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Evaluating Diesel Particulate Trap Technology at Noranda - Brunswick Mining Division

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TABLE OF CONTENTS

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Overview

This project will investigate the effectiveness and reliability of state-of-the-art Diesel Particulate Filter Systems (DPFs) in Canadian hard rock mining environments. By using these systems, European mining and tunnelling operations have met roughly similar DPM PELs as the Diesel Emissions Evaluation Program (DEEP) would now like to demonstrate (0.05 to 0.15 mg DPM/m3).

This is one of two complementary research proposals for projects that will take place at Noranda Mining - Brunswick Mining Division and INCO - Stobie Mine over a period of 18 months. DEEP, INCO, Noranda, and the manufacturers of DPFs and diesel engines will provide cash and in-kind contributions. By hosting the project at two separate mining companies the burden of in-kind contributions, as well as the knowledge and experience gained, can be shared. Four to five production vehicles will be tested at each mine. These vehicles will be equipped with particulate traps with with different regeneration technologies as well as duty cycle logging instrumentation. Brunswick Mine will conduct measurements which will be in addition to those done at INCO.

Monitoring and measurement will be undertaken at four levels. Undiluted monitoring of both gases and particulates will be done regularly as part of the standard scheduled maintenance procedure on the vehicles. At this time the systems will also be inspected for visible or obvious damage and wear. At Brunswick Mining, personal exposure sampling will be performed with gravimetric analysis over the entire length of the study . Samples will be gathered 4 times per week , rotating between different vehicles in the study. An ambient zone study with DPM mass analysis will be conducted at Brunswick Mining. This is due to a situation where Brunswick has a location available where an isolated closed ventilation circuit is available for such a study. All of the traps used in the study between the two sites will be bench tested at the beginning and end of the project. The bench testing will be conducted by an independent third party to be chosen by the trap manufacturers. These tests will be financed as an in kind contribution by the manufacturers. During bench testing the traps would most likely be tested for efficiency with respect to mass, particle count, size, distribution, and chemical characterisation.

Stage 1 - Identification and Selection

- Acquire personal sampling baseline
- Acquire undiluted emission baseline for four test vehicles
- Install dataloggers and sensors
- Acquire data on engine duty cycles
- Prepare trap selection matrix designed for matching traps to engines

Stage 2 - Characterisation and Selection

- Analyze duty cycle data

- Select the trap technologies to be used from matrix in conjunction with Technical Adviser and trap manufacturers
- Acquire the particulate traps and instrumentation required for doing the study
- Perform baseline ambient study in production test zone with four vehicles

Stage 3 - Installation and Training - Implementation
- Install the particulate traps and instrumentation on four production vehicles
- Train operators and mechanics
- Put all vehicles equipped for project into regular production
- Monitor backpressure and temperature with weekly data downloads for evaluation for first month and monthly thereafter
- Monitor undiluted gases and particulates at scheduled maintenance intervals
- Monitor operator exposures with personal sampling
- Operators and mechanics to fill in log books specific to operation and maintenance issues with each trap system

Stage 4 - Interim Analysis and Evaluations [every 3 months]
- Perform non intrusive inspection and evaluation on condition of traps and deterioration with site maintenance personnel
- Every 3 months conduct tests using the Matter portable system for particle count and size distribution
- Conduct interim meetings every 3 months to discuss results of dataloggers, undiluted testing, personal exposure sampling, condition of traps, implementation, operation and maintenance issues [log books]
- Produce interim report on findings and recommendations on possible go / no go decision

Stage 5 - Extended Evaluation
- Continue operation of all vehicles in full production with interim meetings every three months to discuss testing results and implementation issues
- Over 18 month period monitor undiluted gases and particulates at scheduled maintenance intervals
- Over 18 month period monitor operator exposures with personal sampling at 4 samples/week
- At the 12 month milestone (approx. 2000-3000 hours) conduct another ambient test zone study with each of the four vehicles in the study to evaluate performance independently

Stage 6 - Analysis and Final Report
- After 18 months total evaluation or approximately 3000 - 4000 hours of operation remove the traps and send out for bench testing, tear down and inspection at CANMET [two trap systems only]
- Compile data from ambient, undiluted, and personal exposure sampling
- Analyse data and produce final report on findings

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Objectives

The purpose of this project is to determine the effectiveness and economic maintainability of current-generation Diesel Particulate Filter Systems (DPF) as applied to U/G mining operations (excluding coal). This can only be determined by conducting research in an actual working production environment. The primary objectives are to:

1. **establish a methodology for selecting DPFs for mining vehicles, including the use of duty cycle information, DPF and mine characteristics;**
2. **determine the overall effectiveness, durability, maintainability, and costs of current-generation DPFs in a long term production study;**
3. **develop Canadian expertise with new DPF and measurement technologies by involving mine personnel, corporate technical and OSH personnel, independent R&D service providers, engine manufacturers, vehicle manufacturers, and local DPF suppliers**
4. **quantify the effect of the technology on exhaust gases (CO, NO, NO2, SO2).**
5. **quantify the effectiveness of the technology in DPM reduction specific to mass and size distribution in ambient closed ventilation circuit tests as well as operator exposure levels with personal sampling.**
6. **To quantify the effectiveness of the technology in DPM and gas reduction for undiluted exhaust**

Priorities - It should be noted that the field tests are designed primarily to assess the operational viability of the DPFs. Therefore the emphasis is on operability, reliability, and robustness of DPFs. Trap efficiency, backpressure and regeneration characteristics will be ascertained in VERT certification tests beforehand, and will also be assessed in bench tests at the end of the field tests. The operating conditions for reliability and safety of trap regeneration will require close monitoring.

It is proposed that DEEP adopt the VERT specifications for DPFs as presented in Appendix II, with several exceptions also noted in that appendix.

The emphasis of this project is on DPFs offering a much wider range of operating conditions and engine characteristics than passive filters can provide. This includes DPFs incorporating technologies that:

- reduce DPM (mass & nanoparticle count), or catalyze its oxidation at lower temperatures (such as fuel additives, alternative fuels, or even more advanced engine designs); and/or
- actively control exhaust temperatures or composition (eg. NO2) to ensure periodic regeneration.

However, considerable operational experience has been accumulated at Noranda with passive (no fuel additives etc) DPF, which are limited in application to vehicles/tasks that result in periodic exhaust temperatures high enough and of sufficient duration to ensure that the DPF won't plug up with soot. Noranda may wish to test a passive (catalyzed or uncatalyzed) trap meeting the VERT specifications.

Background

Concern over the potential health impacts of diesel particulate matter (DPM) emissions has increased over the last decade on the basis of epidemiological and toxicological studies. (1,2,3,4). This has led to lower DPM exposure limits in Europe, and proposals for similar reductions in the US mining industry. These levels are typically on the order of 0.15 mg DPM/m3, but a recent ACGIH notice suggest 0.05 mg DPM/m3, versus current maximum levels of roughly 1 to 1.5 mg DPM/m3.

A broad range of technologies are available to reduce DPM emissions, such as engine design (injection pressures, turbulent mixing, electronic controls, piston ring design), fuels, fuel additives, diesel oxidation catalysts (DOCs), and diesel particulate filters (DPF) (5,6,7,8,9). However, at the current time it is felt that Diesel Particulate Filter Systems (DPFs)are the only commercially available technology that can deliver the extremely low DPM levels being proposed (10).

