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Opportunity Bulletins

Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

In today's economy, the need to reduce costs is increasingly critical to assuring the success of U.S. companies in the international marketplace. At the same time, difficult environmental issues that require creative and aggressive solutions are being identified. Both the U.S. government and industry play key roles in restoring and protecting the environment, as well as in fostering effective competitive markets for U.S. goods and services.

To enhance and maintain a clean environment while improving the nation's productivity, the U.S. Environmental Protection Agency (EPA) is joining with private industry to seek new, cost-effective technologies to prevent and control environmental pollution. Under the Federal Technology Transfer Act of 1986, EPA has established cooperative research and development agreements (CRADAs) between the Agency's Office of Research and Development, industry, and academic institutions. These agreements serve as mechanisms for the Federal government to work with companies in developing new pollution control technologies and bringing them to the marketplace. Promising technical areas for collaborative research and development with EPA are presented in this report.

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Office of Environmental Engineering and Technology Demonstration

Air and Energy Engineering Research Laboratory

Advacate

Status of Technology: ADVACATE has been successfully tested at bench scale. Short-term pilot scale testing at Ohio Edison's Edgewater Plant indicated capability to achieve high SO_2 removals. Large integrated pilot testing is underway at the 10 MWe pilot facility at TVA's Shawnee Steam Plant. The process has been awarded five patents to EPA/University of Texas. Patents have been licensed on an exclusive basis to ABB/Flakt. The EPA and ABB/Flakt have a Cooperative Research and Development Agreement (CRADA) to develop the process at pilot scale.

Technology Description: An innovative flue gas cleaning process for low cost, high efficiency SO_2 control from coal-fired power plants and other sources. ADVACATE utilizes a unique high surface area calcium silicate sorbent, generated by the reaction of lime and fly ash to adsorb SO_2 in an existing flue gas duct. The ADVACATE process allows for high efficiency (90-95%) removal of SO_2 and other acid gases from both existing and new coal-fired boilers. ADVACATE yields a high level of control with low capital and operating costs compared to conventional technologies. The process was jointly developed by AEERL in-house staff and the University of Texas (UT). AEERL has evaluated the process at bench and small pilot scales. AEERL is working cooperatively with TVA and the commercial licensee, ABB-Flakt, to test the process at large pilot scale (10 MWe).

Applicability: Applicable to most existing and new coal-fired boilers requiring sulfur dioxide removal 90% or greater.

Cost of Control Implications: Based on a cost study conducted by Electric Power Research Institute, the estimated capital cost of ADVACATE is $85 per kW ($130 per kW less than a conventional flue gas desulfurization system). In the United States, if 10 to 25% of utility boiler capacity is retrofitted with ADVACATE to meet Phase 2 emission limits under Title IV of the CAAA of 1990, major cost savings would be realized over a five-year period (1995-2000):

- Capital cost savings: $1 to $3 billion
- Operating cost savings: $4 to $10 billion

Opportunities for Collaboration:

- Potential for sub-licensing technology from ABB-Flakt.
- Similar process using other silica sources (glass, sand, etc.) available for license and or CRADA as a multipollutant control system for municipal waste combustors, industrial furnaces, etc.
- Potential for funding participation at pilot scale and co-funding a full scale (greater than 100 MWe) demonstration.

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New Chemical Alternatives for CFCs and HCFCs

Status of Technology: Due to stratospheric ozone depletion, CFCs and HCFCs need to be replaced in all end-uses since ozone-depleting CFCs and HCFCs are scheduled for production phaseout. A very limited slate of non-chlorinated, non-brominated, nonflammable alternatives has been proposed by industry. EPA/AEERL's candidates extend the slate of possible alternatives for industry's consideration and development. For some chemicals in some uses, there are acceptable replacement chemicals or technologies. There are many uses for which no permanent solutions have been identified. The genesis of the new chemicals research was a recommendation for such research by an industry and academia expert panel convened by EPA. AEERL took the initiative in establishing the R&D program. Work has been done cooperatively with Clemson University, the University of Tennessee, and the Electric Power Research Institute. Current evaluation of the new chemicals is being done in-house while seeking industry cooperation. New chemical alternatives are a possibility. An extensive set of thermophysical property data has been acquired on the new chemicals. Larger quantities (ca.4kg) of each of the leading candidates are being procured to evaluate flammability, toxicity, materials compatibility, atmospheric lifetime, and performance (e.g., refrigeration and foam insulation).

Technology Description: Several new chemicals have been identified as possible alternatives for CFCs and HCFCs. The new chemicals have zero potential to deplete stratospheric ozone and thermophysical properties, which appear to make the chemicals excellent candidates as refrigerants. Properties of the chemicals for refrigeration and other uses such as foam insulation are being evaluated.

Applicability: The proposed new chemicals appear to be excellent candidates to replace CFC and HCFC refrigerants and, possibly, foam blowing agents and fire/explosion suppressants. Developing countries currently are allowed a longer time for CFC phaseout. AEERL's new proposed chemical alternatives, if commercialized, would be available for use by developing countries when needed. These alternatives may be superior to other candidates for concerns relative to developing countries (e.g., energy efficiency).

Cost of Control Implications: It is doubtful that the new chemicals would offer cost advantages over chemicals proposed as transition alternatives. This is because both the starting materials (feedstocks) and the production processes are likely to be more costly for the new AEERL chemicals. In most applications, the cost differential should not be significant.

Opportunities for Collaboration: Manufacturers and users of ozone-depleting chemicals, especially those where the only suggested near-term alternatives are HCFCs, have a great interest in finding the most environmentally and cost-effective solutions. There are many opportunities for cooperative R&D with the private sector. EPA has already been approached by several industrial firms to explore this possibility. AEERL has filed a patent application for certain mixtures of the new chemicals as refrigerants. Industry partners are being sought to encourage application-specific development and greater availability of the new chemicals. The pure chemicals are not patented. Major technical issues to be yet resolved are: all toxicity end-points, scale-up of production processes, applicability in end-uses, and optimization for specific end-uses.

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Corona Destruction for VOC/HAP Control

Status of Technology: The corona destruction technology has been extensively tested at the bench scale (flow rates of 1 Liter per minute), and has shown promising results. At optimum conditions, greater than 90% destruction efficiency can be achieved for a number of toxic hydrocarbon compounds. Current R&D is focused on scaling up the technology to a 2/3 cubic foot per minute (CFM) element and optimizing performance. The research will emphasize achieving maximum hydrocarbon destruction efficiency while maintaining acceptable power usage and system costs. Assuming successful demonstration, an industrial scale demonstration is planned for 1994. The process provides for high efficiency removal of VOCs and air toxics from contaminated streams especially at low concentrations where the conventional control technologies have severe limitations.

