FINAL REPORT

July 1, 1994 to December 15, 1998

Continuous Dust Monitor (CDM) for Underground Coal Mines

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OVERVIEW and SCOPE:

This is the nineteenth and last report of the contract launched July 1, 1994. In this report we describe the success of the coal dust monitor in providing both real-time and recorded dust concentration measurements. We also provide some suggestions for improving and enhancing the instrument. Under this contract R&P built and mine tested 1 "tethered" mass monitor (phase1), built and mine tested 2 self-contained monitors (phase 2). We then constructed 10 "production monitors" (phase 3). We have installed and supported 5 of these 10 monitors and provided several service calls (phase 4). The last R&P obligation under this contract is to conduct a training session scheduled for the week of January 4 to 8 at MSHA's Beckley Campus. Labor and travel charges for the training session will exhaust all remaining funds.

OBJECTIVES:

A primary goal of this effort was to develop a machine-mounted coal dust monitor for underground mines which could provide accurate real-time information to the miners themselves for use in adjusting and maintaining their dust control equipment and strategies. Another primary goal was to provide recorded information which could be used by government and industry dust control engineers to study and improve work practices and equipment used for dust control. A secondary goal was to provide a tamper-resistant record of the coal dust concentration at the machine location, which when combined with correlation studies performed at a variety of sites, could be used to predict accurate dust exposures of the individual coal miners on a section or longwall crew.

CONCLUSIONS:

The above goals were clearly met. Graphs A through E, appended to this report, show the information which was available to the miners in graph and digital format. These graphs clearly demonstate that the monitor worked well and gave clear guidance to the miners as to the dust levels they were experiencing.

Descriptions of data:

A) Graph A shows data from a western KY mine, with the dust monitor mounted on a shield near the headgate on a longwall. The main air flow at this location is towards the headgate, so high levels of dust were found. Typically 1 to 2 mg of coal dust were collected per shift. The short term average concentration (approx 4 min) ranged from 1 to 4 mg/m^3. The filter accumulated a little over 9 mg during the 2 day period shown. Longer term averages are less noisy than the 4 min average: The 30 min average stays mostly between 1 and 3 mg/m^3. The full shift average (FSA) starts out each new shift with spikes similar to the 5 min average because it is a short term average at the beginning of the shift. At this mine, when a full 8 hour shift is worked, average dust levels for the shift are apparently 3 mg/ m^3 at the monitor location.

B) Graph B shows data from an eastern KY mine, with the dust monitor mounted on a shear on a longwall. High levels of dust were found. Typically 3 to 5 mg of coal dust were collected per shift. The short term average concentration (approx 4 min) ranged from 1 to 12 mg/m^3. Three filters accumulated a little over 22 mg during the 1.5 day period shown. Longer term averages are less noisy than the 4 min average: The 30 min average stays mostly between 2 and 8 mg/m^3. The full shift average (FSA) starts out each new shift with spikes similar to the 5 min average because it is a short term average at the beginning of the shift. At this mine, when a full 8 hour shift is worked, average dust levels for the shift are apparently over 8 mg/ m^3 at the monitor location. Two filter changes show clearly on the "filter change TM" (total mass) line, where it returns to 0 after reaching about 10 mg each time.

C) Graph C shows data from an eastern KY mine, with the dust monitor mounted on the first continuous haulage bridge behind a continuous miner. Moderate levels of dust were found. Typically 300 to 1000 ug of coal dust were collected per shift. The short term average concentration (approx 4 min) ranged from .3 to 6 mg/m^3. The filter rose over 10 mg during the 2 1/2 day period shown, so the filter changed automatically. Longer term averages are less noisy than the 4 min average: The 30 min average stays mostly between 0.5 and 1.0 mg/m^3. The full shift average (FSA) starts out each new shift with spikes similar to the 5 min average because it is a short term average at the beginning of the shift. At this mine, when a full 8 hour shift is worked, average dust levels for the shift are apparently about .8 to 1.2 mg/ m^3 at the monitor location.

D) Graph D also shows data from an eastern KY mine, with the dust monitor mounted on the first continuous haulage bridge behind a continuous miner. Moderate levels of dust were found. Typically 1000 to 2000 ug of coal dust were collected per shift. The short term average concentration (approx 4 min) ranged from 1 to 10 mg/m^3. The filter load rose over 10 mg during the 3 day period shown, so the filter changed automatically. Longer term averages are less noisy than the 4 min average: The 30 min average stays mostly between 2 and 5 mg/m^3. The full shift average (FSA) starts out each new shift with spikes similar to the 5 min average because it is a short term average at the beginning of the shift. At this mine, when a full 8 hour shift is worked, average dust levels for the shift are apparently about 2 to 3 mg/ m^3 at the monitor location. About 6 weeks separate the data from graphs D and C. Is it possible that some learning took place which brought the average dust levels down from around 3 to around 1 mg/m^3? Without details of how the mining was being done, we can't say, but it would be nice if someone with access to the logs would look at all the data and see if this relation can be found. (It is known that some retreat mining was done around this time so we can't be sure the periods in question are directly comparable)

The above goals were accomplished in stages, taking increasingly highly developed equipment to the field for evaluation. For the first few trials the emphasis was on equipment survival and technical performance, and not necessarily on providing clear information in real time. The final set of trials, now underway, is providing both very clear and useful real time information to the miners and good records to the dust engineers for post analysis. The original end of this contract was to deliver 10 "Beta test" units to co-operating mines for long term evaluation by the mines and MSHA. The contract was extended to have R&P support the installation and service of the first few units in the field.