Studies of early-generation DPFs in the underground mining environment date back to the Diesel Advisory Panel collaboration between the Province of Ontario's Ministry of Labour, CANMET, and the US Bureau of Mines from 1981-1985 culminating in the "PILP Program" managed by Engine Control Systems(ECS) and supported by NRC and Canmet. (11,12,13) This type of DPF is still being used at Brunswick Mining Division of Noranda in Canada (14). Current-generation DPFs rely on more active means of ensuring that soot accumulation is burned off , thereby minimising lost production time. Since early 1996 the Austrian Tunnel Construction Company Beton-und Monierbau has focussed on Oberland Mangold fuel additive systems for its heavy duty tunnel construction equipment (15). Sudwestdeutsche Salzwerke AG in Germany has been using KHD-Deutz-Service fuel-burner-regenerated DPF since March 1993 on heavy-duty diesel engines (16). These units rely on backpressure and temperature sensors, together with sophisticated burner controls to be able to regenerate during any vehicle load condition. Light duty vehicles are equipped with Deutz cartridge filter systems.

In late 1993, a major study of DPM reductions technologies and measurement methods was undertaken by VERT, a European joint project (18,19,20). DPM reduction options (only DPFs qualified) have been confirmed during 18 months of field tests on earth moving construction equipment. The VERT program is of particular relevance to DEEP because of the similarity of the objectives and the nature of the technical work, and because legislation in Europe has driven operational and market progress beyond its current state in North America.

European regulations for busses and heavy-duty diesel emissions in large urban centres for the year 2005 are widely expected to require DPF or other aftertreatment technologies. If this market does materialise, its size may drive costs of DPF downward, and lead to rapid improvements in DPF performance, quality, availability, and specialty niche products may appear. This market could also enable engine manufacturers to consider changes in engine materials and design better adapted to these after-treatment devices.

Noranda Inc. - Brunswick Mining Division

Brunswick Mining will test 4 trap systems for this project. A project leader, site champion, 16 equipment operators, 8 mechanics, and 2 ventilation technical staff will be involved in 18 months of on site testing. There may be a possibility that BMD could allocate a co-op student working with the ventilation department to manage the sample cassettes from the personal and undiluted sampling instruments. In addition to the human resources the mine will provide 4 production vehicles to be instrumented for the entire length of the study. The UGAS technology for measuring undiluted exhaust emissions is currently integrated into the maintenance program at Brunswick and will be included in this project as well. The Matter particle analysis system will be employed at a minimum of every 3 months. At present it is anticipated that Brunswick will be able to share the use of an instrument which will be purchased by CANMET. As CANMET staff will have a considerable on-site presence at Brunswick for the duration of this project, the use of the Matter instrument every 3 months will be easily handled by representatives of CANMET, NTC and Brunswick.

Technical Support Group - CANMET and Noranda Technology Centre

Technology transfer will be a critical component in the success of this project. A Technical Support Group will be involved in every measurement and evaluation component from start to finish of the project. This will ensure that all knowledge to be gained from this project has been shared with one or more independent agencies. The agencies involved would be CANMET and Noranda Technology Centre. Participation would include all stages including datalogging, selection, installation and training and ongoing measurement.

There will be two stages in the project where ambient DPM emissions will be evaluated in a closed ventilation test area of Brunswick Mine. The team from CANMET in Sudbury has done several of these exact tests at Brunswick in the past, most recently the DEEP project for evaluation of sampling methods. It is anticipated that each of these tests will include two CANMET staff for a period of 10 days, evaluating the DPM contributions from each of the four test vehicles using both the EC/TC method of analysis as well as size distribution analysis. The breakdown of each 10 day test cycle is outlined below. The total amount of $45K would be multiplied by two to cover the ambient test stages in the project.

Cost Area	Amount
Labour - 2 people X 10 Days	$32K
Travel	$3K
Accommodations	$3K
Shipping and Handling - Test Apparatus	$0.5K
Analysis of Samples	$6K
TOTAL (per test)	**$45K**

The Technical Support Group will also be involved in the onsite testing with the Matter particle sampling system. This system would be used for evaluating both ambient and undiluted DPM concentrations. The undiluted tests would be done every 3 months at

Brunswick with a graduated technology transfer approach from TTM / Matter to the Technical Support Group and the mine personnel. As project leader, Noranda Technology Centre will be working on-site at Brunswick at a minimum of every 3 months for interim evaluation. This will facilitate the technology transfer to the site people at Brunswick on the use and relevance of measuring with the Matter instrument.

CANMET - Bells Corners Laboratories

At the conclusion of the project, 2 of the DPFs will be sent to CANMET - Bells Corners laboratories for bench testing. This will facilitate the transfer of the certification process and technology from VERT to CANMET. An ideal opportunity exists here to compare the MAPTEST protocol to the VERT certification protocol so that CANMET will be prepared to carry this out in the future as required. The same analysis protocols will be followed between the bench test laboratories in Europe and CANMET. This will include both the IGF and NIOSH 5040 methods for EC analysis.

Primary Technical Adviser - TTM - Andreas Mayer

Based on previous research done with the VERT consortium in this specific area, the expertise of Andreas Mayer will be drawn upon for implementation and technology transfer. The Technical Adviser will work with at least one member of the Technical Support Group on the following primary tasks:

- Analysis of engine data retrieved from dataloggers
- Selection of most suitable particulate trap technology
- Co-ordination with filter manufacturers for bench testing, installation and training
- Installation and training with selected systems
- Testing and training with the Matter particle analysis system
- Co-ordination and analysis of all data at finish of project

The Technical Adviser will visit Brunswick Mine at least four times to assist in installation and training on trap systems, measurement systems, as well as interim and final evaluations.

Paul Nothiger - Supplier of Datalogger Technology

The units for monitoring engine exhaust backpressure and temperatures will be supplied by Paul Nothiger. Technical details of the instruments are explained in later sections of this document. Installation and training for these instruments will require a period of one full week (5 working days) on-site for Mr. Nothiger to transfer the technology. Representatives of Noranda Technology Centre, Brunswick Mining, and CANMET will be participating in the installation of these systems. There is a strong likelihood that at the termination of the project, CANMET will purchase these instruments from DEEP for future use. There will be a total of 5 units purchased for Brunswick to cover 4 vehicles plus one spare.

Workplace, Health, Safety, & Compensation Commission of New Brunswick

A representative of WHSCC, Lee O'Blenis, will be required to actively participate in the on-site evaluation of the DPF at Brunswick Mine. At a minimum, this would entail participation in the two ambient studies in the test production zone and participation in the reporting of results at those stages in the project. It would also be recommended that WHSCC be partially involved in the undiluted and personal sampling processes as well.

Particulate Trap and Engine Manufacturers

The manufacturers of the selected trap technologies along with the engine manufacturers will actively participate in this project. A total of 8 DPFs to cover the 4 test vehicles with spare units for contingency will be required. In addition the manufacturers of both traps and engines will be called upon for technical consulting and support in implementation and maintenance of these systems. As this project will provide the trap manufacturers with a unique test environment and marketing opportunity, they will be solicited for in kind contributions with respect to:

- Provision of test units
- Pre and post bench testing of test units
- Travel and accommodations

Vehicle Manufacturer - Atlas Copco Wagner

The collaboration of Atlas Copco will be sought to assist in the installation of the trap systems on the vehicles. Noranda recently entered a preferred partnership arrangement with Atlas Copco to supply all U/G mobile production equipment. Assuming that the trap technology will become a standard component on future mobile applications, the manufacturer will need to be capable of engineering the engine/trap installations for maximum performance and durability. For this reason it will be critical that Copco be present to participate in the technology transfer during installation and implementation.

