Attachments to MARG Coalition Comments On MSHA Diesel Particulate Matter (DPM) Standards for Underground M/NM Mines

An Evaluation of the Effects of Diesel Particulate Filter Systems on Air Quality and Personal Exposure of Miners at Stillwater Mine
Case Study: Production Zone

Report

April 1, 2004

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TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

INTRODUCTION

The Metal/Nonmetal Diesel Partnership, a coalition whose membership includes, the National Institute for Occupational Safety and Health (NIOSH), the National Mining Association (NMA), MARG Diesel Coalition, the National Stone, Sand and Gravel Association (NSSGA), the United Steel Workers of America (USWA), and the Mine Safety and Health Administration (MSHA), was formed to examine, enhance, and facilitate implementation of emissions control technology that will reduce the exposure of underground miners to diesel particulate matter (DPM) and toxic gases. The first step toward fulfilling this objective was to identify controls that might be technically and economically feasible to use to curtail diesel particulate matter emissions from existing and new diesel powered vehicles in underground metal and nonmetal mines. The study of diesel particulate filters (DPFs) at the Stillwater Mine was organized under the auspices of the Metal/Nonmetal Diesel Partnership to continue the effort of identifying practical DPM control technologies.

Surveys revealed that some miners in U.S. underground mines were exposed to the highest concentrations of DPM of all occupations [McDonald et al. 1997, 68 Fed. Reg. 48668 2003]. The reasons behind such elevated DPM concentrations in certain underground mines include the confined space, the limited supply of fresh air, a large number of older engines, and the limited use of advanced emission control technology. In January 2001, MSHA promulgated rule [Fed. Reg.5706 (2001)], which set standards for total carbon (TC) concentrations in the mine air, thereby regulating the exposure of underground metal and nonmetal miners to DPM [30 CFR 57.5060]. The underground metal/nonmetal mining community has been looking for viable solutions to reduce the DPM concentration in mines to below the interim standard of 400 $\mu g/m^3$ of total carbon (TC) or the recently negotiated equivalent of 308 $\mu g/m^3$ of elemental carbon (EC) [68 Fed. Reg. 48668 2003]. Improvements in ventilation, use of cleaner diesel engines, emissions-based diesel engine maintenance, and the implementation of various diesel emission control technologies, including DPF systems and reformulated fuels, are believed to be the methods with the greatest potential to achieve these reductions.

Both laboratory evaluations [Mayer et al. 1999, Larsen et al. 1999] and long-term and short-term underground mine tests [Watts et al. 1995, McGinn 2001, Bugarski and Schnakenberg 2001, Bugarski and Schnakenberg 2002, Bugarski et al. 2002] showed that DPF systems have the greatest potential of all methods available to underground mining industry for radical reduction of exposure of miners to DPM. Watts et al. [1995] reported significant reductions in DPM concentrations in two underground mines where vehicles equipped with DPF systems were operated. Similar reductions were found in two other studies conducted at Noranda's Bathurst Mining and Smelting Mine [McGinn, 2001, Bugarski and Schnakenberg 2001] and International Nickel Company's Stobie Mine [Bugarski and Schnakenberg 2002] as well as in the isolated zone study conducted recently at Stillwater Mine [Bugarski et al.2003]. It should be noted that the efficiencies for the DPF systems achieved in the mining studies did not always agree with the efficiencies reported in the laboratory studies. These studies also demonstrated that considerable effort is needed to select and optimize DPF systems for individual underground mining applications.

The Stillwater Mine study was designed and executed in two phases. In Phase I of the study, the potential of DPF systems and biodiesel blends to reduce DPM emissions from selected production vehicles was examined through tests conducted in an isolated zone and tailpipe emissions measurements. The isolated zone tests showed that the two used and one new DPF system reduced ambient EC concentrations by 88, 96 and 99%, respectively [Bugarski et al. 2003]. The same systems reduced ambient total particulate matter (TPM) concentrations by 74, 75 and 89%, respectively. The difference between the observed changes in ambient EC and TPM concentrations confirm that the laboratory determination of DPF efficiencies, based on reductions in total DPM mass (fairly equivalent to TPM), substantially underestimates the ability of DPF systems to reduce EC emissions, the metric used by MSHA for compliance. These tests also showed a 26% and 48% reduction in ambient EC concentration when No. 2 diesel fuel was substituted with 20% (B20) and 50% (B50) biodiesel blends, respectively. Another finding of interest from the Phase I study and of significant concern was that the tested DPF systems and diesel oxidation catalyst (DOC) increased ambient NO_2 concentrations; increases between 180% and 270% were found for the DPFs and 26% for the DOC. Each DPF system and the DOC were washcoated with platinum-based catalysts. None of the alternative fuels showed a statistically significant effect on NO_2.

The objective of Phase II of this study was to determine the effects of those DPF systems being used on production vehicles at Stillwater Mine on workplace concentrations of EC and regulated gases in an actual mining application where multiple diesel-powered vehicles operated simultaneously during full-shift mining activities. The effects of the DPF systems were examined by comparing ambient concentrations of EC, carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), and nitrogen dioxide (NO_2) in the production area for two different tests conditions: For the baseline condition, all vehicles that operated within the ventilation split were equipped with standard exhaust systems – a DOC and muffler. For the second condition, three of the vehicles, an LHD and two haulage trucks had their DOC-muffler systems replaced with DPF systems. These three vehicles were selected because a preliminary analysis identified them as major sources of DPM. In addition, based upon engine size and duty cycles during production, Stillwater mine, as part of their own research, had retrofitted those or similar vehicles with passively regenerating DPF systems. This report describes the experimental procedure and results for Phase II of the study.

Due to the nature of the study, Phase II did not address other and no less important matters related to implementation of DPM control technologies in underground mines. These matters include selection of DPF regeneration strategies, economic, logistical, and technical feasibility of implementation of various DPF systems on mining vehicles, and the reliability and durability of the systems in mine settings. Addressing those matters would require a different and more comprehensive type of feasibility study yet to be performed.

EXPERIMENTAL PROCEDURE

Test Methodology

The primary objective of this study was to quantify the effects of the selected DPF systems on the ambient concentrations of elemental carbon and selected gases in an actual mine setting for a production cycle. The systems, all passively regenerating DPFs, were being studied by the mine as possibly the only potentially feasible way, from those then available, to reduce DPM emissions. Those vehicles used by the mine and considered by the mine to be suitable for the use of passive DPFs represent a small fraction of the mine's fleet of diesel-powered equipment.

Figure 1 shows the section of the Stillwater Nye mine that was selected as the test zone. This section is located in the west side of the ventilation split on 3500 level (3500W). The elevation of the mine portal is 1525 m (5003 ft) above sea level and the elevation of 3500W is approximately 1067 m (3500 ft) above sea level. 3500W is ventilated with fresh air from the 3200 level. The two raises situated at 1250 m (4100 ft) and 1890 m (6200 ft) to the west of the 3500 split are used to exhaust the contaminated air from 3500W. An orepass is situated off the main drift approximately 215 m (705 ft) west of the split. The average cross-sectional dimensions of the opening in the main drift are approximately 3.6 m (12 ft) high by 3 m (9.8 ft) wide. The drift is in a horizontal plane. At the time of the tests, ore was mined from seven active stopes located between approximately 200 m (656 ft) and 2100 m (6890 ft) west of the 3500 split. In addition, development work was being conducted approximately 2400 m (7874 ft) west of the 3500 split.

Diesel-powered equipment, primarily LHDs and haulage trucks, were extensively used in the process of ore extraction and transport. In a typical operation, ore was transported from the heading to a stope muck bay with a MTI LT 270 LHD or a MTI LT 350 LHD (Mining Technologies International, Sudbury, Ontario). At the stope muck bay, a single loader, either a CAT R1300 LHD (Caterpillar Elphinstone PTY LTD, Burnie, Tasmania, Australia), loaded ore into one of the two haulage trucks, either the MTI DT-1604 or the Tamrock EJC515 (Sandvik Tamrock, Sandviken, Sweden). It typically required two LHD buckets to fully load a haul truck. Once loaded, the haul truck transported the ore or waste rock to the orepass located approximately 200 m (656 ft) west of the 3500 split. The waste rock from the development work was managed with a development LHD, usually a CAT R1300. The same LHD and two haul trucks used to transport ore from the stopes were used to load and haul the rock from the development muck bay to the orepass.

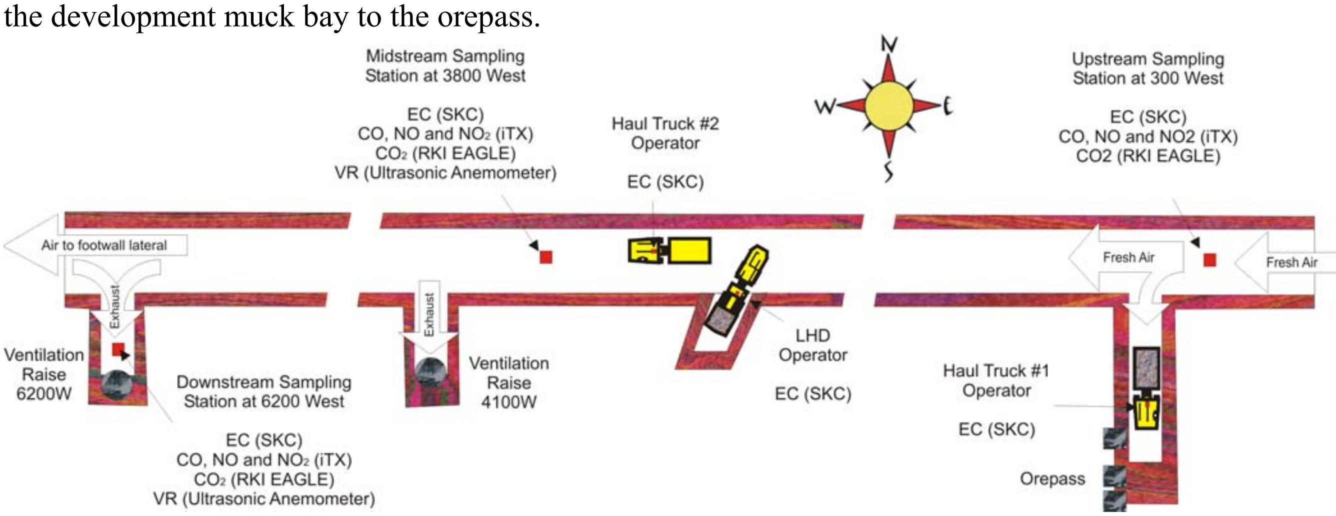

Figure 1. Schematic of the test zone (not to scale)

The vehicles selected as target vehicles for this study were identified as the major contributors to concentrations of DPM and toxic gases in mine air for several reasons including, the size and type of their engines, the type of duty cycle they perform, and the number of operating hours. Due to their size and nature of their duty cycles, those vehicles were also found to be the most suitable for DPF retrofit program of all vehicles available in the mine fleet.

It is important to note that during all four tests, a significant number of other diesel-powered vehicles, besides the aforementioned LHD and two haulage trucks, operated in the test zone on an intermittent basis. Multiple LHDs were used in the stopes and in the development section along with various light-duty vehicles used as personal and supply carriers and by maintenance crews. A road grader was also intermittently used in the test zone. Since the study objective was to evaluate effects of tested DPFs in a typical production setting, this incidental and variable traffic was not limited in any way during the tests. The heavy traffic in the test zone made it impossible to record all the instances during which diesel engines operated therein. However, because of the direct relationship between the amount of fuel consumed and the carbon dioxide concentration, carbon dioxide concentrations were measured at all area sampling locations and used to compensate for day-to-day variability in the usage of diesel-powered equipment.

The study took place from Monday, September 8th through Friday, September 12th, 2003 (Table 1). The initial plan was to conduct a total of six tests, three with the target vehicles equipped with DPF systems and three with the same vehicles equipped with the mine-standard DOCs and mufflers. However, due to the early curtailment of two DPF tests because of high ambient concentrations of nitrogen dioxide encountered by the vehicle operator and technical problems with truck #92133 on Wednesday, September 10th, only four tests were conducted. For three of these tests, the targeted vehicles were equipped with DPF systems while the rest of the vehicles, which operated in the zone on a continuous or intermittent basis, were each equipped with DOCs and mufflers. The fourth test was conducted with all of the vehicles, including the selected LHD and two haulage trucks, equipped with the mine-standard exhaust system consisting of a DOC and muffler.

Table 1. Test matrix

Test# (Date)	Test Type	Vehicle Type	Vehicle #	Aftertreatment System Type	Aftertreatment System Model	Bacharach Smoke Number (0-9)	Operator
1 (September 8)	DPFs	LHD	#92535	DPF	DCL MineX 5223-SA	0	Ed
		Truck 1	#92133	DPF	Engelhard DPX 9308	3.5	Brandon
		Truck 2	#92136	DOC*	Engelhard DOC*	>7	Cliff
2 (September 9)	DPFs	LHD	#92535	DPF	DCL MineX 5223-SA	0	Ed
		Truck 1	#92133	DPF	Engelhard DPX 9308	>3.5	Brandon
		Truck 2	#92139	DPF	Engelhard DPX 9308	>4.5	Jeff
3 (September 11)	DPFs	LHD	#92535	DPF	DCL MineX 5223-SA	0	Ed
		Truck 1	#92133	DPF	Engelhard DPX 9308	3.5	Chad
		Truck 2	#92135	DPF	Engelhard DPX 9308	3	Jeff
4 (September 12)	DOCs	LHD	#92535	DOC	DCL MineX 3206 MD	N/A	Lorry
		Truck 1	#92133	DOC	DCL MineX 3206 MD	N/A	Mike
		Truck 2	#92135	DOC	DCL MineX 3206 MD	N/A	Troy

* The haulage truck #92136 was initially believed to be equipped with Engelhard DPX®, a DPF.

Vehicles and control technologies

Due to technical problems and availability of the vehicles, four haulage trucks were used during this study. Vehicle #92133 was available for all four tests, #92135 for two tests, and #92136 and #92139 were used in one test each. Trucks #92133, #92135, #92136 were MTI Model DT-1604. Each has a box capacity of 8.2 m^3 (10.8 yd^3) with a rated load capacity of 14545 kg (32000 lb). They are powered by Deutz BF6M1013 FC engines. The truck #92139 was a Tamrock EJC515. This truck has a rated load capacity of 15000 kg (33070 lb) and was powered by a Deutz BF6M1013EC engine.

A single LHD, vehicle #92535, a Caterpillar Elphinstone Motel R 1300, was used in all four tests. It has a rated load of 6500 kg (14333 lb) and has a bucket capacity of 2.8 m^3 (3.7 yd^3). This particular vehicle is powered by a Caterpillar CAT 3306 DITA engine rated at 123 KW (165 HP). Unlike the Deutz engines, the Caterpillar engines do not capture emissions from crankcase ventilation/exhaust blow-by. It is important to note that those emissions contribute DPM to the mine air.

An Engelhard DPX® (Engelhard Corporation, Iselin, New Jersey) DPF system was installed on three tested haulage trucks, #92133, #92135, and #92139. Those systems had accumulated 1024, 0, and 171 hours in production prior to the study, respectively. The haulage truck #92136 was initially believed to be equipped with Engelhard DPX®. After the tailpipe emissions measurements and field tests indicated unusually low efficiency of the aftertreatment device installed on the vehicle, mine personnel found that #92136 was actually equipped with DOC. After that discovery truck #92136 was replaced with truck #92139. A DCL MineX Sootfilter® DPF system (DCL International, Concord, Ontario) was installed on LHD #92535 shortly before the study.

Both types of DPF systems tested in this study are passively regenerated systems designed around a Corning cordierite wall-flow monolith filter element washcoated with proprietary platinum-based catalysts. In general, the platinum-based catalysts are applied to DPF element to lower combustion temperature of the soot trapped within the filter and help regeneration of DPF. The platinum-based catalysts were also known to enhance the oxidation of CO and hydrocarbons to CO_2 and the oxidation of NO to NO_2. While from the perspective of controlling exposure of underground miners to toxic gases the two former processes are seen as desirable, the conversion of NO to NO_2 adversely affects air quality.

The other DPF systems evaluated in the Phase I of this study [Bugarski et al. 2003 and Bugarski et al. 2004] including passive systems from CleanAir Systems and ECS, active systems from DCL and system using disposable filter elements from Donaldson were not available for Phase II evaluation.

Smoke samples were collected from the tailpipes downstream of the DPF for each of the target vehicles using the True Spot® Smoke Test Kit (Bacharach, Inc., 621 Hunt Valley Circle, New Kensington, Pennsylvania). The smoke number was determined by comparing the soot spot to a supplied scale in which white is a 0 and black is a 9. Smoke number samples were taken while the vehicle/engine was operated at torque converter stall conditions. These results were used as a quick way to verify the filtration performance of the DPF systems used in each test. A smoke number of 0 for the nearly new DCL DPF system (see Table 1) indicated that this system was efficiently removing DPM and EC from the exhaust of LHD #92535. The relatively high smoke numbers (above 3) observed for the samples collected downstream of the Engelhard DPF systems installed on vehicles #92133 and #92139 indicated that these used systems were providing significantly lower reductions in DPM concentrations than the brand new DCL unit (see Table 1). Those filters did not satisfy previously established criteria[1] on efficiency of DPF systems to be included in the study. In an attempt to find a vehicle with the DPF systems that satisfy the criteria, vehicle #92139, used during second test, was replaced in the third test by an alternate haulage truck #92135 which was equipped with a similar DPF system. The smoke number measured after the test downstream of the DPF on #92135 was about 3, indicating that this DPF system also did not satisfy criteria. The DPF system on vehicle #92133 was replaced before the third test with another similar DPF system, but downstream smoke number measurements showed only slight increase in efficiency. The DPF systems on #92535, #92133, and #92135 were replaced before the fourth test with DCL MineX DOCs and mufflers.

Therefore, when interpreting the test results one should take into consideration the actual condition of the tested DPF systems. However, efficiency of DPF systems encountered in this study might be representative of the in-use DPF systems that have accumulated some time in underground mining operation.

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[1] Uncompromised (used or new) DPFs using a Corning Cordierite element typically exhibit smoke numbers below 1.

Fuel

Stillwater Mine uses No. 1 diesel fuel supplied by local refinery (Cenex, Columbus, Montana) for its entire underground fleet. The basic properties of that fuel are presented in Table 2. This diesel fuel surpasses MSHA requirements (30 CFR 57. 5065, 1995) for diesel fuels used in underground mines and was used by the mine to reduce exposure of underground miners to diesel emissions.

Table 2. Properties of the fuel used in this study

Type of analysis	Method	Units	Cenex No. 1 diesel
1	2	3	4
Cetane Number	ASTM D613	N/A	42.8
Density	ASTM D4052	g/ml	0.8
Sulfur Content	ASTM D5453	ppm	125.0
Flash Point	ASTM D93	°C	57.2

Equipment and instrumentation

Three area sampling stations were established for the 3500W test zone. On the first day of testing, the midstream and downstream stations were established at approximately 900 m (2952 ft) and 1500 m (4921 ft) west of the 3500 split. These sampling locations were later found to be inappropriate, since they were inside the internal ventilation circuits of two active stopes. Therefore, the results of this test were compromised and will not be discussed further in this report. On the remainder of the test days the area sampling stations were established in more appropriate locations (see Table 3 and Figure 1). By convention, sampling stations and other features such as ventilation raises are identified by their distance in feet west of the 3500 split. The upstream sampling station (300W) was situated approximately 90 m (295 ft) from the 3500 split. The midstream sampling station (3900W) was located in the main drift approximately 90 m (295 ft) upstream of the 4100W raise and approximately 1190 m (3904 ft) downstream of the 3500 split. Both of these stations were positioned in the upper third of the drift, above and out of the way of passing vehicles. The downstream sampling station (see Figure 2) was located in the center of the 60 m (197 ft) long stope connecting the main drift with 6200W raise.

Table 3. Sampling stations

Area Sampling Station	Distance Relative to 3500 Split [m (ft)]	Cross Sectional Area [m^2 (ft^2)]
300W	90 (295)	11.87 (127.8)
3900W	1190 (3904)	11.54 (124.2)
6200W	1900 (6234)	12.64 (136.1)

Personal elemental carbon exposure samples were obtained for each of the three operators from the muck haulage team.

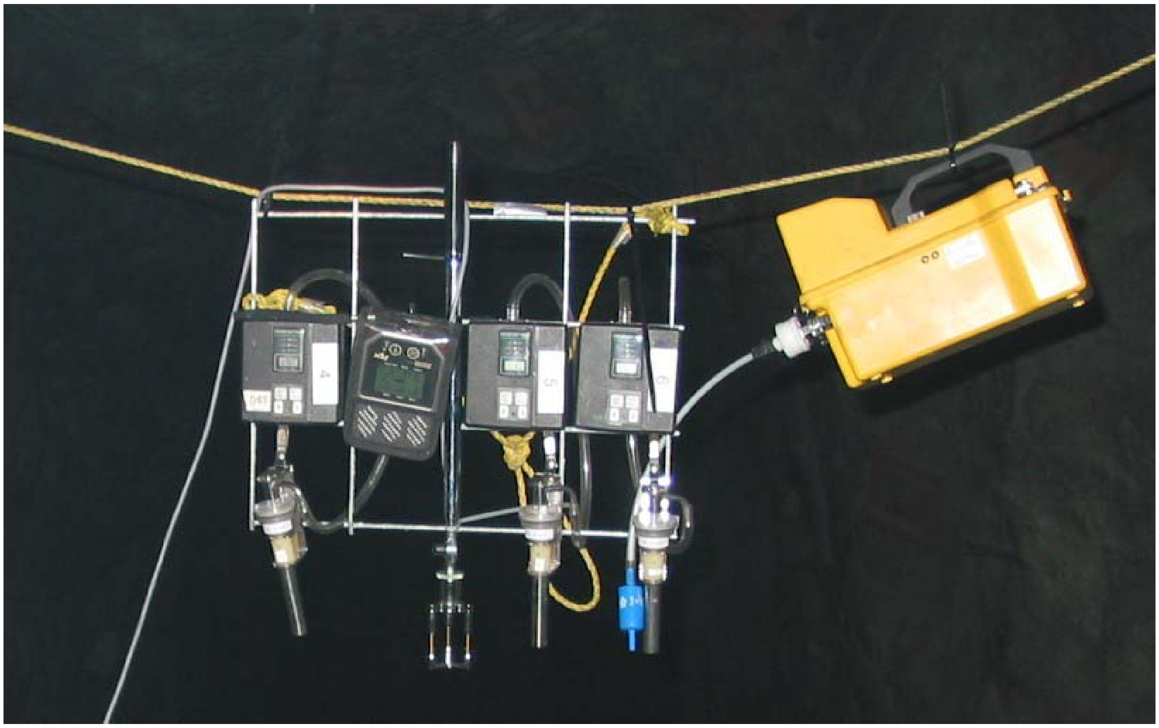


Figure 2. Downstream sampling station consisting of three compliance samplers for EC, an iTX gas monitor, anemometer head, and the RKI (yellow box) sample inlet fastened to a wire grid

Elemental carbon sampling and analysis

Area samples for elemental carbon were collected in triplicate at each sampling station for the duration of each test. In addition, one personal sample was collected from the breathing zone of each of the three operators from the muck haulage teams. The sampling train used for area and personal sampling was similar to the one used by Mine Safety and Health Administration (MSHA) for DPM compliance monitoring [66 Fed. Reg. 5706 and corrections 66 Fed. Reg. 35518 2001]. It consisted of a flow controlled MSA Elf Model pump (Mine Safety Appliances Company, Pittsburgh, Pennsylvania), a 10 mm Dorr-Oliver cyclone, and an SKC DPM cassette (SKC, Inc., Eighty Four, Pennsylvania). The SKC DPM cassette contained a single stage impactor and two stacked 37 mm quartz fiber filters. The pumps were operated at 1.7 l/min and were calibrated at the mine at the beginning of the study. The flow rate for each of the sampling pumps was measured and recorded before and after each sampling event using a Gillibrator II bubble flow meter (Sensidyne, Clearwater, Florida). If the measured flow rates deviated by more than 5 percent from 1.7 l/min the pumps were recalibrated.

The time at which each sampling pump was started and stopped were noted. The duration of sampling period was used in the calculation for determining elemental carbon concentrations from the SKC DPM cassettes. The actual start and stop times for sampling at the area stations for each test were used in determining of the average gaseous concentration and ventilation rate for that test and sampling location from the logged data (see below).

Exposed SKC DPM cassettes were shipped to NIOSH PRL and analyzed by the NIOSH PRL analytical laboratory for elemental carbon content using the NIOSH 5040 Analytical Method [NIOSH 1999, Birch and Cary 1996]. The elemental carbon concentration at a sampling station for a test was the average of the concentrations of the three samples obtained at that station and test. In addition, the coefficient of variation (CV), the standard deviation expressed as a percentage of the average, was calculated for each of the triplicate samples. Each average EC concentration was then normalized with respect to its respective average CO2 concentration for that sample location and test to account for variations in vehicle activity (fuel burned).

Concentrations of CO, CO_2, NO, and NO_2

The ambient concentrations of CO, NO, and NO_2 were measured at all three sampling locations using iTX multi-gas monitors (Industrial Scientific, Oakdale, Pennsylvania) (see Figure 2). One iTX multi-gas monitor was dedicated to each of the three sampling locations for the duration of this study. The ambient concentrations were measured every 10 seconds and stored in the monitor's memory. The logged data was downloaded to a spreadsheet and averaged over the sampling period of the area samples for elemental carbon. The instruments were calibrated at the site each day, prior to sampling.