No significant funding has yet been allocated for R&P to participate in evaluation of performance of these units in the field trials. Significant findings have been made in the field trials, especially those where the equipment was used in ways and on equipment that had not been encountered in field trials of the prototypes. These findings point towards ways of improving the hardware and software, and are detailed below. No funds have yet been allocated towards the implementation of these performance and reliability improvements, so many are on hold waiting such action.

RECOMMENDATIONS:

Detailed hardware change recommendations for acting on the information turned up in the long-term trials for both the current 10 units and any future units are described below under "Design Issues". In general, the units have performed well, but could use some updates based on what has been learned. Most updates can and are being handled as minor repairs under service calls or installation preparations. A few, such as engineering a remote display, a more robust isolation system for the electronics package, and finding and testing a more robust power supply will take significant engineering, lab and shop time.

Software updates, mainly relating to better documentation and some modification of system responses to various combinations of faults or errors, will also take a significant expenditure of time and money to produce. This is the most efficient time to do this, now that it is known through lengthy experience at a variety of sites which are the common and significant combinations of events to be addressed. In a complex set of software programs such as are used here, documenting every possible response to every possible combination of inputs before field-testing would have been an extraordinarily large and wasteful task.

We recommend that once the technical issues of accuracy, correlation with miner exposure, and suitability for purpose are confirmed, and we have every expectation that they will be, that the next stage of this program be to delineate and carry out a program of hardware and software updates as described below. The proper time to start this effort is probably after 4 or 5 more installations (i.e., those 4 or 5 occurring after 1/1/99) of the current units. This would provide the sufficiently wide variety of conditions at the significant time intervals needed to make sound judgements as to which environmental challenges are merely unique extremes and which need to be thoroughly addressed. The implementation of this effort should be to retrofit at least a few of the existing units with these improvements and then take them for even longer term testing and evaluation at what appear to be the most challenging but not unique sites. The overall goals of such a task would be to increase reliability and MTBF through physical and software improvements. A significant advance could be made by reorganizing the extensive self-diagnostics somewhat. We need to record all faults and possible tampering, but not let faults which don't need to be corrected until the regular monthly service interval interfere with the real-time display.

CONTINUING WORK BEYOND CONTRACT:

Under purchase orders from MSHA, we will continue to support the installation, re-installation and service calls for all CDM's. Any cost of final assembly and calibration, at R&P, of units 10,11,or 12 not covered by remaining contract monies will be covered by R&P.

RESULTS: OVERVIEW OF RECENT WORK AND INDIVIDUAL UNIT STATUS:

In general, the 5 units taken into the field are performing as well as expected for a new technology in a new environment for the first long-term test. Some units have run trouble free for a month or more after installation and some have had initial problems. Nine hardware items have had to be changed, reinforced, or replaced due to failure, fatigue, or component manufacturing defects which did not show up until the unit had been in the field for some time. In most cases, these repairs were made promptly and the changes retrofitted to all units quickly. Lessons learned on early units were applied to later units before they left R&P. Units being serviced for one problem were brought up to date on all the other known issues whenever practical.

Unit 3 was released from R&P in October of 1997. It was used extensively at the PRC for calibration of both the mass sensor and the preseparator and for refereed dust loading tests at various levels of dust concentration and humidity. It has been held back as a spare unit and parts have been "borrowed" from it several times to speed up repairs to units in the field. It is now back at R&P for updating to the latest standard. It is scheduled to be sent to Peabody Federal #2 mine after being used for the hands-on portion of the training at Beckley during the first full week of January.

Unit 4 was installed for "durability testing" at Consol's Shoemaker mine in mid September. Unit 4 was installed at this mine because a prototype used previously at Shoemaker had some real time display noise problems which might have been related to the severe service environment at that mine. The machine on which unit 4 was installed was apparently not used very much (or the monitor was left turned off a lot), but in any case, when used it gave good results until it sustained a very hard hit (600+ lb. rock from roof?) on the sensor unit inlet in mid October. The hit pinched and cut an internal temperature sensor wire. This problem was quickly diagnosed using the data files and handheld terminal. The unit was repaired at the PRC and returned to service. Again, viewing the data files shows that either the miner or the monitor was not being used much. Both the mine dust control system and the dust monitor itself were performing satisfactorily during those times when the monitor was turned on. Unit 4 was removed and transported to Consol's Blacksville mine on 12/9, but was not reinstalled. During final checkout above ground, a small leak was found in the pneumatic system which could not be located and repaired on site. It was decided to transport the unit back to R&P to both fix the leak (now known to be caused by some defective pneumatic "tee" fittings which deteriorate over time) and to perform all updates. It is now scheduled to be returned to Blacksville after being used for the hands-on portion of the training at Beckley during the first full week of January.