Stage 1 - Identification and Selection

In this stage all critical decisions will be made as to logistics. The first step will be to identify team members to undertake specific responsibilities and tasks within the project. These resources will come from Brunswick Mining Division, CANMET, Noranda Technology Centre, WHSCC of New Brunswick, filter trap manufacturers, engine manufacturers, vehicle manufacturers, and TTM - Andreas Mayer.

Noranda Technology Centre will undertake the project leadership. The site champion at Brunswick will be responsible for co-ordinating all equipment, resources, and ongoing tasks for the 18 month period of on-site testing. The project leader will be responsible for co-ordination between the site champion, Primary Technical Advisor, and Technical Support Group. In a collaborative effort this team will identify the most ideal test process at the mine and which vehicles would best fit into the project.

Once the vehicles have been selected the team will proceed to installation of the dataloggers for determining engine operating duty cycles. Once again, this will be a collaborative effort with the entire team. Maintenance personnel at the mine will instrument the vehicles so that the ongoing support while collecting duty cycle data will be in house.

In parallel to the collection of duty cycle data, a baseline for personal exposure to operators on the vehicles will also be done at Brunswick Mining. This will require involvement of mine ventilation and Occupational Health & Safety people to co-ordinate this task. Personal sampling will be ongoing for the entire project so a system for mounting the samplers in the operator's compartment on the vehicles instead of on the operators themselves will likely be the best solution. All samples gathered will be sent out to CANMET laboratories in Sudbury for analysis.

Also in parallel to the datalogging process, a matrix of available trap technologies will be compiled for evaluation of the most logically suitable engine/trap combinations. This will aid in better understanding which technologies are best suited for which applications and what the capabilities are. The example below outlines the engine/vehicle profile to be used in the project. The matrix of trap systems would then be matched against this to narrow down the final selection.

Example - Vehicle / Engine / Trap Selection

Vehicle	Wagner ST8B LHD	Wagner ST8B LHD	Wagner MT433 Truck	Wagner MT433 Truck
Engine	DDEC S60 11.1L 242 kW single exhaust	DDEC S60 11.1L 242 kW single exhaust	DDEC S60 12.7 L kW single exhaust	DDEC S60 12.7 L kW single exhaust
Expected Duty Cycle	Moderate load cycle Inconsistent regen temperatures Active	Moderate load cycle Inconsistent regen temperatures Active	High load cycle Frequent regen temperatures Passive should work	High load cycle Frequent regen temperatures Passive should work
Exhaust temperature	Med Temp May have periods of heavy soot accumulation?	Med Temp May have periods of heavy soot accumulation?	Med to Hi Temp Hi temps for extended periods when hauling up ramp	Med to Hi Temp Hi temps for extended periods when hauling up ramp
Exhaust backpressure	< 100 mbar	< 100 mbar	< 100 mbar	< 100 mbar
Special operating conditions				
DPF candidates	Electrical Diesel Burner Off-Board	Electrical Diesel Burner Off-Board	Catalysed Fuel additive Electrical Diesel Burner Off-Board	Catalysed Fuel additive Electrical Diesel Burner Off-Board
Recommended DPF				

Stage 2 - Characterisation and Selection

After sufficient data has been gathered to determine the duty cycles it will be downloaded and sent via Internet to Andreas Mayer - TTM for analysis. With this data Mayer, in collaboration with the entire project team, will determine which traps are best suited to the vehicles in this study. This list will be used to contact the trap manufacturers and establish which model of trap can be procured for the project. It is anticipated that the manufacturers will supply the traps at no cost as a contribution to this study. Bench testing of the selected traps for the study will be done at the discretion of the manufacturers and the ensuing costs assumed as their in-kind contribution.

The DPFs will be bench tested at laboratories selected by the manufacturers to establish a baseline for performance values before going into the mine production environment. This will provide comparison criteria for the final bench testing of the devices at the end of the production tests.

A baseline ambient study of DPM will be performed at Brunswick Mine. This will be conducted with four vehicles at a suitable closed ventilation circuit test area. At this time the vehicles will be evaluated with the existing exhaust aftertreatment systems. Each vehicle will be tested for two full shifts of operation. The study will be performed with resources and equipment from CANMET, with analysis and results supplied afterwards. The site team at Brunswick will provide support and maintenance to CANMET as required during the one-week ambient study. A representative from WHSCC of New Brunswick will be requested to participate in the ambient baseline study, as well as subsequent ambient tests. Technical considerations for the ambient isolated zone testing are explained later in this proposal.

Stage 3 - Installation and Training - Implementation

Under the guidance and recommendations of the manufacturers, the team at Brunswick will install the traps on the vehicles. Representatives from the trap manufacturers will be requested to be on-site for installation and training. This will be co-ordinated with the INCO project so that only one trip from Europe will be necessary to install traps at both locations. The site team will be responsible for monitoring and maintaining the traps on the vehicles on an ongoing basis as well as the instrumentation and data logging equipment on board the vehicles.

Once the traps are installed and functioning properly, the vehicles will be sent out into normal production with the test equipment for a three-month period. During this period the vehicles will be brought back to the shops for schedule PM maintenance. Undiluted testing will be done using two technologies and incorporated into the scheduled PMs. The UGAS system, which is already in place and well established at Brunswick, will be used to gather data on undiluted gas emissions, temperatures, and back pressure. The personal sampling units in the operator compartments on the vehicles will continue to monitor operator DPM exposure through this period also. It is anticipated that a co-op student assigned to the ventilation department at Brunswick be assigned to this project. This would allow the student to devote considerable time to this project and manage the sampling cassettes from installation to analysis and data banking. The log books for operators and mechanics would also be managed by the co-op student and stored as a component of the test data to be analysed at each 3 month interim.

Stage 4 - Interim Analysis and Evaluation

After the first three months of operation, the traps will undergo a thorough non-intrusive inspection by maintenance staff from the mine to evaluate their mechanical condition. This will be done under guidance and recommendations from the manufacturers. Testing will also be done with the Matter Particle Analysis System for each site at every 3-month interim inspection. With the results of these inspections and the data from testing and logbooks, the site team will conduct interim evaluation meetings to discuss critical issues encountered thus far. This could be considered as a go/no-go decision for some of the trap systems depending on performance to that point. Interim reports will be drafted outlining the sampling results to date and implementation issues in carrying out the project. Andreas Mayer - TTM will be requested to assist on-site in the 3 month and 15 month interim evaluations.

Stage 5 - Long Term Analysis and Evaluation

The vehicles will be sent back to regular mine production on a continuous basis with interim evaluations every three months. Over the extended term, the undiluted testing, scheduled maintenance, particle sampling, and log books will be critical in gauging performance of the traps. While the on-site team should be evaluating systems continuously, it is the responsibility of the project leader to ensure that this is happening. Personal exposure samples will be gathered from all vehicles in the Brunswick study for the duration as well.

At the twelve-month milestone of the project the second ambient test study at Brunswick Mine will be run. The traps should have accumulated approximately 2500 operating hours at this point. The vehicles will be tested for two days each, with one day with the trap on and one off.

