40kg of lead styphnate could exist within the ground. It is known that soda ash was used periodically during the operation to assist with desensitisation of the lead styphnate but this was not done frequently.

3. Discussion

3.1. Lead Styphnate

Explosives are classified as either primary or secondary based on their susceptibility to initiation. The more common primary explosives, include mercury fulminate, DDNP, lead azide and lead styphnate and all are highly susceptible to initiation. Lead styphnate is a primary or initiating explosive. Due to its extreme sensitivity to initiation by flame it was typically used in the manufacture of plain detonators for capped fuse. It will detonate wet or dry. (Rowe, 2016)

Lead styphnate is particularly sensitive to fire and the discharge of static electricity and is the most sensitive explosive in this category. When dry, it can be reliably detonated by static discharges from the

human body and it is sensitive to stab, flame, heat and impact. Given its sensitivity, its insolubility in water and stability at temperatures up to 80°C, it remains a highly dangerous contaminant in the ground for an unknown period of time. (Szendrei, 2017)

Table 1: Comparison of explosive properties of lead styphnate, lead azide and TNT (Division 1.1)

Properties	Lead styphnate	Lead Azide	TNT
Physical form	Orange-yellow to dark brown crystals	Colourless	Pale yellow crystals
Empirical formula	C ₆ H ₃ N ₃ O ₉ Pb	Pb(N ₃) ₂	C ₇ H ₅ N ₃ O ₆
Molecular weight	468.3	291.3	227.1
Density (g/cm ³)	3.0	4.8	1.6
Lead block test	130 cm ³ /10g	110 cm ³ /10g	300 cm ³ /10g
Sand Crush test	25% TNT	40%TNT	100
Heat of explosion (kJ/kg)	1900	1540	4564
Volume of explosion gases (litre/kg) at STP	300	308	825
VOD (m/s)	5200 at SG=2.90	5300 at SG=4.3	6700

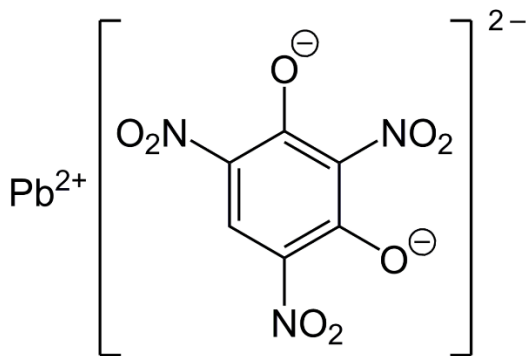


Figure 1: Lead Styphnate Structure



Figure 2: Lead Styphnate powder

3.2. Ground Penetrating Radar

In 2012, the Council for Scientific and Industrial Research (CSIR) conducted a ground penetrating radar (GPR) survey at the RL26 facility. The aim of the survey was to detect possible subsurface storage or drainage structures that may have been constructed several decades earlier during the development or operation of the facility. No reliable subsurface utility maps or records were available to confirm the presence of such structures in the area of interest. The only visible evidence that such a structure might exist is the PVC drainpipe that originates from inside RL26 and extends a couple of metres away from the building where it disappears into the ground (see Figure 3).