Technology Description: Corona destruction is an innovative control technology to destroy organic compounds in gaseous waste streams. The corona technology consists of the application of high voltage across a packed bed or along a wire. The corona process generates excited atomic and molecular species which attack VOCs to form carbon dioxide and water.

Applicability: The technology can potentially be applied to many industrial and commercial operations, such as painting and coating, food and pharmaceutical processing, dry cleaning, restaurants and bakeries, and printing. Over the next ten years, the technology could be applied to sources emitting at least 30% of the total environmental loading of VOCs. This amounts to the destruction of approximately 6,000,000 tons/year of VOCs. The elimination of these VOC emissions should contribute to critical Agency and national goals of attaining the ozone standard in more than 100 non-attainment areas nationwide.

Cost of Control Implications: Significant savings should result from the use of the corona destruction process instead of conventional technologies. Especially for low concentrations, corona destruction may result in significant savings, compared to carbon adsorption, catalytic incineration, and thermal incineration. Further development and demonstration is required to substantiate this potential.

Opportunities for Collaboration: Interest in collaborative work on corona destruction has been expressed by the DOD, several industries, the Canadian government, the Russian Academy of Sciences in Moscow, and several academic institutions in the United States. The U.S. Navy has provided resources through an interagency agreement. Following successful scale-up, the technology will be advertised for CRDAs and/or licenses for one or more applications.

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E-SO_x

Status of Technology: The E-SO_x process was evaluated in-house on the 1/3 MW pilot unit with both calcium and sodium based reagents. It was further evaluated on the 5 MW pilot unit at the Ohio Edison Burger Station, with a calcium based reagent. The final report from the Burger Station evaluation, which was sponsored by EPA, the Ohio Coal Development Office, DOE, and Babcock & Wilcox, concluded that the process should be demonstrated at full-scale. U.S. Patent No. 4,885,139 was issued December 5,1989. The technology has been offered for license.

Technology Description: E-SO_x is a control technology for simultaneous removal of acid gas (e.g., SO_2) and particulate matter within an existing electrostatic precipitator (ESP). The inlet section of the ESP is removed and the space is fitted with an array of nozzles for injection of the reagent, as a slurry or solution, for reaction with the acid gas. The remainder of the ESP is upgraded, using advanced technology, to collect not only the original particulate matter but also the dried reagent. Use of the existing ESP makes the process very low in cost. The E-SO_x process allows, on a retrofit basis, the collection of an acid gas in an existing ESP, which becomes important if there is no room available for add-on technology. If the acid gas is SO_2, 50-60% can be collected with a calcium based reagent and up to 90% if the reagent is sodium based. E-SO_x was developed in-house by AEERL personnel.

Applicability: The E-SO_x technology is applicable on a retrofit basis to ESPs ranging in size from moderate to large. A potential emerging application for E-SO_x is as a very low-cost control technology for offset of SO_2 emissions that may be required to accommodate growth. The technology is especially applicable to the pulp and paper industry because of the large quantities of sodium based materials available at those facilities for reagent use. There is strong potential for application in the Commonwealth of Independent States and Eastern Europe.

Cost of Control Implications: Based upon a cost study performed by Gilbert-Commonwealth the capital cost for a 500 MW plant burning 2.5% sulfur coal and achieving 50% control, would be about $40 per kW. This compares to more than $200 per kW for conventional flue gas desulfurization. On a per ton of sulfur removed, the cost would be about $150, as compared to $500 - $700 for flue gas desulfurization

Opportunities for Collaboration:

- Potential for licensing from EPA or sub-licensing from the licensee.
- Potential for funding participation in full-scale demonstration of the technology for both calcium and sodium based reagent applications.
- Participation in the East European E-SO_x program.

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Upgrading of ESP with Retrofit of Electrostatically Augmented Fabric Filters (ESFF)

Status of Technology: The ESFF concept was researched in the mid-1980's at AEERL and small-scale proof-of-concept was done for both reverse-air and pulse-jet operating modes. Modelling work to assist in the design of a commercial system has been performed. Pilot scale development is needed before the concept is commercially demonstrated. The retrofit ESP concept (REF) was filed with the U.S. Patent Office on January 24, 1992. A prior patent on ESFF was issued February 27, 1990 (U.S. Patent 4,904,283). The inventions were formally offered for license/ CRADA on March 5, 1992.

Technology Description: Upgrading of an ESP with Retrofit of Electrostatically Augmented Fabric Filters (ESFF) - An ESP is improved by using pulse jet air, electrostatically augmented fabric filters (FF) in place of the final ESP section. With significant applicability as a new hybrid FF/ ESP concept, focus is on low-cost retrofit of an existing ESP by replacing the last section with ESFF components. Particle emissions from ESPs include: (1) fine particles in which the majority of the toxic heavy metals and condensed organics reside, (2) sneakage, and (3) re-entrainment. The ESFF augmentation eliminates (2) and (3) and subjects (1) to additional filtration by impingement on the filter medium or filter cake which is further enhanced by electrostatic removal of the charged particles. The result is significantly lower mass dust emissions and significantly improved control of fine particles, without the penalty of excessive pressure drop. This concept provides a low-cost method of upgrading deficient ESPs, and is especially suited to provide badly needed assistance in decreasing the emission of air-toxics-bearing particulate matter. This is exclusively an in-house AEERL invention, along with the predecessor ESFF concepts.

Applicability: (1) Upgrade of existing ESPs for fine PM/air toxics control and for restoring control capability for increased ESP inlet loading, such as could be caused by injecting sorbent upstream of the ESP for SO_2 control, (2) new ESPs.

Cost of Control Implications: The concept has not been tested on a large scale and no cost studies have been made. A rough estimate is $10 - 15/kW capital and very low (approx. 1 mill/kWh) operating costs. This is considerably less expensive (and potentially more effective for air-toxics control) than adding additional collecting area to an existing ESP (EPRI estimates about $25/kW for a typical size increase of 1/3 to 1/2).

Opportunities for Collaborators:

- Potential for licensing or sub-licensing.
- Potential for participation in demonstration of technology.
- Potential for CRADA to provide further technology development.

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Fuzzy Logic Motor Control

Status of Technology: A computer simulation of the first version of a fuzzy logic based energy optimizer for adjustable speed drive AC motors has been tested. Efficiency improvements achieved ranged from approximately 0.2% to 14%, depending on the motor application examined. More sophisticated versions of this controller are under development. Extensive computer modeling and laboratory testing are underway to determine the performance characteristics of the controllers.