Unit 5 was installed at Garmeada mine at the end of August. It worked well and became popular with the miners. In late September, an improperly secured flow controller connector fell out of place and although this did not affect the proper data collection (the disconnected flow controller is only used to bypass flow during rock dusting, and is not used when coal is being cut) it put an error message on the screen which interfered with reading the real-time graph. The problem was quickly diagnosed and fixed. One other problem surfaced with this unit when a power supply component vibrated loose. Again the unit was fixed within a couple days and returned to service. Garmeada mine will soon be switching to low coal equipment and not using the Bridge where unit 5 was mounted. The unit is now in transit to will be returned to R&P for inspection and updates, and will also be used at Beckley for the training. It will be returned to Garmeada when they are ready to start using their new equipment setup, at which time it will probably be installed on a haulage vehicle.

Unit 6 was installed at Shamrock mine in eastern KY at the end of October. From the miner's reports, it would seem that it encountered vibration and shock far more severe than ever anticipated or specified in the contract scope of work. The power supply module and pneumatics module suffered several broken parts. The sensor unit and computer survived. It was returned to R&P for autopsy and reinforcement. It was repaired and the electronics were re-packaged on internal shock isolation mounts in a larger, steel XP box. It was returned to the mine on 12/6. It is still working well after several weeks in this very severe service, and is changing filters a lot in the average 7 mg/m^3 environment on the shear.

Unit 7 was installed in October at Baker mine in western KY. It has been running in very high dust levels, changing filters every other day. After about a month of this it went down with an unknown problem after failing to change one filter properly. R&P is reviewing the data files and will make a recommendation shortly on whether it can be field serviced or needs to be returned to R&P.

Again, not a bad record for a brand new piece of gear going into a very tough environment for the first long-term trials.

Units 8 and 9 are undergoing final alignment and calibration at R&P and will also be used at Beckley for the training. Unit 9 will be left without enclosures so that students can see the "works".

Units 10, 11, and 12 are undergoing final assembly at R&P. A few parts to be provided by or on loan to Bernie Olson at U Minn. will be needed to complete these units by late January in time for their scheduled installations.

DESIGN ISSUES:

A few issues with hardware, software, training, and documentation are coming to light with the field trials, as expected.

The hardware issues which have emerged are as follows:

1) Connectors: Access holes were not put in the pneumatic module chassis to allow installation of locking screws for the flow controller cable connectors. All modules now have these access holes and future ones will have them. No further action needed.
2) Power Supplies: Two large capacitors in one of the two power supplies were supported only by their lead wires. Vibration fatigued and broke the wires in two cases. It was not obvious from casual inspection that the support was this flimsy. For now, the capacitors are being glued to the boards to provide additional support. This should extend the life indefinitely for mild to moderate vibration environments and to a year

or more in those few cases where constant high vibration levels are found. Longer term we would like to use a better quality supply. A medium sized capacitor in the expensive IS supply also is supported only by its leads. It did not fail but would probably fail after several years at high vibration levels if not reinforced. Gluing it to the board is a permanent fix and will be performed as time permits on in-use supplies. Future supplies will be reworked when received until the vendor can be convinced to fix the potential problem.

3) High vibration and shock modifications: Where very high vibration and shock are encountered, such as on a longwall shear cutting lots of rock at mid panel, shock and vibration caused severe damage to a few structural parts of the modules in the XP box. Among the casualties were the welds on the pneumatic module's chassis uprights, scuffed wires, and several screws which backed out and became wedged in the modest suspension system for the electronics platform. The loose uprights and screws caused some collateral damage, such as cut hoses and wires, and damage to other components on the power supply board.

    3.1) Pneumatic module chassis: A prototype of a reinforced pneumatic module chassis is installed at Shamrock mine. Future units will use this design. No other units in mines have shown a tendency to fail this way so it has not been decided yet whether it is necessary to rework all current units this way.

    3.2) Larger box, better suspension: The steel XP box originally obtained to allow a horizontal window is strongly recommended for use in any installation which is anticipated to involve extra high shock and vibration. (Continuous miners, longwall shields, and continuous haulage bridges are not considered extra high). This particular steel box has more clearance around the electronics modules. This extra space will prevent scuffed wires or hoses and allows room for both a physically larger and lower resonant frequency suspension (higher degree of isolation) and the larger sway space it requires. A prototype of the improved version is installed at Shamrock mine. It is not known if Shamrock is a unique case. There are other benefits to the steel box as well, although its cost is about 3x the cost of the standard box. A somewhat smaller (1" shorter, 2" smaller front to back) steel box, preferably with remote mounted display, would be ideal for all cases and is our recommendation for future purchases. Steve Richardson at Mining Controls (MC) has provided drawings of a designed-for-MSHA but as yet untested and unapproved design fairly close to what would be needed for a remote display. MC is prepared to proceed with refining and testing the design if funds become available for design and integration. It is recommended that such a steel box be adopted as standard for any future units. As part of this change, it would be logical to use a somewhat larger electronics module base plate made of steel. The larger, stiffer plate would allow direct mounting of the shock mounts (prototypes are on subplates mounted on standoffs) and lower the cost of the overall assembly.