The ambient concentrations of CO_2 were measured at all three sampling locations using RKI Eagle CO_2 monitors (RKI Instruments Inc., Hayward, California) (see Figure 2). The ambient concentrations were logged every 10 seconds and stored in the monitor's memory, downloaded to a spreadsheet, and averaged over the sampling period. These instruments were calibrated at NIOSH PRL and the field results were corrected for the air pressure at the elevation of sampling. The average carbon dioxide concentrations for each sampling location were used to normalize the corresponding elemental carbon concentrations.

Ventilation rates

Air velocities in the test zone were measured continuously at the midstream and downstream sampling station using an Anemosonic UA6 digital ultrasonic anemometer (Airflow Developments Limited, High Wycombe, England). The sensing head of the anemometer was attached to the sampling grid and oriented to the flow (see Figure 2). The output from the anemometer was logged in 10-second averages using a MiniLogger portable data logging system (Logic Beach, La Mesa, California). The data was downloaded to a spreadsheet and was multiplied by the corresponding cross sectional area for the sampling station to obtain an estimate of the ventilation rate at that station. The average ventilation rates during the tests were determined by averaging the data over the sampling period.

The air velocities were also measured on September 9th (test day 2) and tenth by a mine ventilation engineer, at the midstream (3900W) and slightly upstream (6000W) of the downstream (6200W) locations, using a vane anemometer and the full cross sectional traverse method. The ventilation rates were estimated by multiplying the average air speeds by the cross sectional areas determined for the corresponding sampling stations. The air velocities were not measured by traverse on the other test days.

Vehicle emissions

In the afternoon of the third day (09/11/2003) of the study, maintenance personnel from Stillwater Nye mine measured tailpipe emissions of oxygen (O_2), CO, NO, and NO_2 upstream and downstream of the DPF systems and downstream of DOC systems installed on the vehicles #92133, #92135, and #92535. The emissions were measured while the vehicles were parked in maintenance area of the surface shop at Stillwater Nye mine.

An Enerac 400 Micro-Emission Monitoring System (EMS) was used for real-time measurements of emissions generated while the tested vehicles were operated over transient cycle consisting of four steady-state operating conditions performed in the following sequence: low idle (LI), high idle (HI), torque converter stall (TCS), and low idle (LI). Each of the tests cycles was preceded by warm-up session.

The Enerac 400 EMS uses electrochemical sensors to directly measure concentrations of O_2, CO, NO and NO_2. The emissions of CO_2 and NO_x were calculated from the measured values.

ECOM Model KL portable emissions analyzer (ECOM America, Norcross, Georgia) was used to sample DPM using the Bacharach smoke number. The numbers were determined by comparing samples to spots on the gray scale chart (0-9) supplied by ECOM America.

RESULTS AND DISCUSSION

The midstream and downstream sampling locations (2952W and 4921W respectively) used during the test conducted on the first day of the study were found to be inadequate since they were within the ventilation circuits of the two active stopes. Therefore, the results of this test were compromised and they will not be discussed further in this report.

Ventilation rates

The average prevailing ventilation rate, calculated from the velocity measurements obtained using the ultrasonic anemometers at the midstream (3900W) and downstream (6200W) sampling station for each of the test runs, are presented in Table 4.

Table 4. Ventilation rates estimated from ultrasonic anemometer measurements

Test # (Date)	Sampling Location	Average Velocity [m/s]	Average Velocity [ft/min]	Area [m^2]	Area [ft^2]	Average VR [m^3/sec]	Average VR [ft^3/min]
2 (September 9)	3900W	2.53	497.20	11.54	124.20	29.14	61752
	6200W	1.84	362.59	12.64	136.10	23.29	49349
3 (September 11)	3900W	2.47	485.49	11.54	124.20	28.46	60298
	6200W	4.99	981.97	12.64	136.10	63.07	133646
4 (September 12)	3900W	2.22	436.22	11.54	124.20	25.57	54178
	6200W	4.56	898.54	12.64	136.10	57.71	122291

The average prevailing ventilation rates, calculated from the velocity measurements obtained, using a vane anemometer and the full cross sectional traverse method on September 9th and 10th, are presented in Table 5.

Table 5. Ventilation rates estimated from vane anemometer measurements

Test # (Date)	Sampling Location	Average Velocity [m/s]	Average Velocity [ft/min]	Area [m^2]	Area [ft^2]	Average VR [m^3/sec]	Average VR [ft^3/min]
2 (September 9)	3900W	3.05	601.00	11.54	124.20	35.23	74644
	6000W	1.44	283.00	12.64	136.10	18.18	38516
N/A* (September 10)	3900W	3.32	654.00	11.54	124.20	38.33	81227
	6000W	1.64	323.00	12.64	136.10	20.75	43960

*Test was not conducted on this day

It is important to note that the results of the measurements with these two methods obtained during test #2 on September 9th generally agreed. The differences can be attributed to the spatial and temporal fluctuations of the air velocities (see Figure 3 and letter by Jason Todd attached to this document) and different sampling locations. Unfortunately, the vane anemometer ventilation measurements were not available for the last two days of testing. They could have been used to verify the change in the ventilation rates observed for tests three and four. According to mine ventilation engineer (see attached letter from Jason Todd) the air speeds observed with ultrasonic anemometer measurements during these tests are “not possible without disrupting the entire off shaft west ventilation system.”

Figure 3, Figure 4, and Figure 5 show the ventilation changes observed. Figure 3 shows the real-time ventilation rate for test #2 on September 10^{th} when the traverse with the vane anemometer was also done. The midstream ultrasonic anemometer speeds are represented by the upper trace. Figure 4 and Figure 5 show greatly elevated air speeds at the downstream sampling location indicating an additional air source between the midstream and downstream sampling stations.

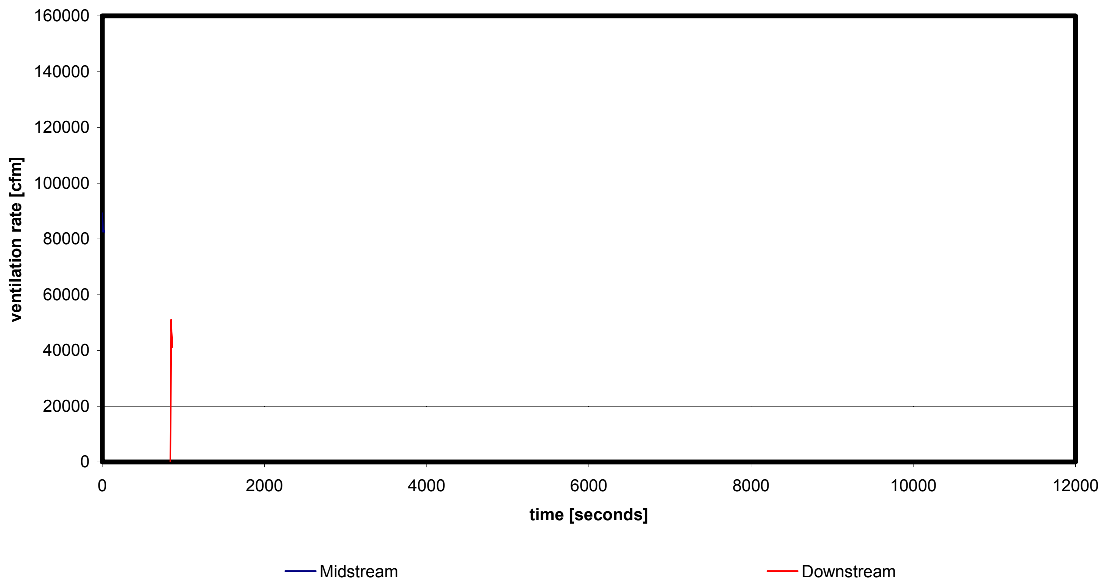


Figure 3. Instantaneous ventilation rates estimated from the ultrasonic anemometer measurements for test #2

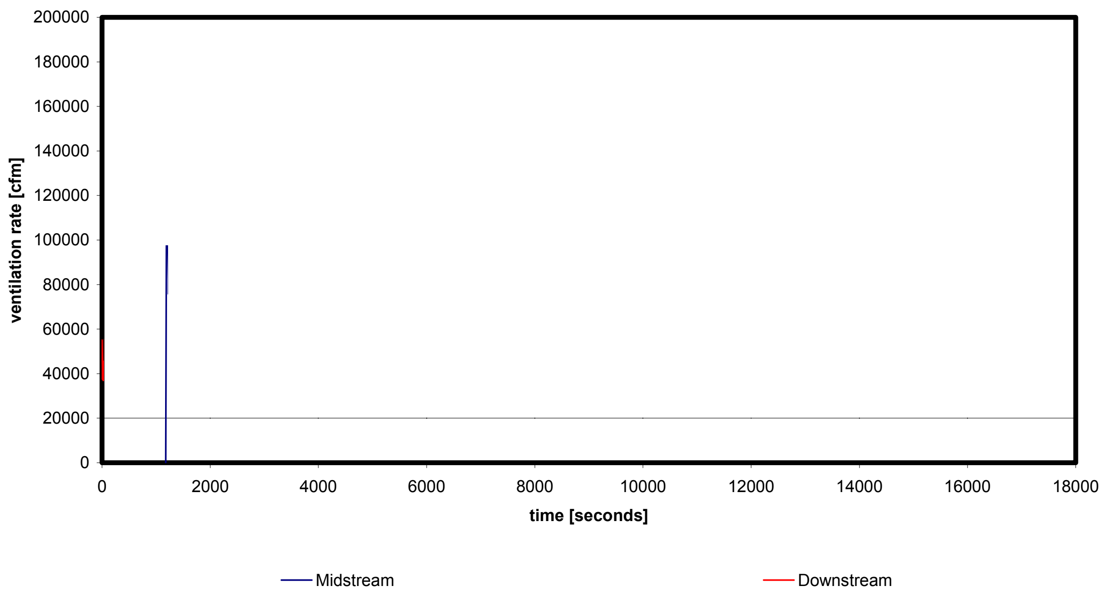


Figure 4. Instantaneous ventilation rates estimated from ultrasonic anemometer measurements for test #3

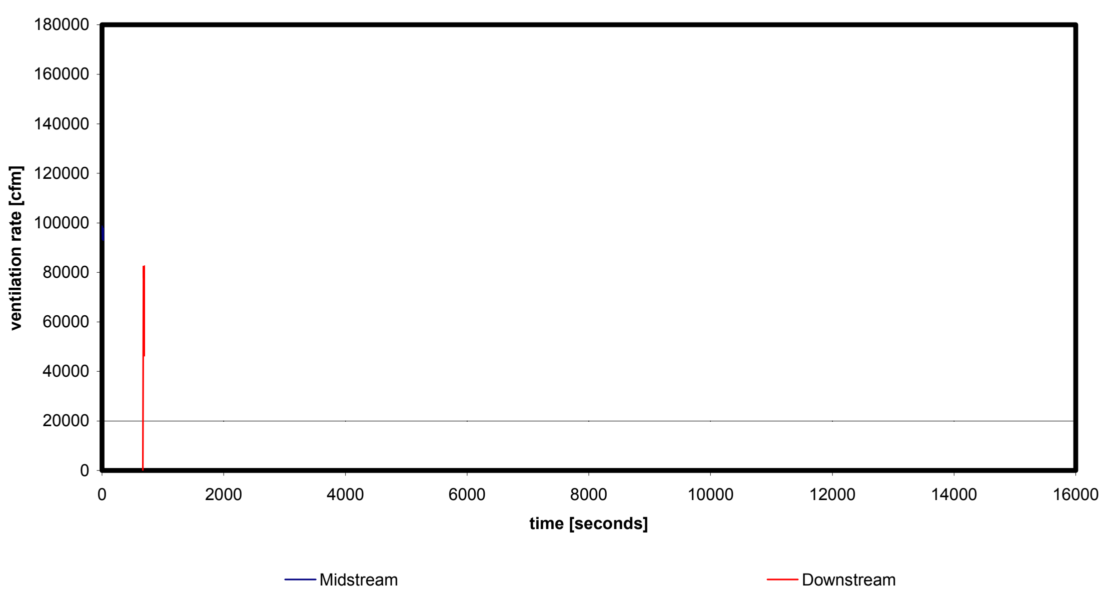


Figure 5. Instantaneous ventilation rates estimated from ultrasonic anemometer measurements for test #4

Concentrations of CO_2

The results of the continuous measurements of CO_2 concentrations are shown in Figure 6 through Figure 8. These concentrations illustrate the differences in production cycles among three test days. The high concentrations of CO_2 observed at the midstream station and the relatively constant concentrations at the downstream station for test #3 reflects the fact that the mucking crew was working exclusively east (upstream) of the midstream station (Figure 7). In contrast, during test #4 significantly higher concentrations of CO_2 were observed at the downstream station than at the midstream station (Figure 8). That, and the large number of peaks at both the midstream and downstream stations, reflect the fact that the mucking crew spent most of the time moving muck from the development section, west of the 6200W, to the orepass (near 300W), passing by both the downstream and midstream sampling stations in the process.

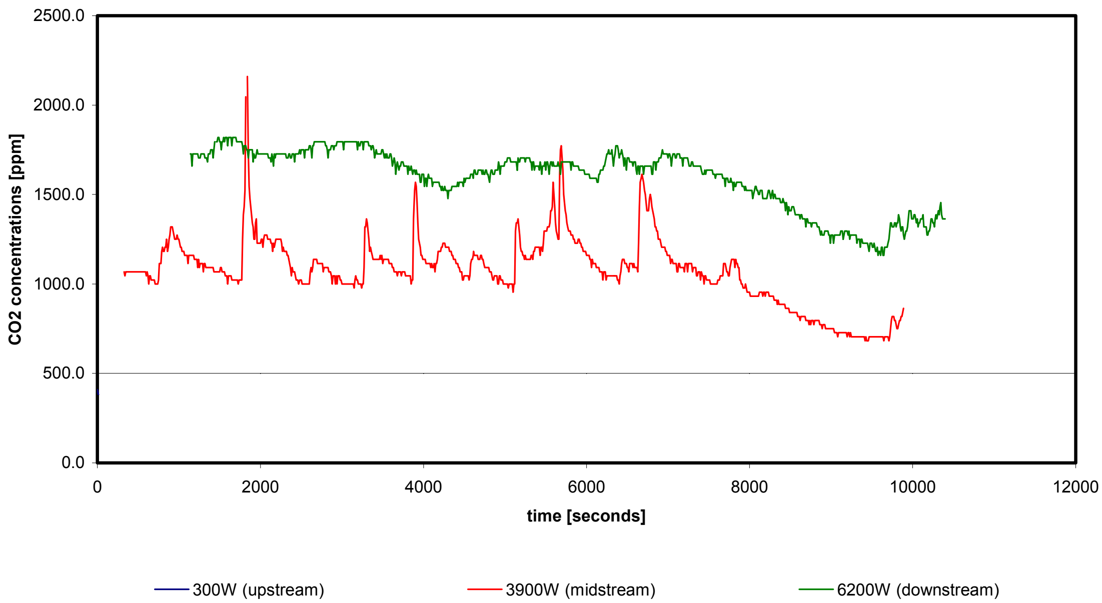


Figure 6. Concentrations of CO_2 observed during test #2

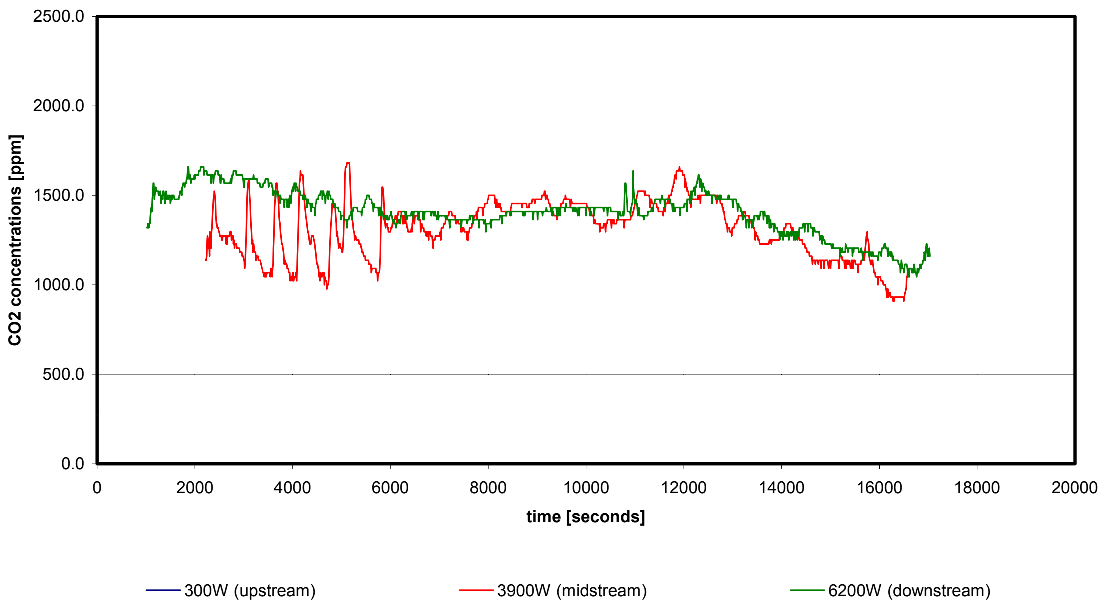


Figure 7. Concentrations of CO_2 observed during test #3

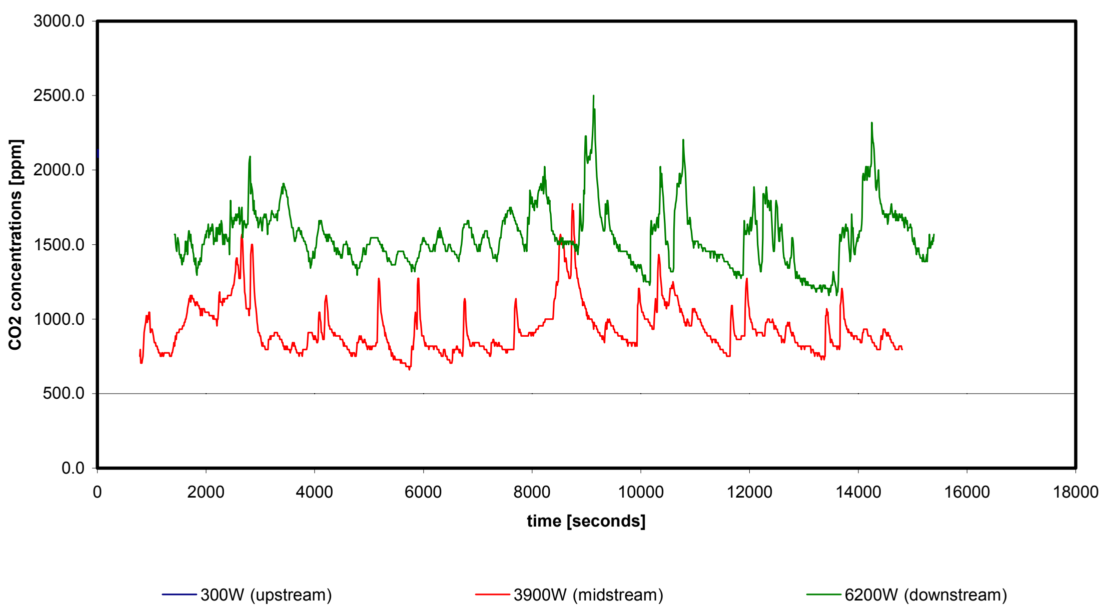


Figure 8. Concentrations of CO_2 observed during test #4

The average and peak concentrations of CO_2 observed during tests #2, #3, and #4 are shown in Table 6. The average values were used to normalize elemental carbon concentrations to the vehicle activity (fuel consumed) upstream of each sampling location. The normalization with respect to the CO_2 concentrations minimizes the effects of the duty cycle and ventilation rates on the results for EC and the other measured pollutants. The normalized data should be exclusively used for comparing the effects of the control technologies.

Table 6. Average and maximum CO_2 concentrations

Test # (Control Systems)	Sampling Location	Average CO_2 Concentration [ppm]	Maximum CO_2 Concentration [ppm]
2 (DPFs)	300W	347	818
	3900W	1073	2160
	6200W	1593	1819
3 (DPFs)	300W	381	1700
	3900W	1312	1480
	6200W	1405	1460
4 (DOCs)	300W	461	2100
	3900W	932	1560
	6200W	1554	2200

Concentrations of elemental carbon (EC)

The EC concentrations measured during this study are summarized in Table 7. The average values were calculated from the triplicate samples collected at each sampling station. The relatively low coefficients of variation indicate a consistency in the sampling and analytical procedures.

The results show relatively low concentrations of the EC at the upstream sampling station (ventilation air supplied from 3200 level) during the tests. The EC concentrations at the midstream and downstream sampling stations were found to be lower during the tests when the three targeted vehicles were equipped with DPF systems than when they were equipped with DOCs plus mufflers (Table 7). However, the ambient concentrations of EC at downstream sampling locations were higher than 308 $\mu g/m^3$ in both cases when three test vehicles were equipped with DPF systems. These results may have been influenced by the fact that two of the DPF systems were not performing up to nominal specifications (smoke number 0 to 1) for such systems, as indicated by a tailpipe smoke number greater than three and by the presence of other diesel equipment operating in the area.

Table 7. Results of elemental carbon analysis performed on the area samples

Test # (Control Systems)	Sampling Location	SKC Sample #	EC [$\mu g/m^3$]	Average EC [$\mu g/m^3$]	Coefficient of Variation (STD/AVG) [%]	Average CO_2 Concentrations [ppm]	Average Normalized EC [(ng/m^3 of EC)/(ppm of CO_2)]
2 (DPFs)	300W	0015957	22	22	6.0%	347	64.1
	300W	0015946	24				
	300W	0015951	21				
	3900W	0015945	226	225	6.7%	1073	210.0
	3900W	0016005	240				
	3900W	0015981	210				
	6200W	0016019	400	387	4.7%	1593	242.8
	6200W	0016028	366				

Test # (Control Systems)	Sampling Location	SKC Sample #	EC [μg/m³]	Average EC [μg/m³]	Coefficient of Variation (STD/AVG) [%]	Average CO_2 Concentrations [ppm]	Average Normalized EC [(ng/m³ of EC)/(ppm of CO_2)]
	6200W	0016022	394				
3 (DPFs)	300W	0015965	33	34	5.2%	381	88.3
	300W	0016017	36				
	300W	0016027	32				
	3900W	0016023	228	218	7.6%	1312	165.8
	3900W	0016008	198				
	3900W	0015971	226				
	6200W	0015995	360	358	0.9%	1405	254.8
	6200W	0016016	354				
	6200W	0016026	360				
4 (DOCs)	300W	0016021	65	69	10.0%	461	149.2
	300W	0016001	77				
	300W	0016015	65				
	3900W	0015857	291	282	2.8%	932	302.7
	3900W	0015853	279				
	3900W	0015858	276				
	6200W	0015865	763	740	5.1%	1554	475.9
	6200W	0015892	759				
	6200W	0015897	696				

The EC concentrations from the personal samples are summarized in Table 8. During the test #4, when all tested vehicles were fitted with DOCs and mufflers, the average EC concentrations to which the operators were exposed, particularly the operator on LHD #92535, exceeded 308 μg/m³. During tests #2 and #3, when target vehicles were fitted with DPFs, the average EC concentration for each of the three operators were significantly below 308 μg/m³ and the results in test #2 were well above the final DPM exposure limit of 123 μg/m³ EC (equivalent to 160 μg/m³ TC). However as discussed previously, the DPF systems on trucks #92133 and #92136 were performing below specifications. These results indicate that even when the DPF systems are performing below expectations, they can significantly reduce the EC concentrations when compared to conditions when the DPF systems were not used. For test #2, the result of carbon analysis on the personal sample for LHD operator is not available since sampling pump flow fault occurred during the test.

Table 8. Results of elemental carbon analysis performed on the personal samples

Test # (Control Systems)	Vehicle Operator	SKC Sample #	EC ($\mu g/m^3$)
2 (DPFs)	#92133	0015987	180
	#92136	0016014	174
	#92535	0016029	flow fault
3 (DPFs)	#92133	0016012	82
	#92136	0015990	86
	#92535	0016031	78
4 (DOCs)	#92133	0015879	397
	#92136	0015866	382
	#92535	0015890	1100

Concentrations of CO, NO, and NO_2

The results of the measurements of CO, NO, and NO_2 concentrations are summarized in Table 9. These data were not collected on midstream sampling station for test #3 due to a failure to initiate the logging session. The average concentrations of CO, NO, and NO_2 were found to be well under the corresponding 1973 ACGIH TLVs® adopted by MSHA (30 CFR §57.5001, 1995). The NO_2 concentrations were found to be elevated in test cases when the vehicles were equipped with either the DPFs or the DOCs (Table 9, Figure 9 and Figure 10).