Technology Description: Fuzzy Logic Control of Electric Motors and Motor Drives - An innovative approach for extracting maximum energy performance from AC induction motors in a cost effective manner. To minimize power losses, it is necessary to control motor speed and thereby match motor speed to load requirements. The most recent, and successful, approach is the adjustable speed drive (ASD). ASDs use semiconductors and switching circuits to vary the voltage, current and/or frequency of a motor's power supply. Fuzzy logic control is being developed as the core of the ASD control block, to analyze system feedback and select frequency/voltage/current combinations that result in optimizing the energy efficiency of the motor/drive and meet load requirements. At its culmination, the project will provide a set of application-specific integrated circuits (ASICs) which will interface with induction motor drive systems. The fuzzy logic based ASICs will be demonstrated in a year-long test of a large horsepower induction motor at a selected industrial site.

Applicability: Applicable to most existing and new ASDs with little additional power requirements.

Cost of Control Implications: It is estimated that the fuzzy logic energy optimizer can offer energy savings of about 0.1 kWh/hp/day. The controller cost is essentially independent of motor size, with costs amortized in approximately 3 months for a 100 hp motor. Application of this technology, with concomitant reduction in fossil energy demand, is expected to result in a net cost saving.

Opportunities for Research and Development Collaboration: Potential for a phased program administered by AEERL via a Cooperative Research and Development Agreement (CRADA) and/or licenses. EPA, via its Pollution Prevention Program, will fund the program through technology development and testing phases. For the later phases of the program (technology verification and licensing), EPA sees itself as a partner with an organization that has a serious interest in developing motor controls for energy efficiency and pursuing the project through commercialization.

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Hydrocarb

Status of Technology: Process evaluations are based on equilibrium process simulation studies and preliminary cost estimates by AEERL and Brookhaven National Laboratory. A pilot plant evaluation will be undertaken based on the results of those studies which indicate multiple environmental and economic benefits, in addition to reduced production cost and increased quantities of alcohol fuel that can be derived from given biomass supplies. Construction of a 110 gal/day research unit is expected to begin early in 1993, under cosponsorship of EPA and the South Coast Air Quality Management District of California.

Technology Description: By sequestering by-product carbon and replacing petroleum fuels with biomass-derived methanol, the Hydrocarb process can nullify the net effect of CO_2 emissions from motor vehicles. By utilizing carbonaceous municipal wastes as feedstocks, the process can reduce disposal problems while producing a clean transportation fuel. Methanol is produced from biomass and natural gas in three steps involving hydrogasification, with gas recycle, methane pyrolysis, and methanol synthesis. In addition to woody biomass, potential feedstocks include: sewage sludge, digester gas, and most of the organic materials that comprise half of landfilled municipal solid wastes. An optional by-product is carbon that is free of ash, sulfur, and nitrogen and, therefore, a potentially valuable, clean solid fuel for industrial boilers.

Applicability: Areas with high biomass productivity and domestic supplies of natural gas and/or coal could benefit environmentally and economically, especially areas of the world without current domestic petroleum supplies. Municipalities that generate large quantities of wastes would benefit from successful demonstration of the process, especially in ozone non-compliance areas where clean alternative fuels may be required.

Cost of Control Implications: Compared to other options for production of biogenic alcohol fuels, Hydrocarb methanol may be 50 percent cheaper than conventional or new ethanol processes and 30 percent cheaper than other biomass gasification processes.

Opportunities for Collaborators: Collaborators for research on technical issues or pilot studies are welcome. Initial opportunities are greatest for operators of landfills and municipal wastewater treatment plants with high waste disposal costs. Large producers of agricultural wastes would also benefit from successful demonstration of the process, especially where future markets are anticipated for clean liquid transportation fuels.

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Rotary Kiln Transient Suppression Packaging

Status of Technology: Preliminary prototype design testing was completed in 1991. Preliminary results indicate a 60-70% reduction in transient emissions while using this container design. An AEERL innovative R&D project was awarded in FY92 to further develop the concept.

Technology Description: This process proposes new packaging for contained liquid hazardous wastes that are batch charged into rotary kiln incinerators. Current feeding practices can cause transient upsets in combustion conditions resulting in increased CO and hydrocarbon emissions. Innovative container designs have been developed to minimize these transient excursions.

Applicability: Rotary kilns are uniquely versatile in that they allow large fractions of their waste load to be charged in batch mode. This container design concept would be applicable to rotary kiln systems feeding batch charges of organic compounds and any other thermal destruction process that treats waste in batch mode.

Cost of Control Implications: Based on preliminary design concepts, added costs to implement this technique would be negligible.

Opportunities for Collaboration: Given the potential for simultaneously reducing transient emissions and increasing batch waste feed rate, EPA is actively seeking industrial partners to develop this concept to full-scale. Experimental facilities are available for further development under a CRDA. Licensing of the technology is also anticipated.

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LIMB/Lignosulfonate

Status of Technology: The recently completed demonstration at the Edgewater plant showed $S0_2$ removals of 55 to 72% depending on sorbent type (commercial or with additive) and extent of flue gas conditioning via humidification. The program demonstrated that despite the threefold increase in particulate loading, the electrostatic precipitator could perform to original levels with only a modest amount of flue gas humidification. Additionally, SO_2 capture incrementally improved with both the addition of calcium lignosulfonate and flue gas humidification to deep levels, i.e., 20 degree approach to the adiabatic saturation temperature. The ongoing demonstration of LIMB technology on a tangentially fired boiler will evaluate similar issues on this second major class of coal-fired boilers.

Calcium lignosulfonate-modified calcium hydroxide has been awarded three patents, and a fourth patent is pending. Foreign patents are also pending. The patents have been licensed on an exclusive basis to the Genlime Corporation.

Technology Description: LIMB is EPA's acronym for **L**imestone **I**njection with **M**ulti-stage **B**urners and is descriptive of a technology for simultaneous control of NO_x and SO_2 from coal-fired utility boilers. The process uses low-NO_x burners for reducing NO_x emissions by up to 50% and employs furnace sorbent injection for reducing SO_2 emissions by 50% or more. A commercial calcium hydroxide is the most commonly used sorbent for reaction with the SO_2 contained in the boiler flue gas. An improvement in the efficiency of SO_2 capture has been observed by the addition of small amounts (about 1% by weight) of an additive (calcium lignosulfonate) to the calcium hydroxide. $S0_2$ reductions of up to 72% have been shown under optimum conditions of sorbent, stoichiometry and flue gas conditioning. At equivalent SO_2 reduction levels, LIMB offers capital and operating costs that can be more cost effective than competing technologies such as flue gas desulfurization (FGD).