3.3) Loose screws: It has been the practice to use appropriate torque, Locktite, and/or locking nuts on all screws used in assembly of both the sensor and control units. None have come loose in the sensor units, where all screws were properly sized and all joints were designed to hold tight under severe vibration without the use of threadlocker when properly torqued. It has, however, become apparent that there are screws on purchased electronic components which are undersized or not properly torqued and retained for high vibration service. These will need to be removed, have threadlocker applied, and be properly torqued when re-assembled. This is now standard practice for new units and will be applied to existing modules if they come back to R&P for other service.

4) Tray guide: Over time it was found that dust was building up on the filter change tray and increasing the friction encountered as it slides into the mass transducer to remove filters. It was also found that the tray could bounce up under high shock loads and move to an inappropriate location. Both problems are cured by removing the hold-down springs on the tray and installing a fixed guide plate in its place to positively retain the tray from bouncing up. 10 pieces were made of this guide plate and all units have been refitted at this time. New units will have a small extension machined on the mass transducer intermediate plate which will serve the same function.

5) Armored Cable: Two different termination methods were used for this cable on prototypes, and both gave no trouble. In longer-term service and with more severe bending of the cable, however, it became apparent that the compression fitting used to terminate the armor was loosening up when the armor was twisted. A welded-on pipe nipple on slightly larger and heavier gage tubing, as used on units 6 and 7 shows much higher durability. The new design is simpler and cheaper,

but does require longer to obtain because the supplier has to be given the exact length and enough lead time to produce the assembly. We will use this setup for all new cables made for installation or re-installation and will use it for any new units ordered.

6) An assembly oversight led to installation of an improper value resistor for one of the heat zones in a few sensor units. This did not affect the safety or function of the heat zones but did cause a decrease in voltage available to the hand held computer and prevented its use during warm-up in one case. All affected units have had the offending resistor replaced or disconnected (disconnecting adds 5 min to warm-up time, has no other effect). A new value was selected for replacement use to leave a wider margin of available voltage for the hand held. For future units, we will want to revisit the sizing of both the dropping resistor on the handheld and this heater resistor to optimize both handheld performance and warm-up time.
7) Pneumatic Tees: This is perhaps our most insidious problem. Easy to cure, but it was very hard to diagnose. 9 nylon plastic "tee" fittings are used in each unit; mainly to provide vacuum or vent to dual cylinders or to provide pressure measurement taps on flow lines. These parts initially seal well and pass all tests, but apparently start to leak after several months due to relaxation of the tubing over some flash left on the "barbs". They also have the perverse property that they leak more under low flow rates and low vacuum than high vacuum and high flow rates, thus escaping detection when subassemblies were tested using "house" vacuum. We are presently on a campaign to replace all such fittings with a better made polypropylene tee with less flash and a slightly larger diameter. All units except 6 and 7 will have the new tees by 12/21, and some current problems with 7 may be a result of this delayed action defective component. Obviously all new units will have the improved tees.
8) An assembly misunderstanding resulted in leaving out the weather-stripping along the piano hinge at the back of the sensor unit cover on several units. This resulted in one unit shipping some water in a case where a water spray was trained directly on the unit for 24 hours. No permanent damage occurred, just some surface rust on internal unpainted steel structural components. The missing piece of seal will be installed on all units in the field at the first service call.

The software issues, which have emerged, are as follows:

1) Error messages: Better handling of error messages is needed. As written, the software displays messages for "errors" resulting from transient, self-correcting events, long after the error condition has cleared itself. This has caused confusion among many users. Education will help, once the classes take place, but a re-write of this

function is in order. A more serious problem is that a persistent error, even if it is of a type which could wait for correction until regular monthly service, can disrupt use of the real-time graphical display.

2) PRC definition. A more comprehensive list of all the possible entries which the program itself can put into the PRC's is needed and is being put together. These will aid in diagnosis of problems or tampering events.
3) The post-mine data viewing software has gone through many changes to combat the tendency of MS Windows to mess with the time scale and offset it by several hours when translating the data from the compacted binary format to the expanded format suitable for plotting. This needs to be checked by new users and monitored as it is tried out on more computers, since system settings and computer brand seem to be involved also. The check is easy: The first data entry time should be within a minute or two of the time used as part of the file name. Unfortunately this is one of those we-can't-fix-it-till-its-broke type of issues, so each time a new installation is made it needs to be checked for proper operation.
4) The PRC list needs to be reorganized in a more logical fashion, the names of the PRC's need to be more concise and more descriptive, and the numbers need to show on the handheld when scrolling. A start was made at renaming and re-ordering, but was halted when phase 3 was wrapped up. This is still worth doing when time and money are available.
5) The SOD list needs to be made easier to use and understand by simplifying the entries to a single range for each file. It would also be nice to allow changing PRC setpoints on the SOD screen so that one trip through the list could be used to set up an entire instrument. It now takes 2 trips, one through the150 item PRC list and one through the 300 item SOD list, with up to 5 entries required per PRC.