Table 9. Results of measurements of concentrations of CO, NO, and NO_2

Test # (Control Systems)	Sampling Location	CO [ppm]		NO [ppm]		NO_2 [ppm]	
		Average	Maximum	Average	Maximum	Average	Maximum
2 (DPFs)	300W	0.0	3.0	0.1	5.0	0.0	0.3
	3900W	0.3	4.0	6.3	12.0	0.9	3.5
	6200W	5.2	18.0	11.3	13.0	1.2	1.8
3 (DPFs)	300W	0.0	4.0	0.3	12.0	0.0	1.9
	6200W	3.7	10.0	6.6	9.0	1.1	1.7
4 (DOCs)	300W	0.1	9.0	0.6	13.0	0.0	2.1
	3900W (1)	0.1	6.0	4.2	8.0	0.2	1.4
	3900W (2)	0.1	6.0	4.4	9.0	0.3	1.6
	6200W	3.6	11.0	7.4	12.0	1.1	2.6

Both tests #2 and # 3 were terminated, during the sampling period, due to high concentrations of NO_2 detected by the personal multi-gas monitor carried by the operator of the truck #92135. During test #2, while vehicles #92135 and #92535 were at the development section, the monitor showed NO_2 concentrations higher than 5 ppm, the 1973 ACGIH short term exposure level (STEL) for this gas adopted by MSHA (30 CFR 57.5001 1995). During test #3, when vehicle #92135 was at the orepass, the monitor carried by the operator showed concentrations in excess of 5 ppm. Elevated NO_2 exposures resulted in the removal of personnel from the work area. Exposures above 5 ppm were not reported during test #4; however, the peak concentrations of NO_2 measured at the downstream sampling station (Figure 10) indicate that personal exposures might have been relatively high in this case as well.

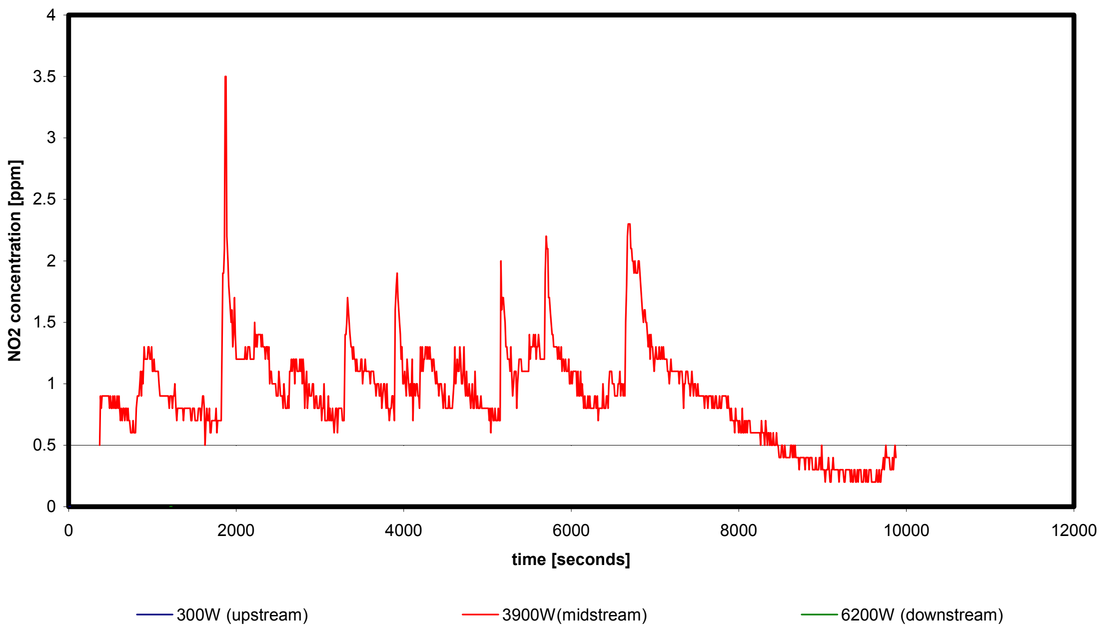


Figure 9. Concentrations of NO_2 observed during test #2

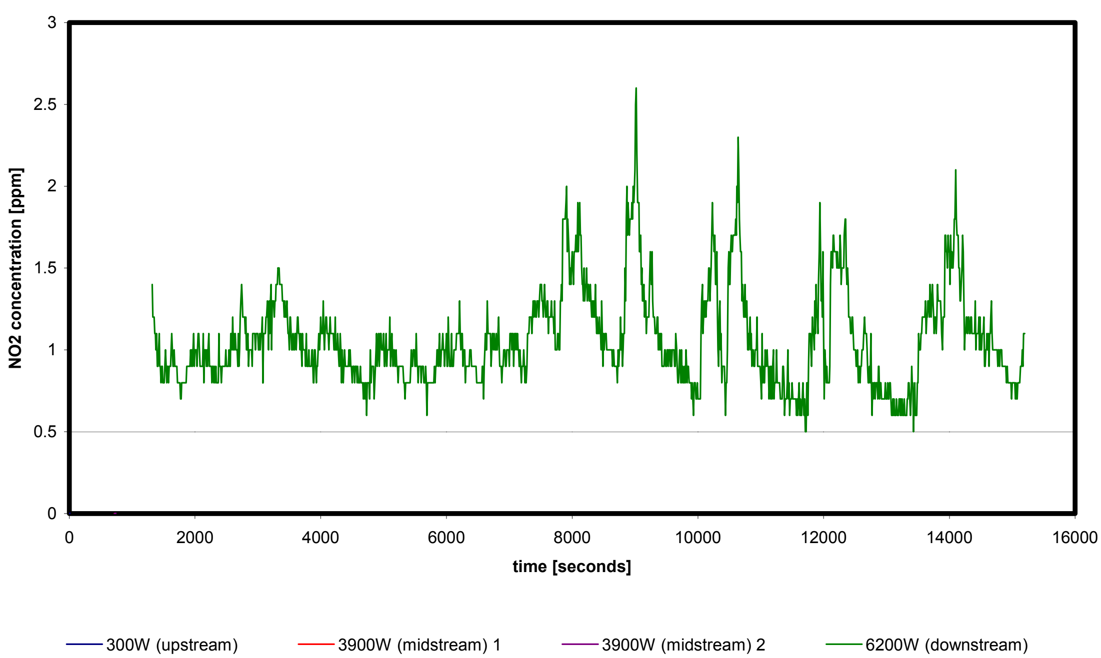


Figure 10. Concentrations of NO_2 observed during test #4

Tailpipe emissions measurements

The emissions of O_2, CO_2, CO, NO, NO_2, and NO_x, measured upstream and downstream of the DPF systems and the DOCs installed on #92133, #92135, and #92535, are shown for three steady-state test conditions in Table 10, Table 11, and Table 12. The values for smoke numbers measured at torque converter stall conditions are shown in the same tables.

Table 10. Gaseous and PM emissions for truck #92133 (Deutz BF6M1013 FC with EMR governor)

Engine Operating Conditions	Sampling Location	O_2 [%]	CO_2 [%]	CO [ppm]	NO [ppm]	NO_2 [ppm]	NO_x [ppm]	Smoke Number (0-9)
Low Idle	upstream of DPF	17.9	2.2	156	327	14	342	N/A
	downstream of DPF	17.8	2.3	9	200	97	298	N/A
	downstream of DOC	18.2	1.9	0	149	83	232	N/A
High Idle	upstream of DPF	14.8	4.4	438	354	67	421	N/A
	downstream of DPF	14.8	4.5	6	235	127	362	N/A
	downstream of DOC	15.9	3.6	20	241	0	241	N/A
Torque Converter Stall	upstream of DPF	9.8	8.2	194	516	0	516	7
	downstream of DPF	9.7	8.3	17	380	53	433	1
	downstream of DOC	12.2	6.4	19	356	0	356	7

Table 11. Gaseous and PM emissions for truck #92135 (Deutz BF6M1013 FC with EMR governor)

Engine Operating Conditions	Sampling Location	O_2 [%]	CO_2 [%]	CO [ppm]	NO [ppm]	NO_2 [ppm]	NO_x [ppm]	Smoke Number (0-9)
Low Idle	upstream of DPF	18.5	1.7	230	197	0	197	N/A
	downstream of DPF	18.1	2.0	0	132	109	241	N/A
	downstream of DOC	18.7	1.5	2	144	0	144	N/A
High Idle	upstream of DPF	15.3	4.1	704	271	0	271	N/A
	downstream of DPF	16.4	3.3	11	197	0	197	N/A
	downstream of DOC	17.6	2.4	29	163	0	163	N/A
Torque Converter Stall	upstream of DPF	9.9	8.1	246	505	0	505	7
	downstream of DPF	12.5	6.2	10	306	0	306	0
	downstream of DOC	14.7	4.5	20	246	0	246	7

Table 12. Gaseous and PM emissions for LHD #92535 (Caterpillar 3306 DITA)

Engine Operating Conditions	Sampling Location	O_2 [%]	CO_2 [%]	CO [ppm]	NO [ppm]	NO_2 [ppm]	NO_x [ppm]	Smoke Number (0-9)
Low Idle	upstream of DPF	18.6	1.6	85	165	28	194	N/A
	downstream of DPF	17.8	2.2	7	252	217	469	N/A
High Idle	upstream of DPF	14.3	4.8	195	245	21	267	N/A
	downstream of DPF	14.1	5	0	239	137	377	N/A
Torque Converter Stall	upstream of DPF	11.7	6.8	63	580	0	580	3
	downstream of DPF	11.4	7	19	598	26	625	0

The results of CO_2 emissions measurements indicate that the engines were loaded relatively consistently during the test involving DPFs. The CO_2 emissions downstream of the DOC systems were consistently somewhat lower than corresponding emissions measured upstream and downstream of the DPFs. This might be explained by lower backpressure imposed by DOC than by DPF systems. Therefore, using emissions measured upstream of DPF systems as engine-out (baseline) emissions for the test involving the DOC systems and comparing them to the emissions measured downstream of the DOC systems is not acceptable practice.

The engine-out CO emissions from truck #92133 (see Table 10) were found to be higher than equivalent emissions from truck # 92135 (see Table 11). The engine-out emissions from both Deutz-powered trucks were quite a bit higher than the equivalent emissions from Caterpillar 3306 DITA engine powering LHD #92535 (see Table 12). It is important to note that electronically controlled Deutz BF6M1013 FC engines powering trucks #92133 and #92135 were originally acquired as mechanically controlled Deutz BF6M1013 ECP engines. Those engines were afterward modified by replacing mechanical governor with EMR governors. The results presented in Table 10, Table 11, and Table 12 show that catalyzed DPFs and DOCs used on #92133, #92135, and #92535 during this study were efficient in curtailing CO emissions.

The results of measurements of NO and NO_2 emissions were relatively inconsistent and less conclusive. That can be particularly concluded for NO_2 measurements performed in exhaust of #92135 (see Table 11) where no NO_2 was detected in exhaust for majority of the tests. Despite this uncertainty, the results of tailpipe emissions measurements support the findings from the tests conducted underground on 3500W. The fact that NO_2 emissions were substantially higher downstream of the DPF systems might explain high ambient concentrations of NO_2 observed during the tests when #92133, #92135, and #92535 were equipped with DPF systems.

The smoke numbers obtained during shop tests were consistently lower than smoke numbers determined during underground spot checks. This discrepancy in the results can be partially attributed to the different methods and instrumentation used for these tests.

ACKNOWLEDGEMENTS

Special thanks to Stillwater Mining Co. for hosting the study.

REFERENCES

30 CFR 57.5001 [1995]. Exposure limits for airborne contaminants. Air quality-surface and underground. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

30 CFR 57.5060 [2001]. Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners. Limit on Concentration of Diesel Particulate Matter. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

30 CFR 57.5065 [2001]. Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners. Fueling practices. Code of Federal Regulations, Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

30 CFR 75.1909(a) [1996]. Nonpermissible Diesel-Powered Equipment; Design and Performance Requirements. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

66 Fed Reg. 5706 [2001] Mine Safety and Health Administration: Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners; final rule. (To be codified at 30 CFR 57.)

68 Fed. Reg. 48668 [2003]. "Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners; Proposed Rule," Mine Safety and Health Administration. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Birch ME and Cary RA [1996]. Elemental Carbon-Based Method for Monitoring Occupational Exposures to Particulate Diesel Exhaust. Aerosol Science and Technology Vol. 25, pp. 221-241.

Bugarski A, Schnakenberg G , Noll J , Mischler S , Patts L , Hummer J, Vanderslice S, Crum M, and Anderson R [2003]. The Effectiveness of Selected Technologies in Controlling Diesel Emissions in an Underground Mine - Isolated Zone Study at Stillwater Mining Company's Nye Mine, Draft Report to M/NM Diesel Partnership, September 8.

Bugarski A, Schnakenberg G, Noll J, Mischler S, Crum M, and Anderson R [2004]. Evaluation of Diesel Particulate Filter Systems and Biodiesel Blends in an Underground Mine. SME 2004. Denver, February 23-25.

Bugarski AD and Schnakenberg HG [2001]. Field Evaluation of Diesel Particulate Filters: Size Selective Measurements of Aerosols in Mine Air and Engine Exhaust. Mining Diesel Emissions Conference MDEC 2001, Markam, Ontario. November.

Bugarski AD and Schnakenberg HG [2002]. Evaluation of Diesel Particulate Filter Systems at INCO Stobie Mine. Mining Diesel Emissions Conference MDEC 2002, Markam, Ontario. October.

Larsen CA, Levendis YA, and Shimato K [1999]. Filtration Assessment and Thermal Effects of Aerodynamic Regeneration in Silicon Carbide and Cordierite Particulate Filters. SAE Paper 1999-01-0466.

Mayer A, Matter U, Czerwinski J, and Heeb N [1999]. Effectiveness of Particulate Traps on Construction Site Engines: VERT Final Measurements, DieselNet Technical Report. World Wide Web [URL=http://www.dieselnet.com/papers/9903mayer/index.html], March.

McDonald JF, Cantrell BK, Watts WF, Bickel KL [1997]. Evaluation of a Soybean Oil Based Diesel Fuel in an Underground Gold Mine, CIM Bulletin, 90, pp. 91-95.

McDonald JF, Purcell DL, McClure BT, and Kittelson DB [1995]. Emissions Characteristics of Soy Methyl Ester Fuels in an IDI Compression Ignition Engine, SAE Paper 950400.

McGinn S [2001]. Brunswick Mine Particulate Trap Project: Performance Evaluation. Mining Diesel Emissions Conference, MDEC 2001, Markham, ON, Canada, November.

NIOSH. National Institute for Safety and Health [1999]. Elemental Carbon (Diesel Particulate): Method 5040, Issue 3 (Interim), In NIOSH manual of analytical methods. 4th rev. ed. Cincinnati, OH: U.S. World Wide Web [URL=http://www.cdc.gov/niosh/nmam/pdfs/5040f3.pdf].

Schaberg PW, Myburgh IS, Botha JJ, Roets PN, Viljoen CL, Dancuart LP, and Starr ME [1997]. Diesel Exhaust Emissions Using Sasol Slurry Phase Distillate Process Fuels, SAE Paper 972898.

Schnakenberg G and Bugarski A [2002]. Review of Technology Available to the Underground Mining Industry for Control of Diesel Emissions, U.S. Department of Health and Human Services Information Circular IC 9262. [http://www.cdc.gov/niosh/mining/pubs/pdfs/ic9462.pdf]

Watts FW, Cantrell BK, Bickel KL, Olson KS, Rubow KL, Baz-Dresch JJ, Carlson DH [1995]. In-Mine Evaluations of Catalyzed Diesel Particulate Filters at Two Underground Metal Mines, U.S. Bureau of Mines Information Circular RI 9571.

Watts, WF, Spears M, and Johnson J [1998]. Evaluation of Biodiesel Fuel and Oxidation Catalyst in an Underground Metal Mine, Report to DEEP Technical Committee.

To: Aleksandar Bugarski

From: Jason Todd

Date: October 9, 2003

Subject: 35w Ventilation during Phase 2 DPM study

CC: Rick Anderson, Michael Crum, John Jordan, Chris Zimmer

The ventilation on the 35w FWL consists of air flowing onto the level at 35e900 and splitting east and west. The westward split has historically been in the 75-85 kcfm range. When the air reaches the 4100w return air raise a portion exhausts the level and flows up to the 38w FWL. The remaining air flows westward to the 6200w return air raise. This air flows up the raise to the 38w FWL. Air flows from 35w4100-35w6200 have historically been on the order of 40-55 kcfm. These air flow variances are due to minewide air door settings, muckpass levels, ambient air temperature and other variables. The air flows are not static and change throughout any given time frame. On the 38w FWL at both 4100w and 6200w there are fans (125 hp and 150 hp) which pull air up the raises from the 32w FWL and the 35w FWL.

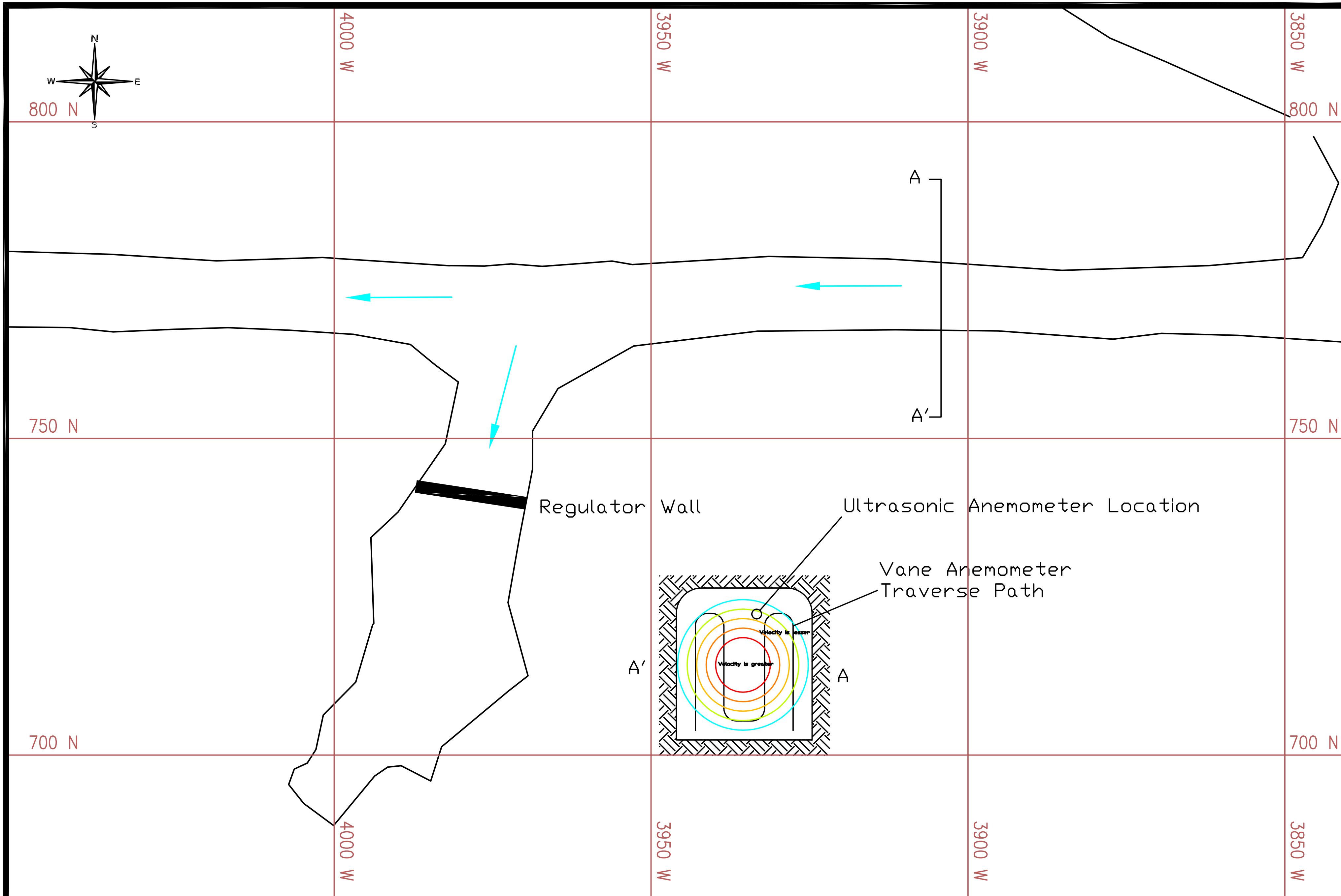
Measurements were taken in this area on September 09-10, 2003. The results are shown below:

Date	Location	Area(ft2)	Corrected Velocity (ft/min)	Quantity (cfm)
9/9/2003	35w3900	124.2	601	74,644
	35w6000	136.1	283	38,516
9/10/2003	35w3900	124.2	654	81,227
	35w6000	136.1	323	43,960

Measured with a Davis Instruments Vane Anemometer using two 60 second traverses.

The measurements taken by NIOSH personnel indicate air was intaking onto the 35w FWL at 4100w. This situation is not possible without disrupting the entire off shaft west ventilation system. There were no reported disruptions to the ventilation systems the week of September 08-12. SMC ventilation personnel have never observed the 4100w raise adding additional air to the 35w FWL.

The results of the ultrasonic anemometer are suspect and do not accurately represent the quantities of air flow in this area of the mine. Quantities measured by SMC are done using a full cross sectional traverse in a relatively straight run of drift. This is done to collect a better representation of the actual airflows in an area (see Fig 1 and Fig 2). The downstream anemometer used by NIOSH was set into a cross cut where the air flow is not as uniform (Fig 2). The ultrasonic anemometer collects data at a single point. This single point is not representative of the airflow for the cross sectional area it represents. A correction factor can be calculated to more accurately approximate the velocity of the air flow to a specific point. These factors for a centerline measurement are usually on the order of 70-90%.



STILLWATER MINING COMPANY

HC – 54 Box 365

Nye, MT 59061

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DRAWN BY: JDT	SCALE: 1"=20'
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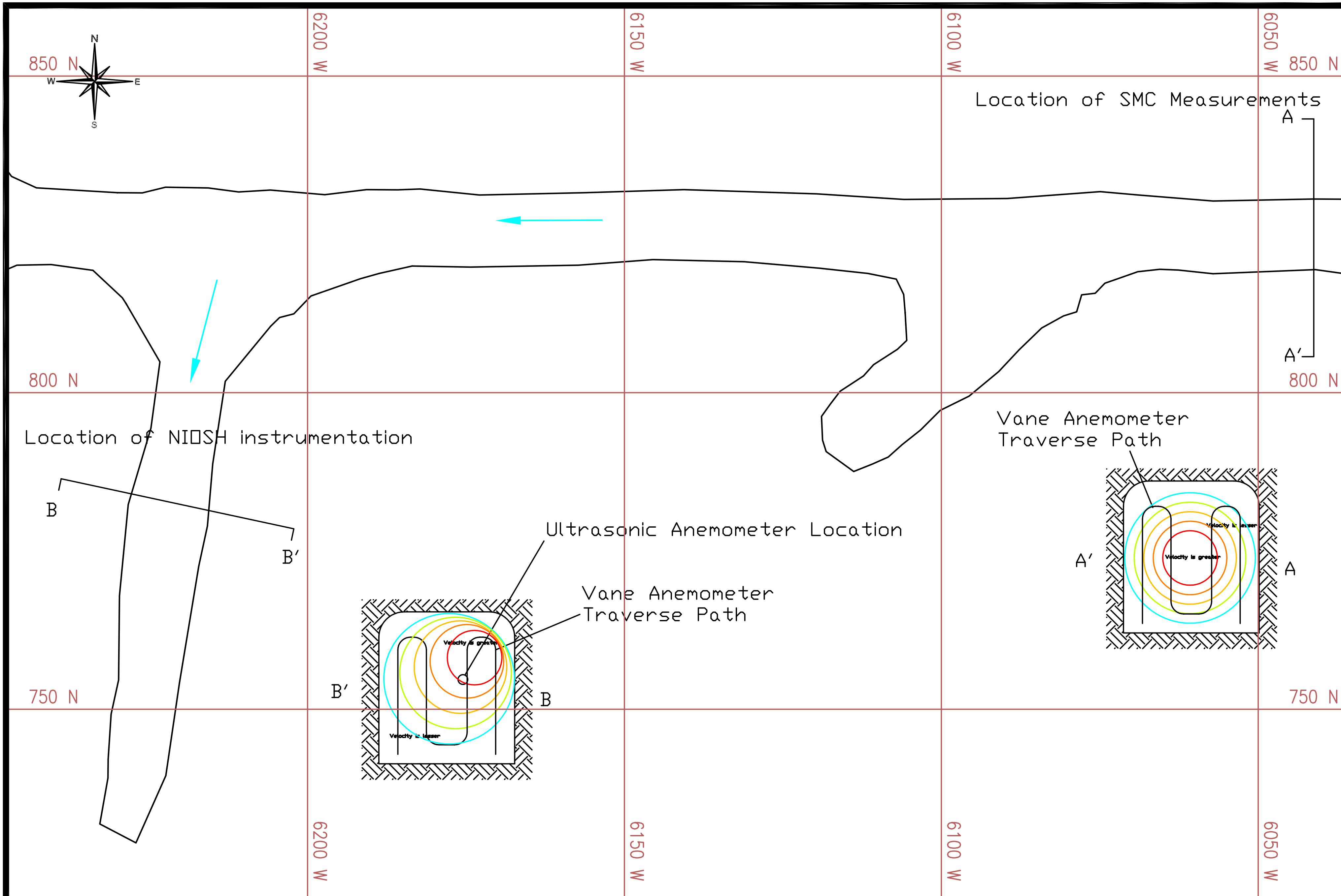

STILLWATER MINING COMPANY
HC – 54 Box 365
Nye, MT 59061

TITLE: 35W6100 AIR FLOW Figure 2	
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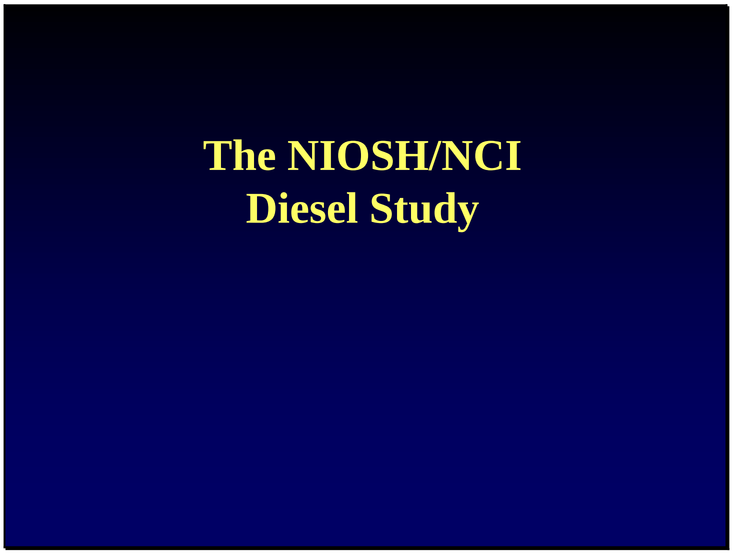
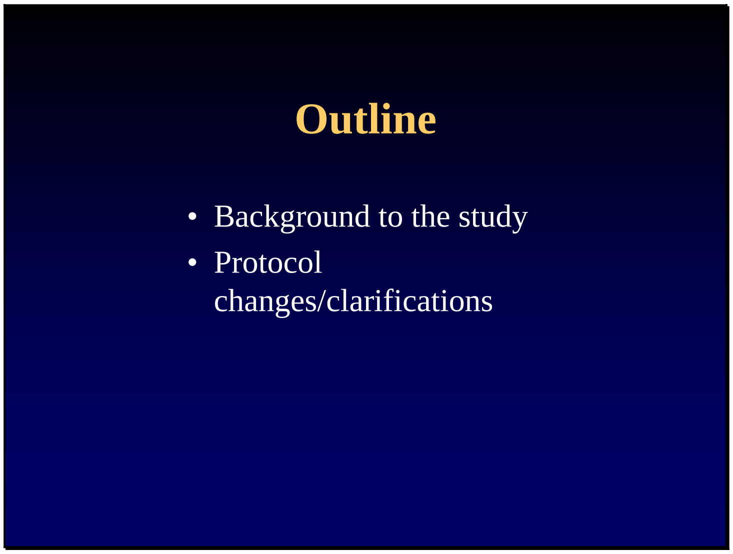
Introductory Presentation and Data

Slide 1



This short presentation serves as an introduction to the remainder of the procedures to occur today.