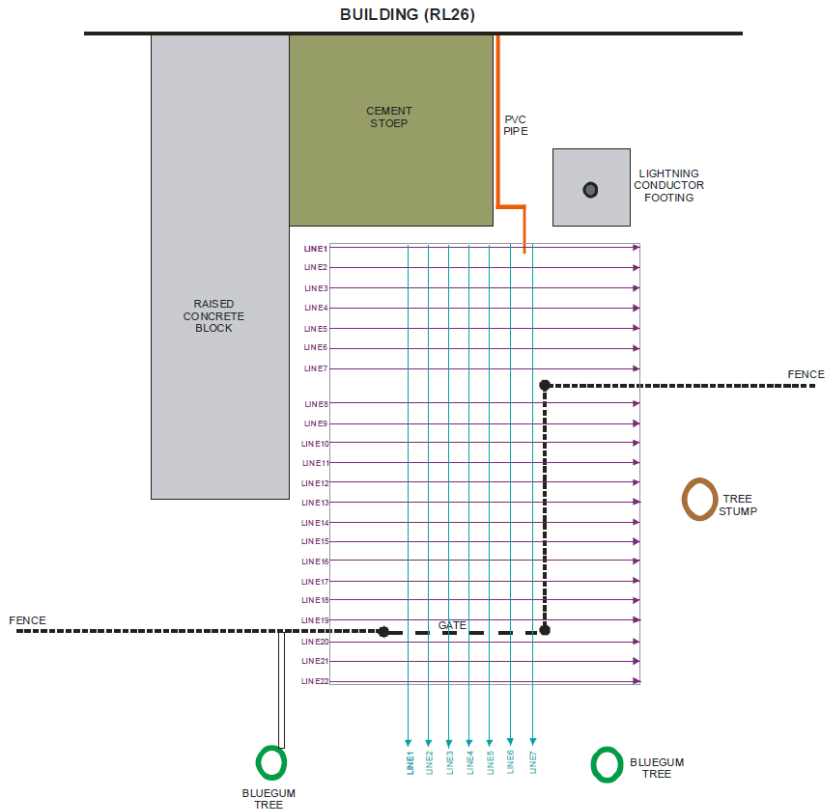


Figure 3: Schematic of RL26 area, given by the CSIR (van Schoor, 2012)

Results from the ground penetrating radar indicated that a pipe existed that extended approximately 1.8-2.0m away from the edge of the cement area. Profiles also suggested the presence of a man-made dipping horizon between approximately 1 m and 2.5 m deep. These observations, although not conclusive, do provide some evidence for the existence of a French drain structure. If such a structure exists, it slopes away from the building. (van Schoor, 2012)

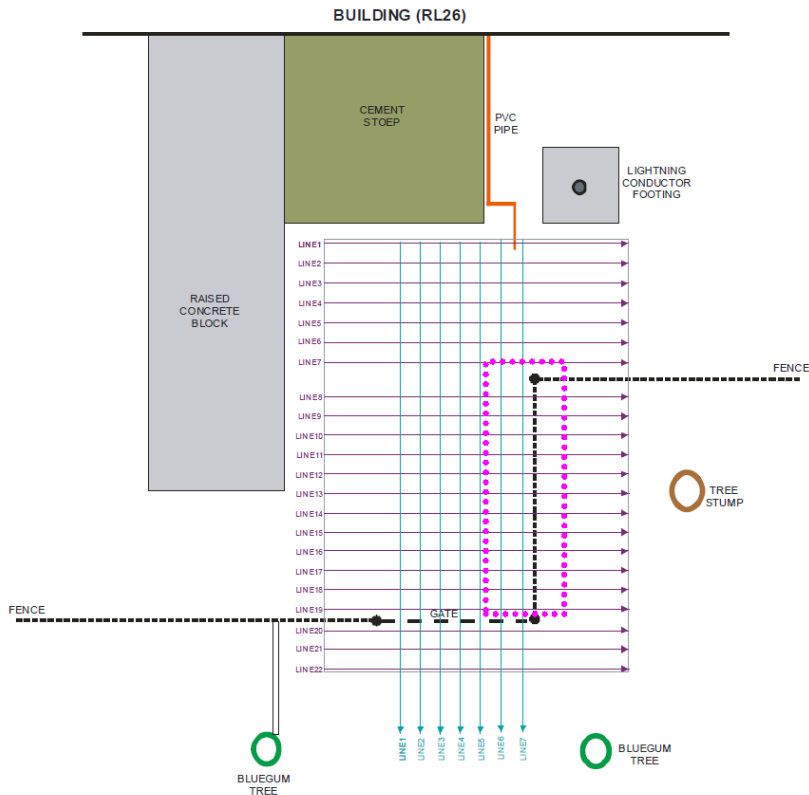


Figure 4: Schematic of RL26 area indicating possible location of French drain, given by the CSIR (van Schoor, 2012)

3.3. Remote Drilling

A possibility existed that the lead styphnate had migrated through the ground. Due to this, the full extent of the area of contamination was uncertain. As such, a remotely operated drill rig was brought in to sample the area around the building. Drilling was done to a depth of 3m and samples of the ground were taken every 500mm. The samples were tested for the presence of lead and hot plate testing was also conducted. It was found that the contamination of the ground was localised to an area of 6.0 x 3.0m. Figures 5-8 illustrate the remote drilling and soil sampling.



