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# The Effects of Depth on Diesel Engine Emissions in an Underground Mine

**2007 Mining Diesel Emissions Conference**

**Toronto, ON**

**October 3, 2007**

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## Project Goals

- Many Canadian mines are approaching or have surpassed 10,000ft depth.
- HD diesel production vehicles will soon be operating at depth.
- Goal was to determine the effect of depth on modern diesel engine emissions.
- “Real world” test in an operating deep mine in Canada.
- Transient and steady-state emissions.
- Engine performance / robustness of electronic control systems.

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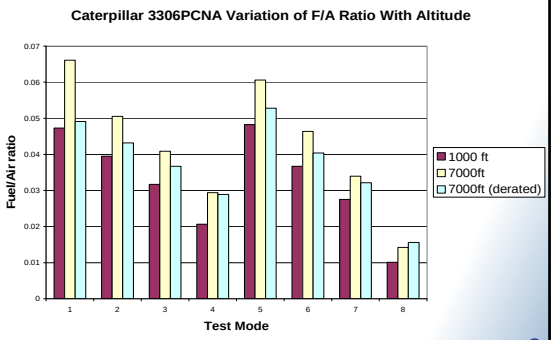
# Literature Survey

- Literature survey revealed considerable research on high altitude operation.
- But very little prior work on diesel operation at depth.
- MSHA work on altitude found to be the most comprehensive.

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# Project Review

- Insufficient data in the literature on depth.
- Proceed with a formal study.
- Full depth simulation chamber too costly.
- Reasonable preliminary data could be obtained from an in-mine test at depth.
- Added bonus of real world cycle tests in addition to steady-state.

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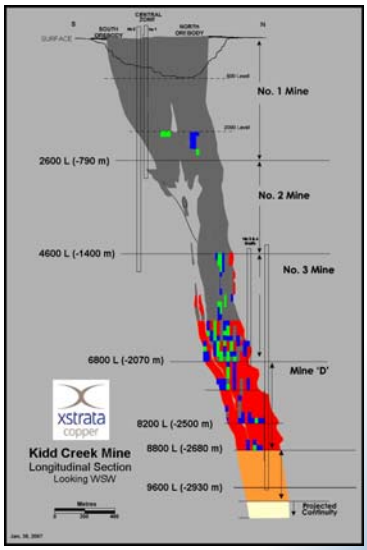
# U/G Field Study

- Underground field study at Xstrata Copper Canada – Kidd Mine.
- Access to operations at depth – served by ramp to surface.

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# Test Vehicle

- Toro Tamrock LHD

| | |
|---|---|
| Make | Detroit Diesel |
| Model | Series 60 (EPA Tier 2) |
| Type | Inline 6 cylinder |
| Combustion | DI, Electronic |
| Aspiration | Turbo, aftercooled |
| Bore | 5.12 in (130mm) |
| Stroke | 5.47 in (137mm) |
| Displacement | 11.1 litres |
| Rated Power | 325 hp @ 2100 rpm |
| Peak Torque | 1150 lbft @ 1200 rpm |
| Idle speed | 600 rpm |
| Vehicle | Toro Tamrock LHD |
| Hours | 502 |

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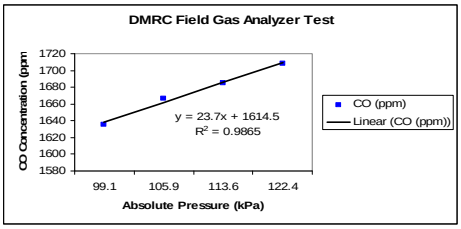
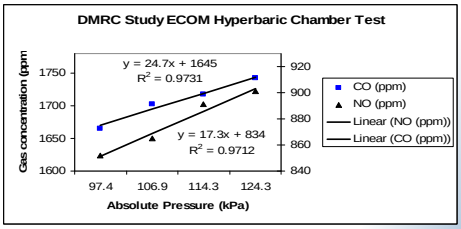
# Instrumentation (1)

- Initial work with portable gas analyzers found the electrochemical cells were inadequate for the work.

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# Instrumentation (2)

- Abandon EC cell in favour of lab-based measurement principle analyzers.
- Sensors Inc. SEMTECH-D


| | Range | Resolution | Accuracy |
|---|---|---|---|
| $CO_2$ | 0 – 20% | .01% | ± 0.1% or ± 3% of rdg |
| CO | 0 – 8%<br>0 – 8% | 10 ppm<br>.001% | ± 50ppm or ± 3% of rdg<br>± 3% or ± 0.02% of rdg |
| THC | 0 – 100 ppm<br>0 – 1,000 ppm<br>0 – 10,000 ppm | 0.1 ppm<br>1 ppm<br>1 ppm | 2 ppm or ± 1% of rdg<br>±5 ppm or ± 1% of rdg<br>± 10 ppm or ± 1% of rdg |
| NO | 0 – 2,500 ppm | 1 ppm | ± 15 ppm or ± 3% of rdg |
| $NO_2$ | 0 – 500 ppm | 1 ppm | ± 10 ppm or ± 3% of rdg |