Slide 2

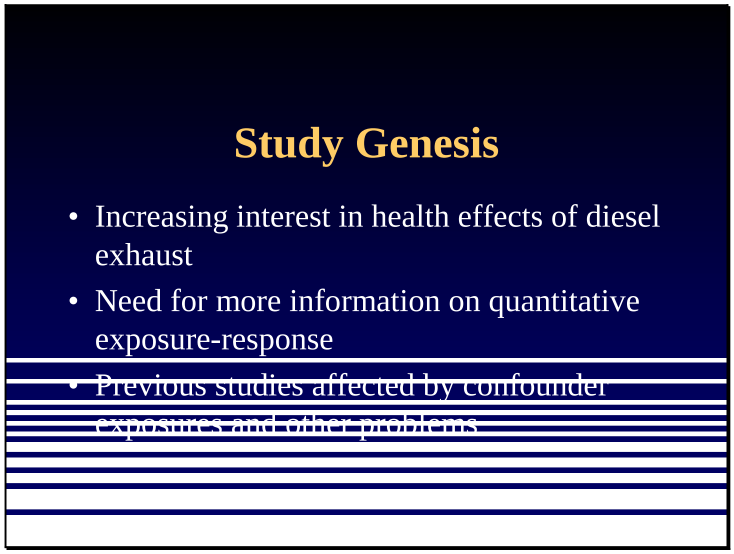


It concerns two things.

First, it provides a short overview of the background to the study for those who may be new to the topic.

Second, it describes the changes to the protocol that have occurred during the course of the study since it began.

Slide 3

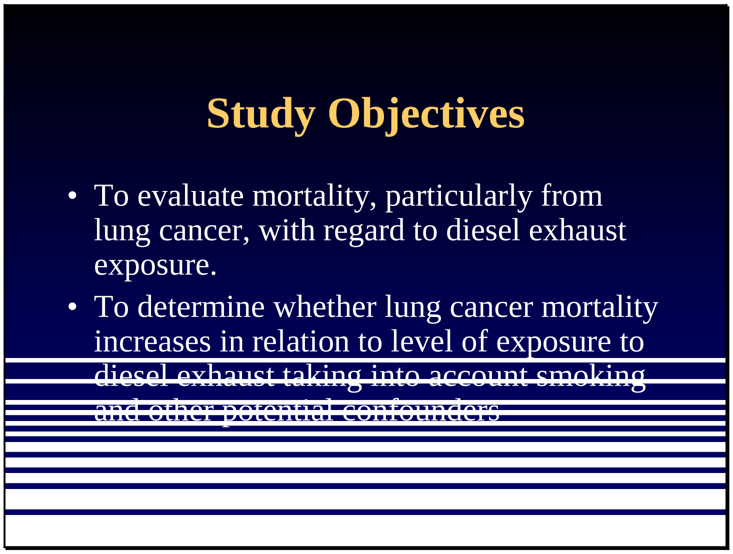


The study was conceived in response to increasing interest in the health effects of diesel exhaust – an interest that continues today.

That interest indicated a need for further information, particularly concerning assessment of exposure-response based on quantitative measured exposures and estimation of risk.

Existing studies were defective in various ways, mainly because few had measured exposures and many were impacted by confounder issues.

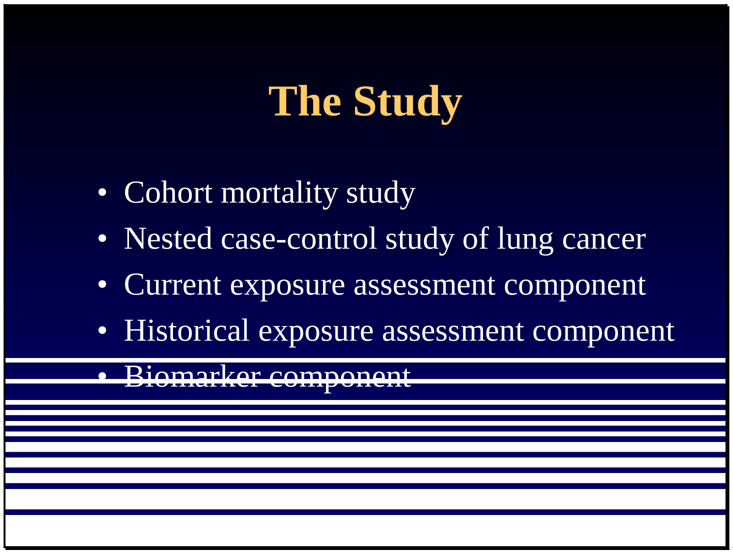
Slide 4



These are the study objectives.

To evaluate mortality, particularly from lung cancer, with regard to diesel exhaust exposure.
To determine whether lung cancer mortality increases in relation to level of exposure to diesel exhaust taking into account smoking and other potential confounders

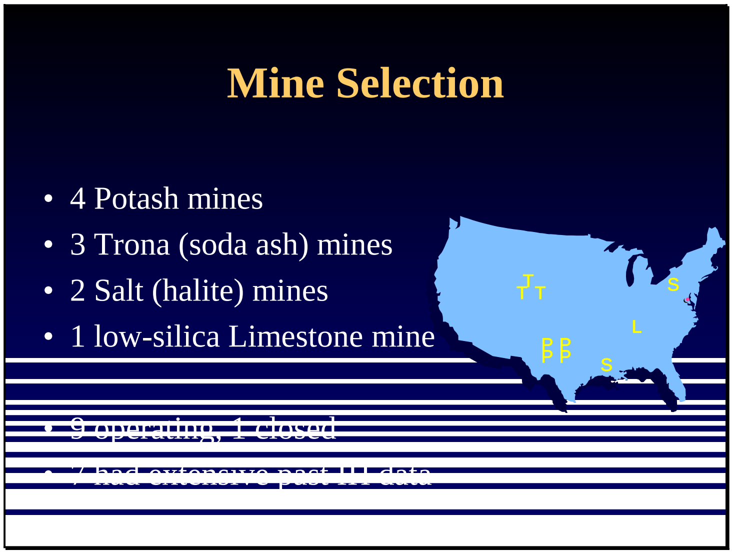
Slide 5



Five components to the study were developed:

Cohort mortality study
Nested case-control study of lung cancer
Current exposure assessment component
Historical exposure assessment component
Biomarker component

Slide 6



Mines were selected on the basis of information from an intensive, detailed pilot study.

Mines were selected because of the potential for high exposures.

Non-metal mines were selected because levels of potential confounders are low in those mines and rock strata.

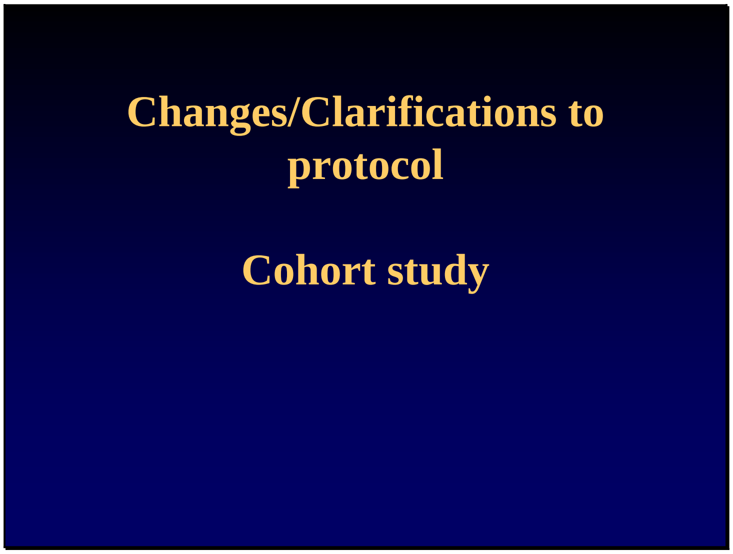
10 mines were chosen, 4 Potash mines
3 Trona (soda ash) mines
2 Salt (halite) mines
1 low-silica Limestone mine

Nine were operating, and one was closed. Most had extensive prior exposure information from past surveys, from MSHA databases, or other sources.

Slide 7

The presentations which follow this provide an update on each study component.

Slide 8

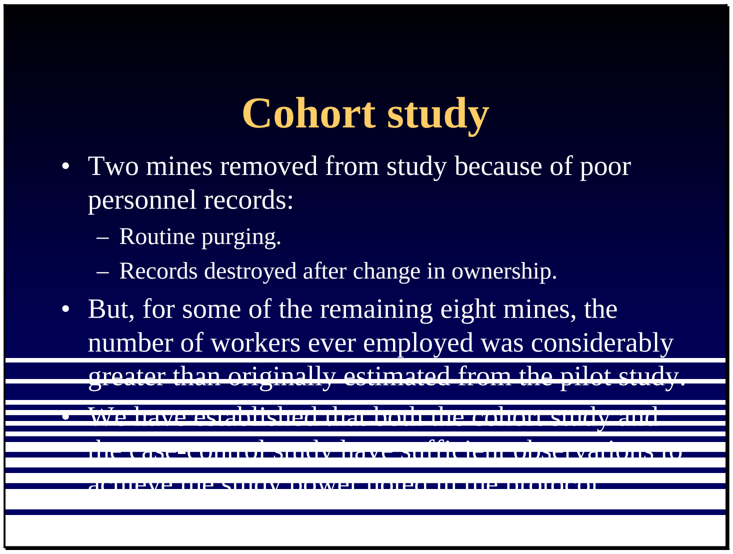


Changes and clarifications to the protocol.

Some of these are minor changes that improve the study or have little impact. Other listed items are clarifications – topics that were intended to be done but which were omitted from the original protocol. Because questions have been asked about them, we show them here for completeness.

Cohort study

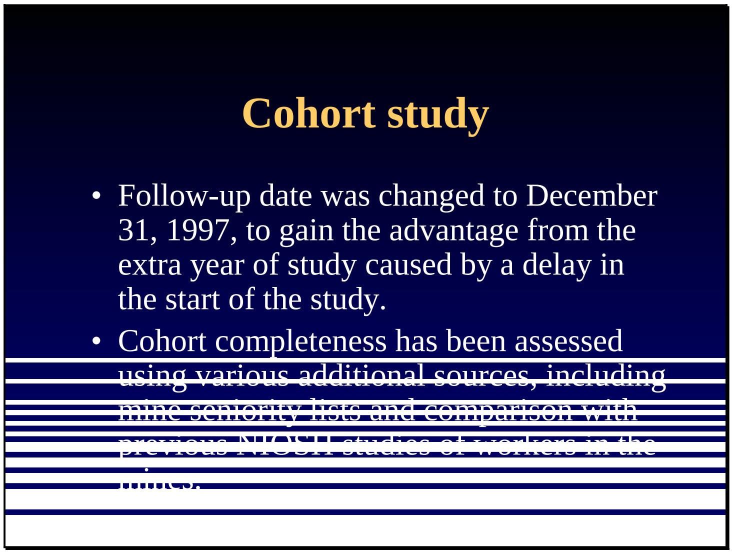
Slide 9



Cohort study

Two mines removed from study because of poor personnel records:
Routine purging.
Records destroyed after change in ownership.
But, for some of the remaining eight mines, the number of workers ever employed was considerably greater than originally estimated from the pilot study.
We have established that both the cohort study and the case-control study have sufficient observations to achieve the study power noted in the protocol.

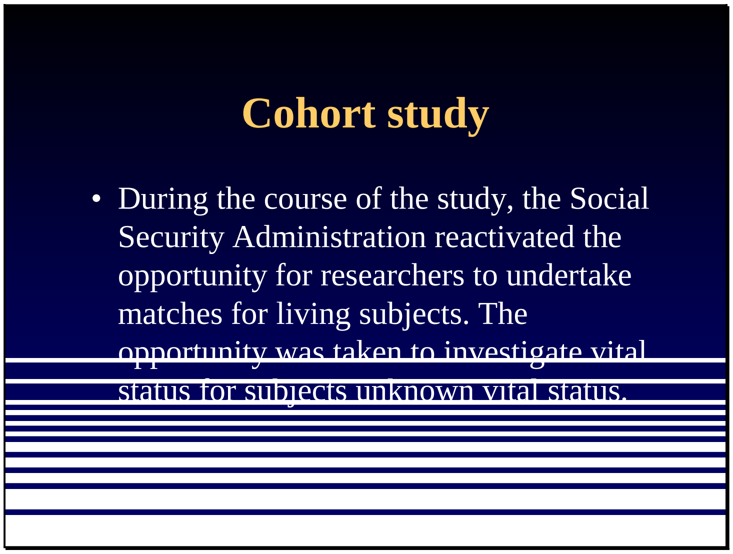
Slide 10



Cohort study

Follow-up date was changed to December 31, 1997, to gain the advantage from the extra year of study.
Cohort completeness has been assessed using various additional sources, including mine seniority lists and comparison with previous NIOSH studies of workers in the mines.

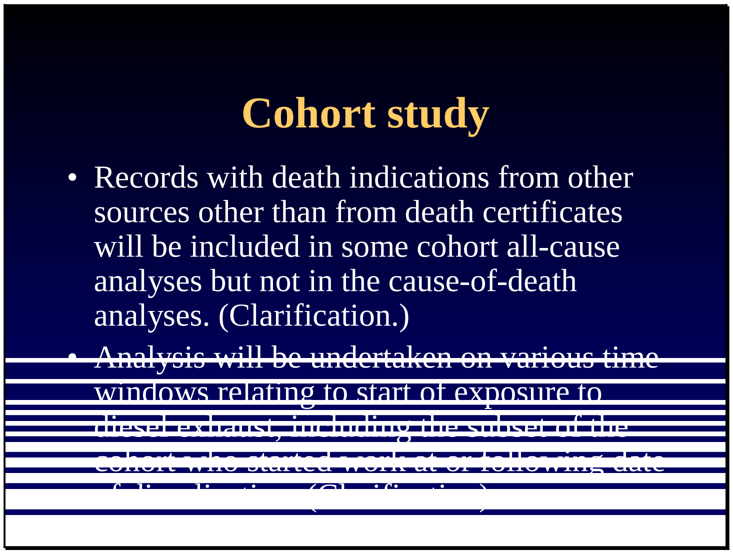
Slide 11



Cohort study

During the course of the study, the Social Security Administration reactivated the opportunity for researchers to undertake matches for living subjects. The opportunity was taken to investigate vital status for subjects unknown vital status.

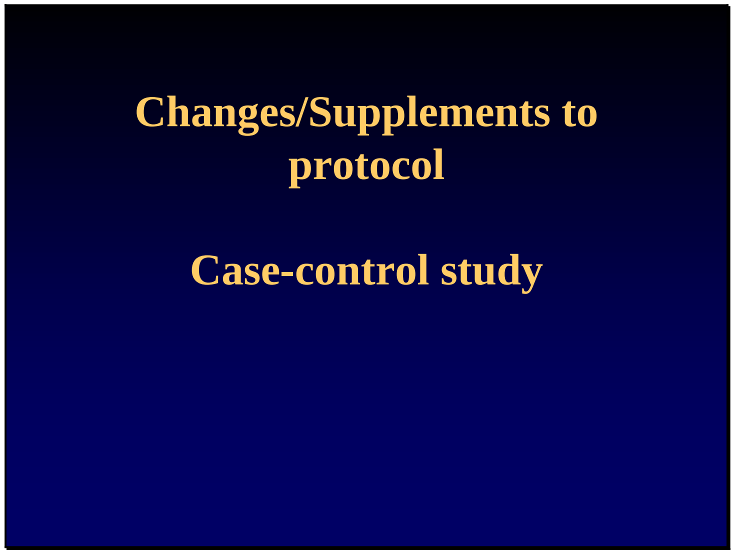
Slide 12



Cohort study

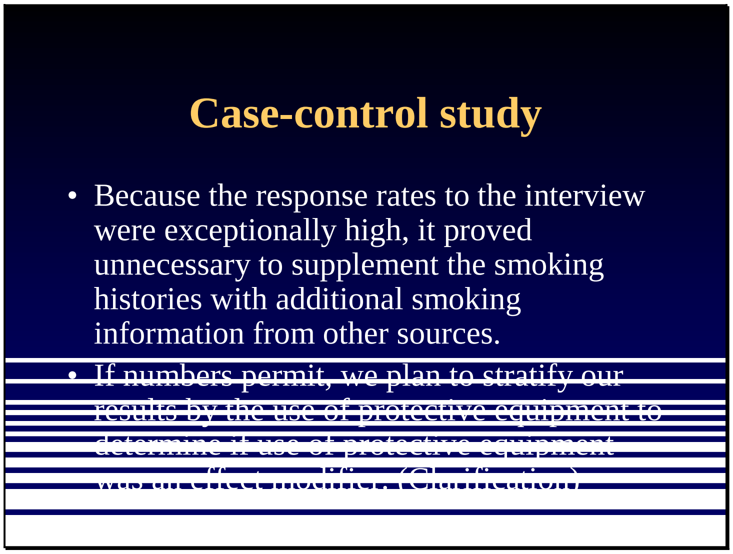
Records with death indications from other sources other than from death certificates will be included in some cohort all-cause analyses but not in the cause-of-death analyses. (Clarification.) Analysis will be undertaken on various time-windows relating to start of exposure to diesel exhaust, including the subset of the cohort who started work at or following date of dieselization. (Clarification)

Slide 13



Case-control study

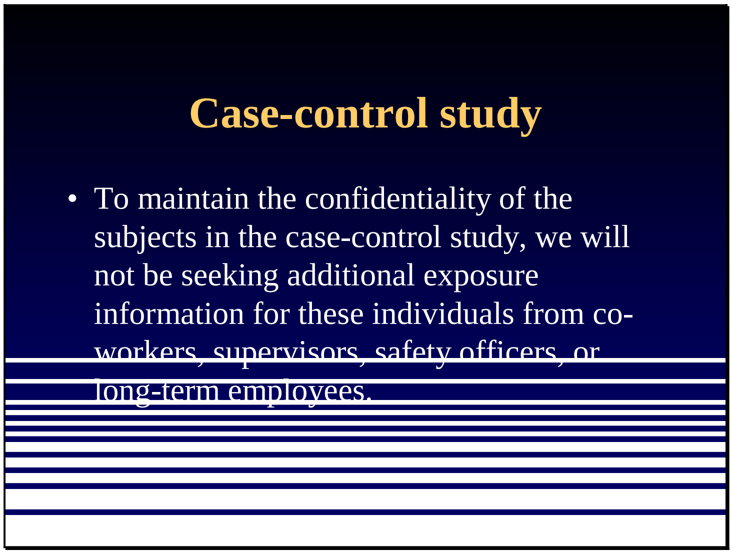
Slide 14



Case-control study

Because the response rates to the interview were exceptionally high, it proved unnecessary to supplement the smoking histories with additional smoking information from other sources.
If numbers permit, we plan to stratify our results by the use of protective equipment to determine if use of protective equipment was an effect modifier. (Clarification)

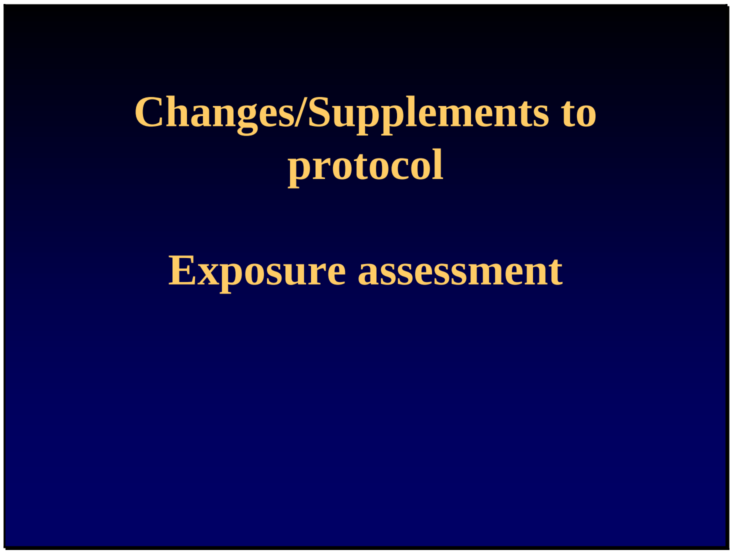
Slide 15



Case-control study

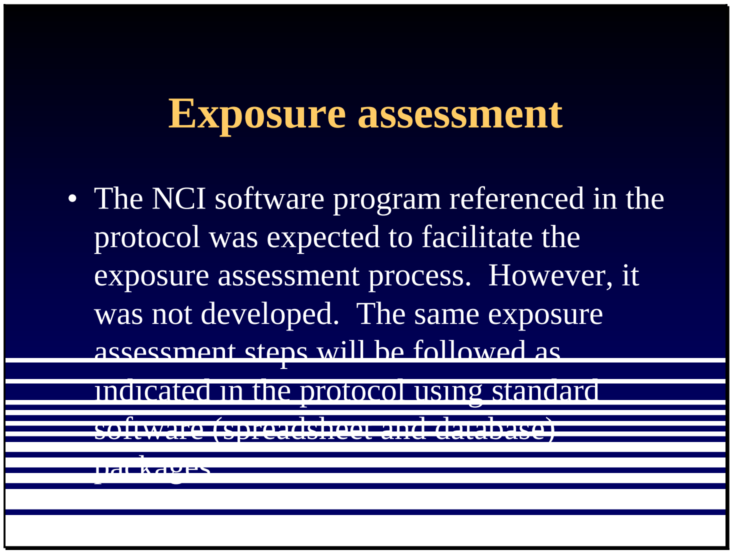
To maintain the confidentiality of the subjects in the case-control study, we will not be seeking additional exposure information for these individuals from co-workers, supervisors, safety officers, or long-term employees.

Slide 16



Exposure assessment

Slide 17



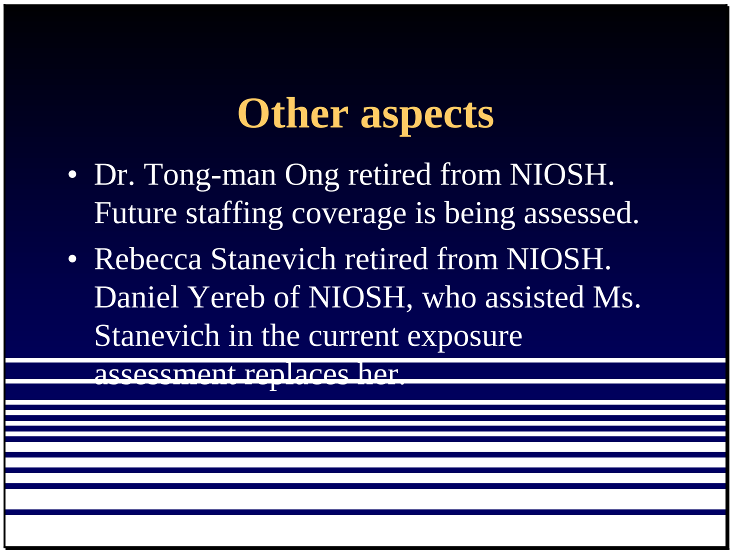
Exposure assessment

The NCI software program referenced in the protocol was expected to facilitate the exposure assessment process. However, it was not developed. The same exposure assessment steps will be followed as indicated in the protocol using standard software (spreadsheet and database) packages.

