Paper Number:
DOE/MC/29118-97/C0794

Title:
Field-Usable Portable Analyzer for Chlorinated Organic Compounds

Authors:
W.J. Buttner
W.R. Penrose
J.R. Stetter
R.D. Williams

Contractor:
Transducer Research, Incorporated
600 N. Commons Drive, Suite 117
Aurora, IL 60504

Contract Number:
DE-AC21-92MC29118

Conference:
Industry Partnerships to Deploy Environmental Technology

Conference Location:
Morgantown, West Virginia

Conference Dates:
October 22-24, 1996

Conference Sponsor:
Morgantown Energy Technology Center

Disclaimer

To be published in the Morgontown Energy Technology Center Conference on Industry Partnerships to Deploy Environmental Technology, Morgantown, West Virginia, October 22-24, 1996.

Field-Usable Portable Analyzer For Chlorinated Organic Compounds

William J. Buttner (wbuttner@interaccess.com; 630/978-8802)
William R. Penrose (wpenrose@interaccess.com; 630/978-8802)
Joseph R. Stetter (jstetter@interaccess.com; 630/978-8802)
Transducer Research, Inc.
600 N. Commons Drive, Suite 117
Aurora, Illinois 60504

Roger D. Williams (rwilliam@tsi.com; 612/490-2863)
TSI Incorporated
P.O. Box 64394
St. Paul, Minnesota 55126

INTRODUCTION

In 1992 a chemical sensor was developed which showed almost perfect selectivity to vapors of chlorinated solvents (Stetter and Cao, 1993); no measurable response has been observed for a broad range of compounds including organic hydrocarbons (e.g., benzene, toluene, and xylenes--BTX), petroleum products (POLs), inorganic contaminants (e.g., NOx), and both organic and inorganic sulfur compounds (e.g., hydrogen sulfide, mercaptans). Thus, when interfaced to an instrument, a chemical analyzer will be produced that has near-absolute selectivity to vapors of volatile chlorinated organic compounds (CVOC). The design and deployment of such an instrument system was the theme of a project supported by the DOE Morgantown Energy Technology Center.

Transducer Research, Inc. (TRI) has just completed the second of a two-phase program to develop this new instrument system. In the Phase I effort, prototype instruments were built and tested in actual DOE operations. Special emphasis was placed upon making the instrument user-friendly. Because of the high selectivity to vapors of chlorinated solvents, the instrument was call the RCL MONITOR ("R" refers to a general organic molecule and "CL" refers to chlorine). Through interactions with DOE personnel during the Phase I effort, numerous applications were identified which would benefit from use of a selective chlorinated solvent vapor monitor. These operations can be categorized as:

Support provided by the Environmental Management Office of Technology Development through Morgantown Energy Technology Center under DOE Contract: DE-AC21-92MC29118 with Transducer Research, Incorporated, 600 N. Commons Drive, Suite 117, Aurora, Illinois 60504 (telefax: 630/978-8854).

- Environmental Compliance
- Health and Safety
- Process Monitor (e.g., Vacuum Extraction)
- Environmental Modeling Studies
- Site Characterization

In Phase II, the RCL MONITOR was deployed in several EM40 operations. This expanded deployment resulted in case studies representative of a broad range of environmentally significant applications. Phase II applications encompassed clean-up process monitoring, environmental modeling, routine monitoring, health and safety, and technology validation. The effort not only involved the technical deployment of the RCL MONITOR for specific operations, but also close interaction with cognizant regulators to assure that the technology and methods will fulfill necessary regulatory requirements. The focus of the program was to develop new technology that has expanded capabilities and lower operating costs relative to existing methods. Independent cost analysis indicated that significant cost saving could be achieved with the RCL MONITOR for many applications (Energetics, 1993). A cost benefit analysis was performed to quantify the cost savings associated with using the RCL MONITOR. In addition, advanced sampling systems are being developed to allow chemical analyses to be performed on aqueous samples. A description of the development and deployment of the RCL MONITOR is available (Buttner et al., 1995, 1996).

A commercial version of the RCL MONITOR (Figure 1) is now available. Industrial funding has made this new technology available to all potential user groups. Vapor levels between 0 and 100 ppm can be determined in 90 s with a lower detection limit of 0.5 ppm using the hand-portable instrument. The RCL MONITOR can save operating costs and pay for itself in a short time. Further, it allows field personnel to operate with increased safety.

OBJECTIVES

Chlorinated solvents, such as carbon tetrachloride or trichloroethylene, were extensively used as degreasing agents in industrial operations. Because of past handling, storage, and disposal procedures, environmental contamination occurred at many of these sites, transforming them into hazardous waste sites. CVOC contamination of soil and ground water is recognized as a major hazardous waste problem at numerous government and private installations (OTA, 1991). There are extensive ongoing environmental restoration programs for the removal of subsurface CVOC contamination. During the remediation process, from site characterization to closure, chemical monitoring is necessary to assure worker safety, locate contaminants, verify environmental compliance of standards, automate process equipment, and track the actual cleanup process.

Until recently, the only available technology to selectively analyze for chlorinated organics was a gas chromatograph (GC) equipped with electron capture detector or mass spectrometer detector or FTIR spectrometry. Other detectors (e.g., photoionization detectors) can not distinguish between chlorinated and nonchlorinated compounds like BTX which often occur in much higher concentrations. In addition to being expensive, gas chromatography requires grab samples and does not easily provide real-time answers. FTIR is expensive, non-portable, and can suffer from interferences. The shortcomings of laboratory methods have been recognized for certain applications that demand quick response or analyses of large numbers of samples. Field analytical methods (FAMs) are being developed as attractive and cost-effective alternatives (Carpenter et al., 1994). The RCL MONITOR is capable of providing valuable data quickly and accurately. This in turn allows for informed decision making in a timely manner heretofore not possible.