APPROVAL ISSUES:

Units 3 thru 7 have been inspected and approved for experimental use by MSHA, and the 110 vac connections for 4 thru 7 have been inspected and approved in place on various types of mine machinery. A schedule needs to be set for units 8 thru 12. R&P would prefer having our own technician perform the extensive disassembly and re-assembly required.

WORK PLANNED

Dec.
Finish assembly, calibration and test of units #8&9

Jan. 99
Finish assembly, calibration and test of units #10, 11, 12
More installations
Classes at Beckley

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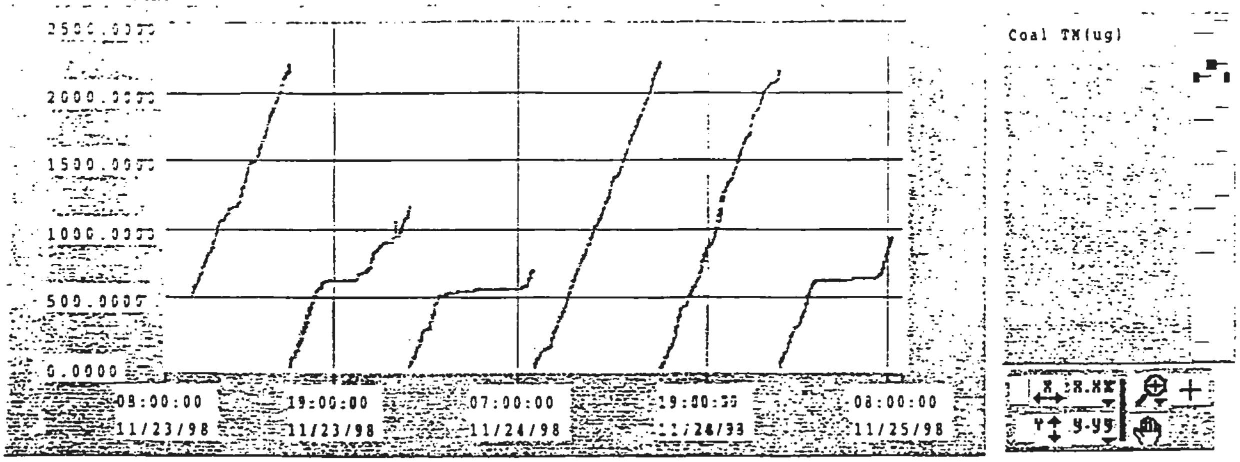
Graph 1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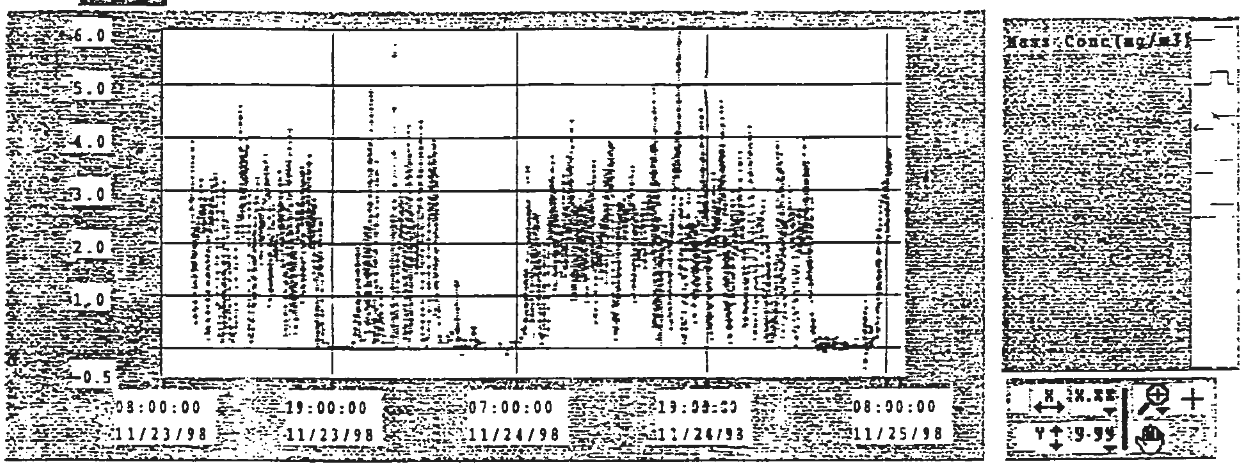
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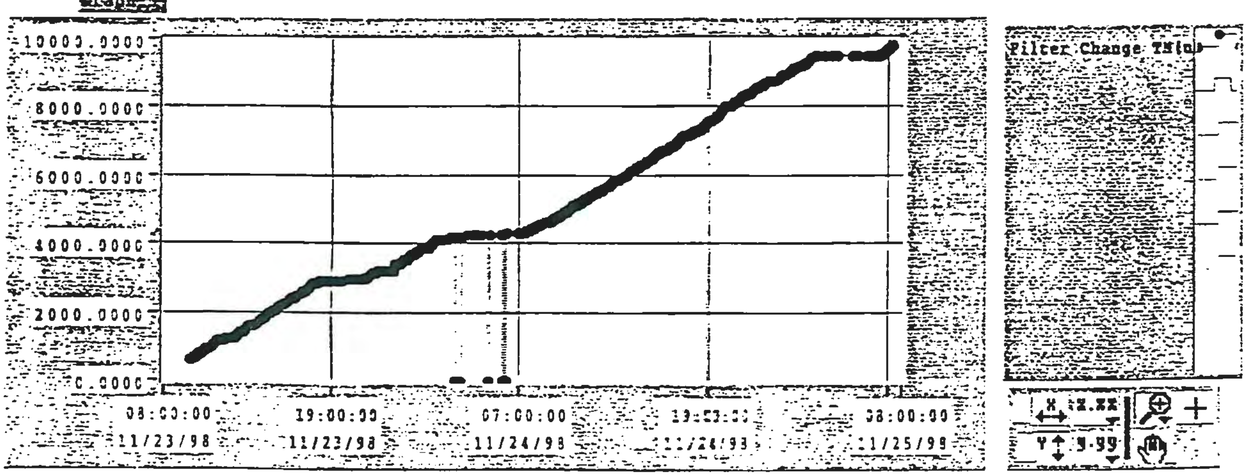
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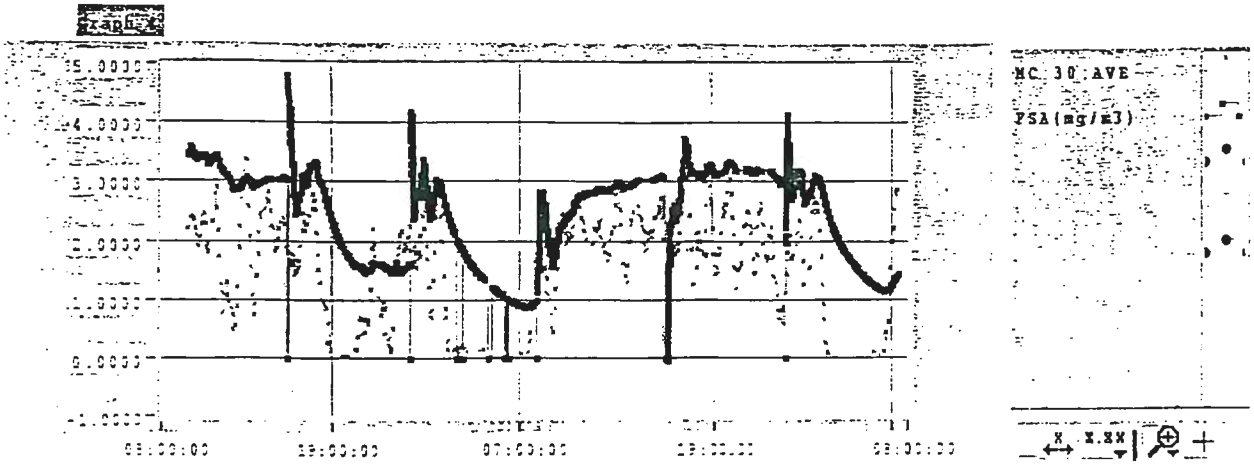
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08:00:00
MC 30 AVE
PSA(mg/m3)
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DM Graph Screen
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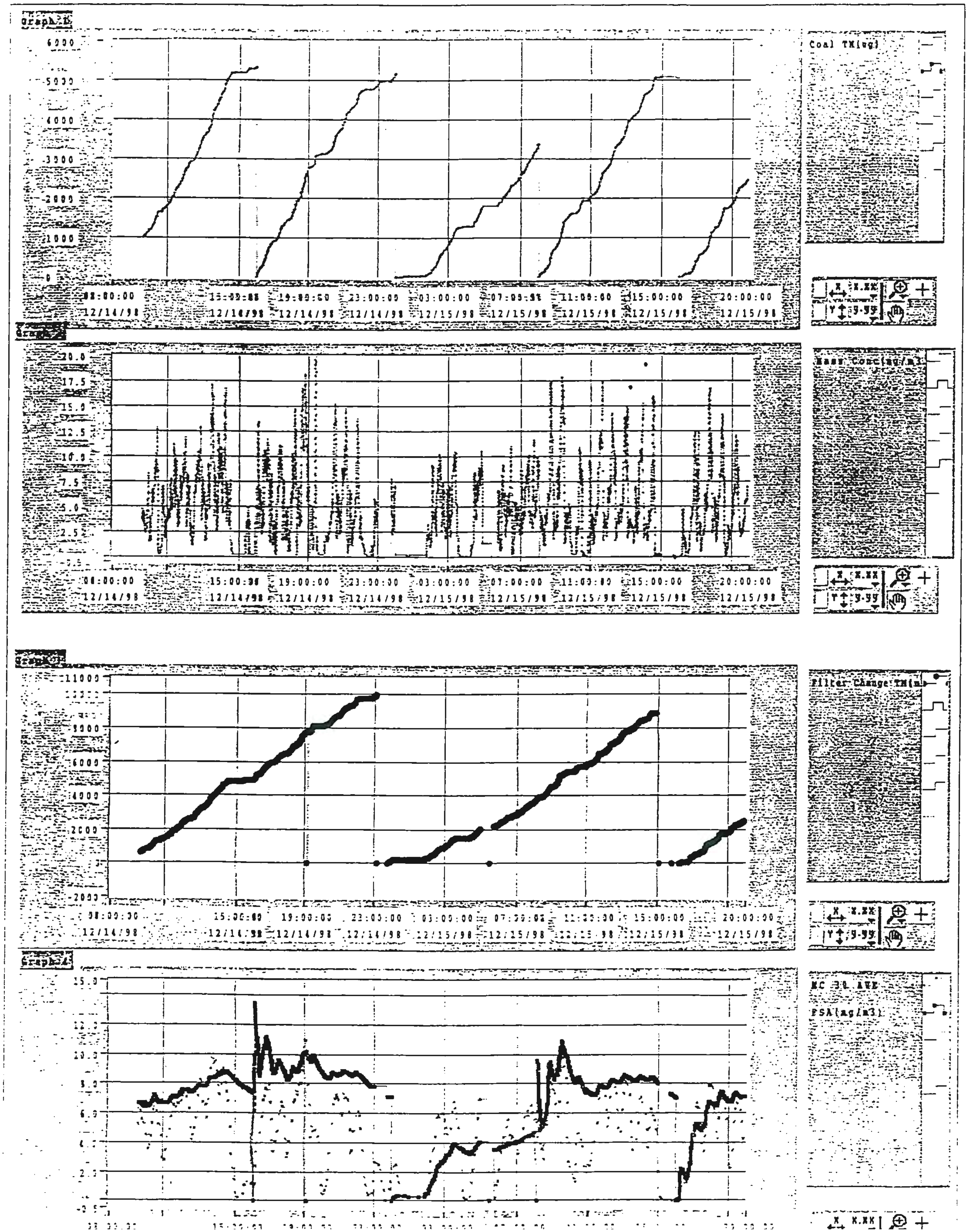