Slide 18

Other aspects of the study

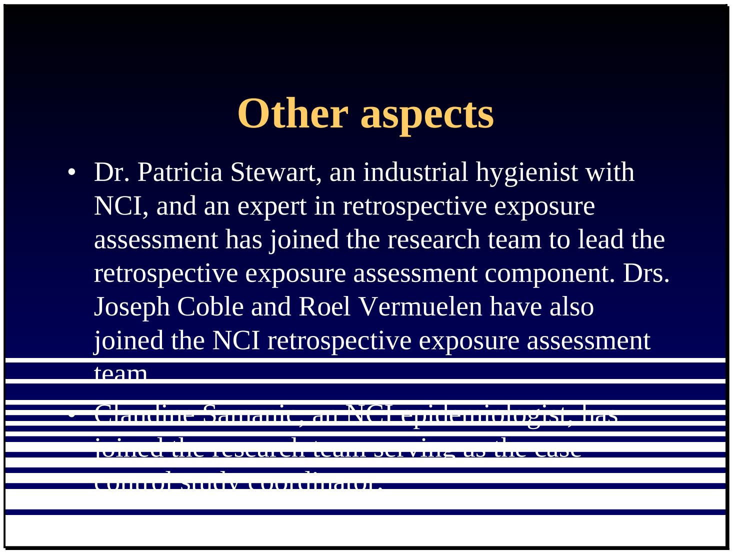
Slide 19



Other aspects

Dr. Tong-man Ong retired from NIOSH. Future staffing coverage is being assessed.
Rebecca Stanevich retired from NIOSH. Daniel Yereb of NIOSH, who assisted Ms. Stanevich in the current exposure assessment replaces her.

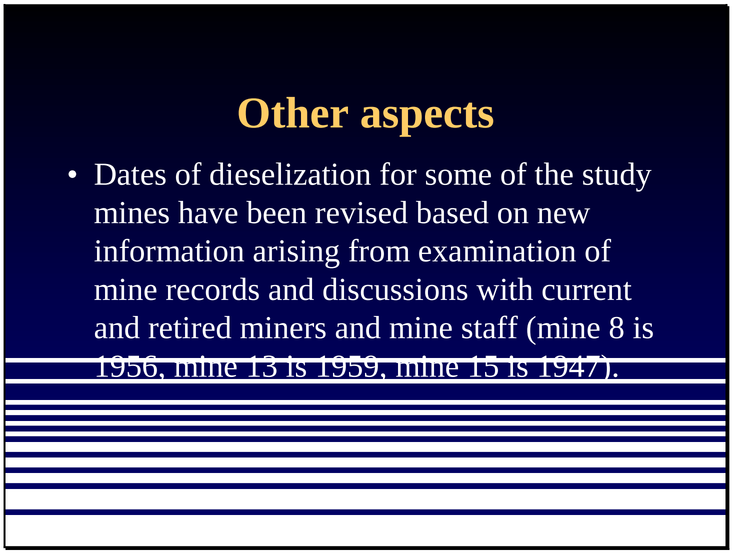
Slide 20



Other aspects

Dr. Patricia Stewart, an industrial hygienist with NCI, and an expert in retrospective exposure assessment has joined the research team to lead the retrospective exposure assessment component. Drs. Joseph Coble and Roel Vermuelen have also joined the NCI retrospective exposure assessment team.
Claudine Samanic, an NCI epidemiologist, has joined the research team serving as the case-control study coordinator.

Slide 21

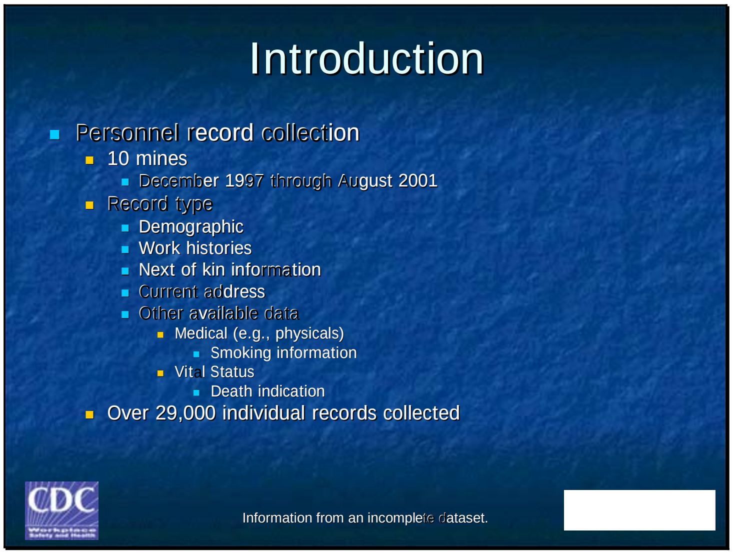


Other aspects

Dates of dieselization for some of the study mines have been revised based on new information arising from examination of mine records and discussions with current and retired miners and mine staff (mine 8 is 1956, mine 13 is 1959, mine 15 is 1947).

Cohort Mortality Study Presentation and Data

Slide 1



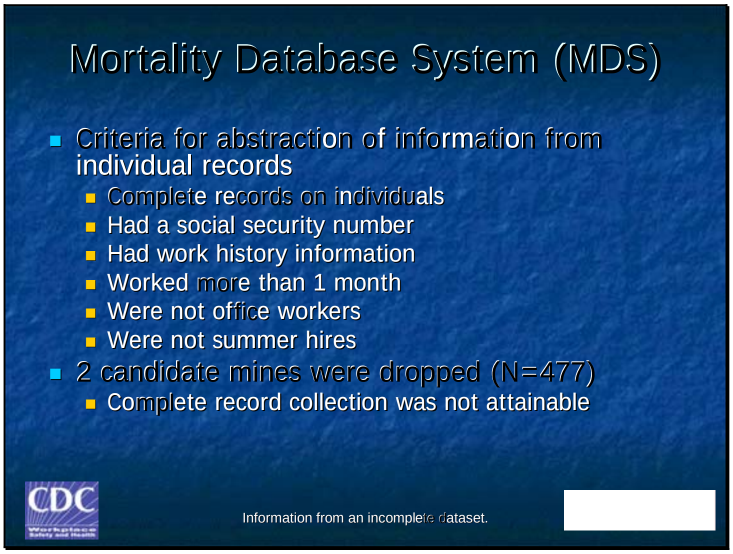
Personnel information was collected from the 10 mines in the study during the period 1997 – 2001. It included demographic (e.g., name, address, date of birth, SSN), prior and current work histories, next of kin information, and other data where available (smoking, relevant medical, and death indications).

Overall, we acquired records for 29,000 individuals. Some of these were the same people at different mines, and a lot were short-term and temporary employees.

Personnel information was collected from the 10 mines in the study during the period 1997 – 2001. It included demographic (e.g., name, address, date of birth, SSN), prior and current work histories, next of kin information, and other data where available (smoking, relevant medical, and death indications).

Overall, we acquired records for 29,000 individuals. Some of these were the same people at different mines, and a lot were short-term and temporary employees.

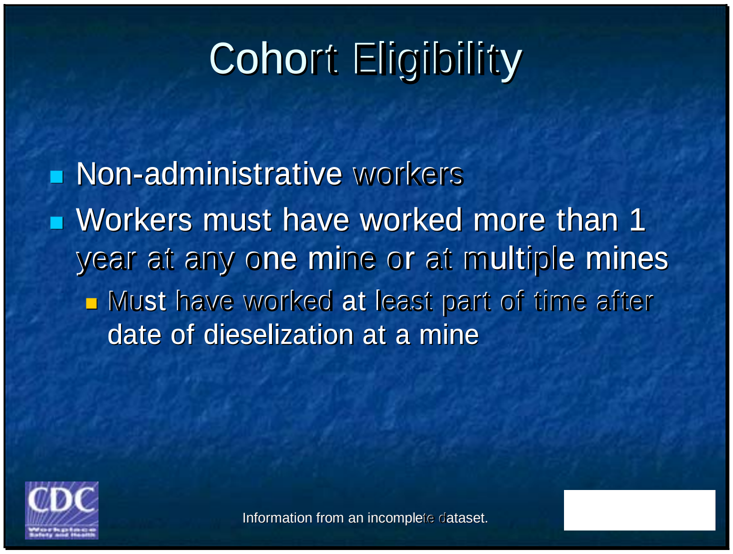
Slide 2



Once we had the records, we examined each, and abstracted information for those meeting the criteria for study inclusion. These included those with complete records, with a SSN, having a work history, worked more than 1 month, had worked as a blue-collar worker, and were not summer hires. The 1 month criterion was a preliminary filter to catch all potential cohort members. Later we planned to eliminate those who did not meet the 1 year criterion.

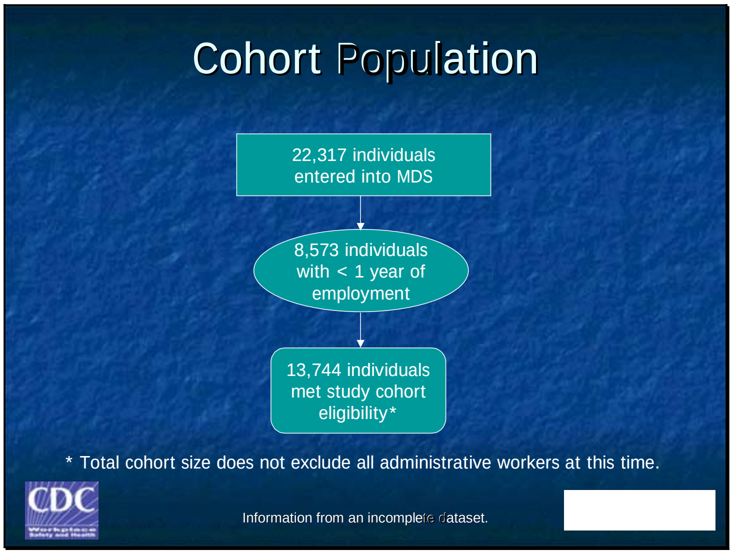
When we visited the mines we found that the personnel records were inadequate for our purpose. In one case the mine had changed ownership, and the records had been moved and many probably purged. In the second case, we discovered that the records had been routinely purged, and so were incomplete. For these reasons we were forced to drop the two mines from the study.

Slide 3



These are the criteria for inclusion of individuals in the study. I should clarify the text on this slide. Non-administrative refers to individuals who had worked as blue-collar workers.
The exact criterion for duration of employment is working one or more years after dieselization (that is, at least one year with potential for exposure to diesel exhaust).

Slide 4



Of the over 29,000 individuals whose records were acquired, 22,317 were entered into the mortality database. Of these, after checking for work at multiple mines, 8,573 were found to have <1 year of employment in the study mines after dieselization. Currently, we have 13,744 individuals who meet the cohort study criteria for eligibility. However, job lists at the mines are still being studied, and may result in some jobs being classified as purely administrative, leading potentially to the loss of further workers from this number. We expect this to be few.

Slide 5

Cohort Information

Gender	Count	Percent
Males	13,002	94.6
Females	637	4.6
Not reported	105	0.8
Total	13,744	100.0

Information from an incomplete dataset.

This is the current distribution by sex. Almost 95% of the workers were male.

Slide 6

Year of Birth

Birth Year	Count	Percent
< 1910	565	4.2
1910-19	1004	7.4
1920-29	1459	10.7
1930-39	1902	13.9
1940-49	3186	23.4
1950-59	4015	29.5
1960-69	1233	9.1
1970-79	238	1.8
Total	13,602*	100.0

* 142 individuals had a missing year of birth.

Information from an incomplete dataset.

This is the distribution of workers by year of birth. About one-third were born before 1940, about 50% between 1940 and 1959, and just over 10% in 1960 or after.

Slide 7

Initial Year of Exposure

Exposure Year	Count	Percent
< 1950	436	3.2
1950-60	1768	12.9
1960-70	2732	20.1
1970-80	5836	42.8
1980-90	1846	13.6
1990-00	1004	7.4
Total	13,622*	100.0

* 122 individuals had a missing start year.

Information from an incomplete dataset.

The distribution of initial year of exposure to diesel exhaust is given here. This computation is based on our knowledge of first use of diesel equipment at each mine and the work history for each individual. About three-quarters of the individuals had their first exposure to diesel exhaust before 1980, and over one-third before 1970.

Slide 8

Cohort by Mine

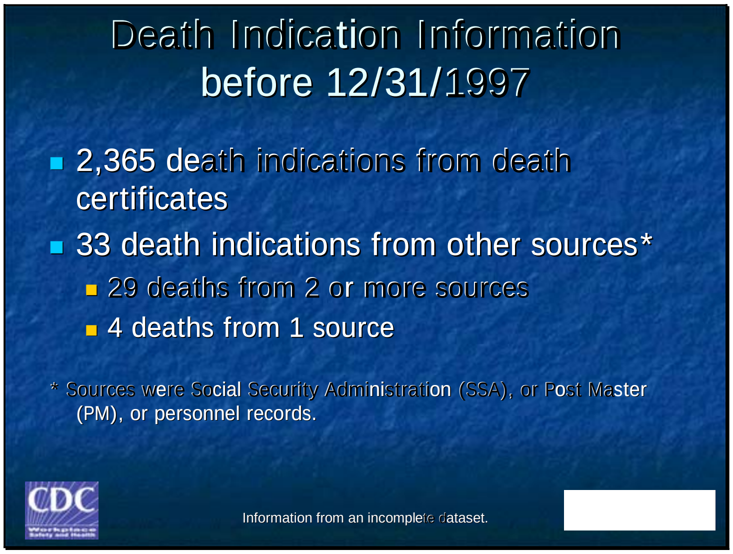
Mine	Count	Percent
A	921	6.7
B	1837	13.4
C	599	4.4
D	1290	9.4
E	2151	15.6
F	2896	21.1
G	2218	16.1
H	1832	13.3
Total	13,744	100.0

CDC Workplace Safety and Health

Information from an incomplete dataset.

This is the distribution of individuals by mine. Mines vary in size, but no one mine predominates.

Slide 9



We found death certificates (or National Death Index information) for 2,365 deceased individuals. There were another 33 indications from various sources (of varying reliability). Despite our best efforts, were unable to trace the death certificates for these 33.

Slide 10

Lung Cancer Deaths* by Mine

Mine	N	Lung Cancer Counts	Lung Cancer Percent
A	101	10	9.9
B	504	46	9.1
C	86	12	14.0
D	123	13	10.6
E	200	23	11.5
F	384	23	6.0
G	609	62	10.2
H	358	42	11.7
Total	2,365	231	9.8

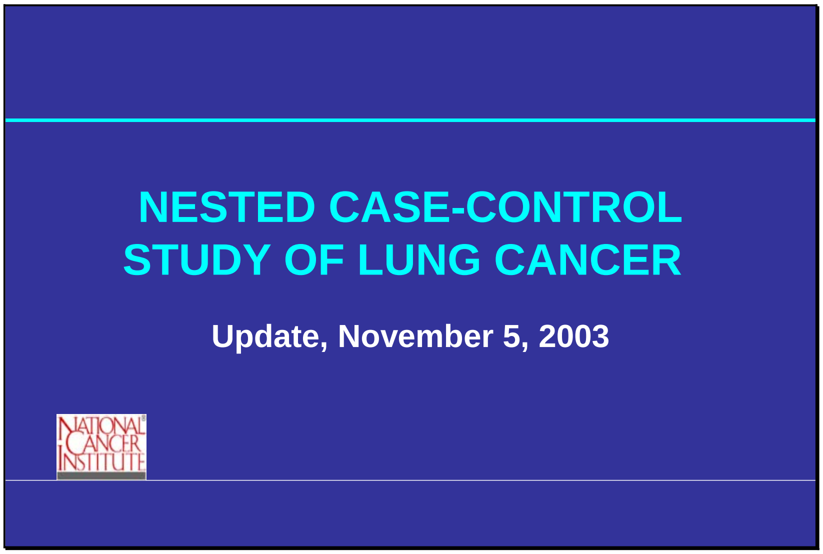
* Death indication from death certificate.

Information from an incomplete dataset.

Finally, this is the distribution of lung cancer cases by mine. 231 cases were ascertained from the death certificates or NDI. These are underlying or contributing causes.

Nested Case-Control Study of Lung Cancer Presentation and Data

Slide 1



Slide 2

PURPOSE OF STUDY

To evaluate the association between levels of diesel exposure and lung cancer mortality among non-metal miners, while controlling for cigarette smoking and other potential confounding factors

Slide 3

CASE SERIES

- All deaths from lung cancer identified during the follow-up stage of the cohort (217 lung cancer deaths identified from 1947-97)
- Pathology review

Slide 4

CONTROL SERIES

- Selected by random sampling from among all members of the study base alive prior to the day the case died
- Controls:Cases = 4:1
- Matching factors: Mine
  Gender
  Race/Ethnicity
  Year of Birth (± 5 years)
- Exposure in controls truncated at the age that the case died

Slide 5

INTERVIEWS

- Telephone interviews
- Next of kin: Dead Subjects
  (All cases and dead controls)
- Direct interviews: Living controls

Slide 6

DATA ANALYSIS

- Conditional logistic regression to quantify exposure-response relationship between lung cancer and diesel exhaust exposure, after adjustment for confounding factors
- Measures of exposure: Average intensity
  Duration
  Cumulative exposure

Slide 7

POTENTIAL CONFOUNDING FACTORS

- Age
- Gender
- Race/Ethnicity
- Cigarette Smoking
- Use of Pipes & Cigars
- Employment in High-Risk Occupations
- Asbestos Exposure
- Silica Exposure
- Arsenic Exposure
- Medical Conditions
- Diet
- Family History of Cancer
- Urbanicity

Slide 8

RESPONSE RATES

	Cases		Controls	
Response	No.	%	No.	%
Interviewed	213	98.2	611	94.0
Refused	2	0.9	23	3.6
Not Locatable	2	0.9	16	2.4
Total	217	100.0	650	100.0

Slide 9

GENDER*

Gender	Cases	%	Controls	%
Men	200	99.0	559	98.8
Women	2	1.0	7	1.2
Total	202	100.0	566	100.0

*Based on 7 out of 8 study mines. Data are preliminary and subject to revision.

Slide 10

RACE/ETHNICITY*

Race/Ethnicity	Cases	%	Controls	%
White	180	89.1	510	90.1
Black	5	2.5	1	0.2
Hispanic	4	2.0	6	1.0
American Indian	13	6.4	49	8.7
Total	202	100.0	566	100.0

*Based on 7 out of 8 study mines. Data are preliminary and subject to revision.

Slide 11

YEAR OF BIRTH*

Birth Year	Cases	%	Controls	%
<1910	33	16.3	80	14.1
1910-19	68	33.7	179	31.6
1920-29	60	29.7	189	33.3
1930-39	29	14.4	88	15.6
1940-49	9	4.5	24	4.2
1950-59	3	1.5	6	1.1
Total	202	100.0	566	100.0

*Based on 7 out of 8 study mines. Data are preliminary and subject to revision.

Slide 12

SUBJECTS BY MINE*

Mine	Cases	%	Controls	%
B	41	20.3	115	20.3
C	12	5.9	29	5.1
D	12	5.9	43	7.6
E	19	9.4	49	8.7
F	22	10.9	68	12.0
G	59	29.2	152	26.8
H	37	18.3	110	19.4
Total	202	100.0	566	100.0

*Based on 7 out of 8 study mines. Data are preliminary and subject to revision.

Slide 13

NEXT OF KIN'S RELATIONSHIP TO SUBJECT*

Relationship to subject	Cases	%	Controls	%
Spouse	72	35.6	105	30.1
Child	77	38.1	191	54.7
Sibling	22	10.9	23	6.6
Other	31	15.4	30	8.6
Total	202	100.0	349	100.0

*Based on 7 out of 8 study mines. Data are preliminary and subject to revision.

Slide 14

NUMBER OF YEARS KNEW SUBJECT

No. of Years	Cases	%	Controls	%
≤5	4	2.0	1	0.3
6-25	28	14.0	14	4.1
>25	166	82.0	330	94.4
Unknown	4	2.0	4	1.2
Total	202	100.0	349	100.0

*Based on 7 out of 8 study mines. Data are preliminary and subject to revision.

Slide 15

EDUCATION*

Level of Education	Cases	%	Controls	%
Elementary School	16	7.9	36	6.4
Middle School	52	25.7	145	25.6
High school	100	49.5	281	49.7
College	19	9.4	74	13.1
Unknown	15	7.5	30	4.2
Total	202	100.0	566	100.0

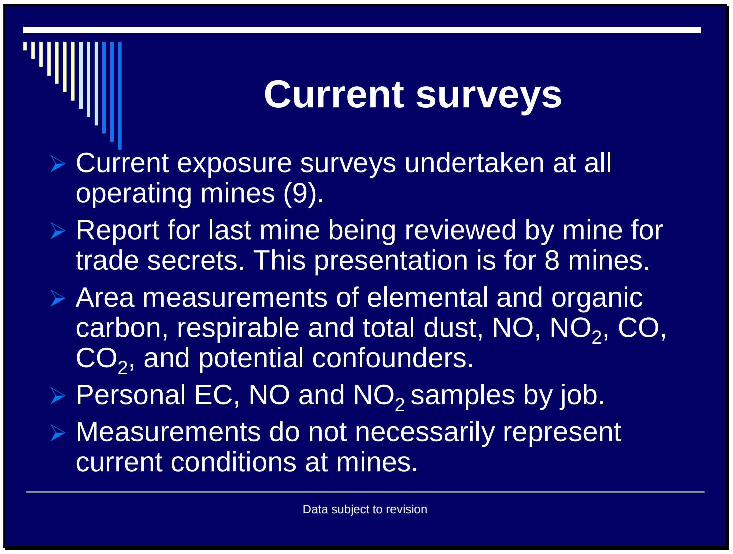
*Based on 7 out of 8 study mines. Data are preliminary and subject to revision.

Current Industrial Hygiene Presentation and Data

Slide 1

This presentation concerns information from the current industrial hygiene surveys undertaken at each operating mine.

Slide 2



Nine mines were operating and each had a current industrial hygiene survey. Typically, our survey team visited a mine for a week and undertook extensive sampling for diesel exhaust surrogates and potential confounders on the surface and underground.

Reports for all mines have been completed and released for 8. The last report is at the mine being reviewed for proprietary and trade secret information.

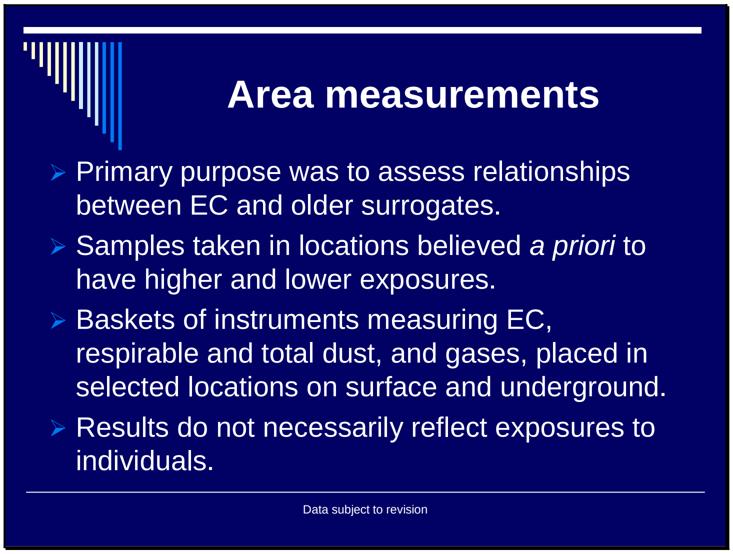
The surveys including area measurements of elemental and organic carbon (total, respirable, and impactor), respirable and total dust, NO, NO2, CO, CO2, and potential confounders including asbestos, arsenic, radon, and silica.

Personal measurements were made on selected workers in all or most jobs for elemental and organic carbon, NO and NO2.

All of the following tabulations are based solely on data already released to Congress, the mines and labor organizations.

Since our data were collected some time ago (1998 – 2001), they do not necessarily represent current conditions.

Slide 3

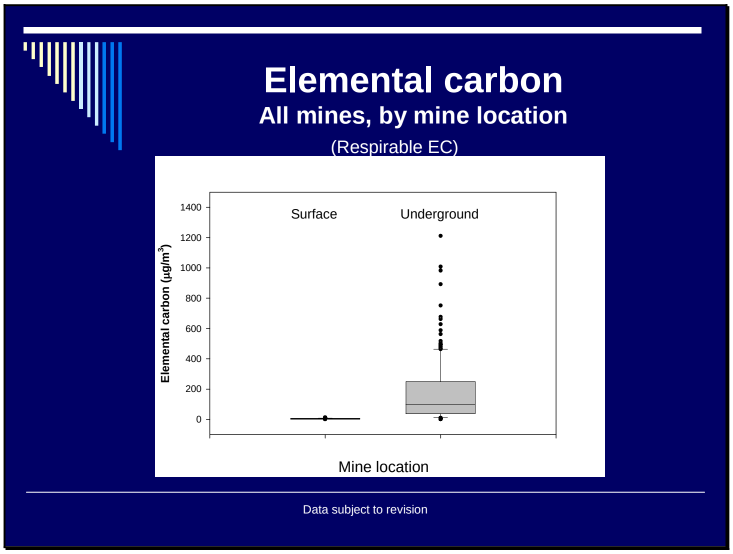


The area sampling was undertaken with the main purpose of deriving relationships between the newer and older surrogates of diesel exhaust (for example, a comparison between EC and NO). To facilitate determination of these relationships, the sampling selections were chosen to have a wide range.

Side-by-side sampling was undertaken with baskets of instruments in these selected locations, both surface and underground.