Stage 6 - Data Analysis and Final Report - Recommendations

It is anticipated that over the course of the study the traps will accumulate between 3000 - 4000 operating hours. At 18 months the traps will be removed and sent to the manufacturers for bench testing and complete disassembly and inspection. Andreas Mayer and the trap manufacturers will draft a report on the bench test results and inspection.

The final report and recommendations will be based on analysis of sampling results including undiluted testing, particle analysis, ambient test zone studies, personal sampling, as well as information from the daily log books.

Analysis of the data will be based on a combination of qualitative and quantitative findings. As a component of this project, the goals and targets will be established in a separate document. This will be done in a consultative process between the DEEP

Technical Committee, mine site representatives, Technical Adviser, and Technical Support Group. Preliminary documentation distributed initially for discussion would lead to a face to face/conference call meeting to finalise the goals and targets for the project.

Each agency involved in the project will be responsible for providing complete analysis and reporting for their involvement. This would be done on an individual and or collaborative basis with other participating agencies in the project.

The test data components are gathered and managed by many resources within the project. The project leader will be responsible for warehousing of all data throughout the project duration. All incoming data will be continuously monitored by the project leader and Andreas Mayer for validity and possible alarms. Other than the ambient zone studies, all test data will be compiled, analysed, and included in each 3 month interim evaluation report. Upon completion of the project, Andreas Mayer, the project leader and the Technical Support Group will integrate all analysis and reporting and produce a single final report.

Test Data Management

Data Component	Form	Sample Frequency	Analysis Frequency
Engine Datalogging	Quantitative	Continuous	3 mth interim
UGAS Testing	Quantitative	PMs	3 mth interim
Matter Particle Test	Quantitative	Tri monthly	3 mth interim
Log Books	Qualitative	Daily - as required	3 mth interim
Personal Exposure Sampling	Quantitative	Weekly	3 mth interim
Ambient Zone Studies	Quantitative	Baseline / 12 Mth	Final Report

Measurement Components

Five components for measuring the performance of the traps have been included in this proposal. Each component has specific value to the project as well as a capital cost.

Dataloggers

Instrumentation will be used for analysing and monitoring engine duty cycles. This information is essential in determining an ideal match between engine and trap. All vehicles in the study will be instrumented with identical datalogging equipment for consistency. The loggers will be capable of storing data for extended periods of at least one week. The physical points to be measured will be exhaust temperature both upstream and downstream and exhaust backpressure. The dataloggers will remain with the vehicles for the entire length of the project to verify engine duty cycle operation. As part of the instrumentation package, an alarm for exhaust backpressure will also be incorporated with the pressure sensor to warn the operator in case of system failure to protect the engine and trap. There will be 4 vehicles in the study instrumented with datalogging instrumentation.

Undiluted Testing

The project will require an effective tool for continuous evaluation of the trap's performance from a maintenance standpoint. As with the VERT study, this tool would be used as PASS/FAIL criteria. The tool would require the capability of measuring both undiluted gases and soot. Noranda is currently using a tool designed specifically for this purpose at Brunswick Mining. The UGAS system has been proven over the last two years to be an efficient tool for maintenance people to understand diesel emissions. It is also currently in use as the primary technology behind the DEEP Maintenance Project. It is capable of measuring both gaseous emissions as well as soot concentration with the ECOM AC+ gas analyser. The soot concentration is obtained using a measured volume of exhaust across a heated chamber with a paper filter. The soot concentration on the filter paper is determined with a 0-10 bacharach grey scale. All of these components have been integrated into one package with a UGAS software application and relational database. Similar instrumentation was used in the VERT study, however opacity measurement was used in some cases for determining soot concentration.

The UGAS system is currently in place and fully implemented at Brunswick Mining which provides a natural head start for the project as far as capital costs, training, and baseline data are concerned.

Daily Log Books

Log books will be kept for each vehicle to monitor fuel consumption, maintenance activities, costs, time, and personal comments on performance and reliability. Both operators and mechanics will be responsible for entering information in separate logs. The operator log will be filled out each shift and the mechanical log will be filled out each time maintenance is performed in association with the trap. The log books will be uploaded on a regular basis to be interfaced with data from the existing maintenance system (CMMS) and data from undiluted testing.

Personal Exposure Sampling

Researchers hope to collect 4 personal exposure samples per week, depending on the availability of a co-op student to manage the sampling. Ideally, this would allow one sample/week from each vehicle in the study. The samplers would be mounted on the machine in the operator's compartment near the dash or within the vicinity of the operator's upper body. This would allow the operators the freedom of not having to carry the samplers on their belt. To assist in the resource requirement for preparing and handling the samplers the possibility exists for using co-op students to participate. If resource requirements are absolutely not available the frequency of personal sampling will have to be reduced. Analysis of the samples will be done at CANMET laboratories in Sudbury using the thermal optical - elemental carbon method. Results from the sample analysis will be transferred to the project leader as soon as they become available so that they can be included with all other data and information for interim evaluations and reporting.

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Matter Particle Analysis System

A tool for field measurement of particle emissions from combustion exhaust has recently been successfully tested in Europe [21]. At this point there is optimism that this system will be available for this project. Current estimates put the cost of this system at $30K per unit and availability at April '99. The present documentation indicates that this system has the technical capability to fit within this project. There will be a need to discover further information with respect to availability, cost, implementation and training.

The primary components of the system are:

- Coarse Particle Precipitation (heated)
- Rotating Disk Diluter (heated)
- Thermodesorber - extraction of volatile fraction
- Detectors
  - Condensation Particle Counter
  - Diffusion Charger - particle surface description
  - Photoelectric Aerosol Sensor (PAS) - soot / non soot fraction

Tests to date have compared well to Scanning Mobility Particle Sizer (SMPS), aetholometer, and gravimetric measurements. Once confirmation has been obtained on availability and field worthiness, the system will be added as a valuable component to the study. The instrument will be purchased by CANMET and used for particulate measurement by staff from the CANMET technical support group and Noranda Technology Centre. These measurements will be done during the 3 month interim evaluations at a minimum as well as scheduled maintenance intervals when available. The instrument will also be used during the bench tests at CANMET for a direct comparison to the SMPS instrument which is recognized as a standard for particle analysis.

Ambient Zone Studies

There will be two ambient zone tests in total, one at the start for a baseline measurement, and the second at the 12-month milestone in the project. It is anticipated that by the 12-month stage the traps will have accumulated sufficient operating hours to indicate relevant change in durability and performance characteristics.

Each study will consist of 10 days of on-site sampling in an isolated controlled ventilation zone with only the production vehicle being monitored inside. This eliminates the possibility of interference from other vehicles or sources of DPM other than the vehicle being measured. Each vehicle will be measured for 2 full ten-hour shifts with 1 day with the trap installed and the second day with raw exhaust. This will provide the best test scenario for demonstrating actual efficiency in an underground production environment and potential capabilities for achieving proposed DPM levels of 0.15 mg/m3. Sampling trains for DPM mass will be set up at the intake and exhaust stations of the test zone and compared using the thermal optical-elemental carbon method. In addition to mass sampling, the Matter system will also be used for determining particle count and size in ambient concentrations. This will provide a good correlation of the Matter system to mass analysis methods and evaluation of the efficiency of the Matter system for ambient measurement.