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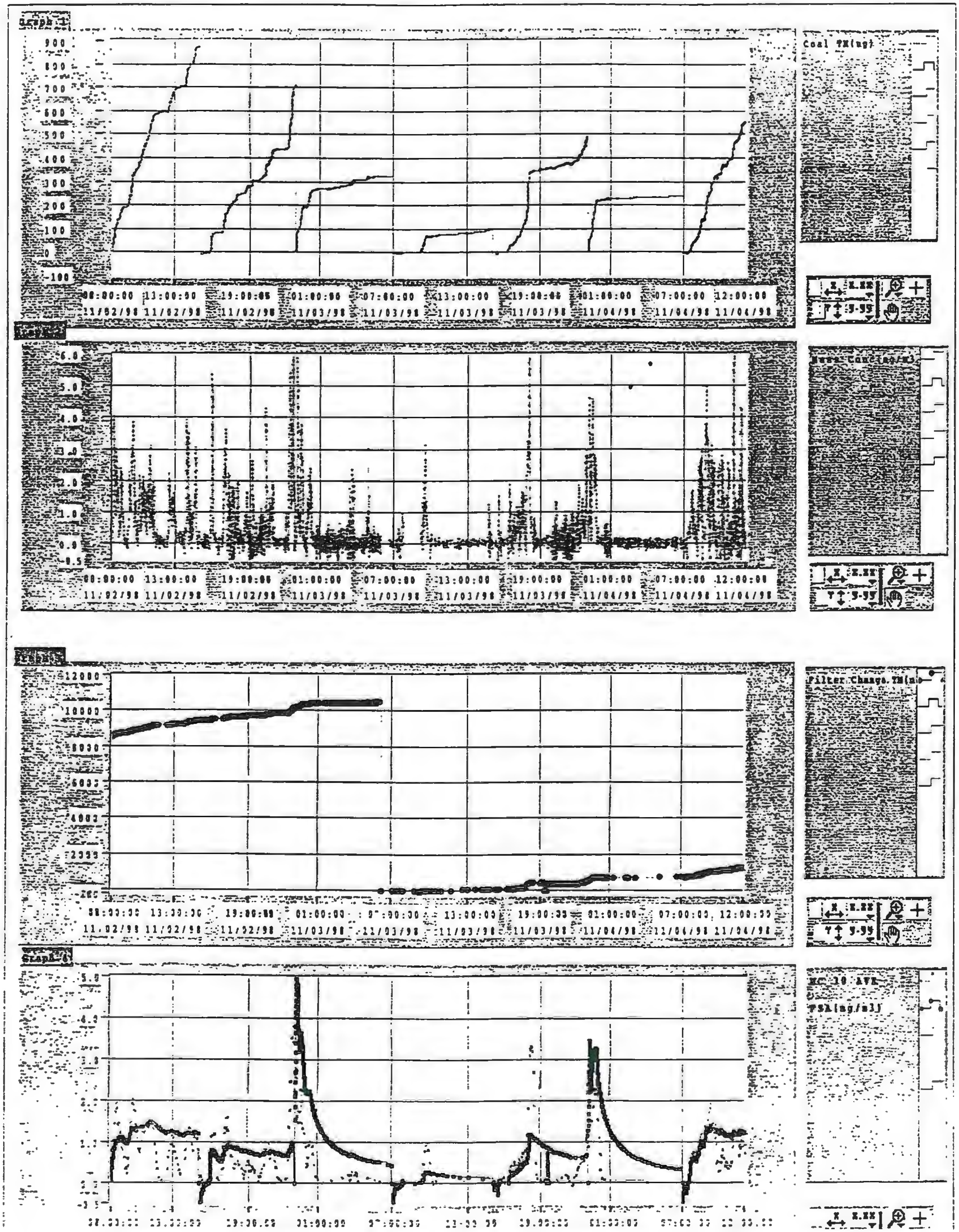