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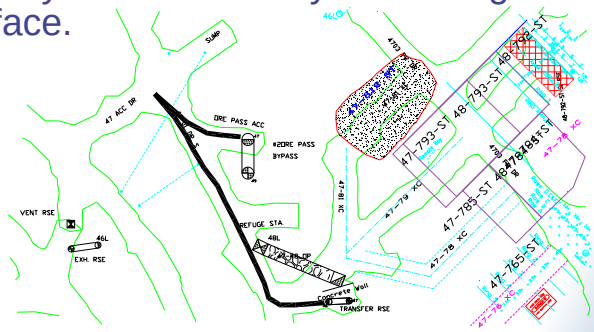
# Test Procedure

- Vehicle would operate over a normal production duty cycle with on-board instrumentation. Transient LHD cycles.
- Steady-state cycle simulated by ascending the ramp to surface.

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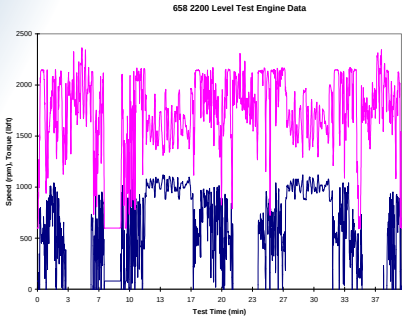
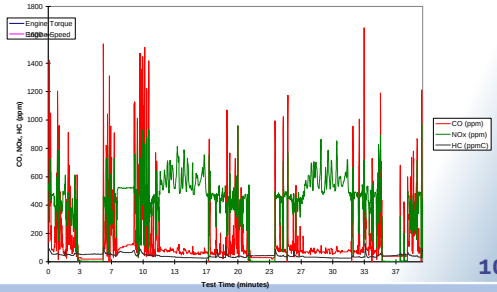
# Results -Transient

- Gaseous emissions, DPM integrated over cycle. High emission peaks.

Transient Cycle Average Emissions Index (g/kg fuel)

| Depth (ft) | CO | $CO_2$ | NO | $NO_2$ | NOx | THC | DPM ($mg/m^3$) |
|---|---|---|---|---|---|---|---|
| 1000 | 10.0 | 3394.7 | 32.7 | 1.9 | 34.5 | 1.4 | 49.6 |
| -1200 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| -3700 | 16.0 | 3382.6 | 32.6 | 3.1 | 35.7 | 1.3 | 61.7 |
| -5900 | 6.5 | 3400.7 | 28.9 | 2.5 | 31.3 | N/A | 27.8 |
| -7000 | 9.9 | 3400.2 | 32.7 | 2.3 | 35.0 | N/A | 46.3 |

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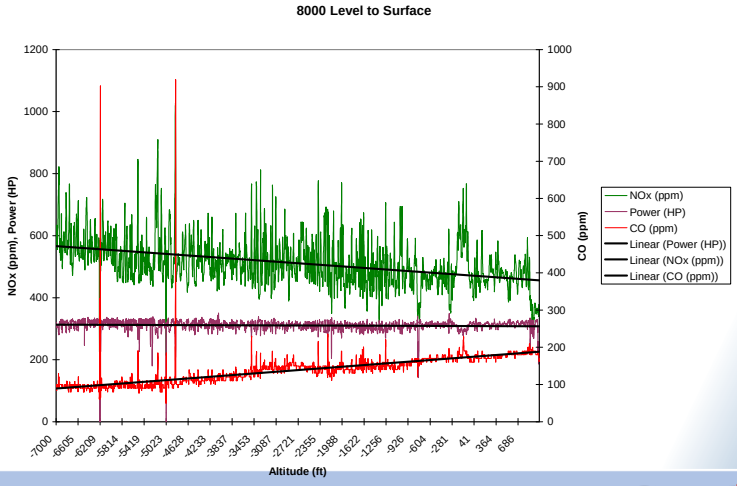
# Results – Steady-state

- Better resolution of the effects of depth.

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# Emissions and Depth

- Clear trend for reduction in CO emissions with increasing depth.
- This was expected with higher air density (lower fuel/air ratio).
- Trend also for increased NOx emissions with increasing depth.
- Likely due to pressure effect on combustion NOx formation.