Figure 5: Drill Rig



Figure 6: Drill operator



Figure 7: Soil samples collected at various depths

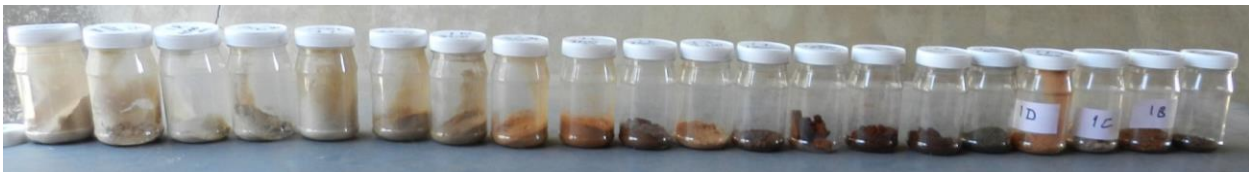


Figure 8: Soil samples prepared for analysis

3.4. Options for Decontamination

Several options were considered for decontaminating the area. The options included the use of MuniRem (a liquid system used to break down the explosive), digging the area to remove contaminated ground, desensitisation with soda ash and blasting of the contaminated area. These options were evaluated through risk assessment and the safest option was found to be the blasting of the contaminated area.

3.5. Decontamination through Blasting

3.5.1. *Preliminary study and blast predictions*

Technical specialists were consulted to do a preliminary study. This study involved determination of the effects that unintentional ignition of lead styphnate contaminated soil at RL26 might have on the surrounding buildings, including those in public areas inside and outside the office park area. Explosive quantities were estimated to be between 5 and 40kg, based on documentation written by expert analysis of the area. The purpose of this preliminary work was to determine the radial extent of potential damage to structures on site and in public areas. This could serve as the starting point for understanding how best to attenuate explosion violence at source and to identify potentially vulnerable structures, at least out to 500m from the source. (Szendrei, 2017)

Initiation of a quantity of lead styphnate, would generate the following hazards to the R&D area, office park and the surrounding public areas: (Szendrei, 2017)

- (a) Ground cratering
- (b) Ejection of soil lumps and other missiles over a large area
- (c) Propagation of a blast wave, which would exert dynamic pressure forces on built structures
- (d) High intensity (i.e. high dB-level) sound waves.

The diameter of the crater that could be formed was estimated to be between 2½ m and 5m in dry ground, and up to 8m in moist ground. The depth would lie between 0.75m and 1.5m in dry ground, and up to 3m in wet ground. Ground thrown from the crater would have a maximum range of 70m to 140m. If lumps of rock or concrete are present in the ground, the throw range would increase to between 110m and 200m. Noise levels would remain high (>140dB) up to 500m away for all surface charges 5kg to 40kg. The pressure pulse transmitted through the air is potentially damaging on built structures up to 60m (5kg) and 200m (40kg). General window breakage would extend to 100m, with some breakages occurring at a distance of up to 170m.

3.5.2. *Decontamination Blasting and Final blasting report*

Blasting was planned for the week of 9th July to 13th July 2019, 10am to 2pm. As mentioned above, the blast area was determined to be 6m x 3m, as determined by ground penetrating radar and soil sample analysis. Legal requirements dictate that perimeter of 500m be set up. An exclusion zone of 200m was set up, based on the predictions given in the expert report (as mentioned above). The exclusion zone extended to approximately where the fence separating R&D offices from the R&D Test Range along its southern boundary is located. These are both shown in figure 9.

Also to the south, a powder dryer plant was located 20m from the blast site and was vulnerable to impact damage on the profiled IBR sheeting that made up its walls and roof. To lessen the danger of rocks and other missiles being thrown to the south, a curtain of blasting barricades (as used on mines) was erected. The barricade was 6m high and 12m wide. It comprised heavy panels of thick plastic tiles with metal links between them fixed to a framework of steel cables (figure 10).