Applicability: LIMB technology is generally applicable to all major coal-fired boiler designs. The technology offers the advantages of relatively easy retrofit and low space requirements. LIMB is especially attractive for boilers: firing intermediate level sulfur coal (1.5 - 2.5%); of intermediate size (up to 300 MWe); having relatively short remaining useful life (up to 20 years); operating with low to intermediate capacity factors (up to 65%); and with space problems to accommodate pollution control equipment.

Cost of Control Implications: Recent cost analyses conducted by the Electric Power Research Institute, the Environmental Protection Agency and the Babcock & Wilcox Company indicate that LIMB has capital costs that are about one-third that of FGD and has cost effectiveness (dollars per ton of SO_2 removed) competitive to FGD. These are important considerations for utilities in their selection of control technologies for meeting Phase 1 and 2 emission limits set forth in the Clean Air Act Amendments.

Opportunities for Collaboration: Potential for sub-licensing of sorbent manufacturing technology for lignosulfonate-enhanced sorbent.

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Sicore

Status of Technology: The proof-of-concept testing on a pilot scale furnace is completed. Heretofore, the concepts of the technology were proven solely from bench scale results testing distinct steps in the formation of dioxin/furan. Additional parametric testing on a small scale is underway. The technology is currently being advertised as available for licensing with the hope that it can soon be implemented on a full scale. About 15 industries have been contacted and express interest. AEERL hopes to have a license signed by this summer. AEERL has received one patent (U.S. Patent No. 5,021,229) for this technology and has applied for another. Both the patent and application have been published in the Federal Register as available for licensing. No private industrial partner has been involved in this research.

Technology Description: AEERL research has shown that formation of toxic chlorinated dioxins and furans from waste combustion systems can be **prevented** by the proper application of sorbent injection processes. The sorbent reacts with and ties up the chlorine precursor that is necessary for subsequent dioxin/furan formation. Prevention of dioxin/furan formation in waste combustors will eliminate an important source of this carcinogenic pollutant in air emissions and scrubber waste solids. Very recent evidence confirms and adds to past concerns, suggesting that there is no "threshold value" of carcinogenicity and that dioxin/furans also act to suppress immune systems and hormonal functions. This technology is likely to be as effective as, and of significantly lower capital cost than, control measures currently used as the basis for EPA regulations on new, large municipal waste combustors. Sorbent injection is also a retrofittable technology that is well-established for other pollutants and systems. AEERL has been the sole developer of this technology over the last 4 years. The idea for the research was derived from an AEERL researcher doing related work.

Applicability: Under current, proposed U.S. regulations, this technology is applicable for acid gas and dioxin/furan emission control for "old" waste combustors. "New" combustors are required to achieve performance equivalent to spray dryer/fabric filter; however, it has not been determined whether this process can achieve these acid gas removal levels as a *stand-alone* system. Combined control systems make this technology available to a broader market. Current development of highly reactive sorbents may extend the relevant market to new combustors.

Cost of Control Implications: While no extensive cost estimates have been made, sorbent injection costs for similar systems (SO_2) compare favorably with spray dryer/fabric filter systems. Capital costs are generally low, and operating costs primarily reflect purchase of sorbent.

Opportunities for Collaboration: The technology is advertised as being available to licensees who wish to demonstrate, apply, and market these concepts on full scale systems.

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Super ESP

Status of Technology: The components of the Super ESP make use of state-of-the-art or near state-of-the-art ESP technology. Testing of the critical components has been done on the EPA 1/3 and 5 MW pilot ESP units. A computerized ESP performance prediction model, with Super ESP capability has been developed. U.S. Patent No. 5,059,219 was issued October 22, 1991. Patent Cooperation Treaty applications allow filing in major industrial countries through March 26, 1993. The technology has been offered for license.

Technology Description: The Super ESP is a major advancement in the philosophy of electrostatic precipitator (ESP) design that makes use of a number of short charging and collecting section pairs, each of which has the particulate removal efficiency of the current, much longer conventional ESP section. This results in an ESP that is both insensitive to particulate matter resistivity and significantly smaller and less costly than an ESP that uses a number of the larger conventional collecting sections. The Super ESP allows high efficiency particulate matter collection in a smaller space and at lower cost than currently achievable with conventional ESP technology. The compact design provides the flexibility to build a highly efficient collector for air-toxic bearing fine particles with a system smaller than that of conventional ESP technology. The Super ESP is a less costly, highly efficient, resistivity insensitive ESP technology, and was developed in-house by AEERL personnel.

Applicability: The small size of the Super ESP, relative to conventional ESP technology, makes it applicable to virtually all new and retrofit applications.

Cost of Control Implications: Super ESP costs have not been thoroughly studied. However, aspects of the technology that bear favorably upon the costs are:

- The majority of the new installations and retrofits of high efficiency ESPs for coal fired utilities are being designed for the range in which the Super ESP offers cost savings of from 25 to as much as 50%.
- The cost of conventional high efficiency ESPs ranges from about $50-100/kW, depending on size and design efficiency. For a typical size 500 MW new power plant, the reduction could be from $30 to $20 million.
- The compact design philosophy of the Super ESP lends itself to modular construction, which leads to additional cost savings and quality control, compared to conventional ESPs, which require considerable field construction and erection.

Opportunities for Collaboration:

- Potential for licensing from EPA or sub-licensing from the licensee.
- Potential for funding participation in demonstration of technology.
- Potential for a CRADA for additional improvement of particulate control, especially for air-toxics.

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Gas-Enhanced Woodstove (GEW) Technology

Status of Technology: The technology has been proven effective in long-term laboratory tests. GEW stoves will be tested in 20 field applications during the winter of 1992-1993. Success in these tests will lead to commercialization of the technology in late 1993.

Technology Description: The Gas Enhanced Woodstove (GEW) technology is an innovative approach to achieve a >90% reduction in particulate emissions from residential woodstoves. The GEW utilizes a small gas flame to ensure full-time, stable combustion of organic particulate matter. The products of incomplete combustion (smoke, volatile hydrocarbons and carbon monoxide) released from the wood in the lower combustion zone pass through the upper combustion zone where they are destroyed.