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# Validation of work

- No other comparable studies at depth.
- Some altitude effects studies:
  - Best work from MSHA
  - Looked at CO / NOx / DPM from NA and turbocharged - aftercooled engines at sea level up to 8000 ft altitude.
  - Cummins CTAA8.3C
  - Deutz BF4M1013C

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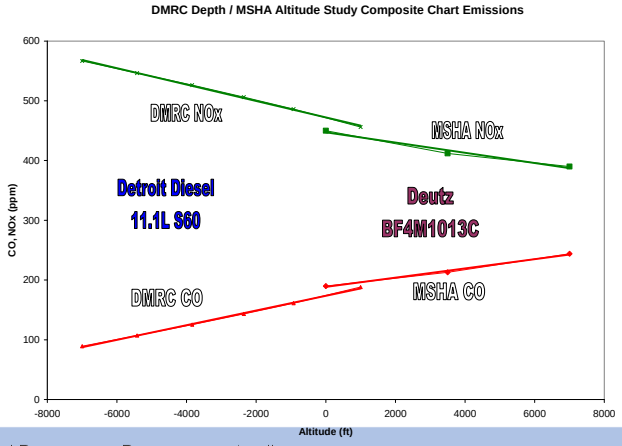
# Linkage to MSHA

- Connect DMRC work at depth to MSHA work at altitude with composite chart.

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# Altitude vs. Depth

- CO and NOx trends are in the same direction for both altitude and depth.
- This generally validates the DMRC diesel work.
- Absolute numbers are different due to different engines used.
- Engines were similar type, so comparison was reasonable.

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# Conclusions

- Significant effect on emissions at depth.
- Decrease in CO and other fuel/air ratio sensitive emissions was expected.
- Increase in NOx was found to be significant and at a greater rate than CO.
- Consideration should be given to revision of MMSL 02-084 recommendations for operation at great depth.
- CSA M424.2 and M424.1 review.

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# Recommendations

- If more mines continue to expand operations at depth, the construction of a laboratory-based depth simulator may be warranted.
- Do the effects hold for alternative fuels like biodiesel? NOx/PM aftertreatment?
- How do engine thermal emissions change with depth?
- The unsuitability of EC instrumentation needs to be investigated further as many mines rely on this type of analyzer.

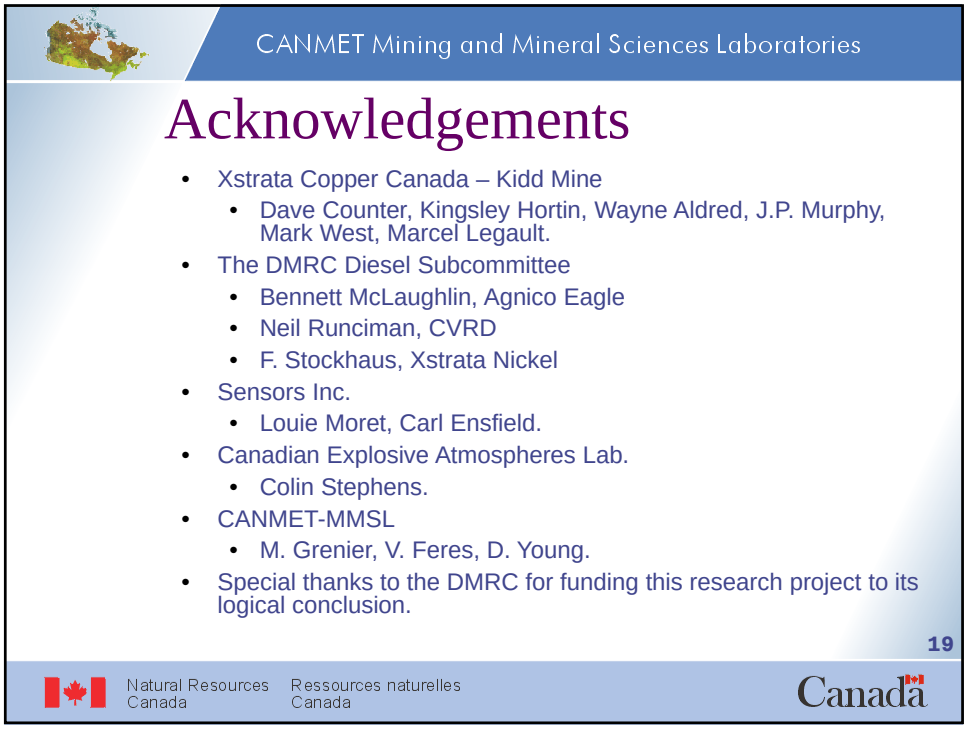






# Future Work

- Communication of EC cell concerns to manufacturers, CITI, Draeger.
- Development of mining-specific ECU calibration with HD engine manufacturers.
- Possible to trade-off CO and DPM emissions to get reduction in NOx at depth.
- Must maintain certification exhaust quality index (EQI) at depth.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Acknowledgements
• Xstrata Copper Canada – Kidd Mine
• Dave Counter, Kingsley Hortin, Wayne Aldred, J.P. Murphy, Mark West, Marcel Legault.
• The DMRC Diesel Subcommittee
• Bennett McLaughlin, Agnico Eagle
• Neil Runciman, CVRD
• F. Stockhaus, Xstrata Nickel
• Sensors Inc.
• Louie Moret, Carl Ensfield.
• Canadian Explosive Atmospheres Lab.
• Colin Stephens.
• CANMET-MMSL
• M. Grenier, V. Feres, D. Young.
• Special thanks to the DMRC for funding this research project to its logical conclusion.
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