Although our efforts focussed entirely on government operations, there exists a need to monitor CVOC vapors in the private sector as well. While there are moves to limit or ban the use of chlorinated organic compounds, these compounds are still critical components in industrial processes. Production of various chlorinated solvents is still strong as indicated by the following list (Hileman and Long, 1994):

methylene chloride	237 million pounds
carbon tetrachloride	340 million pounds
trichloroethylene	102 million pounds

Although the production of many of these compounds did decrease significantly from 1980, they remain critical components in the pharmaceutical, photochemical, petroleum and other industries. Regulatory controls on these chemicals have become increasing stringent, with lower exposure limits and lower allowable emissions. These tighter controls emphasize the need for an inexpensive method for CVOC analyses to protect human health and the environment.

APPROACH

Prior to working with METC, TRI had produced a chemical monitor based upon the selective response of the RCL Sensor. Deployment of the early versions of this instrument demonstrated that a need exists for a convenient method to measure chlorinated solvents (Vaughn and Martin, 1993). This early instrument, while exhibiting unique and essential analytical properties, had shortcomings which impeded its general deployment. TRI recognized that to exploit the analytical properties of the RCL sensor, it would be necessary to develop an instrument system that was reliable and easy to use. The opportunity to redesign and test a new instrument based on the RCL Sensor was provided by DOE METC. The prototype instruments developed in the Phase I effort accomplished this goal. It was then necessary to test the instrument in the field as well as over a full range of applications for which it might be useful. During the Phase II effort, the RCL MONITOR was deployed in five EM40 operations. While these case studies were being performed, the design and performance of the RCL MONITOR was continuously assessed. On the basis these case studies, TRI, in conjunction with TSI Incorporated, our parent corporation, embarked on a final commercialization of the instrument to fulfill all field applications. At the same time as the deployment in EM40 operations was ongoing, TSI Incorporated evaluated the private sector market and did indeed identify a need for the RCL MONITOR. TRI and TSI Incorporated have made a significant investment of in-house funds to support product development of both the RCL MONITOR and the RCL Sensor. This in-house investment has resulted in the availability of a commercial product line with much higher reliability and improved performance compared to the prototype instrument systems that were actually used in the case studies.

PROJECT DESCRIPTION

The RCL MONITOR was developed, field tested and deployed. Several DOE EM40 operations were identified that would benefit from the selective detection and quantitation afforded by the RCL MONITOR. Case studies have been performed at DOE Hanford, Savannah River Site (SRS), and the Idaho National Engineering Laboratory (INEL). The selected operations are representative of activities throughout DOE. Specifically, the RCL MONITOR was evaluated in the following EM40 activity:

- Routine Quarterly Monitoring (INEL)--(Monitoring wells)
- Health and Safety Applications (Hanford)--(Survey and workspace monitoring)
- Vapor Extraction System (Hanford)--(Process control)
- Environmental Modeling Studies (Hanford)--(Research)
- Environmental Technology Demonstration (SRS)--(comparison and validation)

The deployment plan included use of the RCL MONITOR for the specific operation, interaction with the cognizant regulator (including Project Manager, State Environmental Officers, and local DOE Officers), and assessment of benefits. To facilitate deployment, TRI has developed a formal training class on operation of the RCL MONITOR

From an operational point of view, applications for the RCL MONITOR can be classified into two general categories--discrete sampling with manually initiated analyses (e.g., operation of the instrument in SURVEY Mode) and unattended continuous operation (e.g., operation of the instrument in MONITOR Mode). The RCL MONITOR is capable of both applications because the software will configure the instrument to automatically perform the operation selected by the user.

Discrete Sampling Applications (SURVEY Mode). Discrete sampling and analysis is simply the operation of the instrument in the manual mode (e.g., SURVEY). It is relevant for health and safety measurements when the results are needed immediately. Discrete sampling is also used for area surveys which involve on site analyses of samples, such as well head or soil gas samples. Accuracy and reliability can be verified on-site simply by performing validation runs using vapor mixtures of known concentrations.

Continuous Monitoring Applications. It may not be convenient or even possible to manually perform analyses, especially if the measurements must be performed around the clock. Continuous monitoring allows for unattended repetitive operation and is useful both as a process monitor and as a continuous monitor for fugitive emissions. The major difference between continuous monitoring and discrete sampling applications is simply that the user does not have to be present during analyses. The instrument may be set up as a monitor to collect analytical data, or it may be set up to alarm when threshold concentrations are exceeded. Because of the need for extended reliable operation, continuous monitoring is significantly more demanding than discrete sampling.

The parameters and requirements for using the RCL MONITOR are defined primarily by whether the instrument is operated continuously or discretely.

RESULTS

Routine Quarterly Monitoring (INEL)

The Routine Quarterly Monitoring (RQM) consisted of a mandatory quarterly groundwater and vapor sampling and analysis for chlorinated organic contamination in wells surrounding the Radioactive Waste Management Complex within the INEL site, and was an ideal example of the discrete sampling protocol. Samples were obtained from vapor ports and analyzed using a remote on-site gas chromatograph to determine the total concentration of chlorinated organic constituents. Groundwater samples are collected and sent off-site to an analytical laboratory. The RQM requires the collection and analyses of 66 vapors samples from 21 wells and six water samples from six wells. The wells are sampled to characterize the distribution of organic contaminants in the saturated and vadose zones. Original protocols required the collection, transport, and remote analyses of all samples by gas chromatography. Approximately two man-weeks of effort were required for the vapor analyses, and an additional one to two man-weeks for the water samples. Being performed four times annually, this was a labor-intensive exercise which ties up trained personnel. The RCL MONITOR was deployed as an auxiliary analytical tool for the vapor portion of the RQM in June of 1994. Excellent agreement was obtained between the two methods. Because of this agreement, the RCL MONITOR was used as the baseline technology for the vapor portion of the RQM. Since samples no longer need to be transported to a remote laboratory for analysis, a significant time and cost saving is achieved with using the RCL MONITOR. The vapor analyses can be completed in less than 2 days, compared to the 2 man-weeks normally required. A cost analysis, presented in Table I, summarizes the expected savings. The local regulators allowed the use of this field method because of the proven performance of the RCL MONITOR.