Applicability: Applicable wherever wood is used for domestic heating/cooking and where a gaseous fuel is also available. The technology is applicable to all new woodstoves, and it could easily be retrofitted to existing stoves. Use of wood for residential heating accounts for 90% of the polynuclear organic matter (POM) emitted by all stationary sources in the United States. Wood smoke consists almost entirely of respirable, condensed organic droplets <10 μm in diameter. Wood smoke has been shown to be potentially carcinogenic. In addition to the visible, condensed organic particles, wood stoves emit large quantities of volatile hydrocarbons and carbon monoxide. The GEW technology promotes ignition of these hydrocarbons and the CO, which then also combusts the organic constituents comprising the visible smoke/ PM_{10} fraction of the emissions.

Cost of Control Implications: With the GEW technology, wood use is directly offset by the gas consumed. Since natural gas costs no more than wood, there is no increase in operating cost. If a more expensive gas is required, then there would be a corresponding increase in operating costs. The GEW will add about $50.00 to the initial cost of a stove. There should be very little additional maintenance cost involved.

Opportunities for Collaboration: EPA is negotiating a cooperative research and development agreement (CRDA) and an exclusive license for further development and commercialization of the GEW technology.

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Risk Reduction Engineering Laboratory

Hybrid Drinking Water Treatment Package Plant Development for Small Communities

Status of Technology: There is a tremendous need to develop knowledge of package plant cost, performance, and long-term reliability for small systems. There have been few systematic evaluations of package plants, and given their current design, they are probably not capable of meeting, in many circumstances, the Surface Water Treatment Rule, the future Disinfection/Disinfection By-Product Rule, and the ever increasing number of individually regulated contaminants.

Technology Description: Package plants are factory-built, skid-mounted, and pre-designed ready to be operated in the field requiring only minimal site preparation. They exhibit lower capital cost than custom designed facilities built onsite. Any drinking water treatment process can be incorporated into a package plant system. The most common package plants are conventional media filtration preceded by sedimentation and flocculation often using chemical additives to enhance effectiveness. Technologies being considered for Best Available Technology (BAT) status are membranes and advanced oxidation processes. Other promising technologies include photocatalytic oxidation, bag filters, and solar disinfection. It is with these, along with conventional drinking water treatment technologies, that unit processes must be merged, modified, and adapted into new treatment trains to remove a broader variety of contaminants and be capable of being operated by part-time or minimally trained operators. Thus, another technology to be developed is dealing with remote control telemetry which exists for other industrial applications but is lacking in this context. The figure shown on the next page is an example of a membrane package plant.

Applicability: Although there are hundreds of package plants already in use throughout the United States, the tens of thousands of small community and non-community drinking water systems (serving less than 3300 people) will have difficulty complying with the ever increasing number of regulated contaminants. Currently, it is estimated there will be over 100,000 violations of the Safe Drinking Water Act annually. Nearly half of these are for Maximum Contaminant Level (MCL) violations. Of these, the majority are microbiological violations by the small systems. There are approximately 50,000 small community systems and 140,000 non-community systems in the United States accounting for over 25 million people as potential users.

Cost of Control Implications: Package plants typically cost only 10-20 percent of custom designed treatment plants. However, this is still quite a financial burden for most small communities. Long-term operating and maintenance costs are also considerations that need to be minimized. A hidden cost to package plants is in their efficiency or lack thereof if not properly designed and operated and the production of poor quality drinking water. It is important not to sacrifice efficiency for low capital costs.

Opportunities for Collaboration: The USEPA Test & Evaluation (T & E) Facility located in Cincinnati, OH, is the site for the Drinking Water Research Division's (DWRD) Small System Drinking Water Research Program. Several package plants are either already onsite or planned to take advantage of the 24,000 square feet of floor space, analytical laboratories, and expertise of the DWRD personnel. Dechlorinated tap water can be spiked with any number of contaminants including primary effluent, *Giardia*, *Cryptosporidium*, MS-2 bacteriophage, etc., to produce any quality of raw water desired. Ohio River water is also available in limited supplies. Collaboration can be accomplished through the FTTA mechanism, Memorandums Of Understanding (MOUs), and Cooperative Agreements (non-profit organizations only). Field projects are also underway throughout the United States and can be a valuable mechanism to verify and guide research.

Key Publications:

Goodrich, J. A., Adams, J. Q., Lykins, Jr., B. W., and Clark, R. M., "Safe Drinking Water from Small Systems: Treatment Options," *Journal*

Hybrid Drinking Water Treatment Package Plant Development for Small Communities

of American Water Works Association, Vol. 84, No. 5, pp. 49-55, May 1992.

Lykins, Jr., B. W., Clark, R. M., and Goodrich, J. A., *Point-of-Use/Point-of-Entry for Drinking Water Treatment,* Lewis Publishers/CRC Press, Chelsea, Michigan, December 1991.

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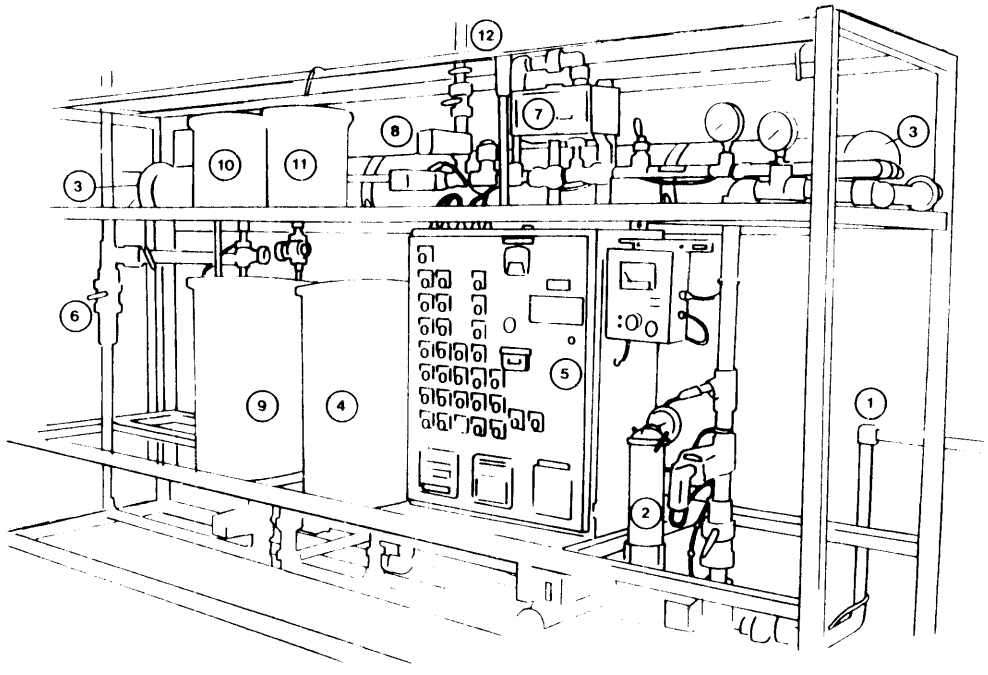