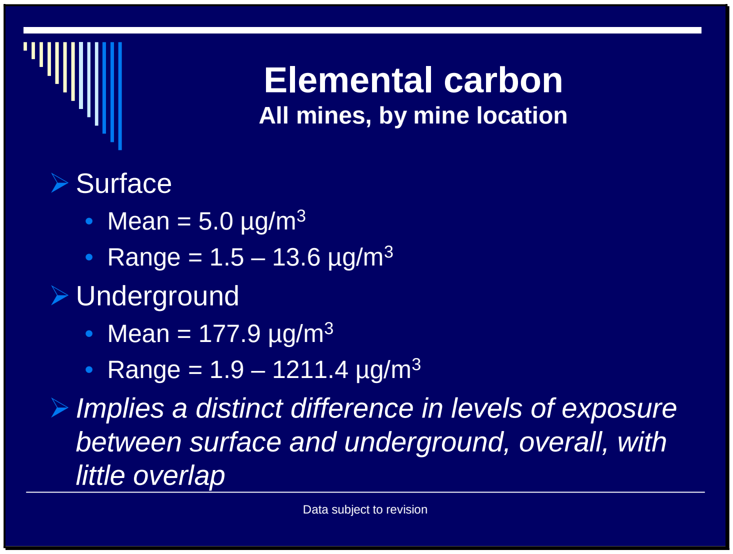
Since some of the sampling stations were deliberately selected to sample in high concentration areas, the area data do not necessarily represent workers’ actual exposures.

Slide 4



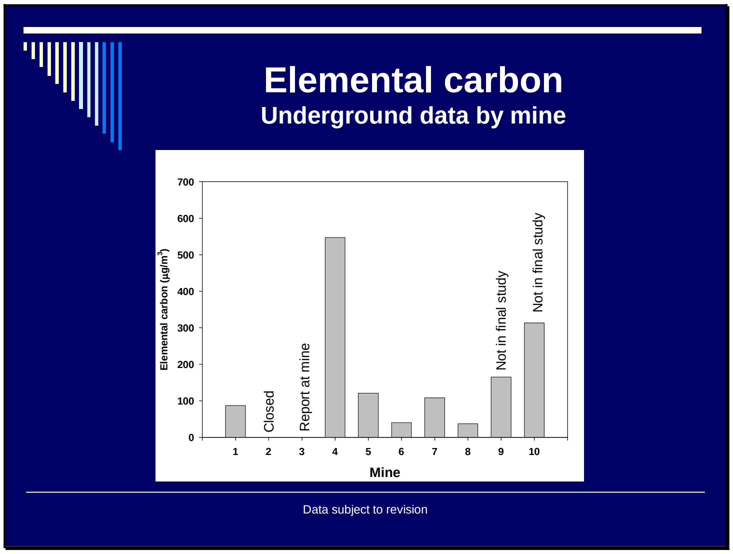
This is the overall distribution of respirable elemental carbon across all mines for surface and for underground locations.

Slide 5



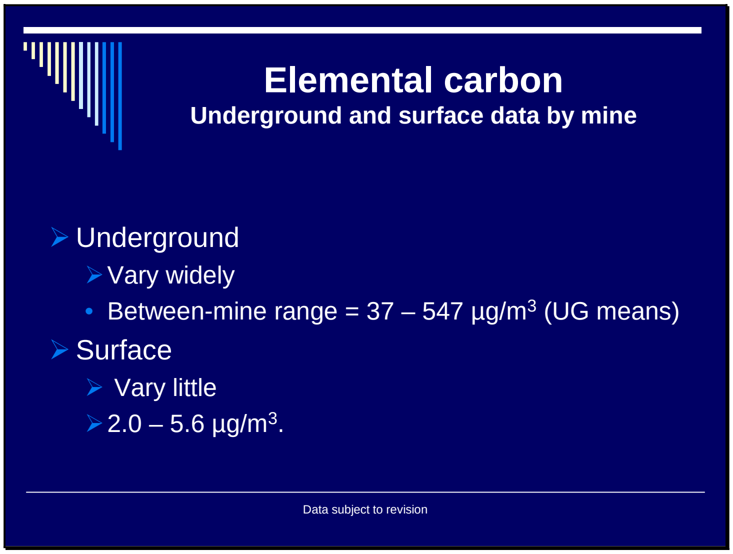
There is a distinct difference in mean levels between the surface and underground – from 5 – 188 micrograms per cubic meter. Moreover, there is only the slightest overlap in the two ranges. This clear difference indicates that the exposures of underground workers will typically be an order of magnitude higher (for given tenure) than among surface workers. If diesel exhaust poses a risk for workers, this sharp gradient in exposure should facilitate its detection.

Slide 6



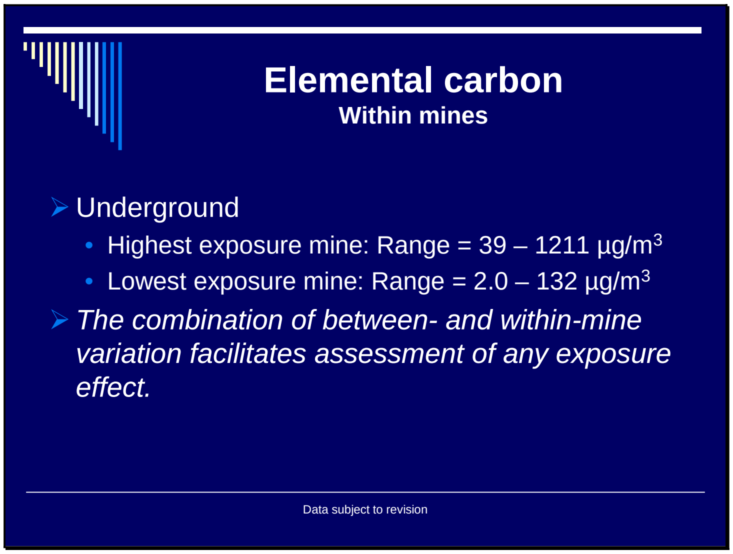
This is the distribution of EC across underground locations in the 8 mines, with the lowest being at mines 6 and 8, and the highest at mine 4.

Slide 7



Considerable differences can be seen. These likely occurred because of varying use of diesels underground (number, size, and duration of use), ventilation, and the type of mine structure. Underground the range was from a mean of 37 to an average of 547 micrograms per cubic meter. On the surface the mines all had similar, and very low, levels.

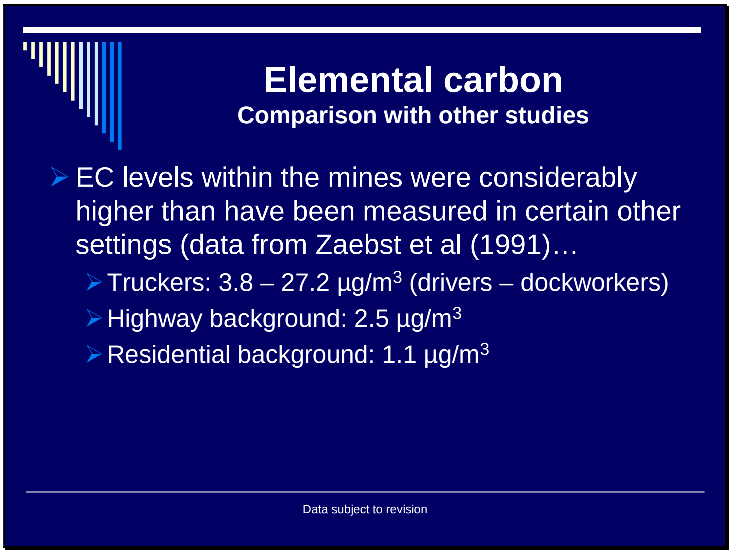
Slide 8



Variation underground, within the mines was also quite distinct. In the highest exposure mine, EC levels ranged from 39 – 1211 micrograms per cubic meter. In the mine with the lowest underground exposures, the range was from 2 - 132 micrograms per cubic meter.

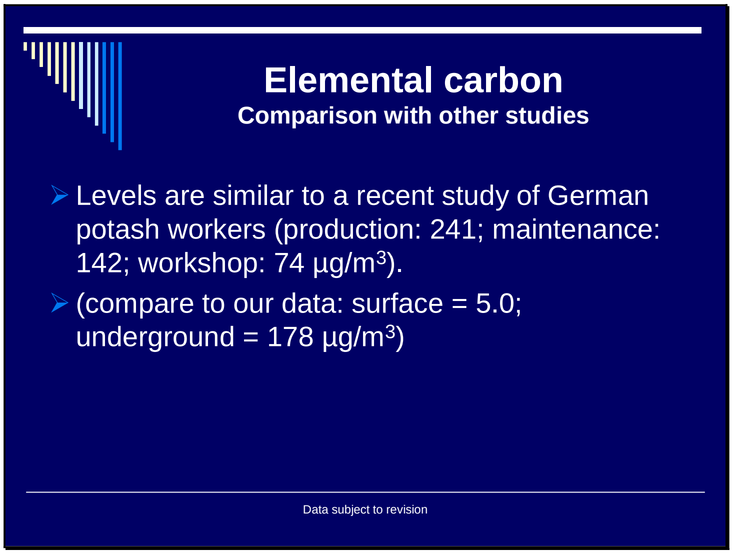
Overall, the combination of between-mine and within-mine variation (both between surface and underground, and between underground locations) implies substantial variation in workers' exposures, facilitating detection of any overall effect and any exposure-response relationship.

Slide 9



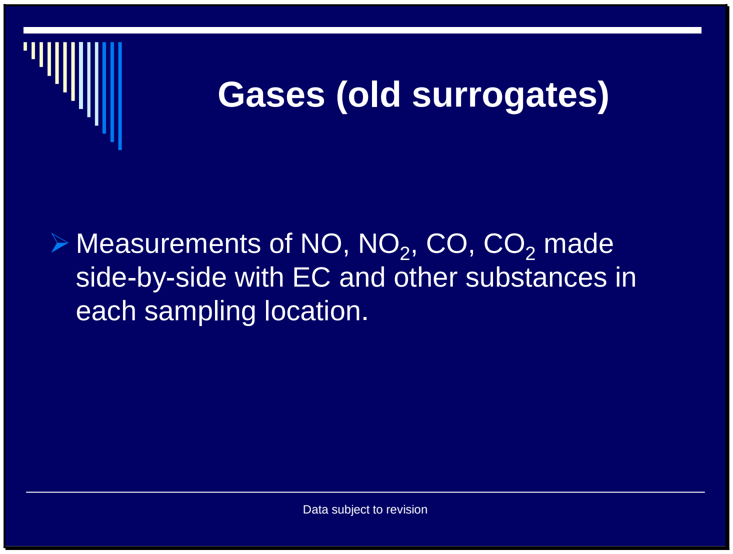
EC levels within the mines were considerably higher than for other workers. Note that the mean levels underground at our lowest exposed mine were still typically greater than for the highest exposed truckers (37 versus 27 micrograms per cubic meter). General environmental exposures are even lower.

Slide 10



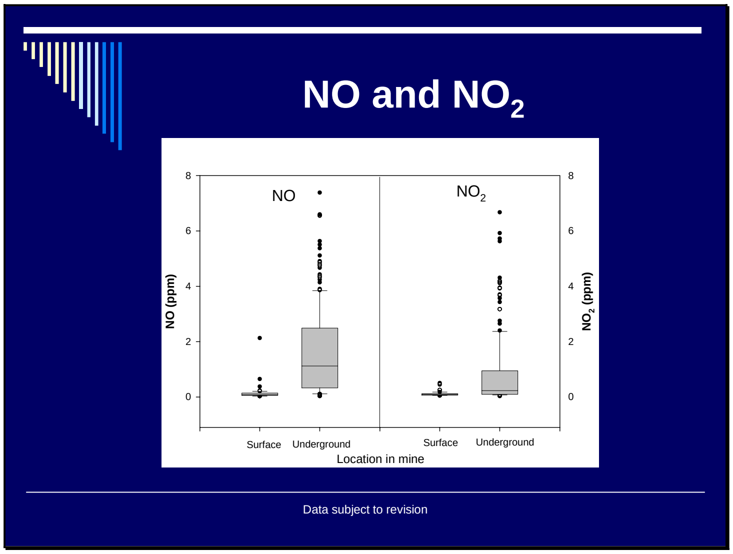
But our exposures are quite similar to those from a recent study of German potash workers.

Slide 11



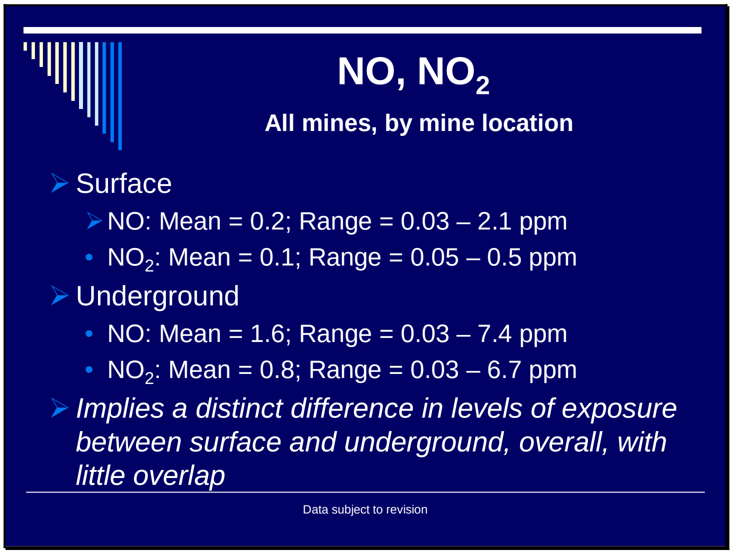
As well as EC, we measured certain gases. There is a history of these gases being sampled in the mines, and they serve as old surrogates of diesel exhaust. The historical data is being employed to assess worker exposures to diesel exhaust.

Slide 12



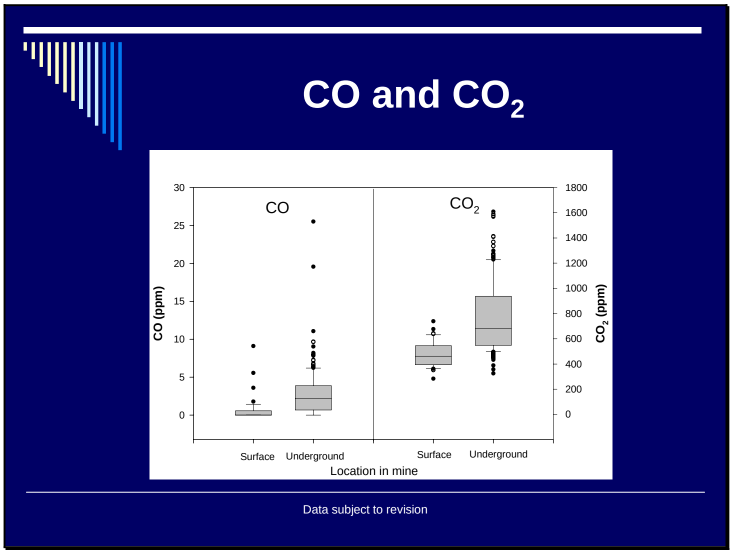
Here’s the NO and NO2 data by surface and underground locations across all mines. As with the EC, the means for the two locations are distinctly different.

Slide 13



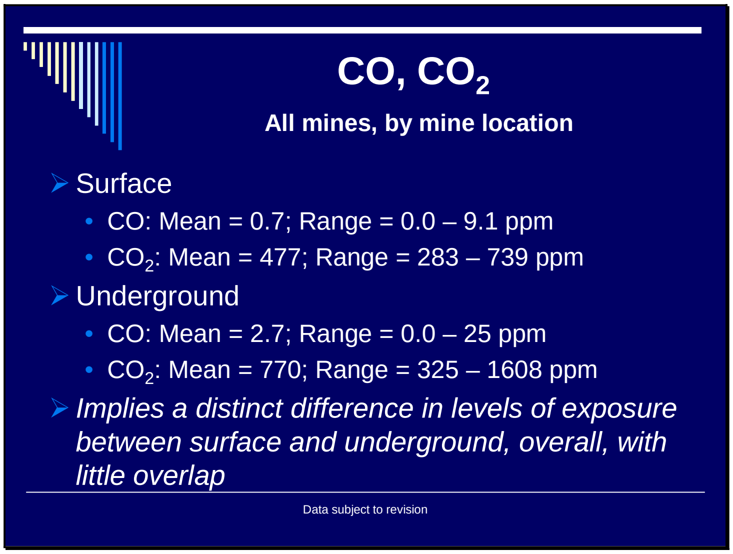
Here's the overall means for NO and NO2 by location.

Slide 14



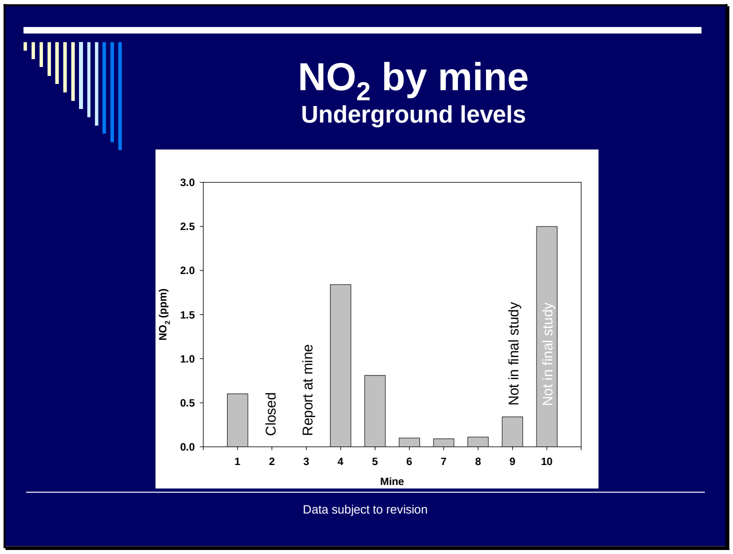
And here’s the CO and CO2 data the same way and showing basically the same picture.

Slide 15



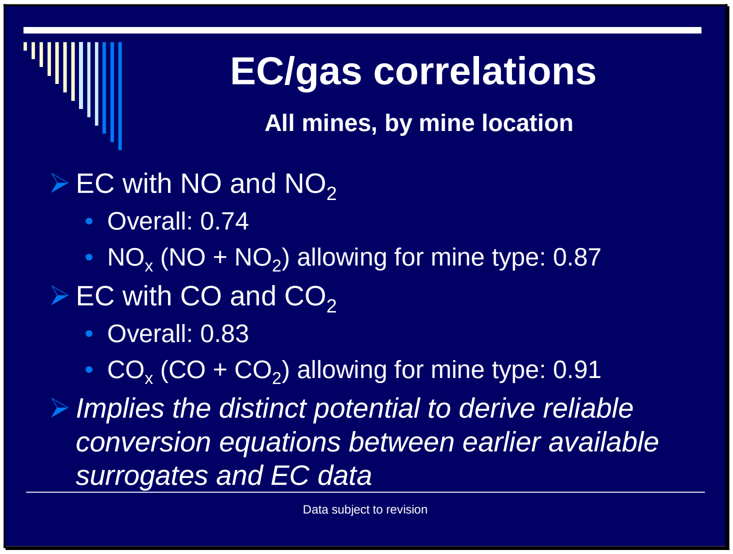
And here are the mean levels overall by location.

Slide 16



Mine means for underground data for NO2 are shown here, and reflect the pattern of levels for EC across mines. Similar trends were seen for the other gases.

Slide 17



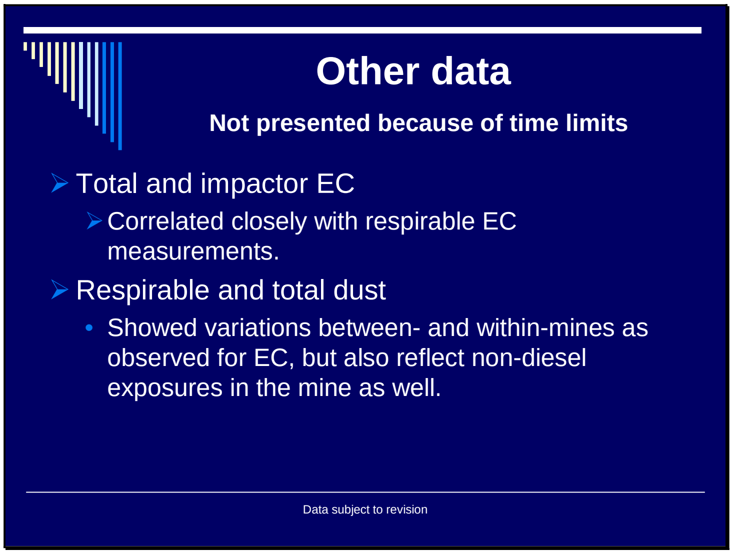
Some preliminary calculations have been done to determine relationships between the old surrogates (i.e., gases) and new surrogates (i.e., EC). These relationships are intended to be used to extrapolate past levels from the existing older surrogate data at the mines.

This slide shows correlations. For EC with NO and NO2, the correlation was 0.74. Using NOX (the sum of NO and NO2), a somewhat better correlation was obtained, at 0.87.

Using CO and CO2 in place of NO and NO2 gave correlations of 0.83, and 0.91 for COX.

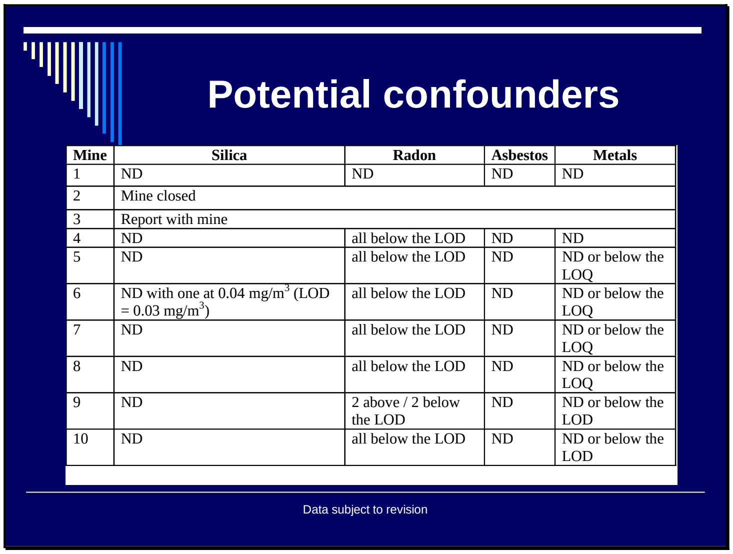
Further work is continuing in this area.

Slide 18



Other data were collected but are not presented here. There are two reasons for this. They provide no further major insights, being similar to other data, or they are of secondary importance, and time does not permit further description.

Slide 19

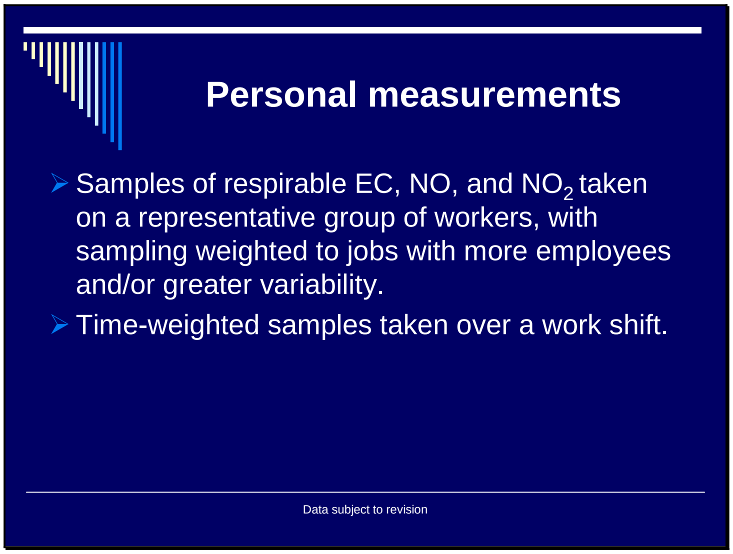


Mine	Silica	Radon	Asbestos	Metals
1	ND	ND	ND	ND
2	Mine closed			
3	Report with mine			
4	ND	all below the LOD	ND	ND
5	ND	all below the LOD	ND	ND or below the LOQ
6	ND with one at 0.04 mg/m^3 (LOD = 0.03 mg/m^3)	all below the LOD	ND	ND or below the LOQ
7	ND	all below the LOD	ND	ND or below the LOQ
8	ND	all below the LOD	ND	ND or below the LOQ
9	ND	2 above / 2 below the LOD	ND	ND or below the LOD
10	ND	all below the LOD	ND	ND or below the LOD

Finally – when this study was designed, the mines were chosen because they were felt to have low or non-existent levels of confounders associated with lung cancer development. Four confounders were considered potentially important – silica, radon, asbestos, and arsenic.

In our studies we assessed levels of these four substances in areas where they could potentially arise. In the event, we found extremely low levels, virtually all being non-detectable or at the limit of detection. Based on this, we feel very confident that these substances will not cause confounding in our study analysis.