Health and Safety (Hanford)

Health and Safety of site workers is the most important application of the RCL MONITOR and illustrates the need for real-time measurements better than any other application. The RCL MONITOR was originally designed to protect the health and improve worker safety, which incorporated two generic applications: survey measurements, or spot checks, manually initiated by the operator to determine the presence of hazardous vapors; and continuous (generally unattended) measurements, taken at regular intervals, for monitoring workspaces and breathing zones. In the RCL MONITOR, we refer to these operating modes as SURVEY and MONITOR, respectively.

During a four-month deployment, nearly 100 measurements were taken by our collaborator at Hanford (Buttner et al., 1995a). Although many of the measurements were used to check vapor levels at well drilling operations, most were used to survey cuttings from well drillings. The results of these measurements determined whether the cuttings were to be treated as hazardous waste or simply discarded. No contaminated drill cuttings were detected. Large but undocumented cost savings resulted from this simple operation, since the six drums of cuttings from each well would have been treated as hazardous waste, if the RCL MONITOR had not been available.

Continuous monitoring was used during the field trials of an alternate method for recovering liquid carbon tetrachloride from soil vapor, developed by PURUS Inc. The PURUS prototype was enclosed in a tent; air from the breathing zone inside the tent was drawn outside to an RCL MONITOR housed in a protective enclosure. Persons entering the tent were expected to consult the display of the RCL MONITOR before entering. Measurements were taken at 15 minute intervals for four months; the only failure occurred when a direct lightning strike disabled both the PURUS prototype and the RCL MONITOR. Usually, carbon tetrachloride vapor levels were near background, but one week of data at the beginning of the project showed several interesting features, including spikes of CCl_4 that nearly reached 20 ppm (Figure 2). In this application, the RCL MONITOR improved worker safety.

Vapor Extraction System (Hanford)

During the plutonium production period, between 363,000 and 580,000 liters of carbon tetrachloride were discharged in three locations within Hanford. As part of the Accelerated Cleanup Activities (the Carbon Tetrachloride Site Expedited Response Activity), medium-scale vacuum extraction systems have been set up in the 200W area of Hanford to suck soil gas from the waste sites and absorb the carbon tetrachloride on activated charcoal. Three cartridges containing 1000 lb. granular activated charcoal (GAC) each were connected in series to assure that the exhaust to the atmosphere contained less than 25 ppm CCl_4. The most critical sampling point in the system was between the first and second cartridges. Breakthrough was detected here and indicated when it was time to change cartridges. When breakthrough occurred, the carbon tetrachloride vapor concentration could increase from a few ppm to 1000 ppm or higher over a few hours. This concentration was outside the range of the RCL MONITOR, so we developed a custom sampling interface that automatically diluted the incoming sample until it was within range (Penrose et al., 1995).

Data were collected at roughly 1.5 hourly intervals for a five-month period. Representative data for one week are shown in Figure 3. Carbon tetrachloride concentrations were correlated with the logbooks for the vacuum extraction systems, such as GAC breakthrough and replacement, power failures, waterlogging of the system, and holiday shutdowns. Reliability of our sampling system, defined conservatively as full weeks of uninterrupted data, was only 65% overall, although for the last three months, this improved to 80%. The main failure modes were sensor failure, unscheduled power outages, and lightning strikes. The deployment was ended when it became unlikely that the RCL MONITOR would not be adopted as a process controller for the vacuum extraction system. We did demonstrate that the RCL MONITOR can operate as a process controller or monitor when properly installed and maintained.

Environmental Modelling Studies (Hanford)

Geological and geophysical modeling research at Hanford supports the ongoing cleanup activities. A promising technology is passive soil vapor extraction, which uses natural excursions in barometric pressure to pump contaminant-laden vapor from soils. This process proceeds regardless of human intervention, so research is aimed at improving and assessing its effectiveness. Wells already present at the contaminated sites increase the total amount of carbon tetrachloride emitted into the air as barometric pressure falls. Other improvements such as valves to force a one-way flow of air are being developed. Passive soil vapor extraction is viewed as a cost-effective complement, rather than a replacement, for energy-consuming active methods such as vacuum extraction (Rohay et al., 1994).

Under this project, we provided RCL MONITORs and automatic dilution systems (developed for the process control application, above) to Hanford geologists to measure carbon tetrachloride emissions. Data for a one-month period are shown in Figure 4, together with the barometric pressure readings for the month. The correlation between pressure decreases and CCl_4 emissions is clearly seen. These studies are continuing beyond the end of the METC-funded part of the project. The RCL MONITOR offers a new capability that is valuable to field research activity.

Summary

A large database on the performance capabilities of the RCL MONITOR was obtained from the deployment in EM40 operations. From this expanded database, it was recognized that certain design features were not completely adequate for field use, and accordingly it was necessary to embark on a redesign of the internal features of the RCL MONITOR. Prior to releasing the instrument for sale, it was necessary to confirm that the performance of the revamped RCL MONITOR would be similar to that obtained with the design used in the field studies. This involved extensive evaluations, both in the laboratory and in actual field operations. Following a thorough laboratory testing, the instrument was field tested and results compared to much more sophisticated instrument systems. Specifically, vapors were collected from wells surrounding the RWMC in the INEL and analyzed by the RCL MONITOR and by a B&K Photoacoustic Spectrometer. The vapor concentrations as determined by the RCL MONITOR compared well to the total CVOC concentration as determined by a B&K Photoacoustic Spectrometer (Figure 5). Based on the favorable performance of the RCL MONITOR, the commercial instrument was released for commercial sales on September 20, 1996. Final product specifications are summarized in Table II.

One note in passing: The decision to proceed with the commercialization of the RCL MONITOR resulted in setting up updated production facilities for both the RCL Sensor and Instrumentation. The refixturing of the RCL Sensor Production Facility has resulted in RCL sensors with improved reliability, stability, and repeatability. With this new sensor, the use of the RCL MONITOR as a continuous process monitor has also improved in reliability. Figure 6 illustrates the performance of the RCL MONITOR under a worse-case vapor concentration (e.g., maximum level) over a period of 60 hours. Every measurement was within ±10%, much better than the specified ±30% in the published specifications. This new sensor was not available for use in any of the case studies described herein, but it is part of the standard product line currently in production.