1 Raw water inlet
2 100 micron prefilter
3 Membrane module
4 Chlorine reservoir
5 Control panel
6 Recirculation
7 Turbidimeter
8 Chlorine monitor
9 Cleaner tank
10 NaOH reservoir
11 NaOCl reservoir
12 Finished water outlet

Ultrafiltration Package Plant

Life Cycle Assessments

Technology Description: Policy makers, members of industry, environmentalists, and the general public are intensely interested in looking holistically at the cradle-to-grave environmental effects of products and processes. One method to do that has been termed life-cycle analysis (LCA). The LCA concept is not new but one that has been used for over 20 years in the United States and abroad.

While LCA appears to be a promising tool to evaluate the environmental consequences of an activity, product, or process, it still requires a framework to be developed in order to provide consistent use across the board. Also, additional research is needed to enhance the understanding about the steps in the performance of an LCA and its appropriate usage. LCA is a technical, data-based and holistic approach to define and subsequently reduce the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and waste discharges, assessing the impact of those wastes on the environment, and evaluating and implementing opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity encompassing extraction and processing of raw materials, manufacturing, transportation, and distribution, use/reuse, recycling and final disposal.

Recent agreement among LCA researchers and practitioners supports a consensus that LCAs are comprised of three separate but interrelated components: 1) Life-Cycle Inventory, 2) Life-Cycle Impact Analysis, and 3) Life-Cycle Improvement Analysis. Together, these three components form an integrated set of tools which can provide information needed to maximize environmental improvements in the production of consumer and industrial goods. A life cycle approach can be especially important when evaluating the myriad of product choices that are available.

Current Activities: The Pollution Prevention Research Branch (PPRB) of the Risk Reduction Engineering Laboratory in Cincinnati, OH, is conducting research which analyzes the entire life cycle of consumer products and processes. PPRB is involved in promoting LCA methodology as a useful tool for pollution prevention. A draft guidance manual for conducting and evaluating life cycle inventories is being finalized and is expected to be available by fall 1992. Case studies of two consumer products (commercial cleaner and carpeting) have been started to demonstrate the usefulness of this inventory guidance manual and develop an approach for the third step, improvement analysis. Through case studies of consumer products, we are identifying opportunities to reduce environmental impacts, including resource use and environmental releases. LCA is a definite shift from only looking at single issues, such as waste management or recyclability. LCAs identify upstream and downstream effects as well as pollutant transfer from one media to another. LCA is the basis for another RREL guidance manual being developed for product/process design which incorporates the life cycle concept into the design process. Two sites (Allied Signal's Fram Division and AT&T) have been selected as test cases for applying the design manual. After completion of the case studies, the manual will be revisited and revised, if needed.

Opportunities for Collaboration:

- Collaborate with product manufacturers to apply the EPA inventory guidance manual in additional case studies. An Improvements Analysis Team comprised of both manufacturer and EPA will evaluate the information collected during the inventory to identify opportunities for improvement.
- Use the EPA Product/Process Design Manual in test cases to further develop the application of the LCA concept to design. The results will be used to demonstrate pollution prevention through design and, if needed, improve the manual.
- Adapt the inventory procedure to a computer software which will assist users in collecting

Life Cycle Assessments

the appropriate data from a product's life cycle stages. This software would be of use to both skilled LCA practitioners as well as novices.

- Demonstrate that LCA is applicable to processes and activities as well as products. Up until now, LCAs have focused on consumer products and packaging systems. Usefulness extends to other applications.

Key Publications:

"A Technical Framework for Life-Cycle Assessments," Eds. J.A. Fava, R. Denison, B. Jones, M.A. Curran, B. Vigon, S. Selke, and J. Barnum, Society of Environmental Toxicology and Chemistry, Washington, D.C., January 1991.

EPA, "Life-Cycle Assessments: Inventory Guidelines and Principles," (EPA 600/R-92/086), Cincinnati, OH, in draft.

EPA, "Life Cycle Design Guidance Manual: Environmental Requirements and the Product System," Cincinnati, OH, in draft.

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Oil Spill Bioremediation Research and Development Program

Status of the Technology: The Oil Spills Research Program was initiated in response to the Oil Spills Act of 1990 to establish the role of bioremediation as an effective clean-up technology. Initial activities have focused on the need to establish protocols for testing efficacy and toxicity of commercial bioremediation products, especially on open seas. The protocols are being developed for open waters, shorelines, marshes and wetlands, and terrestrial environments. The Risk Reduction Engineering Laboratory has been a leader in developing a sound, laboratory-based screening protocol for determining efficacy of bioremediation products under controlled conditions.

Basic research is being conducted to ensure that the protocols have a sound scientific basis and that a better understanding of hydrocarbon degradation will lead to effective spill countermeasure development. Under this component of the program, information is being developed to provide a decision-making framework for managing bioremediation of spills. The framework will answer such questions as when bioremediation is appropriate, what types of materials (nutrients, inocula, surface active agents, etc.) should be added to the spill site, when materials should be added, and what other clean-up strategies might work well in concert with bioremediation.

Technology Description: Research is being done to improve and refine the protocol. For example, one refinement that offers promise in reducing the cost of the testing involves the use of respirometry (i.e., measurement of oxygen uptake and carbon dioxide production automatically over time). Respirometric analysis offers an inexpensive, automated estimation of biokinetics and acclimation lag time that can be invaluable in screening commercial bioremediation products. Definitive work is being done to correlate cumulative oxygen uptake and oil component degradation. Critical to this task is the evaluation of the effect of such factors as biomass concentration, temperature, degree of mixing, source of water, and the physical characteristics of the oil on product efficacy screening.

Flow-through microcosms are being developed that simulate shoreline and open water spill scenarios. The shoreline microcosms are filled with suitable beach material or soil, contaminated with a selected standard API oil, and subjected to intermittent seawater or freshwater flows to simulate tidal and wave action. The open water microcosms operate on the same principle, but water flows continuously through the system rather than intermittently. The microcosms are connected to respirometric instrumentation to track O_2 uptake, nutrient transfer, and CO_2 evolution continually and automatically as tidal water exchange occurs.