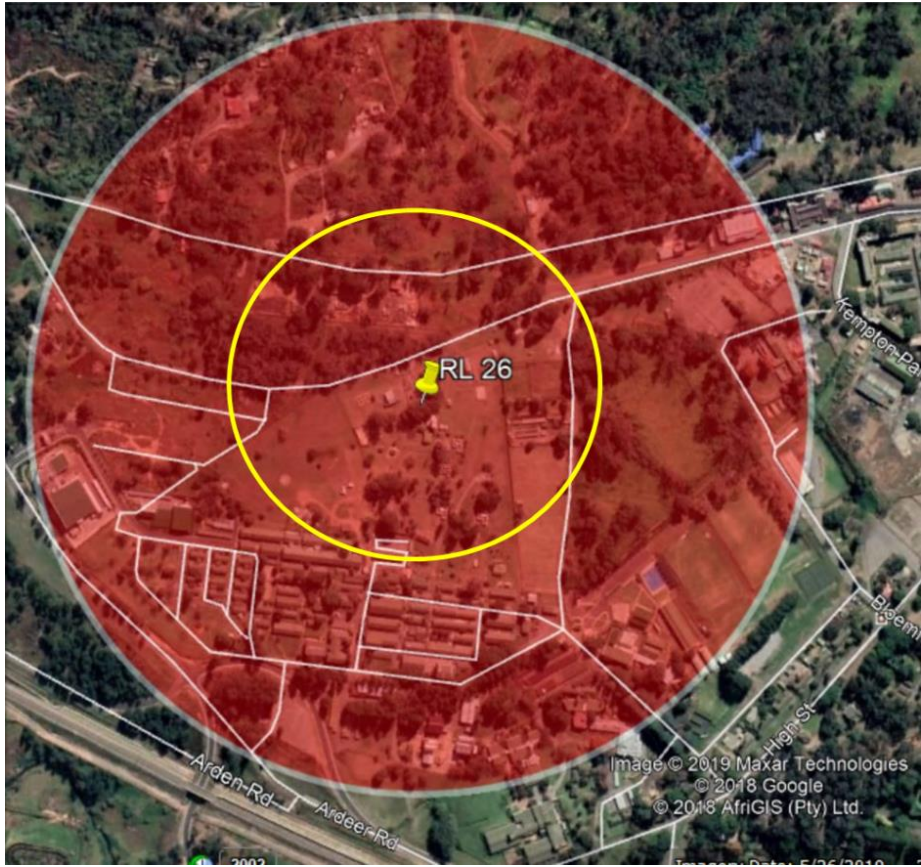


Figure 9: Exclusion and Perimeter Area



Figure 10: Blast barricade

Magnum® watergel cartridges of 38mm diameter and 560mm length were used in all blasting operations. The cartridges have a mass of approximately 830g. Two types of charges were made up with these cartridges. Bundled ‘bombs’ made up of 6 cartridges arranged in a pyramidal shape with layers of 3-2-1. The total mass was approximately 5kg. The second type of charge was a pipe charges made up of cartridges laid end-to-end within lengths of 50mm plastic pipes. To ensure good pick-up and propagation along the length of the pipe, cartridges were trimmed square at their ends. (Szendrei, 2019)

Initiation of the watergel cartridges was achieved using an electric detonator together with a 15g pentolite booster in the end of a cartridge. In the bundled bombs, the booster was embedded in the top cartridge. Pipe charges were initiated with the same detonator-booster combination embedded at both ends. The bombs were used only for blasting surface craters and were placed flat-face down. In the course of 4 days, three craters were excavated.

Pipe charges were used in two instances: 4½ m and 1½ -m lengths in the surface gutter from the sink to the external concrete slab, and a 2.1m length across the slab. In total, 18 blasts were conducted between 9th July and 12th July 2019. Of these, 16 were with 5kg bombs; the remaining 2 used pipe bombs. After placement, bundled bombs were covered with bags of stone-free sand, forming a dome over the bomb of approximately 0.6m in height and 1.3m in diameter. The sandbags weighed approximately 20kg each.

Figures 11-14 below illustrate the blasting activities



Figure 11: Placing of Charge



Figure 12: Dome of sandbags placed over 5kg charge to suppress blast noise



Figure 13: Crater of first bomb after cleaning out the broken ground. Pulverised white deposit in the soil is evident. Apparent diameter $\approx 1\text{m}$.



Figure 14: Final crater after last blast

Three craters were created with repeated blasts. Surface diameters changed little after the 3rd blast and were in the range 2½ m to 3m. The apparent depth of 0.8m was attained after the 4th blast; further advance was hidden by a rubble of dry lumps on the crater bottom. Clearing the rubble by hand revealed that the true depth was significantly greater than the apparent depth. No evidence of any built structure, such as a French drain, could be located. It is unlikely that contamination would exist at depths greater than 1m, due to the position of the drain pipe leading out of the building. A layer of sodium carbonate was encountered between 0.3m and 0.8m in depth. When further investigation was done, it was found that periodically sodium carbonate was washed down the drain in an attempt to desensitise the lead styphnate.