BENEFITS

The instrument is simpler to use than any selective chlorinated hydrocarbon sensor available. Field personnel can be trained in less than five minutes to operate the instrument (a full training session, developed as part of this project requires about 2 hours). Real time data collection, heretofore not possible, on the temporal and spacial characteristics of chlorinated vapor emissions has been obtained using the RCL MONITOR. The use of the RCL MONITOR will provide improved field operations, better worker safety, and significant cost savings in hazardous waste operations. It should be stressed that the RCL MONITOR will not distinguish among different CVOCs in a sample. For those situations where speciation is necessary, some means of separation is required, and the only sure way of speciating complex mixtures of VOCs is with gas chromatography. In many applications, speciation is not necessary and the added expense is not justified.

The RCL MONITOR can provide cost-effective analytical capability not found in any other truly portable instrument system. It is a powerful tool for the rapid on-site determination of chlorinated solvent vapors. A range of 0 to 100 ppm and a LDL of 0.5 ppm were achieved. Independent cost analyses performed during the developmental of the RCL MONITOR indicated that the potential cost savings for the RCL MONITOR could be significant (Energetics, 1993). An actual cost-benefits analyses performed during the field deployment confirmed this proposition. When used at the INEL as the baseline technology for the Routine Quarterly Monitoring, a cost savings of nearly 70% was achieved relative to the traditional laboratory methods originally deployed. The RCL MONITOR was accepted by the local regulatory agencies.

During the deployment of the RCL MONITOR in EM40 operations, it was most successful in the discrete operation mode in which the operator would manually initiate each analysis. These particular operations included the Routine Quarterly Monitoring at INEL and even more importantly, Health and Safety Applications within the 200W area of Hanford. For the Health and Safety applications, there is no other simple portable instrument available which is capable of providing on-site, near real-time selective determination for carbon tetrachloride and other CVOCs at the required levels.

The RCL MONITOR was used as a continuous monitor in EM40 operations, but with limited success. Alternative technology, particularly photoacoustic spectrometers have been adopted by many for continuous monitoring applications. This is particularly true for those applications where analytical costs are not limiting factors, so that the operations can afford the cost of the more expensive instruments. In these applications, site operators were not so inclined to invest the time to operate the RCL MONITOR. However, for those operations on a more restricted capital budget or where portability is critical, the RCL MONITOR can provide a cost effective real-time monitor for total CVOC. For those applications where the vapor level is normally low, such as a breathing zone monitor for health and safety, the RCL MONITOR did prove itself as a continuous breathing zone monitor

FUTURE ACTIVITIES

With support from METC, TRI was able to develop a monitoring technology for CVOC. This technology was demonstrated in numerous DOE EM40 operations. From these case studies, TRI was able to develop the specifications for a commercial product line that is presently under production and is being marketed through the Health and Safety Division of TSI, Incorporated.

We are now expanding the applications of the RCL MONITOR. CVOC contamination in the aqueous phase is a major environmental problem. In 1995 a Self Directed Research Contract (SDRC) proposal was granted from DOE EM-50 to develop a low cost sampling system for use in ground water. The project was a collaboration between the Lockheed Idaho Technology Company of INEL and Transducer Research Incorporated (support provided by LITCO contract # C95-175582; Buttner, Dooley, and Barrie, 1996). The sampling system that was developed could be installed directly into groundwater wells and has been nicknamed the In-Situ Sampler (ISS). The (ISS) is a device that consists of a semi-permeable sample tube coiled inside a protective housing. Several of these samplers can be manually lowered into a well to discrete depths and allowed to remain in the wells for at least 24 hours or until equilibrium is obtained between the groundwater concentration and the vapor concentration inside the sample tube. The vapor sample can then be collected from the sampler and analyzed by any convenient vapor method. This vapor concentration correlates with the concentration in the ground water using calibration curves developed in the laboratory. Methods for TCE have been developed. Figure 7 shows the ISS calibration curve for TCE using the RCL MONITOR and a laboratory GC. As expected, both analytical methods give identical results, although the RCL MONITOR-ISS system has a lower detection limit of 10µg/L, while with the GC the LDL is below 5µg/L. There are several advantages of the ISS relative to the conventional method of pumping water samples to the surface: 1) vertical profiling of plumes can be achieved by deploying multiple samplers at various depths in a well, 2) there is absolutely no waste water pumped to the surface, and 3) the sample can be conveniently analyzed onsite by any CVOC vapor analysis techniques (e.g., the RCL MONITOR).

One second development is the reconfiguration of the RCL MONITOR for deployment in cone penetrometers. The Site Characterization and Analysis Penetrometer System (SCAPS). consists of a hydraulically operated cone penetrometer test (CPT) unit mounted in a custom-engineered 20-ton truck. The truck houses two separate, protected work spaces to allow access to contaminated sites with minimal risk to the work crew. In addition to geophysical measurements, the recent SCAPS developments included the capability to accommodate various sensors and samplers for use in collecting data on specific classes of subsurface contaminants. SCAPS technology can provide chemical contaminant information together with depth profiling (stratigraphy) at a fraction of the time and cost of conventional well drilling and sampling operations (Schroeder et al., 1991). A number of additional penetrometer sensor technologies are being developed by DOD, DOE, and EPA to enable SCAPS to characterize sites containing heavy metals, solvents, and explosives contamination. The RCL sensor and associated circuitry was reconfigured for installation into the SCAPS probe. An umbilical allowed for electronic communication of the sensor signal to the surface. Presently, the sensor response is logged with a computer and data work up is performed using standard spreadsheet software. Field testing demonstrated the viability of the RCL/SCAPS sensor system to provide rapid in-situ contamination depth profiles. In addition to the deployment of the RCL Sensor in SCAPS, a sensor system capable of measuring total VOC contamination (e.g., BTX, POLs, and all other volatile organic contaminants) is being developed for SCAPS and other applications. TRI work on SCAPS was supported by Waterways Experiment Station, Contract No.: DACA39-95-K-0016.