The Alaska oil spill bioremediation project heightened our awareness of the extreme complexity of interactions among physical weathering processes, the degree and location of contamination, hydraulic flow regimes, and microbial degradation. It is impractical to conduct multiple experiments every time an oil or chemical spill occurs to sort out these interactions. A generic approach is needed based on thorough knowledge of all the physical, chemical, and microbiological factors that influence *in-situ* biodegradation. Examples of research ideas being pursued include:

- Fundamental aspects of crude oil biodegradation.
- Development of chemical and microbiological methods for use during oil bioremediation field studies.
- Development of novel delivery systems (microencapsulation or liposomes) for applying nutrients and microbial inocula to oil spills.
- Modeling studies on feasibility of open-sea oil spill bioremediation.
- Field study of bioremediation of spilled crude oil on a cobble beach.

Applicability: The reactor systems will be useful for determining the optimum nutrient and/or microbial culture concentrations and frequencies needed to bioremediate a contaminated environ-

Oil Spill Bioremediation
Research and Development Program

ment. The respirometric microcosms can also be used for product efficacy testing as part of the protocol development program. The basic research will guide implementation of bioremediation technology in the field.

Cost of Control Implications: Once the respirometric microcosms are fully developed and the concept proven for open waters and solid matrices, the cost of product testing will be substantially reduced because of the limited need to conduct extensive analytical chemistry with destructive sampling techniques. These microcosms will be most useful for determining how to bioremediate a contaminated site because all the preparative work needed to establish dose levels and rates will be reduced to the controlled laboratory environment rather than the extremely costly field testing.

Opportunities for Collaboration: The open water microcosm has already led to the collaboration with Southwest Research Institute to test the efficacy of its microencapsulation technology for treatment of an open water oil spill. Such private industry collaboration will be possible when the beach reactor has been fully proven and tested under a variety of conditions. Other opportunities will be possible in the program as more ideas from the private sector converge with those of RREL's.

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Anaerobic, Expanded-Bed, GAC Bioreactor for Hazardous and Industrial Wastes

Status of Technology: Many aqueous industrial wastes contain hazardous components and vary widely in composition and strength. Conventional aerobic biological treatment systems employ excessively long hydraulic retention times to successfully treat these wastes. In addition, some of these wastes resist biological treatment due to the presence of toxics and/or inhibitory materials. Finally, other materials that are volatile in nature may be stripped to the atmosphere during aerobic treatment. These factors represent a significant challenge in treating such wastes to acceptable limits.

Intensive developmental work between the Risk Reduction Engineering Laboratory and the Civil and Environmental Engineering Department of the University of Cincinnati has produced an innovative process for treating hazardous and industrial wastes. The anaerobic, expanded-bed, granular activated carbon (GAC) bioreactor (Figure 1) is ideally suited for the treatment of aqueous hazardous wastes containing mixtures of readily biodegradable and aerobically biologically refractory organic compounds.

Technology Description: Special features of the process are:

- Enhanced **biomass attachment** due to the creviced surface of GAC,
- Buffering of **shock loads** wherein excess substrate is stored on the GAC for later desorption and degradation,
- Efficient performance during **process start-up** due to the combined removal mechanisms of adsorption and biodegradation,
- Ability to render an **inhibitory toxic waste** biotreatable via adsorption of the offending compounds,
- Hydraulic retention times of 3 to 12 hours, representing significant **reductions in bioreactor volume** compared to conventional technologies, and
- Potential for upgrading poorly performing conventional biological treatment systems using a **hybrid configuration** consisting of a small GAC adsorber connected through recirculation to the conventional system.

Applicability: The GAC medium serves to sequester inhibitory and hazardous constituents from the aqueous phase, thus permitting the unhindered utilization of readily biodegradable constituents. In instances where the inhibitory constituents resist biodegradation, a strategy involving periodic replacement of a portion of the GAC medium may be practiced to replenish GAC adsorptive capacity. The adsorptive characteristics of GAC permit the retention of slowly biodegradable organics that require acclimation of specially adapted organisms. In these cases, the adsorptive capacity of GAC can be extended indefinitely due to biologically mediated regeneration.

Several waste types have been effectively treated by the anaerobic, expanded-bed, GAC bioreactor. These wastes include coal gasification effluents, coke oven effluents, refinery sour water stripper bottoms, electronics plant solvent wastes, and landfill leachates in both the United States and Europe. Specific chemicals of interest treated by this process include substituted phenols, chlorinated phenols, polycyclic aromatic hydrocarbons, benzenes, ketones, chlorinated aliphatics, pesticides, and phthalates. These chemicals comprise a variety of volatile and semivolatile organic compounds that appear on the EPA list of priority pollutants. Of 27 toxic compounds tested to date, all were removed to levels of 85% or greater, 22 to levels of 90% or greater, 20 to levels of 95% or greater, and 15 to levels of 98% or greater.

Cost of Control Implications: Use of anaerobic expanded bed GAC treatment for high strength industrial and hazardous wastes provides an economical alternative to aerobic processing in central industrial or municipal wastewater treatment facilities. The anaerobic treatment systems provide cost-effective means for control of volatile organic compounds and generate methane as a

Anaerobic, Expanded-Bed, GAC Bioreactor for Hazardous and Industrial Wastes

usable energy source. Bioregeneration of the GAC support medium substantially minimizes carbon replacement costs. Actual treatment costs are site and waste dependent.

Opportunities for Collaboration: The technology has been carefully evaluated for 10 years including three years of continuous pilot operation. The technology is ready for marketing. The EPA desires to participate with the private sector in marketing the technology for a variety of hazardous and industrial waste treatment applications and for bioremediation at Superfund sites.