3.5.3. Ground Vibration and Airblast Monitoring

Four NOMIS Seismograph permanent monitoring stations were set up by a technical consultant to monitor blast induced ground vibrations and air blast at positions in near to the RL26 site. The positions of the four seismographs are given in table 2 and figure 15. (Burrow & Beattie, 2019)

Table 2: Positions of seismograph stations (Burrow & Beattie, 2019)

Station	Location	Established	GPS Position	Distance from Decontamination site
1	Shell garage in Queen St., Modderfontein	8 th July 2019	S 26° 05' 56.52" E 28° 09' 04.85"	1,090 m
2	Pinelands Business Park Gate.	8th July 2019	S 26° 05' 24.27" E 28° 09' 05.58"	445 m
3	GQ (on site contractor facility)	8th July 2019	S 26° 05' 20.51" E 29° 58' 06.42"	130 m
4	Founders Hill College	8th July 2019	S 26° 05' 34.07"	352 m



Figure 15: Location of monitoring stations

Although there are no formalized limits to vibration, the US Bureau of Mines limits are commonly applied in South Africa. 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. Typically, the ground vibration should not be allowed to exceed 12.7 mm/s at any building to limit the risk of cosmetic or any more serious damage. (Burrow & Beattie, 2019)

Based on work carried out by Siskind in 1980, monitored air blast amplitudes up to 135 dB are safe, provided the monitoring instrument is sensitive to low frequencies (down to 1 Hz). Typical estimates of damage thresholds based on empirical data are given in table 3.. (Burrow & Beattie, 2019)

Table 3: dB-levels required for damage and adverse community response (Burrow & Beattie, 2019)

dB Level	Typical Effects
180	Structural damage
176	Plaster cracks
170	All windows shattered
160	Widespread window breakage
150	Some windows break
140	No window damage expected below this level. Max. acceptable for impulsive sound.
134	USBM threshold for possible cosmetic damage to residences*

128	Deemed acceptable for schools, hospitals, etc. for occasional sources of noise
120	Threshold of pain for continuous sound
115	Complaints likely if repeated
105	Riveting of steel at 10m

All blasts registered an air blast reading at station 3 that exceeded the USBM recommended maximum level for prevention of human irritation (this area was evacuated prior to blasting). Four blasts registered an air blast reading at station 4 that exceeded the USBM recommended maximum level for prevention of human irritation. No blasts registered an air blast reading at stations 1 and 2 that exceeded the USBM recommended maximum level for prevention of human irritation. The results of all blasts can be seen in table 4. (Burrow & Beattie, 2019)

Table 4: result of blasting operations (Burrow & Beattie, 2019)

		Station 1 Shell			Station 2 Pinelands			Station 3 GQ			Station 4 College		
Distance fro m blasting site		1,090 m			445 m			130 m			352 m		
Date	Time	Event No	mm/ s	dB	Event No	mm/ s	dB	Event No	mm/s	dB	Event No	mm/ s	dB
09/07/19	12:00	N/T			N/T			006	2.58	140.1	006	0.58	128.9
09/07/19	13:00	N/T			006	0.46	126.7	007	3.49	145.2	007	0.54	127.6
09/07/19	14:00	N/T			007	0.48	127.0	008	3.82	146.5	008	0.31	125.3
10/07/19	10:00	N/T			N/T			009	1.42	141.9	009	0.38	127.5
10/07/19	11:00	N/T			N/T			010	1.77	141.0	010	0.72	128.3
10/07/19	12:00	N/T			010	0.42	124.1	011	2.39	143.1	011	0.46	129.2
10/07/19	13:00	N/T			011	0.54	128.7	012	4.28	147.5	012	0.46	130.8
10/07/19	14:00	N/T			012	0.52	127.8	013	4.05	145.5	013	0.40	130.9
11/07/19	10:00	N/T			013	0.68	128.7	014	3.39	145.2	014	0.58	132.5
11/07/19	11:00	N/T			014	0.46	125.7	015	2.45	143.4	015	0.58	131.2
11/07/19	12:00	N/T			015	0.46	126.0	016	2.55	143.1	016	0.46	130.8
11/07/19	13:00	036	0.28	121.9	016	0.57	129.3	017	3.91	143.3	017	0.86	132.6
11/07/19	14:00	038	0.38	123.2	017	0.70	132.1	018	4.04	146.7	018	0.97	135.5
12/07/19	10:00	039	0.28	121.6	019	0.66	125.7	020	2.80	142.6	020	0.65	134.2
12/07/19	11:00	N/T			020	0.60	126.8	021	2.29	144.4	021	0.57	132.7