ACKNOWLEDGEMENTS

The assistance and support provided by the Office of Technology Development of EM50; Curtis Nakaishi, the project Contracting Officer Representative (COR) from September 1992 to September 1994; C. Edward Christy, the COR from October 1994 to June 1995; and Rodney Geisbrecht the COR from July 1995 to October 1996 are acknowledged. The authors also acknowledge the assistance and support provided by our colleagues and collaborators working on EM40 operations at the laboratories including Dr. Kirk Dooley and Scott Barrie of the Lockheed Idaho Technologies Company (LITCO) at the Idaho National Engineering Laboratory; Joseph Rossabi of the Westinghouse Savannah River Company; Virginia Rohay, Jon Fancher, Bruce Tuttle, Randy Coffman, and John Fisler of DOE Hanford, Cary Martin and Torry Webb of Nuclear Fuel Systems, Richland, WA. A special thanks is given to Dr. L. M. Fingersen of TSI Incorporated for contributing in-house funds to improve the RCL Sensor and to set up the production of the RCL MONITOR.

REFERENCES

W.J. Buttner and R.D. Williams, "Field-Usable Portable Analyzer for Chlorinated Organic Compounds", Topical Report for DOE Contract DE-AC21-92MC29118, DOE Report DOE/MC/29118--5014 (May 1995).

W.J. Buttner, W.R. Penrose, J.R. Stetter (1995a) Proceedings of the Environmental Development through industry Partnership Meeting, Morgantown Energy Technology Center, Department of Energy (October 3-5, 1995) 445-454.

W.J. Buttner and W.R. Penrose, Field-Usable Portable Analyzer for Chlorinated Organic Compounds, Final Report for DOE METC Contract DE-AC21-92MC29118, Reporting period: 12 June 94 to 10 October 1996

K. Dooley, S. Barrie, W. Buttner, "In-Situ Sampling of Aqueous-Phase Contamination of Chlorinated Solvents", Presented at the DOE Technical Information Exchange Meeting, Santa Fe, NM (April 1996).

Energetics, Inc. and Morgantown Energy Technology Center (1993) "Evaluation of the Cost and Benefit of the Rare Earth Semiconductor Technology for Field Detection of Chlorinated Hydrocarbons" prepared through DOE Contract No. DE-AC-21-92MC29231, in press.

S. Carpenter, P. Doskey, M. Erickson, and P. Lindahl, "Performance Specifications for Technology Development: Application for Characterization of Volatile Organic Compounds in the Environment" Argonne National Laboratory (DOE) Report ANL/ER/TM-3 (July 1994).

B. Hileman and J. R. Long, "Chlorine Industry Running Flat Out Despite Persistent Health Fears", C&E News (November 21, 1994) 12-222.

Office of Technology Assessment, U.S. Congress (1991), "Complex Cleanup: The Environmental Legacy of Nuclear Weapons Production, OTA-404 (Washington, DC: U.S. Government Printing Office, February).

W.R. Penrose, W.J. Buttner, W.C. Vickers, V.J. Rohay, J.D. Fancher, and C. Martin, "Continuous Monitoring of Carbon Tetrachloride During Passive and Active Vapor Extraction of Contaminated Areas", to published in the Proceedings of the ER'95 Conference on Environmental Restoration, DOE, Denver, CO (April 1995).

V.J. Rohay, J. Rossabi, B. Looney, R. Cameron, and B. Peters, (1993) "Well Venting and Application of Passive Soil Vapor Extraction at Hanford and Savannah River", to be published in the Proceedings of the ER'93 Conference on Environmental Restoration, DOE, Augusta GA (Oct. 24-28).

J.D. Schroeder, S.R. Booth, and L.K. Trocki, "Cost effectiveness of the Site Characterization and Analysis Penetrometer System," Los Alamos National Laboratory Report LA-UR-91-4016, December 1991.

J.R. Stetter, and Z. Cao (1993) "Halogenated Compounds Sensor" U.S. Patent 5,226,309 (July 13).

J. Vaughn, and C. Martin (1993), "Carbon Tetrachloride Detection: A Comparison of Direct Reading Instruments" Westinghouse Hanford Company, Report WHC-SA-1900-A (March).

Table I: Cost benefit analysis for using the RCL MONITOR instead of a gas chromatograph for the RQM

VAPOR SAMPLES	GC			RCL Monitor		
SINGLE TIME EXPENSE						
Capital Equipment:	$30,000			$17,400		
Capital Equipment (samplers):	1,000			1,000		
TOTAL:	$31,000			$18,400		
MANPOWER Requirements	man-hrs (RQM)	cost (RQM)	cost annual	man-hrs (RQM)	cost (RQM)	cost annual
LABOR ($62.50/hr)	80	$ 5,000	$20,000	12	$ 750	$ 3,000
EQUIPMENT COST						
Annual Maintenance Cost:			2,000			
Supplies:		100	400		200	800
Equipment Preparation Cost:		500	2,000		100	400
Bags:		500	500		250	1,000
Vehicle Expense						
daily fee ($50.00/day)		400	1,600		50	200
Mileage (120 miles/day)		288	1,152		36	144
TOTAL:		$ 6,788	$ 29,152		$ 1,386	$5,544
				Savings:	80%	80%