Budget

Equipment Costs

Description	Cost	Option Cost
Instrumentation and data logging for 4 vehicles (5 units)	$22.5K	$22.5K
Matter Particle Analysis System [CANMET]		
Total	**$22.5K**	**$22.5K**

Consulting Costs

Description	Cost	Option Cost
TTM - Andreas Mayer	$40K	$47K
CANMET x 2 ambient studies at BM (includes travel & accommodations)	$90K	$90K
CANMET - Gravimetric analysis of personal exposure sampling	$12K	$12K
CANMET - Technical Support Group	$10K	$10K
CANMET - Bench Testing X 2 traps	$20K	$20K
Noranda Technology Centre	$48K	$56K
Contingency - 20%	$43K	$47K
Total	**$263K**	**$282K**

Travel and Accommodations

Description	Cost	Option Cost
Technical Support Group - CANMET	$3K	$3K
Technical Support Group - Noranda Technology Centre (8 trips)	$12K	$12K
TTM - Andreas Mayer - Switzerland <> Bathurst & Sudbury *** 50% of total [one 2 week & four 1 week trips]**	$20K	$24K
Paul Nothiger - Switzerland <> Bathurst & Sudbury *** 50% of total [one 2 week trip]**	$6K	$6K
Matter Representative - Switzerland <> Sudbury *** 50% of total [one 1 week trip]**	$4K	$4K
Total	**$45K**	**$49K**

TOTAL COST (excluding in kind)	***$331K***	***$354K***

In Kind Contribution

Description	Cost
Brunswick Mining / NTC - Human Resources	$160K
Brunswick Mining - Equipment - Lost Production	$2.56M
Particulate Trap Manufacturers - 8 traps for length of study (4 active units and 4 spares) @ $15K/trap	$120K
Particulate Trap Manufacturers - Bench Testing	$40K
Total	**$2.9M**

Special Issues and Constraints

"Executive Actions" Required During the Testing

It is likely that situations will arise during the course of the project that require a quick change in plans, special actions, or incremental expenditures. Limits and boundaries for this will be defined before the project gets underway.

Technology Transfer

The knowledge base to be gained is a large part of the justification in doing this project. Diesel particulate filters have been in use for many years with varying degrees of success.

This project will certainly provide the mine operator with the knowledge of how the latest DPF technology can be implemented effectively, how to match the technology to actual applications, and how to maintain it over a long-term basis. There will also be a reverse flow of technology from the mine to the manufacturers of the DPFs, engine manufacturers, and vehicle manufacturers as to what technology works best under which application, and contribute to design criteria for underground applications. The WHSCC of New Brunswick who will have an active role during this project, and other regulating bodies observing this project, will gain the knowledge accumulated during the course of the project and through the final report and recommendations. CANMET, which already provides mining engine and exposure test services in Canada and engine certifications for several provinces, will play a critical role in the project and benefit from the experience gained in testing these systems under certification conditions that would apply to all Canadian mines in the future.

The overall impact of this project will be to educate the underground mining industry as to the implications of using this technology, specifically, DPM reduction, implementation and application specification, and maintenance.

Environmental Health and Safety

No additional hazards with respect to environmental health and safety will be generated through the course of this study. As noted in the section on Both EH&S and union representatives will be made aware of this project and will be invited to participate in all meetings during the site study. They will also receive all documentation and reports generated by the study.

Benefits

Previous research indicates that DPFs can reduce particulate emissions between 95 - 99% depending on particle size and the technology used. This study will demonstrate whether such reductions can be sustained over time with a variety of systems operating in a normal underground production environment. Should this prove to be the case, mine ventilation in the future stands to reap substantial rewards with respect to both air quality and costs. The knowledge base and experience gained from doing this study would stand to benefit all participants with respect to education on implementation and maintenance of this technology.

Project Risks & Implementation Issues

This is a very large scale project with respect to time, human resources, fixed resources and equipment. There is potential for many unforeseen issues to impact on the budget and schedule of this project.

- There is always the possibility in the mine production environment for extreme damage to be incurred on vehicles due to operating conditions such as burial in the stope. There is also the potential for losing an engine due to operating environment. The trap manufacturers will need to be aware of the operating risks, and should be prepared to provide spare units for each system.
- Associated with the previous point, the trap manufacturers will need to be completely aware of the operating risks and that a strong possibility may exist to provide additional spare units beyond the 1 on-site spare for each system. Should a spare unit be required, a new spare must be shipped to the site as soon as possible to avoid extended downtime for the vehicles waiting for parts.
- The closed ventilation circuit test zone on 725 2-sub at BMD is no longer available for conducting tests. An equally suitable site at the mine will be required for doing the ambient studies. This may become a critical obstacle for the ambient test objective of the BMS project.
- The technology being evaluated in this project is relatively new and untested in an underground production environment. We are assuming for now that the DPFs, once installed, will be able to run consistently on a vehicle for the length of the study without requiring replacement.

Disposal of Fuel Blended with Additives, Alternative Fuels, and DPFs

Project leaders are responsible for ensuring that all fuel containing additives (eg. cerium, ferrocene) be consumed during the testwork. However, if that is not possible, then the fuel blend should not be used in an underground environment, but may be disposed of by removing it to the mine's surface diesel storage for highway transportation. It is the responsibility of DEEP, through a designated assistant to the project leaders, to obtain any necessary permitting for this. All DPFs will ultimately be returned to their suppliers.

Engine Backpressures and Engine Warranties

The protection of engines is a serious consideration of the DEEP field tests, as engine damage could prove to be exceedingly expensive to a mine operator if DPFs malfunction or are not properly designed or operated. DPFs will be sized and operated to avoid exceeding backpressures as specified by engine manufacturer recommendations or warranties.

The "Other" Diesel Emissions

The ash, sulfate, (nitro-) PAH, and Organic Carbon (OC) fractions, as well as exhaust gases (NO, NO2, SO2) should not be increased by a DPF, even during regeneration. These parameters will be evaluated only during the end-of-test bench testing.

Equivalency of Elemental Carbon Analysis

While the IGF - ZH 1/120.44 coulometric analysis and NIOSH 5040 thermal optical methods for analysing DPM yield the same results for Total Carbon (TC), they may differ substantially in their results for Elemental Carbon (EC) due to a different "split" temperature. Elemental Carbon results depend very much on the analytical methodology because of this "sample thermal fractionation" issue. However, for the purposes of DEEP, either approach is acceptable as long as comparisons are made on a consistent basis. To help in determining this equivalency, side by side testing with both analysis methods should be done through all bench testing if at all possible.