9													
12/07/19	12:00	N/T			021	0.58	128.7	022	4.55	148.1	022	0.78	135.0
12/07/19	13:05	048	0.31	120.2	022	0.60	127.8	023	4.19	147.3	023	0.48	132.3
12/07/19	14:00	N/T			023	0.44	125.6	024	4.20	147.2	024	0.60	136.3

3.6. Area clean-up

After blasting was concluded, the blasted earth was removed from the craters. Additional digging was done with a tractor-loader-backhoe (TLB) until hard earth was reached in all directions (figure 16 and 17). Earth remaining between the craters has also been removed, thus leaving one large hole. No evidence of a French Drain was found. Additional soil samples were taken from the bottom and sides of the hole and of the sodium carbonate layer. These have been sent for analysis for lead.



Figure 16: TLB clearing crater of loose material



Figure 17: Single hole after cleaning

4. Conclusions

The following conclusions can be made with regards to this decontamination endeavour:

- Remote drilling and soil sampling indicated that the contaminated area was limited to a 6m x 3m area
- Although ground penetrating radar indicated the possibility of a French drain, no evidence of any structure such as this could be found
- The safest option for decontamination was considered to be blasting the contaminated area. This took place successfully, with 18 blasts in total and a total of approximately 100kg of explosives was detonated in the contaminated area. A layer of sodium carbonate was encountered between 0.3m and 0.8m in depth and additional contamination below the depths that were blasted is not likely
- During the blast, high levels of airblast were recorded on seismograph 3. No persons were affected in this area as this was part of the exclusion zone.
- The final crater was further dug using a TLB until hard rock was reached (remove all loose material generated as a result of the blast). Additional samples were taken from these areas and will require further analysis.

5. Acknowledgements

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- Cheryl Kelly; AECl Mining Explosives

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Appendix: Results of blasting on ground outside RL26 on the south side with bombs of 6 Magnum cartridges (\approx 5kg). (Szendrei, 2019)

Shot No.	Date	Time	Crater no.	Crater Diam.(m).	Crater Depth(mm)	Other Observations
1	2019/07/09	12H00	1	2-2.3 Broken ground \approx 1	\approx 200	Disturbed ground \approx diameter of sandbag heap
2	2019/07/09	13H00	1	2.3-3.0 Broken ground \approx 1.3		
3	2019/07/09	14H00	1	2.7/2.9/2.7	600	
4	2019/07/10	10H00	1	2.8-3.0-3.0	700-800	Crater flat-bottomed
5	2019/07/10	11H00	1	3.0 surface 1.2-1.5 bottom	Filled with lumps	
6	2019/07/10	12H00	1	2.8 – 3.0	800 apparent 1000 cleared	Crater wider at apparent depth than above
7	2019/07/10	13H00	2	\approx 2 Broken ground \approx 1.3	Cleared to depth 300	
8	2019/07/10	14H00	2	1.8-1.9	\approx 500 apparent	
9	2019/07/11	10H00	2	2.2 – 2.5	\approx 700	
10	2019/07/11	11H00	2	2.5 – 2.6	\approx 800	
11	2019/07/11	12H00	2	2.75 – 3.0	\approx 800 apparent	Filled with dry lumps
12	2019/07/11	13H00	6m pipe bomb used in concrete surface gutter alongside RL26 floor slab			
13	2019/07/11	14H00	2	2.75 - 3.0	\approx 800	Filled with dry lumps
14	2019/07/12	10H00	Combination 1½ m pipe bomb and 3-cartridge bomb used on 2.6m x 2.6m concrete slab and Crater 2 respectively.			
15	2019/07/12	11H00	3	1.3 broken ground	200 cleared	

16	2019/07/12	12H00	3	1.7 – 1.7	600 apparent	Sand mound 1400x1200x500mm
17	2019/07/12	13H00	3	2 – 2.2	700 apparent	
18	2019/07/12	14H00	3	2 craters merged	Loose rubble	Placed on a ridge separating Craters 2 & 3