Table II: Features of the Commercial RCL MONITOR

Design Feature	Description
MEASUREMENT	
Discrete	Direct Readout in ppm
Repetitive	Easy to set up (Intervals from 15 minutes to 24 hours)
Range	0 to 100 ppm with a LDL of 0.5 ppm
OPERATION	
Modes	1). SURVEY-LOW (a fast manual mode of analyses, 0.5 to 10 ppm). 2). SURVEY-HIGH (a fast manual mode of analyses, 5 to 100 ppm) 3). Monitor (an automated mode of operation, with same choice of range as SURVEY- LOW or SURVEY-HIGH))
User Interface	Push buttons (accessible with gloved hands)
Startup	One button operation
Transport	Handle and Shoulder Strap
Display	Results presented in "ppm"
Duration (single charge)	6 Hours (25ºC)
OPERATOR SKILL	
Basic use	Minimal training (<5 min)
Advanced use	3 hours training
MAINTENANCE	
Sensor	Easily Accessible
Internal Filters	Easily Accessible
CALIBRATION	
Protocol	Automated 3 point, 0 to 10 ppm procedure (using one source of a 10 ppm standard)
Time Required	36 minutes (maximum), unattended, auto shutoff afterward, 300 cc sample required
DATA STORAGE	
Format	Results stored in report: date, time, concentration, analysis number, mode used
PHYSICAL DESIGN	
Package	All components in one unit 5" x 6" x 12"
Weight	5 kg (12 pounds)
Power	Internal battery (over 6 hours operation at 25ºC) - Replaceable in the field
Pneumatics	- robust quick connects - internal zero filter (externally accessible) - internal particulate filter (externally accessible)

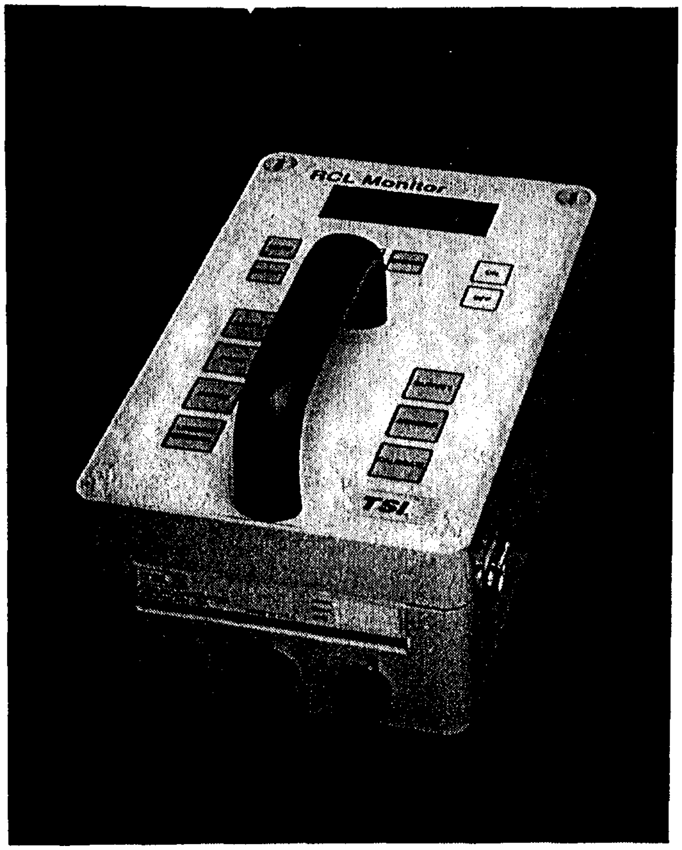

Figure 1: The RCL MONITOR, A commercial version of the RCL MONITOR was released for sales on September 20, 1996,

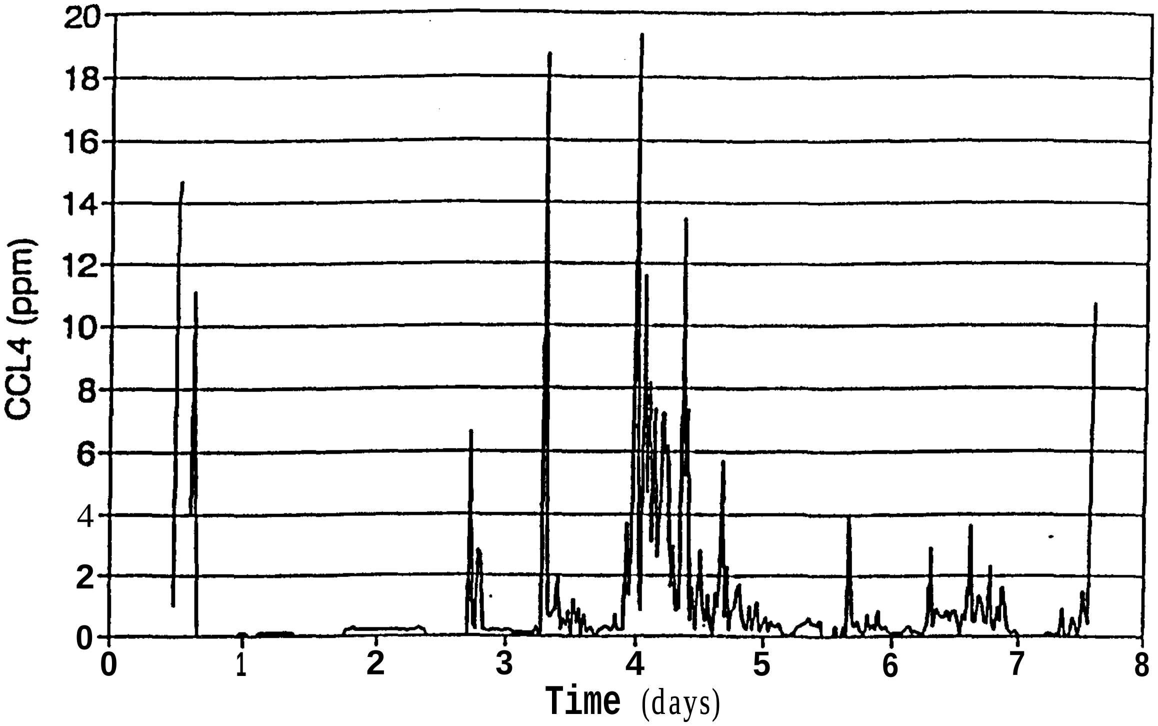

Figure 2: Representative data obtained **from** the RCL MONITOR during continuous monitoring of the work space air during testing of the **PURUS** system