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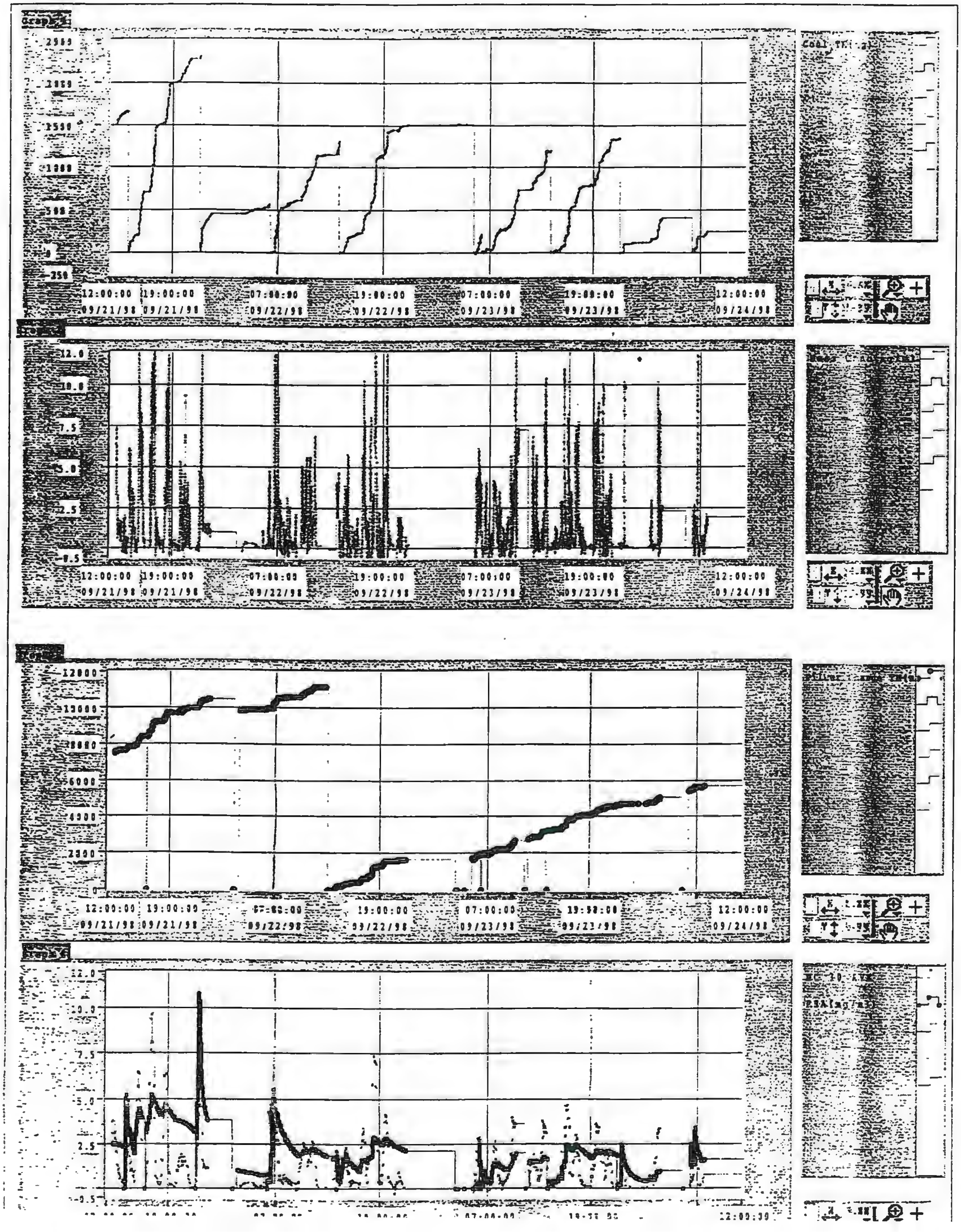

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NIOSH Pittsburgh Research Laboratory Unpublished Reports
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1. Final Contracts Reports

1. Hassel D, Patashnick H, Rupprecht G [July 1994 - Dec 1998].
   Contract No. 1432-H0240001. Continuous dust monitor (CDM) for underground coal mines.