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APPENDIX I - Noranda Inc. - In Kind Detailed Calculation

Brunswick / NTC In Kind Resource Commitment

	RESOURCE IN MAN SHIFTS				
STAGE	**Project Leader**	**Site Champ'n**	**Vent. Dep't.**	**Mtce. Dep't.**	**Mine Prod. Dep't.**
Personal Sampling Baseline			5		
Undiluted Sampling Baseline	2	2		10	
Datalogger Installation	5	2		10	
Acquire Duty Cycle Data	2	2		5	
Ambient Zone Study Baseline	5	2	7	5	5
DPF Installation & Training	10	5	2	20	5
Interim Analysis 3 - month	5	3	5	10	2
Interim Analysis 6 - month	5	3	5	10	2
Interim Analysis 9 - month	5	3	5	10	2
Interim Analysis 12 - month	5	3	5	10	2
Ambient Zone Study 12 - month	5	2	7	5	5
Interim Analysis 15 - month	5	3	5	10	2
Final Analysis 18 - month	5	3	5	10	2
Analysis, Report & Recomm.	25	5	5	2	2
SUB TOTALS	**84**	**38**	**51**	**117**	**29**
TOTAL	**= 319 MAN SHIFTS**				

Calculation

319 Man Shifts @ $500 per = **$160K**

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Lost Production Costs

Note: Based on four production vehicles over 18 month period

Calculation
Ambient Zone Tests - 2 shifts/vehicle
Dataloggers - Installation, maintenance, monitoring - 3 shifts/vehicle
Traps - Installation, maintenance, testing - 36 shifts/vehicle

Total = 41 shifts X 4 vehicles = 164 shifts

Cost = 40 buckets/shift X $600/bucket X 65% utilization X 164 shifts
= $2,558,400

APPENDIX II - Targets and Specifications - Details

VERT Specifications

M	D	**VERT specifications for particulate trap systems on construction engines** (M= mandatory, D= desirable)	**Status 25.8.98**	*new*
		Filtration rate (on the reference engine Liebherr 914 T)		
	*	$ Total particulates, gravimetric (ISO 8178 C1. 4 test points)	80%	75 %
*		$ Elementary carbon EC. Coulometric (rnass)	90 %	85 %
*		$ Soot puff during free acceleration: opacity measurement (turbidity)	< 10 %	< 10 %
*		$ Particulate penetration in the size range 10-500 nm ') (conc. count)	< 5 %	< 5 %
		The above values must be maintained both for the clean filter and also for the filter clogged with soot and/or ash. Compliance is required during the entire life cycle and the limits shall not be exceeded even during regeneration processes.		
		Additional constraints for emissions		
		There shall be no clearly detectable and relevant increase of the folloyang emissions compared to the initial engine conditions. Such increases are not permissible even during regeneration:		
*		$ Sulfuric acid and / or sulfate formation		
*		$ Secondary emissions due to fuel additives		
*		$ Secondary emissions due to dioxin formation		
*		$ Increase of basic emissions CO, HC, NO, NO2 (cycle total)		
*		$ Mineral fiber emissions		
		Emission verification in the field		
*		Vehicles: Verification is according to the method of free acceleration. Maximum opacity of construction diesel engine with soot filter: (corresponds to K = 0.24 1/m, or approx. 1 Bosch or approx, 0.03 g/m^3)	< 10 %	
*		Stationary engines: Blackening measurement at full load Maximum according to MIRA correlation	< 5 mg/m^3	

M	D	VERT specifications for particulate trap systems on construction engines (M= mandatory, D= desirable) (continued)	Status 25.8.98
		Pressure loss at rated RPM / full load	
	*	$ Fresh filter	< 50 mbar
	*	$ Limit till regeneration	< 150 mbar
*		$ Maximum burden (warning)	< 200 mbar
		Regeneration	
	*	$ Preferably in situ and automatically during operation	
	*	$ Additive dosage on board fully automatic with fill-gauge warning. The additive should not be pre-mixed in containers, if there is a rack of other vehicles being fuelled from such tanks.	
		*) During the suitability testing, certain filters attain a non-particulate filtration rate of 99% and more.	
		Filter self testing	
	*	$ Pressure loss controlled electronically with 2 set warning levels	
*		$ 2 waming levels: upper level for filter deposition state / lower level for filter damage	
	*	$ Data storage	
	*	$ Self monitoring	
	*	**Trap size**	< 0.6 l/kW
		Approxirnately the size of the muffler replaced	
		Sight obstruction must comply wfth applicable regulations	
	*	**Muffling**	
		At least equivalent to the muffler replaced	

		VERT specifications for particulate trap systems on construction engines (M= mandatory, D= desirable) (continued)	Status 25.8.98	
M	D			
		Costs of trap system		
	*	Rating 200 kW	< CHF 75/kW	
	*	Rating 100 - 200 kW	< CHF 100/kW	
	*	Rating 50 - 100 kW	< CHF 125/kW	
	*	Operating costs	< CHF 0.02/kW	
	*	Annual maintenance costs	< 10% of filter cost	
		Durability and maintenance	Vehicle:	Stationary engine
*		Life expectancy	5'000 op.h.	20'000 op.h.
*		Usable hours till cleaning and disposal of the residues through the trap manufacturer	2'000 op.h.	2'000 op.h.
	*	Maintenance interval	500 op.h.	1' 000 op.h.
		Suitability for deployment underground		
	*	Availability in 3 shift operation		
	*	Maintenance-free during operation		
*		On-site maintenance		
*		No additional risk of fire and ignition		
*		No toxicity risks		
*		Invulnerable to dusty air and extreme anbient temperatures		
*		Invulnerable to high air humidity and water spray		
		The quality-of-service requirements in the specification are verified according to the VERT suitability test on the reference engine Liebherr D 914 T. The measurements shall be performed in the new state and after field deployment corresponding to 30% of the life expectancy.		

Special Targets for Brunswick Field Test

	VERT Specs	Longterm Desired Specs	This Project's requirmts
Pressure loss at rated RPM / full load			
Fresh filter (mbar)	< 50	< 50	< 50
Limit till regeneration (mbar)	< 150	< 150	< 80
Maximum burden (warning) (mbar)	< 200	< 200	< 100
DPM field emissions – (Matter instrument)			
Total carbon (g/kWh)	N/a	< 0.020	< 0.08
Elemental carbon (g/kWh)	N/a	< 0.015	< 0.05
EC nanoparticles (#/cm3) Integral over 10-200 nm	N/a	< 1e4	< 1e6
DPM operator exposure (vehicle mount)			
Total carbon for isolated vehicle (mg/m3)	N/a	< 0.07	< 0.6
Elemental carbon isolated (mg/m3)	N/a	< 0.03 (?)	< 0.2
Costs			
Capital cost ($Cdn /(kW/100)^0.7)	<100	<100	<200
" - simple lifecycle ($Cdn/kWh)	N/a	< 0.03	< 0.04
Operating costs ($Cdn/kWh)	< 0.02	< 0.02	< 0.05
Maintenance per year (VERT % of trap cost, DEEP k$Cdn/y)	<10%	< 2	< 5
Lost production costs ($Cdn/kWh)	N/a		
Total DPF costs ($Cdn/kWh)	N/a	< 0.06	< 0.15
Reliability and robustness			
Durability or lifetime to replacement (h)	6000	6000	1000
Trap operation until ash removal (h)	2000	2000	1000
Maintenance interval (h)	500	500	250
Lost production time due to DPF (%)	N/a	< 2%	< 10%
Other concerns			
Additive dosage fully automatic on board	Yes	yes	No

Assumes 1 $Cdn ~ 1 CHF (Swiss franc)
h = engine operating hour
Lost production costs only apply to production vehicles (LHD, trucks not pickups, scissors etc)
200 mbar = 0.2 atm = 0.2 * (33 ft water * 12 "/ft) ~ 80 " water

Explanation of the Targets

Note that the special targets for this project are not as restrictive as the VERT specifications, but this is to allow consideration of DPFs that:

- show some potential but which have not evolved through as many commercial generations as other more established systems;
- are perceived by the DEEP Technical Committee to be easily capable of meeting the VERT specifications within five years, but for which field results may currently substantially
- may be incorrectly removed from ongoing testing due to errors in field measurement methodologies;
- can trade off capital, operating, and maintenance costs to achieve an overall cost that is still competitive.