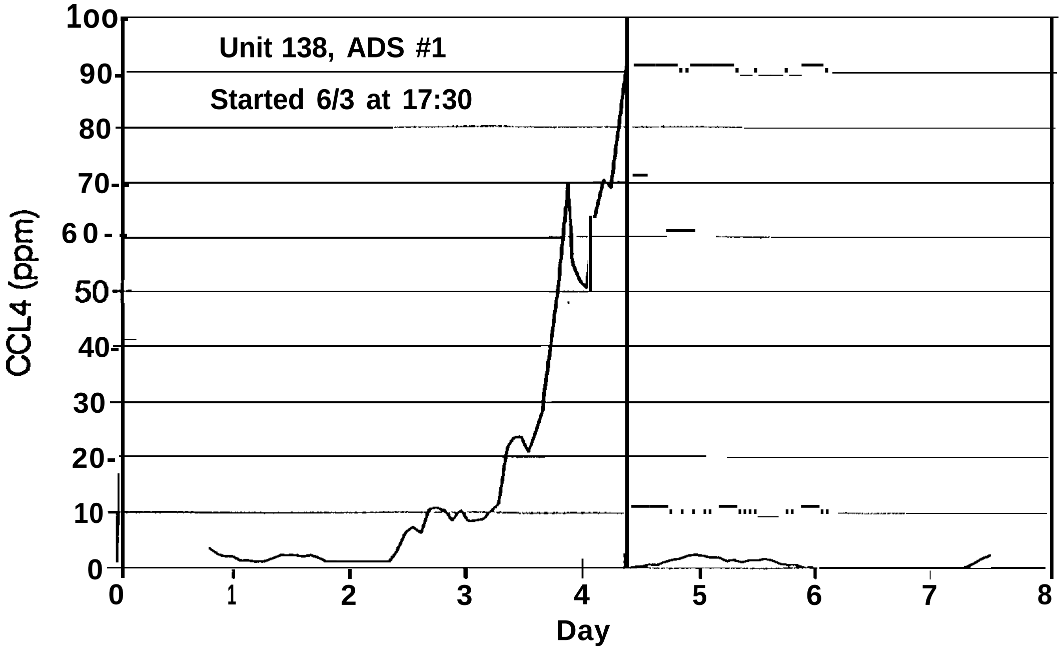

Figure 3: Representative data obtained from the RCL MONITOR during continuous monitoring of the post-primary GAC exhaust. The vapor spike shown demonstrates breakthrough and replacement of a GAC cartridge.

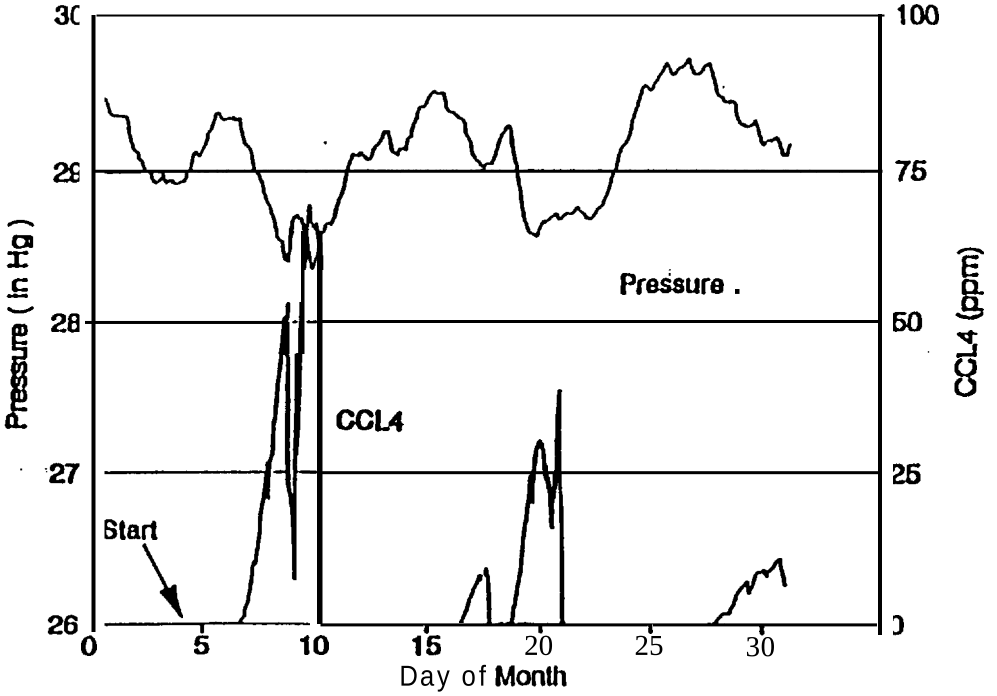

Figure 4: Monthly logging of passively vented of vapors from a well as measured by the RCL MONITOR, Barometric pressure is also shown