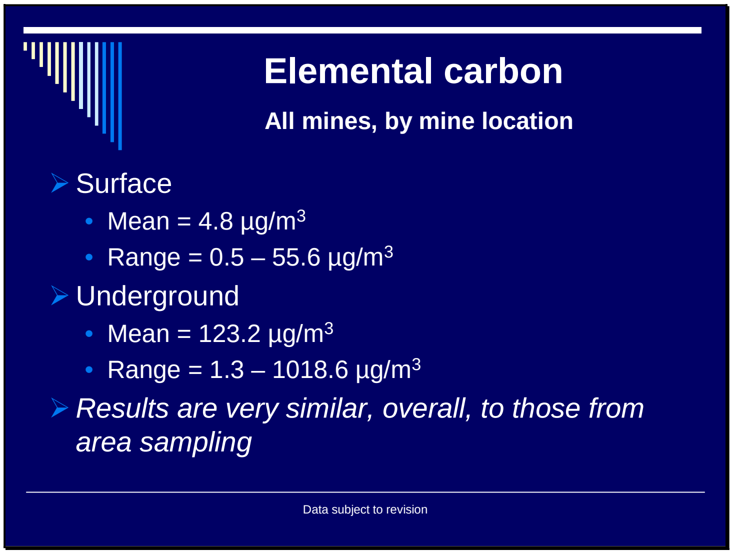
Slide 20



We took many personal measurements at each mine, across all or most jobs, with repeated measurements where possible. To reduce the variability associated with exposure determination, sampling was weighted to jobs having more variation in levels, and/or which included more workers.

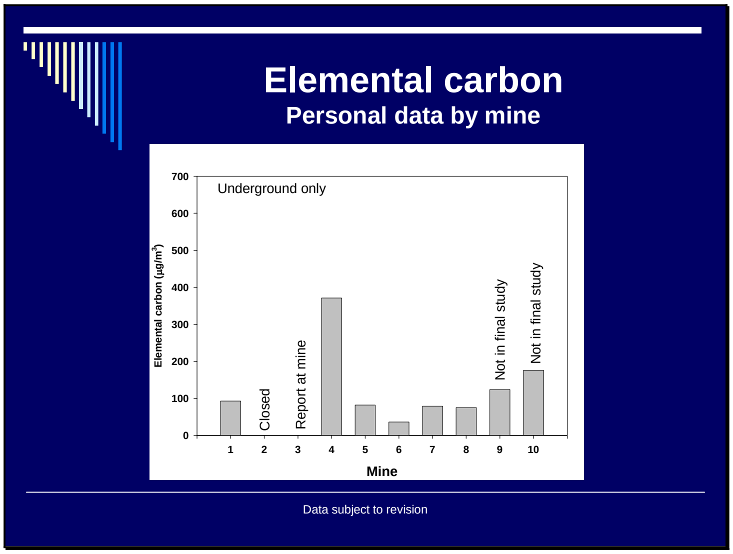
Cross-shift time-weighted averages were determined.

Slide 21



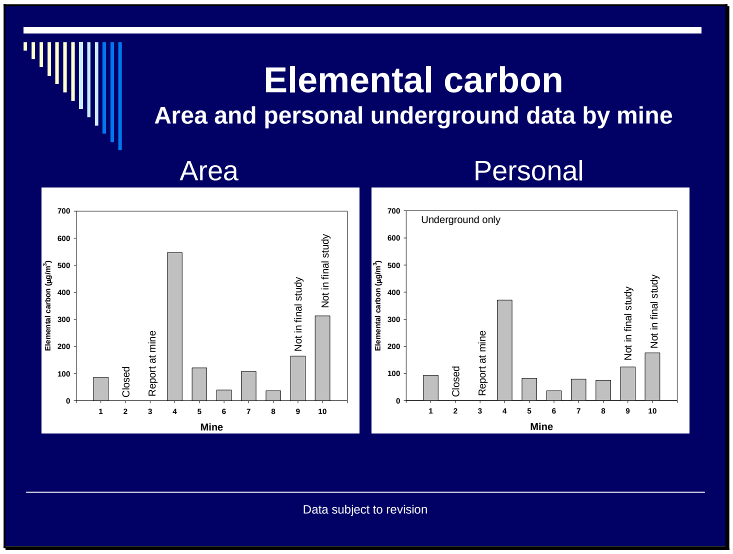
Overall, the personal data findings were very similar to those of the area sampling, showing a marked gradient between surface and underground. A few surface measurements showed quite high levels – these were typically from workers driving or operating heavy equipment. Underground levels, on average, were slightly lower than the area underground data. This may have occurred because the distribution of area locations tended to favor higher exposures slightly more than did the majority of jobs.

Slide 22



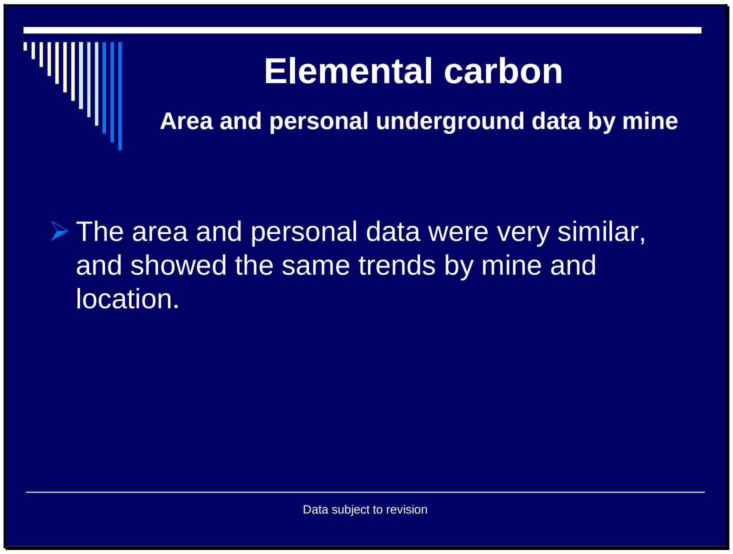
This is the distribution of underground personal measurements across mines

Slide 23



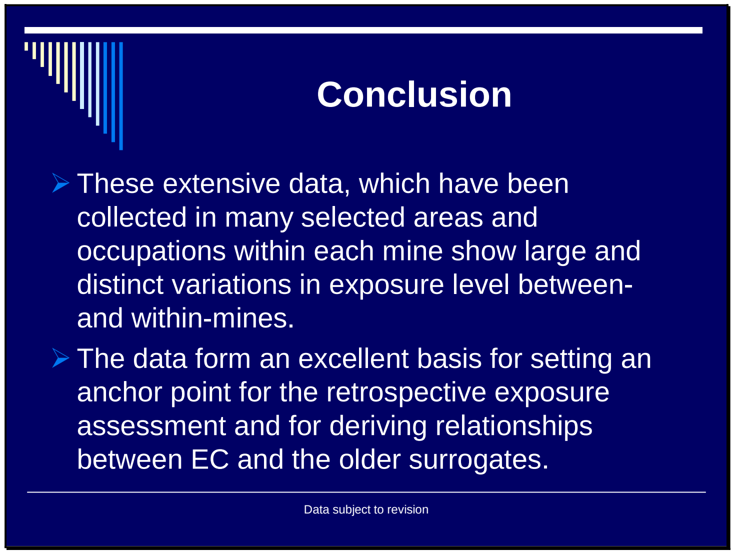
This compares the area and personal measurements across mines, showing the similar pattern provided by both datasets.

Slide 24



Overall, the area and personal data were very similar, and showed the same trends by mine and location.

Slide 25



These extensive data, which have been collected in many selected areas and occupations within each mine show large and distinct variations in exposure level between- and within-mines.

The data form an excellent basis for setting an anchor point for the retrospective exposure assessment and for deriving relationships between EC and the older surrogates.

RETROSPECTIVE EXPOSURE ASSESSMENT

Update, November 5, 2003

Division of Cancer
Epidemiology & Genetics
U.S. Department of
Health & Human Services
National Institutes of Health

Outline

- Concept of exposure and exposure assessment in occupational studies
- Status of exposure assessment in diesel study

Concept of Exposure

- Exposure is generated from particular sources
- Transfer of agent from source to person depends on factors called exposure determinants

Examples of Determinants

Source

- Quantity
- Temperature
- Mechanism of release (spray, agitation, etc)

Transport

- Ventilation
- Indoors/outdoors

Job/individual

- Frequency
- Duration
- Work practices
- Protective equipment

Concept of Exposure Assessment

- Exposure is person-specific, BUT
- Most of the information on people is based on jobs
- SO: Exposure is assessed by job, blinded to disease status of individual

Estimation of Exposures (Job Exposure Matrix)

	98	97	96	95	94	…….
Job 1						
Job 2						
Job 3						
.						
.						
.						

Concept of Exposure Assessment

- **Different jobs have different exposures → job-specific estimates**

Concept of Exposure Assessment

- Different jobs have different exposures → job-specific estimates
- Same jobs in different departments can have different exposures → department-specific estimates

Concept of Exposure Assessment

- Different jobs have different exposures → job-specific estimates
- Same jobs in different departments can have different exposures → department-specific estimates
- Same operations can have different exposures → mine-specific estimates

Concept of Exposure Assessment

- Different jobs have different exposures → job-specific estimates
- Same jobs in different departments can have different exposures → department-specific estimates
- Same operations can have different exposures → mine-specific estimates
- Changes took place over time → time-specific estimates

Concept of Exposure Assessment

Develop exposure estimates for every:

Job/department/work site/year

Components of an Exposure Assessment

- Data collection
- Development of exposure groups
- Estimation of exposures

Components of an Exposure Assessment

- Data collection
- Development of exposure groups
- Estimation of exposures

Data Collection

Multiple site visits

- Interview employees and management
- Take walk-through surveys of processes
- Collect historical monitoring data and other records
- Conduct monitoring

Components of an Exposure Assessment

- Data collection
- Development of exposure groups
- Estimation of exposures

Development of Exposure Groups

Goal: To develop groups of similarly exposed jobs based on similarity of:

- Location
- Tasks
- Environmental conditions

So that estimation of exposure of one individual in group would be comparable to that of all other individuals in the group over a long period of time (e.g., a year)

Development of Exposure Groups

Steps

- Standardize job titles to create a job dictionary
- Review job descriptions, other information, and interviews with workers and management
- Group jobs into exposure groups
- Code exposure groups

Components of an Exposure Assessment

- **Data collection**
- **Development of exposure groups**
- **Estimation of exposures**

Estimation of Exposures

- Goal: To develop quantitative exposure estimates
- Method: Link measurement data to exposure groups and exposure determinants

Estimation of Exposures

Steps:

- **Code measurement data using exposure group codes**
- **Identify determinants of exposure**
- **Review documents and interviews of workers and management to identify changes in determinants over time**
- **Link measurement data to determinants and exposure groups to estimate exposures**

Estimation of Exposures

Steps:

- **Visit companies for review by workers and management**
- **Modify estimates based on review**

Exposure Assessment Process

JOB INFORMATION

- Standardize job titles
- ↓ Develop exposure groups
- ↓ Code exposure groups

EXPOSURE INFORMATION

- Identify changes in determinants by exposure group and year
- Code measurement data by exposure group

↓

Develop exposure estimates from measurement data by exposure group by year

Importance of Exposure Assessment

- Can cause misclassification
- Usually results in missing an association if one truly exists
- Rarely results in causing an association if one doesn't truly exist

NIOSH/NCI Diesel Study

Components of an Exposure Assessment

- Data collection
- Development of exposure groups
- Estimation of exposures

Data Collection (1992-2000)

- Interviewed employees and management
- Took walk-through surveys of processes
- Collected historical monitoring data and other records
- Conducted monitoring

Data Collection

Reviewed historical documents collected and developed draft:

- Job dictionaries of standardized job titles

Total Number of Job Records by Mine*

MINE NUMBER	NUMBER OF JOBS
1	11967
2	11650
3	5217
4	13784
5	5628
6	6425
7	12873
8	14585
Total	82130

*Data are preliminary and subject to revision

Standardize Job Titles

Shuttle car operator:

- SC op
- Shuttle car operator
- SC operator
- Operator SC
- SC

Data Collection

Reviewed historical documents collected and developed draft:

- Job dictionaries of standardized job titles
- Exposure groups

Develop Exposure Groups

Foreman=supervisor

Panel board operator=powerhouse operator

Material handler=loader

Data Collection

Reviewed historical documents collected and developed draft:

- Job dictionaries of standardized job titles
- Exposure groups
- Determinants and changes in them over time

Changes in Determinants over Time

1950	Mine opened using conventional mining
1955	First diesel equipment entered mine
1958	Second shaft put in: increased ventilation to 350,000 cfm
1962	4 diesel shuttle cars bought
1963	2 diesel ANFO wagons bought

Number of Documents by Mine*

MINE NUMBER	TOTAL NUMBER OF DOCUMENTS
1	47
2	63
3	30
4	24
5	21
6	49
7	29
8	36

*Data are preliminary and subject to revision

Dates of Most Recent Visits to the Mines*

MINE NUMBER	DATE OF VISIT
1	June 25-26, 2001
2	November 15-16, 2001
3	November 13-14, 2001
4	August 14-16, 2002
5	September 19-20, 2002
6	November 18-19, 2002
7	November 20-21, 2002
8	June 9-10, 2003

*All operating mines have been visited at least three other times since the start of the study in 1992

Data Collection (2001-2003)

Interviewed employees and management

- Job tasks
- Diesel equipment and horsepower
- Ventilation
- Mining and work practices

Took walk-through surveys of processes

Data Collection (2001-2003)

- Reviewed draft job dictionary and exposure groups
- Reviewed draft list of changes in mine

Components of an Exposure Assessment

- Data collection
- Development of exposure groups
- Estimation of exposures

Development of Exposure Groups

Status:

- Modifying job dictionaries
- Modifying exposure groups

based on information collected on most recent visit

Components of an Exposure Assessment

- Data collection
- Development of exposure groups
- Estimation of exposures

Estimation of Exposures

Status:

Coding measurement data to exposure groups

Number of Measurements by Mine and Contaminant*

MINE NUMBER	CO	CO_2	NO_2	NO	RD	TD	REC	ALL
1	702	603	404	41	163	351	151	2844
2	519	551	274	0	151	325	0	1820
3	754	714	478	115	96	199	71	2535
4	404	321	332	233	147	104	204	2117
5	742	636	684	212	42	152	186	3020
6	957	897	673	234	156	1010	206	4480
7	3958	3577	1887	242	71	344	199	10643
8	4286	3983	2039	211	104	391	218	11642
TOTAL	12322	11282	6771	1288	930	2876	1235	39101

*Data are preliminary and subject to revision; RD=respirable dust; TD=total dust; REC=respirable elemental carbon

Number of Measurements by Mine and Decade*

MINE NUMBER	1970s	1980s	1990s
1	1102	604	830
2	1038	741	19
3	849	914	772
4	128	417	1435
5	918	613	1489
6	230	2055	2142
7	1216	4399	5018
8	965	5360	5226
TOTAL	6446	15103	16931

*Data are preliminary and subject to revision

Estimation of Exposures

Status:

Coding measurement data to exposure groups

Developing information on changes in determinants

- **Diesel equipment and horsepower**
- **Ventilation rates**
- **Production rates**
- **Diesel fuel usage**
- **Mining and work practices**

Diesel Equipment
Cumulative Number of Pieces*

MINE NUMBER	DATE OF DIESELIZATION	CUMULATIVE NUMBER OF PIECES
1	1950	154
2	1952	92
3	1964	168
4	1947	266
5	1959	107
6	1962	235
7	1967	297
8	1956	332
Total		1661

*Data are preliminary and subject to revision

Information on Diesel Engine Horsepower, Production Rates, and Diesel Fuel Usage*

MINE NUMBER	HORSEPOWER	PRODUCTION RATES AND FUEL USAGE
1	X	X
2	X	X
3	X	
4	X	X
5	X	X
6	X	X
7	X	X
8	X	X

*Data are preliminary and subject to revision

Estimation of Exposures

Develop exposure estimates for every:

Exposure group/department/mine/year

Future

- Develop exposure estimates by linking measurement data to determinants and exposure groups
- Visit mines to review estimates
- Modify estimates based on visits

US METAL/NONMETAL UNDERGROUND MINES

Mine ID	SIC	Company Name	Mine/Plant Name	Last Helath Sample	Max DPM	Samples-TC	Samples-EC	Samples-Total	>400	>160	Ls	Es	Citations	Total Overexposures
3300563	Clay (Fire)	THE STONE CREEK BRICK COMPANY	THE STONE CREEK BRICK COMPANY	8/27/2003	633	9	9	18	3	10	4			4
0405509	Gemstones	GOCHENOUR MINERALS & MINING	CRYO GENIE MINE	8/20/2003	N/S	-	-	-						-
2401835	Gemstones	YOGO CREEK MINING LLC	VORTEX MINE	2/25/2003	226	2	2	4	-	2				-
4200854	Gilsonite	AMERICAN GILSONITE COMPANY	BONANZA MINES		N/S	-	-	-						-
4200876	Gilsonite	ZIEGLER CHEMICAL & MINERAL COR	LITTLE BONANZA MINES AND MILLS		N/S	-	-	-						-
4202044	Gilsonite	LEXCO INC	I.T.M. MINE AND MILL		N/S	-	-	-						-
0401299	Gold (Lode and Placer)	ORIGINAL SIXTEEN TO ONE MINE I	SIXTEEN TO ONE MINE	12/5/2003	N/S	-	-	-						-
2602300	Gold (Lode and Placer)	BARRICK GOLDSTRIKE MINE INC	STORM EXPLORATION DECLINE		N/S	-	-	-						-
2602512	Gold (Lode and Placer)	NEWMONT MINING CORPORATION	LEEVILLE	12/18/2003	N/S	-	-	-						-
4200260	Gold (Lode and Placer)	UNICO INC	DEER TRAIL		N/S	-	-	-						-
2602271	Gold (Lode and Placer)	NEWMONT MINING CORP.	CARLIN MINE	12/2/2003	1,581	9	8	17	13	15	4	9	-	13
2602246	Gold (Lode and Placer)	BARRICK GOLDSTRIKE MINES INC	MEIKLE MINE	3/2/2004	1,568	9	7	16	12	16	4	8		12
2602286	Gold (Lode and Placer)	GETCHELL GOLD CORP	TURQUOISE RIDGE MINE	2/3/2004	1,338	8	8	16	2	10		2	-	2
2602374	Gold (Lode and Placer)	NEWMONT MINING CORP.	DEEP POST	12/4/2003	1,063	13	11	24	13	24	2	11	-	13
2602397	Gold (Lode and Placer)	QUEENSTAKE RESOURCES U.S.A., I	LEE SMITH MINE	4/15/2003	872	9	5	14	12	14		12		12
4503336	Gold (Lode and Placer)	ECHO BAY MINERALS COMPANY	K-2 MINE SITE	8/15/2003	783	10	10	20	12	19	10	2		12
2402286	Gold (Lode and Placer)	SMALL MINE DEVELOPMENT, LLC	GOLDEN SUNLIGHT UNDERGROUND MI	11/13/2003	748	4	4	8	6	8	6			6
2602211	Gold (Lode and Placer)	ANGLOGOLD (JERRITT CANYON) COR	MURRAY	11/4/2003	707	10	8	18	4	14	2	6		8
2602481	Gold (Lode and Placer)	NEWMONT MINING CORPORATION	CHUKAR	2/26/2004	597	6	6	12	7	10	2	5		7
2602517	Gold (Lode and Placer)	METALLIC VENTURES U. S. INC.	ESMERALDA PROJECT/MARTINEZ	11/5/2003	524	3	2	5	2	3		2		2
2602299	Gold (Lode and Placer)	ANGLOGOLD (JERRITT CANYON) COR	SSX	3/9/2004	485	10	8	18	6	14		6		6
2602314	Gold (Lode and Placer)	NORMANDY MIDAS OPERATIONS INC	KEN SNYDER MINE	1/13/2004	478	7	6	13	2	11		2		2
2602370	Gold (Lode and Placer)	QUEENSTAKE RESOURCES U.S.A. ,	MCE MINE	10/16/2003	268	6	6	12	-	8				-
2602235	Gold (Lode and Placer)	METALLIC VENTURES (US) INC.	ESMERALDA PROJECT/PROSPECTUS	11/5/2003	250	3	3	6	-	3				-
1300434	Gypsum	UNITED STATES GYPSUM COMPANY	SPERRY MINE	11/19/2003	1,231	15	15	30	21	30	19		-	19
1400309	Gypsum	GEORGIA-PACIFIC	BLUE RAPIDS MINE AND MILL	2/25/2004	496	12	12	24	3	22	3			3
1200429	Gypsum	NEW NGC INCORPORATED	SHOALS MINE	3/13/2004	373	12	12	24	-	12				-
1200427	Gypsum	U.S. GYPSUM COMPANY	SHOALS MINE	12/17/2003	230	6	6	12	-	4				-
4606416	Iron Ore	AKERS SUPPLY INC	AKERS # 1		N/S	-	-	-						-
2300458	Lead/Zinc Ore	THE DOE RUN CO	SWEETWATER MINE/MILL	2/4/2004	2,045	17	17	34	25	34	24		-	24
2300409	Lead/Zinc Ore	THE DOE RUN COMPANY	FLETCHER MINE AND MILL	2/25/2004	1,031	8	8	16	14	14	14		-	14
2300457	Lead/Zinc Ore	THE DOE RUN COMPANY	BUICK MINE/MILL	12/16/2003	758	25	25	50	18	36	18			18
2301800	Lead/Zinc Ore	DOE RUN COMPANY	VIBURNUM #35 (CASTEEL MINE)	1/28/2004	534	10	10	20	7	20	7			7
2300499	Lead/Zinc Ore	THE DOE RUN COMPANY	BRUSHY CREEK MINE/MILL	5/14/2003	485	10	10	20	3	14	3			3
4001627	Lead/Zinc Ore	PASMINCO ZINC, INC.	CLINCH VALLEY MINE	12/10/2003	403	5	5	10	1	8	1			1
2300494	Lead/Zinc Ore	THE DOE RUN COMPANY	VIBURNUM # 28 MINE/MILL	12/18/2003	295	5	5	10	-	8				-
4500366	Lead/Zinc Ore	TECK COMINCO AMERICAN INC	PEND OREILLE MINE	11/25/2002	9	1	1	2	-	-				-
4400082	Lime	CHEMICAL LIME COMPANY OF VIRGI	KIMBALLTON PLANT #1	12/20/2002	317	10	10	20	-	18				-
2300542	Lime	MISSISSIPPI LIME COMPANY	PEERLESS MINE	2/26/2004	231	10	10	20	-	8				-
1518137	Limestone (Crushed & Broken)	RAGLAND QUARRY INC.	RAGLAND QUARRY INC.	1/14/2004	N/S	-	-	-						-
3600033	Limestone (Crushed & Broken)	BRADYS BEND CORP	KAYLOR MINE #3 & PLANT	11/18/2003	2,979	15	13	28	13	23	9	2	2	13
1400159	Limestone (Crushed & Broken)	AMERICOLD LOGISTICS LLC	INLAND QUARRIES	2/25/2004	2,010	30	30	60	36	54	24	12	-	36
3600274	Limestone (Crushed & Broken)	WINFIELD LIME & STONE COMPANY	WINFIELD LIME & STONE MINE AND	6/19/2003	1,741	8	8	16	10	15	2	8	-	10
2302232	Limestone (Crushed & Broken)	HUNT MIDWEST MINING INC	STAMPER UNDERGROUND	11/26/2003	1,559	9	9	18	18	18	18		-	18
1500072	Limestone (Crushed & Broken)	NALLY & GIBSON GEORGETOWN, LLC	NALLY & GIBSON GEORGETOWN, LLC	3/4/2004	1,461	10	10	20	14	20	14		-	14
2302211	Limestone (Crushed & Broken)	ROCCA PROCESSING LLC	INDEPENDENCE MINE	2/25/2004	1,446	9	9	18	11	17	11		-	11
0901038	Limestone (Crushed & Broken)	GLOBAL STONE FILLER PRODUCTS I	MARBLE HILL MINE	11/5/2003	1,368	9	9	18	3	6	3		-	3
2301883	Limestone (Crushed & Broken)	MARTIN MARIETTA AGGREGATES	PARKVILLE QUARRY	3/3/2004	1,260	15	15	30	16	30	17		-	17
4601563	Limestone (Crushed & Broken)	MARTIN MARIETTA AGGREGATES	MANHEIM MINE	12/10/2003	1,194	22	22	44	4	12		4	-	4
2300154	Limestone (Crushed & Broken)	HUNT MIDWEST MINING INC	RANDOLPH MINE	3/3/2004	1,056	14	14	28	12	25	12		-	12
1202176	Limestone (Crushed & Broken)	MARTIN MARIETTA MATERIALS, INC	RIVER AVENUE MINE/MILL	5/20/2003	987	7	7	14	12	14	12			12
1302217	Limestone (Crushed & Broken)	BRUENING ROCK PRODUCTS, INC.	SKYLINE CONSTRUCTION MINE #1	12/10/2003	982	14	14	28	12	20	9			9
1500112	Limestone (Crushed & Broken)	M A WALKER LLC	CLOVER BOTTOM UNDERGROUND	12/10/2003	949	10	10	20	20	20	20			20
1500086	Limestone (Crushed & Broken)	SCOTTY'S CONTRACTING & STONE L	GRAYSON COUNTY QUARRY	11/20/2003	945	5	5	10	2	6	2			2