DPM reductions performance - bench

Filtration rate, emission, and penetration figures refer to the performance of new (conditioned) filter systems on VERT's standard engine, with their standard test cycle, standard fuel (<300 ppm sulfur diesel), based on generic certification tests for a filter model as opposed to tests on individual filters. It is understood that the performance of these systems may not be as good at the end of the field tests, and that individual filter performances are somewhat variable.

DPM field emissions – Matter instrument

Emissions and penetration figures refer to the performance of in-use filter systems tested in the mine during a Preventative Maintenance check with the Matter particulate instrument, during a free acceleration test and/or full stall condition. This target is the intended maximum acceptable value before replacement of the filter should be considered, although to some extent experience may lead to changing this target.

DPM operator exposure (vehicle mount)

This refers to Elemental Carbon occupational exposure samples corrected to an 8 hour shift. These measurements are for situations where a vehicle is alone or is perhaps working in the vicinity of only one other vehicle.

Costs

Capital cost = purchase price FOB Toronto plus installation costs
Operating costs = extra fuel consumption, additives, extra operator time

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APPENDIX III - VERT Approved DPFs

The following information is provided by VERT. A total of 32 DPFs are referenced in the VERT lists.

The following tables are categorize the filter systems into two groups:

List A: Filter systems that satisfactorily completed the first part of the VERT suitability test ;

List B: Filter systems having generally acknowledge positive field performance (VERT suitability test not performed or not yet completed).

Filter systems A

Manufacturer	Filter Type & Regeneration
3M	Wound fiber filter
BUCK	Knitted fiber filter cartridges catalytically coated for regeneration < 420°C optional integrated electrical heating
DEUTZ	Ceramic cell or wound fiber filter full flow diesel burner Replaceable filter (external regeneration) Snap-on filter
ECS	Ceramic cell filter additive regeneration, electric stand-still regen. on board
HJS	Ceramic cell filter CRT-System Sintered metal filter (Type SHW) additive regeneration and/or burner heating
HUG	Woven fiber filter catalytic coating and/or additive and/or burner
HUSS	Ceramic cell filter (new SiC) electrical stand-still regeneration on board
Johnson Matthey	Ceramic cell filter CRT System diesel injection and catalytic ignition, electrical stand-still regen. on board
Oberland-Mangold	Fiber knitted filter additive regeneration and/or catalyst coating and/or electrical internal heating
PCH	Fiber knitted filter catalytic coating an/or additive regeneration and/or electrical internal heating
UNIKAT	Ceramic cell filter (Option: + cat) electrical stand-still regen. on board Replaceable filter (ext.regeneration)

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Filter systems B

Manufacturer	Filter Type & Regeneration
ANSA MARMITE	Ceramic cell filter, twin filter system, partial flow diesel burner
Blaschke	Snap-on filter
CeraMem	Ceramic cell filter pure surface effect with additional fine-pore ceramic membrane, counter-flow
DCL	Ceramic cell filter, catalytic coating
Donaldson	Ceramic cell filter twin filter system, electrical partial flow regeneration Paper filter, disposable when laden
Eberspächer	Ceramic cell filter diesel burner, at stand-still
EHC	Glass fiber filter cartridge Snap-on filter, cartridge disposable
Engelhard	Ceramic cell filter catalytic coating Wound fiber filter (3M) electrical stand-still regeneration on board
ERNST	Wound fiber filter (3M) full flow diesel burner electrical stand-still regen. on board or external additive regeneration
ETB/Heraeus	Ceramic cell filter electrical stand-still regen. on board Replaceable filter
GfA	Ceramic cell filter additive regeneration
Heimbach	Tubular filter, material is SiC regeneration using direct electrical heating (current through-flow)
IBIDEN	Ceramic cell filter, material is SiC additive regeneration, sequential electrical regeneration
INTECO	Knitted fiber catalytic coating and/or burner regeneration
LEISTRITZ AG	Ceramic cell filter twin filter system with partial flow diesel burner
MAGETA	Knitted glass fiber snap-on filter with external burner regeneration
MTU	Sintered metal filter (System SHW) full flow diesel burner
NOTOX	Ceramic cell filter (SiC) additive regeneration
PAAS	Replaceable filter, material is paper exhaust gas cooling - oxi-cat upstream
SVENSKA EMISSIONSTEKNIK	Ceramic cell filter diesel injection and catalytic ignition
ZEUNA STÄRKER	Ceramic cell filter - full flow burner Twin system with partial flow burner Replaceable filter

APPENDIX IV - Datasheets

<table>
<tr><th colspan="7"><h1>Particulate trap system datasheet</h1></th></tr>
<tr><td>Manufacturer</td><td colspan="6"></td></tr>
<tr><td>Canadian sales agent</td><td colspan="6"></td></tr>
<tr><td>Filter medium</td><td colspan="6"></td></tr>
<tr><td>Regeneration method</td><td colspan="6"></td></tr>
<tr><td>Monitoring system</td><td colspan="6"></td></tr>
<tr><td>Deployment range
From / to:</td><td>V(m^3/s)</td><td colspan="2">N (kW)</td><td colspan="2">T exhaust gas (C)</td><td>Soot (mg/m^3)</td></tr>
<tr><td>Trap size / weight
Power rating………kW</td><td>1/kW</td><td colspan="2">1/m^3/s</td><td colspan="2">kg/kW</td><td>Kg m^3/s</td></tr>
<tr><td>Filtration rate, % when
Soot laden:
Regenerated:</td><td>TPM in %</td><td colspan="2">Count in %</td><td colspan="2">Coulom. EC</td><td>OC</td></tr>
<tr><td>Life-cycle: op.h.</td><td colspan="2"></td><td colspan="4">Disposal:</td></tr>
<tr><td>Deployment time: op.h.</td><td colspan="2"></td><td colspan="4">Cleaning:</td></tr>
<tr><td>Experience</td><td>Ariz System</td><td colspan="2">Total kW</td><td colspan="2">Total kWh</td><td>Longest deploy.</td></tr>
<tr><td>Deployed in</td><td>Stationary engine</td><td>Forklift</td><td>Auto-mobile</td><td>Bus</td><td>Truck</td><td></td></tr>
<tr><td>Back pressure (mbar)
At rated flow in … m^3/s</td><td>New</td><td>Laden</td><td colspan="2">Regenerated</td><td>Cleaned</td><td>Limit</td></tr>
<tr><td>Service effort</td><td>Interval</td><td colspan="2">Time</td><td colspan="2">Cost</td><td>Spare parts</td></tr>
<tr><td>Installation effort</td><td colspan="3">Time</td><td colspan="3">Cost</td></tr>
<tr><td>Regeneration effort</td><td colspan="3">kWh</td><td colspan="3">Cost</td></tr>
<tr><td>Noise Suppression (dB)</td><td colspan="6"></td></tr>
</table>

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APPENDIX V - Trap Selection Process Detail

We must accept the following basic statements or assumptions, which might look trivial but are not:

- we can only select trap systems out of a given variety of proven systems available on the market. What means "proven" and what means "available" must be defined first. We define according to the VERT "Filter-List".
- Performance criteria must be fixed first and accepted for the given application and by the given applicants. We assume that performance criteria according to VERT will be accepted. This basically includes the definition of "diesel particulate" and the measurement instruments and test protocols.
- All relevant application parameters must known. This comprises engine data including raw emission, application performance data and application environment including logistics. Missing data must be collected before any selection process can start - see VERT-questionnaire. Selection-sequence according to following steps:
  1. Select filter matrix: Different filters are available: surface and deep bed filters / ceramic and metal substrates / rigid or fiber structures. They have different efficiency and back pressure characteristics, different risk areas, different cost and bulk. If efficiency and back pressure requirements are well defined a first selection of filter matrices is possible. Example: if we require high efficiency even for the clean (regenerated) trap, only deep bed filters can be selected.
  2. Continuous operation (3-shift) required or operation-interruptions accepted ? the following questions must be answered a. can the trap be removed from the vehicle for regeneration ? b. can operation be interupted for regneration, if yes for how many hours ? If a and be will be "no", selection will be clearly limited - external (off board) regeneration (a cheap and proven solution) will be excluded and also all systems which regenerate on board at engine stand still or idling (well proven and safe systems like UNIKAT, ECS and HUSS) must be excluded.
  3. Engine design, performance and emission parameters - Exhaust volume flow and backpressure requirement basically define trap size. Particulate mass (g/kWh) and particulate characteristics influence trap size and system NOx-emission and HC-emission are important parameters for regeneration Emission distribution in the function of speed and load can be important. Exhaust temperature and oxygen content are decisive parameters for regeneration. Transient emission peaks can not be neglected ---> all these parameters are well known by the engine manufacturers and must be made available. Further parameters and options can be of importance to find an optimal match engine/trap: - use of injection characteristics to start or support regeneration - use engine controls to avoid risks due to unexpected back pressure - tune engine and TC to accept higher backpressure level to optimize trap concept. Geometrical design, space requirements (and

possible modifications), max. acceptable heat rejection, and vibration level are also important and must be agreed upon. Engine age as well as fuel and oil consumption must be taken into account. --> engine and vehicle manufacturer must be included in the trap selection process.

4. Fuel and Lube oil: Fuel parameters (Sulfur content, additives) and lube oil parameters (Calcium adn TBN, phosphor, metal additives) influence filtration, inert deposits and regeneration. These parameters must be known. Filter operation can be improved if fuel sulfur content is minimized as well as oil ash size (Negative combination would be high fuel-S with high lube-TBN)
5. Operation parameters: Variation of engine speed and load, exhaust temperature, oxygen content and particulate content is important - variation frequency, statistic distribution as well as dwell times and typical situation which are repetitive. Standard cycles whether steady state (like ISO 8178) or transient like the US-federal transient cycle are of little use since every single application seems to develop an individual character, varying even between operations and dependent on driver habits. Operation parameters must therefore be measured on a sufficient statistical basis by datalogging. Minimum information is exhaust temperature distribution to decide whether fuel additives or catalytical coatings will have a sufficient chance for regeneration or not.
6. Additional operation requirements: Trap installation should not limit visibility (what the driver can see round the vehicle) - increase noise - reject additional heat (eg during regenration) - emit sparks - change vehicle operability - require controls by the driver - require additional maintenance intervals. Can operation environment (logistics) be adjusted or not - can we use special fuels ? - can we use additivate fuels? - can we guarantee fuel and lube oil quality ? - can we drive the vehicle once per shift to place where we have access to electricity - can we check the system somehow once per week/month ? - can operators be trained to interpret alarms ? - can we fix operation or do we need to remain flexible (regarding load factors)
7. Maximum or necessary minimum of emission reduction ? If we ask for maximum of possible emission achievement we may ask for reduction of CO and HC and SO3 in combination with particulate matter, may be even for NOx-reduction. This is very nice and possible but it limits the choice. Priorities simplify selection.
8. Minimum of investment or minimum of overall cost ? Some systems need a rather high investment (DEUTZ) but have very low running cost, running efforts and maintenance requirements. Other systems (using fuel additives) require continuous efforts, logistics and some maintenance but investment is relative low. Some (CRT) have low investment, need no maintenance but require very special fuel where extra cost is relative high as long as demand is low. . Priorities must be clear for selection.
9. Minimum risk ? Risk must be defined from beginning: plugging, leakage, operation interuption, fire ??? Systems can be selected, adjusted or controlled to minimize risk if defined. Best way is to combine traps with electronic trap controls (containing data memory)

and install direct access to engine control eg limit engine power automatically if risk is approaching

10. Minimum of maintenance and controls ? It is easier and safer to design or select a system for given maintenance intervals and controls - It may in the end also be cheaper to use this route instead of insisting to minimize maintenance. Maintenance schedules and controls will influence the selection and should therefore be agreed upon at the beginning of this process.
11. Maximum of life "without touching anything" can be a requirement for the mine application but will be a very strong selection criterion. Fulfilling all conditions may stepwise exclude all trap options. Priorities need to be defined.

Our philosophy regarding selection of traps for this DEEP In-Mine-Trap-Test is to find solutions for size – maximum life - or minimum cost - or maximum emission reduction. At least these 3 options (for in-mine-conditions and operation parameters) should become clear during this test.

TTM, A.Mayer 19.April 1999

Vehicle Logbooks

Each vehicle will have two logbooks:

- an operator's logbook for recording operator comments at the end of each shift;
- a mechanic's logbook for noting Preventive Maintenance results and special repairwork.

Each logbook will have a preface with background information and instructions, and will be filled out in detail each shift. The maintenance logs will be filled out for each maintenance activity on each system.

<u>Operator Logbook</u>

<table>
<tr><td>Date / Shift:
Operator name:
____

Engine hours:
Working time:
Fuel consumption:
Lube oil consumption:</td><td>Highest backpressure: __________ " H2O

Highest engine water temperature: __________ °C / °F

Number of other vehicles in area: __________</td></tr>
<tr><td colspan="2">Kind of work (site, operation)

Unusual observations, problems, as related to the particulate filter
(examples: sudden increase in smoke, strange smells especially with regeneration, problems with regeneration controls, backpressure alarms, increase in noise, delayed engine reactions, etc.)

</td></tr>
</table>

noranda

Maintenance Logbook

Date / Shift: Mechanic:	Engine hours: Backpressure at full load: DPM (Matter instrument):
Description of problem and observations as related to the particulate filter (examples: excessive backpressure at full load, smoke as , strange smells especially with regeneration, problems with regeneration controls, backpressure alarms, increase in noise, etc.) Actual repairs noted will be correlated to the CMMS system in place at Brunswick for inclusion in analysis and reporting.	

Interim Field Test Surveys & Interviews

Surveys and interviews will be conducted every 3 months to be included as part of the interim reporting. All operators, mechanics, and on-site project personnel will be included in an interim summary meeting to go over the log book contents and discuss at an open table environment individual and group experiences with the trap systems. All interim summaries will be consolidated into the final report at the end of the project.

Operators' Issues

1) Improvement to work environment (health)
    a) Smell/odour
    b) Visible smoke
2) Time away from production
    a) System reliability & durability
    b) Time in maintenance shop
    c) Regeneration requirements
3) Acceptance as a function of
    a) Training provided
    b) Opportunity for input
    c) Responsiveness to problems
4) Conditions under which regeneration was inadequate
5) Operational problems with DPF – what caused problems?

Mechanics' Issues

1) Ease of verification & maintenance
    a) Test cycles
    b) Matter instrument
2) Electronics – sensors and controls
    a) System reliability & durability
    b) Time in maintenance shop
    c) Specialized knowledge required – eg ease of data access
3) Acceptance as a function of
    a) Training provided
    b) Opportunity for input
    c) Responsiveness to problems