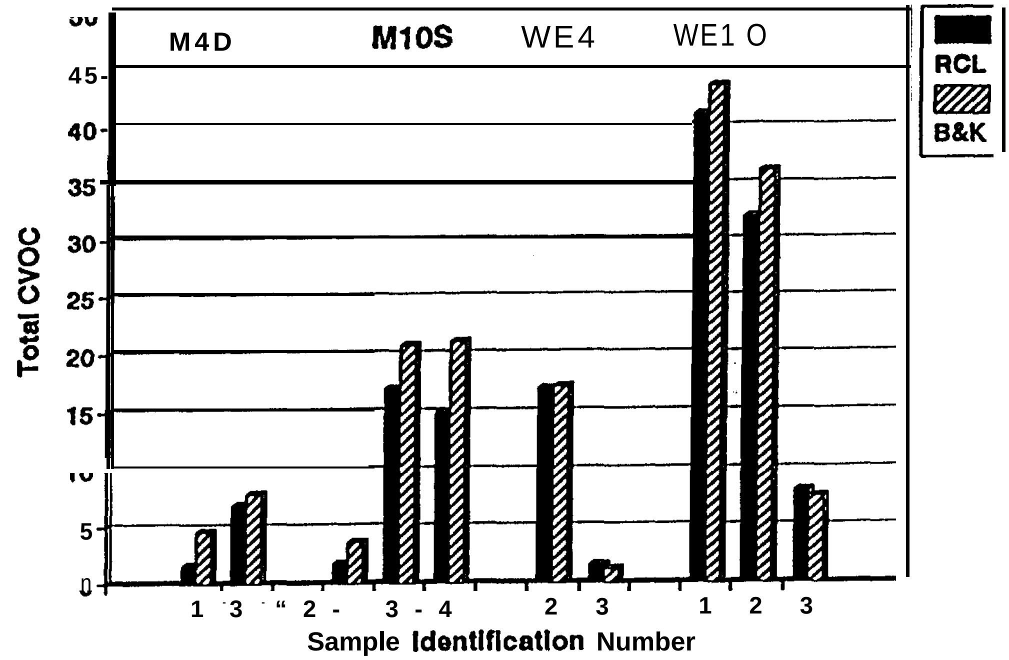

Figure 5: Comparison between the commercial model of the RCL MONITOR and alternative instrumentation. Total CVOC is presented. Comparable correlations were obtained with the RCL MONITOR and a Gas Chromatography (Buttner et al, 1996).

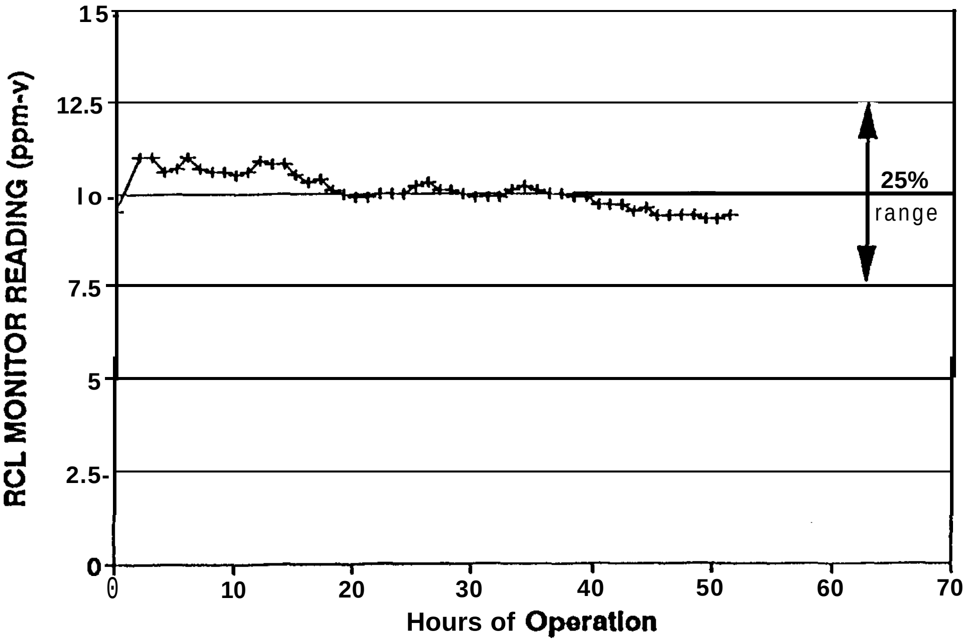

Figure 6: Repeatability of the RCL MONITOR to 10 ppm vapors over a 50 hour performed every 60 minutes. Further testing over a 4 day period were performed at 60 and 30 minutes with over 75 analyses; all of the analyses were well within the instrument specification.

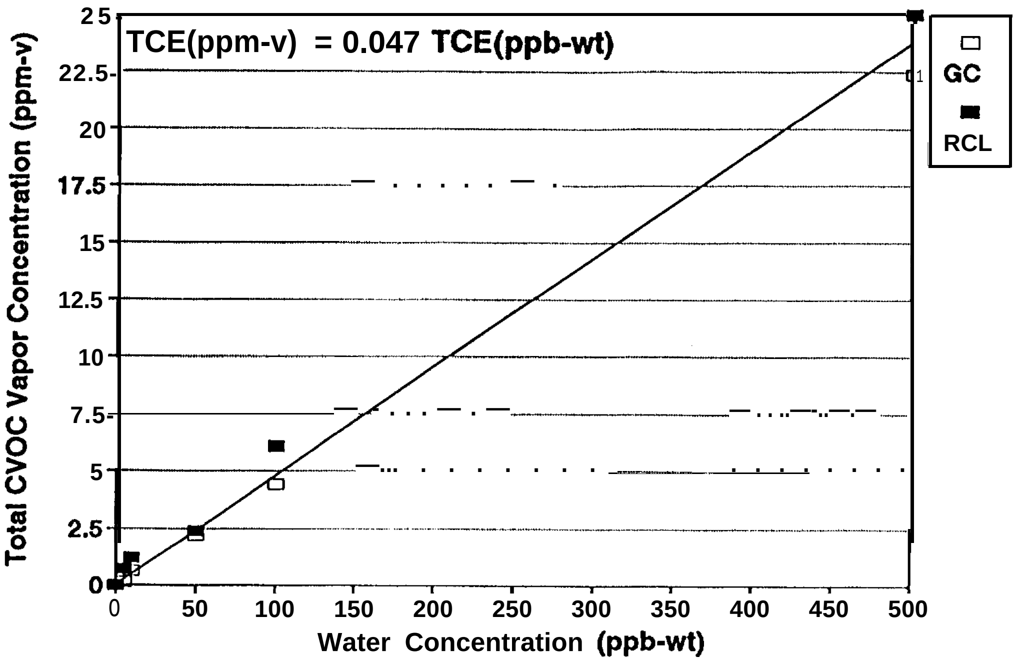

Figure 7: Aqueous TCE concentrations as determined with the In-Situ Sampler interfaced to various analytical methods. With the RCL MONITOR, analyses can be performed is less than 15 minutes and a lower detection limit of 10 ppb-wt.