US METAL/NONMETAL UNDERGROUND MINES

Mine ID	SIC	Company Name	Mine/Plant Name	Last Helath Sample	Max DPM	Samples-TC	Samples-EC	Samples-Total	>400	>160	Ls	Es	Citations	Total Overexposures
4600016	Limestone (Crushed & Broken)	GREER INDUSTRIES, INC. DBA GRE	GREER LIMESTONE	12/11/2002	849	10	10	20	9	15	-	7		7
1500062	Limestone (Crushed & Broken)	CARMEUSE LIME AND STONE INC	UNDERGROUND BLACK RIVER OPERAT	12/17/2003	829	9	9	18	10	14	10			10
2301836	Limestone (Crushed & Broken)	TABLE ROCK ASPHALT CONSTRUCTIO	TABLE ROCK QUARRY #1	1/29/2004	780	12	12	24	9	22	9			9
1301225	Limestone (Crushed & Broken)	MARTIN MARIETTA AGGREGATES OF	DURHAM MINE & MILL	11/19/2003	742	10	10	20	12	17	12			12
1201762	Limestone (Crushed & Broken)	MARTIN MARIETTA AGGREGATES	KENTUCKY AVE. MINE & MILL	2/24/2004	726	14	14	28	6	21	7			7
3604403	Limestone (Crushed & Broken)	M & M LIME CO., INC.	M & M LIME CO., INC.	2/12/2004	705	19	18	37	12	27	1	11		12
3608284	Limestone (Crushed & Broken)	HANSON AGGREGATES PMA INC	WHITNEY PLANT (UG)	2/12/2004	672	9	9	18	2	10	2			2
1300014	Limestone (Crushed & Broken)	MARTIN MARIETTA MATERIALS	AMES MINE	2/4/2004	664	15	15	30	8	27	10			10
1300194	Limestone (Crushed & Broken)	RIVER PRODUCTS COMPANY INC.	COLUMBUS JUNCTION UNDERGROUND	7/17/2003	660	12	12	24	4	13	4			4
1400061	Limestone (Crushed & Broken)	BROMLEY QUARRY & ASPHALT, INC.	BROMLEY MINE & MILL	3/9/2004	626	9	9	18	4	11	4			4
1500043	Limestone (Crushed & Broken)	HANSON AGGREGATES MIDWEST, INC	TYRONE MINE & MILL	1/22/2003	626	5	6	11	1	9	1			1
1201993	Limestone (Crushed & Broken)	MARTIN MARIETTA AGGREGATES	NORTH INDIANAPOLIS UNDERGROUND	4/9/2003	573	7	7	14	4	7	5			5
2500998	Limestone (Crushed & Broken)	MARTIN MARIETTA AGGREGATES	#273 WEEPING WATER MINE	3/10/2004	555	15	15	30	6	28	6			6
4002113	Limestone (Crushed & Broken)	GLOBAL STONE TENN LUTTRELL CO.	CHESNEY UNDERGROUND	2/4/2004	495	8	9	17	3	9	3			3
3600155	Limestone (Crushed & Broken)	COOLSPRING STONE SUPPLY INC	COOLSPRING QUARRY	9/9/2003	480	13	13	26	2	10	2			2
1517419	Limestone (Crushed & Broken)	LITER'S QUARRY, INC.	ROCK SPRINGS MINE	2/18/2004	468	7	7	14	2	7	2			2
4608862	Limestone (Crushed & Broken)	MARTIN MARIETTA MATERIALS INC	BURNING SPRINGS MINE	11/13/2003	455	10	10	20	2	10	-	2		2
2501126	Limestone (Crushed & Broken)	KERFORD LIMESTONE CO	KERFORD LIMESTONE CO	11/5/2003	446	11	11	22	3	14	3			3
1518068	Limestone (Crushed & Broken)	STERLING MATERIALS	STERLING MATERIALS	12/3/2003	445	8	8	16	1	10	1			1
1500107	Limestone (Crushed & Broken)	VULCAN CONSTR. MATERIALS, L.P.	RICHMOND ROAD	10/29/2003	444	8	8	16	2	7	2			2
1514849	Limestone (Crushed & Broken)	ROGERS GROUP, INC.	OLDHAM COUNTY STONE	10/29/2003	441	4	4	8	1	8	1			1
2301892	Limestone (Crushed & Broken)	TABLE ROCK ASPHALT CONSTRUCTIO	TABLE ROCK-QUARRY #3	1/29/2004	438	9	9	18	2	15	2			2
4000087	Limestone (Crushed & Broken)	FRANKLIN INDUSTRIAL MINERALS	CRAB ORCHARD MINE AND MILL	8/20/2003	417	9	9	18	1	16	1			1
1507101	Limestone (Crushed & Broken)	CARMEUSE LIME AND STONE INC	MAYSVILLE MINE	2/4/2004	415	8	8	16	2	14	2			2
1518321	Limestone (Crushed & Broken)	MATSUDA INCORPORATED	BROOKS CRUSHED STONE	1/14/2004	412	8	8	16	1	6	1			1
1300097	Limestone (Crushed & Broken)	LINWOOD MINING AND MINERALS CO	LINWOOD MINE	6/4/2003	389	7	7	14	-	8				-
3304458	Limestone (Crushed & Broken)	THE EAST FAIRFIELD COAL CO.	PETERSBURG MINE	11/20/2002	387	4	4	8	-	5				-
1500006	Limestone (Crushed & Broken)	ALLEN COMPANY INC	BOONESBORO QUARRY	12/11/2003	380	8	8	16	-	1				-
3600047	Limestone (Crushed & Broken)	BETTER MATERIALS CORP	SPRINGFIELD PIKE MINE & PLANT	12/11/2002	379	5	5	10	-	6				-
1500081	Limestone (Crushed & Broken)	YAGER MATERIALS	RIVERSIDE STONE	11/19/2003	374	8	8	16	-	11				-
1100213	Limestone (Crushed & Broken)	MARTIN MARIETTA AGGREGATES	KASKASKIA MINE	12/17/2003	372	7	7	14	-	6				-
2302105	Limestone (Crushed & Broken)	NORRIS ASPHALT PAVING COMPANY	NORRIS AGGREGATE PRODUCTS	3/10/2004	370	6	6	12	-	4				-
1518415	Limestone (Crushed & Broken)	BOURBON LIMESTONE COMPANY	BOURBON LIMESTONE COMPANY	10/9/2003	365	3	3	6	-	6				-
1500016	Limestone (Crushed & Broken)	VULCAN CONSTR. MATERIALS, L.P.	CENTRAL QUARRY	12/30/2003	363	8	8	16	-	8				-
2302239	Limestone (Crushed & Broken)	LAFARGE NORTH AMERICA INCORPOR	COURTNEY RIDGE	3/3/2004	361	10	10	20	-	4				-
2300028	Limestone (Crushed & Broken)	AMERICOLD LOGISTICS LLC	AMERICOLD LOGISTICS LLC	2/22/2004	359	10	10	20	-	6				-
1300032	Limestone (Crushed & Broken)	MARTIN MARIETTA MATERIALS, INC	FORT DODGE MINE	12/18/2003	356	14	14	28	-	5				-
2300094	Limestone (Crushed & Broken)	SPRINGFIELD UNDERGROUND INC	PLANT NO 1 MINE & MILL	12/3/2003	354	10	10	20	-	5				-
1500003	Limestone (Crushed & Broken)	ROGERS GROUP, INC.	MARION MINE & MILL	4/16/2003	349	3	3	6	-	4				-
1202005	Limestone (Crushed & Broken)	ELLIOTT MINERAL EXTRACTION INC	EUREKA UNDERGROUND	4/16/2003	335	8	8	16	-	11				-
1102931	Limestone (Crushed & Broken)	GALENA PLATTEVILLE, INC.	GALENA PLATTEVILLE MINE	11/18/2003	333	10	10	20	-	9				-
1100122	Limestone (Crushed & Broken)	BLUFF CITY MINERALS	BLUFF CITY MINERALS	2/4/2004	323	6	6	12	-	6				-
1300063	Limestone (Crushed & Broken)	MARTIN MARIETTA AGGREGATES OF	SULLY MINE & MILL	3/10/2004	323	10	10	20	-	6				-
3400282	Limestone (Crushed & Broken)	GLOBAL STONE ST. CLAIR, INC.	MARBLE CITY OPERATIONS	11/6/2003	319	9	9	18	-	5				-
0901101	Limestone (Crushed & Broken)	GLOBAL STONE FILLER PRODUCTS	CISCO MINE	12/2/2003	311	6	6	12	-	2				-
0100028	Limestone (Crushed & Broken)	FORT PAYNE QUARRY LLC	FORT PAYNE MINE	11/18/1903	308	5	5	10	-	6				-
4100055	Limestone (Crushed & Broken)	J M HUBER CORP	MICHEL MINE CALCIUM CARBON DIV	3/9/2004	286	11	11	22	-	13				-
1800735	Limestone (Crushed & Broken)	MARYLAND MINERALS INC	THAYERVILLE MINE	2/25/2004	284	15	15	30	-	4				-
4000022	Limestone (Crushed & Broken)	FRANKLIN INDUSTRIAL MINERALS	ANDERSON MINE AND MILL	12/3/2003	284	9	9	18	-	5				-
1103084	Limestone (Crushed & Broken)	JOLIET SAND & GRAVEL COMPANY	JS&G UNDERGROUND MINE #1	11/25/2003	271	9	9	18	-	6				-
4000020	Limestone (Crushed & Broken)	COLUMBIA ROCK PRODUCTS CORP.	COLUMBIA ROCK #1	1/6/2004	256	14	14	28	-	5				-
2500554	Limestone (Crushed & Broken)	PCS PHOSPHATE COMPANY INC	PCS PHOSPHATE COMPANY INC	3/3/2004	241	7	7	14	-	3				-
3608484	Limestone (Crushed & Broken)	HANSON AGGREGATES PMA INC	TORRANCE MINE (UG)	2/2/2004	235	6	6	12	-	5				-
1500012	Limestone (Crushed & Broken)	HINKLE CONTRACTING CORPORATION	CASEY STONE COMPANY	1/23/2003	233	1	1	2	-	1				-

US METAL/NONMETAL UNDERGROUND MINES

Mine ID	SIC	Company Name	Mine/Plant Name	Last Helath Sample	Max DPM	Samples-TC	Samples-EC	Samples-Total	>400	>160	Ls	Es	Citations	Total Overexposures
1518157	Limestone (Crushed & Broken)	ROGERS GROUP INC	JEFFERSON CO. UNDERGROUND	11/19/2003	223	3	3	6	-	2				-
4600029	Limestone (Crushed & Broken)	GREER INDUSTRIES INC SUB DECKE	DECKERS CREEK LIMESTONE COMPAN	12/10/2002	220	10	10	20	-	5				-
1515452	Limestone (Crushed & Broken)	LITER'S QUARRY, INC.	LOCKPORT MINE	8/20/2003	218	5	5	10	-	1				-
3606468	Limestone (Crushed & Broken)	GRAYMONT (PA) INC	GRAYMONT (PA) INC. PLEASANT GA	12/3/2002	217	10	10	20	-	4				-
2300051	Limestone (Crushed & Broken)	DOSS & HARPER STONE COMPANY	DOSS & HARPER UNDERGROUND	11/13/2003	204	5	5	10	-	2				-
1100019	Limestone (Crushed & Broken)	J.M. HUBER CORPORATION	QUARRY	2/19/2004	173	12	12	24	2	8	1			1
0300313	Limestone (Crushed & Broken)	UNIMIN CORP	GUION PLANT	1/28/2003	169	5	5	10	-	2				-
4003132	Limestone (Crushed & Broken)	VULCAN CONSTR. MATERIALS, L.P.	RICHARD CITY UNDERGROUND MINE	12/4/2002	164	4	4	8	-	1				-
1202322	Limestone (Crushed & Broken)	ROGERS GROUP INC.	BLOOMINGTON UNDERGROUND MINE	11/25/2003	161	6	6	12	-	1				-
2302171	Limestone (Crushed & Broken)	LAFARGE CORP	SUGAR CREEK UG MINE	8/6/2003	156	5	5	10	-	-				-
1500019	Limestone (Crushed & Broken)	HINKLE CONTRACTING CORPORATION	TIPTON RIDGE QUARRY	11/18/2003	137	1	1	2	-	-				-
3600131	Limestone (Crushed & Broken)	BETTER MATERIALS CORPORATION	BLUE STONE QUARRY	11/21/2002	135	10	10	20	-	-				-
3605464	Limestone (Crushed & Broken)	KEYSTONE LIME COMPANY INC	EICHORN MINES	2/5/2004	103	7	7	14	-	-				-
1506264	Limestone (Crushed & Broken)	LEXINGTON QUARRY COMPANY	LEXINGTON QUARRY CO.	12/3/2003	82	3	3	6	-	-				-
4200003	Limestone (Crushed & Broken)	CEDARSTROM CALCITE & CLAY CORP	CEDARSTROM CALCITE	11/5/2003	81	2	2	4	-	-				-
0100010	Limestone (Dimension)	ALABAMA STONE CO.	ROCKWOOD MINE	10/7/2003	333	6	6	12	-	6				-
0900030	Marble (Crushed & Broken)	IMERYS MARBLE INC	NEW YORK MINE	11/18/2003	493	10	10	20	1	13	2			2
0901093	Marble (Crushed & Broken)	HUBER ENGINEERED MINERALS	MISS LINDA MINE	2/25/2004	382	11	11	22	-	10				-
0900047	Marble (Crushed & Broken)	IMERYS MARBLE INC	IMERYS MARBLE INC. MINE #4	8/26/2003	347	8	8	16	-	3				-
0900027	Marble (Crushed & Broken)	IMERYS MARBLE INC.	IMERYS MARBLE INC. MINE #1	6/10/2003	64	3	3	6	-	-				-
0504438	Marble (Dimension)	SIERRA MINERALS CORP	YULE QUARRY	12/30/2003	306	5	5	10	-	6				-
4300042	Marble (Dimension)	VERMONT QUARRIES CORP	DANBY QUARRY	12/4/2002	241	5	5	10	-	5				-
4300574	Marble (Dimension)	VERMONT QUARRIES CORP.	UPPER INPERIAL QUARRY	12/4/2002	76	2	2	4	-	-				-
0404218	Metal Ores, NEC	AMERICAN BORATE COMPANY	BILLIE MINE	10/26/2003	530	8	9	17	1	10		1		1
0500790	Molybdenum	CLIMAX MOLYBDENUM COMPANY	HENDERSON OPERATIONS	11/26/2003	469	15	15	30	1	16		1		1
2901267	Molybdenum	MOLYCORP INC	QUESTA MINE & MILL	2/4/2004	157	11	11	22	-	-				-
4703110	Nonmetallic Minerals, NEC	WISCONSIN INDUSTRIAL SAND CO.	MAIDEN ROCK	2/10/2004	875	19	19	38	11	30	11			11
2401879	Platinum Group	STILLWATER MINING COMPANY	EAST BOULDER MINE	3/2/2004	1,795	19	19	38	24	32	18	6	-	24
2401490	Platinum Group	STILLWATER MINING COMPANY	STILLWATER MINE	11/20/2003	900	31	31	62	35	51	27	8		35
2900175	Potash	MISSISSIPPI POTASH INC.	MISSISSIPPI POTASH WEST	11/24/2003	579	14	14	28	2	7	2			2
2900170	Potash	MISSISSIPPI POTASH INC	MISSISSIPPI POTASH,INC EAST MI	12/10/2003	485	15	15	30	4	11	4			4
2900802	Potash	IMC POTASH CARLSBAD, INC.	IMC POTASH CARLSBAD, INC.	12/17/2003	342	15	15	30	-	6				-
1400412	Salt (Rock)	HUTCHINSON SALT COMPANY	HUTCHINSON SALT COMPANY	11/18/2003	824	10	10	20	4	9	4			4
3301993	Salt (Rock)	MORTON SALT DIV OF MORTON INTL	MORTON SALT FAIRPORT MINE	3/9/2004	742	16	16	32	2	19	2			2
3003255	Salt (Rock)	AMERICAN ROCK SALT COMPANY LLC	HAMPTON CORNERS MINE	1/22/2004	583	23	21	44	12	38	6	6		12
1400413	Salt (Rock)	LYONS SALT COMPANY	LYONS SALT COMPANY	10/29/2003	566	12	8	20	7	15		7		7
4200297	Salt (Rock)	REDMOND MINERALS, INC.	REDMOND MINERALS SALT MINES	12/18/2003	451	10	10	20	1	9		1		1
2000552	Salt (Rock)	THE DETROIT SALT COMPANY, L.C.	DETROIT SALT MINE	3/2/2004	405	18	18	36	9	35	9			9
1600509	Salt (Rock)	CARGILL SALT	AVERY ISLAND	11/6/2003	361	13	13	26	-	13				-
3301994	Salt (Rock)	CARGILL DEICING TECHNOLOGY	CARGILL DEICING TECHNOLOGY-CLE	12/11/2002	325	10	10	20	-	7				-
1400411	Salt (Rock)	INDEPENDENT SALT COMPANY	INDEPENDENT SALT COMPANY	11/19/2003	324	8	8	16	-	12				-
1600358	Salt (Rock)	NORTH AMERICAN SALT COMPANY	COTE BLANCHE MINE	11/13/2003	302	10	10	20	-	9				-
4102478	Salt (Rock)	UNITED SALT CORPORATION	HOCKLEY MINE	9/9/2003	284	10	10	20	-	7				-
3000663	Salt (Rock)	CARGILL, INCORPORTED	CARGILL SALT - CAYUGA MINE	2/3/2004	213	15	15	30	-	1				-
4101776	Salt (Rock)	MORTON SALT DIV/MORTON INTL IN	GRAND SALINE OPERATIONS	12/9/2003	147	12	12	24	-	-				-
1600970	Salt (Rock)	MORTON SALT DIV.MORTON INT.INC	MORTON SALT CO.WEEKS ISLD.M&M	11/12/2003	114	9	9	18	-	-				-
1500013	Sandstone (Crushed & Broken)	ROGERS GROUP INC	PRINCETON MINE	6/3/2003	107	5	5	10	-	-				-
5001267	Silver Ores	KENNECOTT GREENS CREEK MINING	KENNECOTT GREENS CREEK MINE		N/S	-	-	-						-
1000088	Silver Ores	HECLA MINING COMPANY	LUCKY FRIDAY	12/8/2003	790	16	16	32	13	27	6	7		13
1000082	Silver Ores	COEUR SILVER VALLEY INC	GALENA MINE	10/23/2003	622	11	11	22	5	14		5		5
5001777	Stone, Crushed & Broken, NEC	DELTA MINE TRAINING CENTER	DELTA MINE TRAINING CENTER		N/S	-	-	-						-
1500020	Stone, Crushed & Broken, NEC	HARROD CONCRETE & STONE CO.	GLEN'S CREEK MINE & MILL	11/19/2003	393	7	7	14	-	10				-
3003138	Stone, Crushed & Broken, NEC	WINGDALE MATERIALS LLC	WINGDALE MINE	9/24/2003	307	15	15	30	-	9				-
4100995	Stone, Crushed & Broken, NEC	TEXAS ARCHITECTURAL AGGREGATE	WHITE MARBLE MINE	11/19/2003	276	4	4	8	-	5				-

US METAL/NONMETAL UNDERGROUND MINES

Mine ID	SIC	Company Name	Mine/Plant Name	Last Helath Sample	Max DPM	Samples-TC	Samples-EC	Samples-Total	>400	>160	Ls	Es	Citations	Total Overexposures
3002245	Talc, Soapstone & Pyrophylite	GOUVERNEUR TALC COMPANY INC	NO. 4 MINE	12/11/2002	343	3	3	6	6	6				-
4800152	Trona	F.M.C. CORPORATION	FMC @ WESTVACO	1/9/2004	407	8	7	15	1	9	1			1
4800155	Trona	GENERAL CHEMICAL SODA ASH PART	GENERAL CHEMICAL MINE	2/24/2004	266	14	14	28	-	4				-
4800154	Trona	OCI WYOMING L P	BIG ISLAND MINE & REFINERY	1/7/2004	231	7	7	14	-	1				-
4801295	Trona	SOLVAY CHEMICALS INC	SOLVAY CHEMICALS, INC	11/13/2003	190	6	6	12	-	2				-
167						1,476	1,454	2,930	619	1,695	460	153	2	615
								18	21%	58%	16%	5%	0.1%	21%

CODE TABLES

STATE CODE TABLE

STATE NAME	ABBREV	IEIO CODE	FIPS CODE
ALABAMA	AL	01	01
ALASKA	AK	50	02
ARIZONA	AZ	02	04
ARKANSAS	AR	03	05
CALIFORNIA	CA	04	06
COLORADO	CO	05	08
CONNECTICUT	CT	06	09
DELAWARE	DE	07	10
DIST OF COLUMBIA	DC	49	11
FLORIDA	FL	08	12
GEORGIA	GA	09	13
HAWAII	HI	51	15
IDAHO	ID	10	16
ILLINOIS	IL	11	17
INDIANA	IN	12	18
IOWA	IA	13	19
KANSAS	KS	14	20
KENTUCKY	KY	15	21
LOUISIANA	LA	16	22
MAINE	ME	17	23
MARYLAND	MD	18	24
MASSACHUSETTS	MA	19	25
MICHIGAN	MI	20	26
MINNESOTA	MN	21	27
MISSISSIPPI	MS	22	28
MISSOURI	MO	23	29
MONTANA	MT	24	30
NEBRASKA	NE	25	31
NEVADA	NV	26	32
NEW HAMPSHIRE	NH	27	33
NEW JERSEY	NJ	28	34
NEW MEXICO	NM	29	35
NEW YORK	NY	30	36
NORTH CAROLINA	NC	31	37
NORTH DAKOTA	ND	32	38
OHIO	OH	33	39
OKLAHOMA	OK	34	40
OREGON	OR	35	41
PENNSYLVANIA	PA	36	42
RHODE ISLAND	RI	37	44
SOUTH CAROLINA	SC	38	45
SOUTH DAKOTA	SD	39	46
TENNESSEE	TN	40	47
TEXAS	TX	41	48
UTAH	UT	42	49
VERMONT	VT	43	50
VIRGINIA	VA	44	51
WASHINGTON	WA	45	53
WEST VIRGINIA	WV	46	54
WISCONSIN	WI	47	55
WYOMING	WY	48	56
PANAMA CANAL ZONE	CZ	53	61
PUERTO RICO	PR	54	72
VIRGIN ISLANDS	VI	55	78
PACIFIC ISLAND POSSESSIONS	PP	52	Mult Nos

COAL MINE STATUS

CODE	MEANING
A	Active
B	Mine Closed by MSHA
C	Temporarily Closed
D	Permanently Abandoned
E	Active, Men Working, Not Producing
F	Active, Men Not Working, Not Producing
G	New, Under Construction
H	New, No Men Working

METAL/NONMETAL MINE STATUS

CODE	MEANING
1	Full-Time Permanent
2	Intermittent (including Seasonal)
3	Non-Producing
4	Permanently Abandoned

CANVASS/CLASS

CODE	DESCRIPTION
1	Coal - Anthracite
2	Coal - Bituminous
3	Not Used (formerly designated sub-bituminous)
4	Not used (formerly designated lignite)
5	Sand & Gravel
6	Stone
7	Nonmetal
8	Metal
9	Contractor

MINE TYPE

CODE	DESCRIPTION
01	Underground-Metal
02	Underground-Nonmetal
03	Underground-Stone
04	Surface - Metal
05	Surface - Nonmetal
06	Surface - Stone
07	Mills - Metal
08	Mills - Nonmetal
09	Mills - Stone
10	Sand and Gravel
11	Underground - Coal
12	Surface - Coal
13	Mills - Coal

SIC CODES (MSHA)

CODE	DESCRIPTION
10110	Iron Ore
10210	Copper Ore
10310	Lead/Zinc Ore
10410	Gold (Lode and Placer)
10440	Silver Ores
10510	Aluminum Ore
10610	Ferroalloy Ores
10611	Chromite
10612	Cobalt
10613	Columbium - Tantalum
10614	Manganese
10615	Molybdenum
10616	Nickel
10617	Tungsten
10920	Mercury
10940	Uranium - Vanadium Ores
10941	Uranium
10942	Vanadium
10990	Metal Ores, NEC
10991	Antimony
10992	Beryl
10993	Platinum Group
10994	Rare Earths
10995	Tin Ore
10996	Titanium
10997	Zircon
11110	Coal, Anthracite
12110	Coal, Bituminous
13111	Oil Shale
13112	Oil Sand
14110	Stone, Dimension NEC
14111	Granite (Dimension)
14112	Limestone (Dimension)
14113	Marble (Dimension)
14114	Sandstone (Dimension)
14115	Slate (Dimension)
14116	Traprock (Dimension)
14220	Limestone (Crushed & Broken)
14230	Granite (Crushed & Broken)
14290	Stone, Crushed & Broken, NEC
14291	Marble (Crushed & Broken)
14292	Sandstone (Crushed & Broken)
14293	Slate (Crushed & Broken)
14294	Traprock (Crushed & Broken)
14410	Sand & Gravel
14530	Clay (Fire)
14550	Clay (Common)
14590	Clay, Ceramic & Refractory, NEC
14591	Aplite
14592	Brucite
14593	Feldspar
14594	Kyanite
14595	Magnesite
14596	Shale (Common)
14720	Barite
14730	Fluorspar
14740	Potash, Soda & Borate Min'ls NEC
14741	Boron Minerals
14742	Potash
14743	Trona
14744	Sodium Compounds
14750	Phosphate Rock
14760	Salt (Rock)
14770	Sulfur
14790	Chemical and Fertilizer, NEC
14791	Lithium
14792	Pigment Mineral
14793	Pyrites
14794	Strontium
14920	Gypsum
14960	Talc, Soapstone & Pyrophylite
14990	Nonmetallic Minerals, NEC
14991	Asbestos
14992	Gemstones
14993	Gilsonite
14994	Mica
14995	Peat (before 1979)
14996	Perlite
14997	Pumice
14998	Vermiculite
28190	Industrial Chemicals, NEC
28191	Alumina (Mill)
28193	Bromine
28991	Salt (Evaporated)
28992	Salt (In brine)
29900	Leonardite
32410	Cement
32740	Lime