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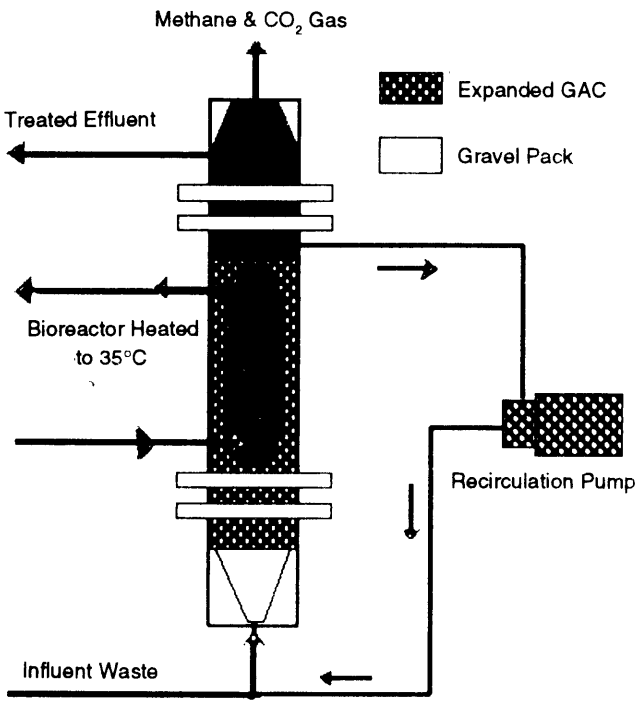

Figure 1. The anaerobic, expanded-BBD, GAC Bioreactor

Simulation Model Software for Water Treatment Processes

Status of Technology: Granular Activated Carbon (GAC) and Air Stripping treatment software were published under an FTTA agreement. Software for membrane processes are in the early development stage.

Technology Description: A set of PC-based computer models have been developed to aid one in evaluating preliminary designs of liquid-phase GAC treatment and packed tower aeration systems for controlling organic contaminants in drinking water. The constant pattern homogeneous surface diffusion model is used to predict GAC breakthrough curves for single-solute contaminants. Adjustment parameters can be applied to account for natural water effects. Cost-estimating models can be used to compare steel pressure and concrete gravity adsorber systems, and evaluate the cost-effectiveness of multihearth, infrared, and fluid-bed reactivation technologies. Air stripping models can be used to examine various system designs and estimate the treatment cost with and without air emissions control of tower off-gases using vapor-phase carbon.

Applicability: These analysis tools are a result of in-house research efforts and studies conducted at various field sites using pilot and full-scale facilities. The models have been used by EPA to examine potential cost and performance impacts on water utilities as a result of proposed and existing drinking water regulations. The models have also been used to evaluate specific treatment scenarios for Superfund applications.

Opportunities for Collaboration: Develop new models for various treatment processes which address performance prediction and cost estimates for constructing and operating systems. Develop step-by-step instructions for using software and demonstrating applications.

Establish agreements/contracts for marketing and publishing computer software for treatment simulation program packages.

Publish scientific journal articles that describe models and results for specific scenarios.

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Hydraulic Fracturing to Enhance Elimination in the Subsurface Soil by Vapor Extraction or Bioremediation

Status of Technology: This technology has been developed over the last four years and is currently being field-tested at contaminated sites.

Technology Description: Problems of Contaminated Soils: Many subsurface soils contain hazardous wastes as a result of leaking storage tanks or unsound disposal practices. Cleaning up these soils often means excavation in addition to some process such as incineration. Excavation is not only costly but leads to exposure of workers and perhaps neighbors to the contaminated soils. This increases liability. Treatment of these soils *in situ* avoids these problems. However, it has been difficult to access these soils to remediate them.

The Hydraulic Fracturing Technique: The hydraulic fracturing technique is a method to access the subsurface soils to allow removal of hazardous wastes or to allow delivery of materials (i.e., to enhance bioremediation) into soils. The Risk Reduction Engineering Laboratory and the Department of Civil and Environmental Engineering of the University of Cincinnati, both at the Center Hill Laboratory, have adapted this established oil field technology to be applied in shallow subsurface soils.

After notching the bottom of a well with a water jet, a guar gum matrix with granular material suspended in it is added under slight pressure (up to 35 PSI) until a pancake-shaped fracture is created. An enzyme is added to break down the guar gum matrix, which can then be pumped back out, leaving a sand lens. These fractures can be stacked as close as 20 cm (6 inches). The permeable sand lenses can be used to retrieve liquids or vapors or to deliver oxygen and nutrients to enhance bioremediation.

Soil Vapor Extraction: The permeable sand lenses increase the overall permeability of the soil, allowing for better removal of vapors from the soil. Several fractured wells have been installed in silty-clay tills of low permeability. Control wells were installed in the same material but contain no hydraulic fractures. Results indicate both an increase in flow rate and radius of influence at the fractured wells. Applying a suction head of 114 cm (45 inches) of water to the fractured well resulted in 2.54 cm (one inch) of suction at a distance of 7.6 m (25 feet) at a depth of 16 cm (6 inches). The same suction head diminishes to 2.5 cm (1 inch) of water less than 1.5 m (5 feet) from the conventional well. Flowrates at the fractured wells increased to tenfold, 5 CFM vs. 0.5 CFM, depending on weather conditions.

***In-Situ* Bioremediation:** The hydraulic fractures can be used to enhance *in-situ* bioremediation by being conduits for electron acceptors and nutrients. Soluble nutrients and oxygen (in the form of hydrogen peroxide) have been added through hydraulic fractures to a site of low permeability glacial till contaminated with hydrocarbons. We have seen a significant loss of hydrocarbons in the fractured soil along with increased bioactivity, compared to the control well (conventional).

We are further enhancing the science of bioenhancement by the development of a slow-releasing solid oxygen source. By placing this slow-releasing solid oxygen source into the hydraulic fracture along with slow-releasing nutrient sources, bioremediation can be enhanced over several months without the need for human intervention or energy-requiring equipment on the site. This reduces exposure, liability and costs.

Applicability: Hydraulic fracturing can be implemented in any overconsolidated soil. Volatile chemicals can be removed with hydraulic fracturing by vapor extraction. Any chemical which can be biodegraded aerobically or anaerobically can be degraded by adding the proper amendments in the hydraulic fracture.

Cost of Control Implications: The comparison in performance between the hydraulically fractured well and a conventional well shows substantial savings in soil vapor extraction applications (a tenfold increase in radius of influence, and a tenfold increase in vapor yield). *In-Situ* bioremediation applications in overconsolidated soils can be enhanced with liquid injection of nutrients and electron acceptors by hydraulic fracturing. Thus, a

Hydraulic Fracturing to Enhance Elimination in the Subsurface Soil by Vapor Extraction or Bioremediation

hundredfold increase in liquid injection rate (compared to a conventional well) is seen with hydraulic fracturing. But hydraulic fracturing also allows for the delivery of solid slow-releasing oxygen and nutrient sources which will provide substantial savings by minimizing human intervention and energy requirements.

Opportunities for Collaboration: There are many more avenues to explore with this research. Several are: further development of additional access techniques to allow for more flexibility in making contact with the soil, slow-releasing nutrient sources to enhance bioremediation, slow-releasing electron acceptors, and slow-releasing encapsulated bacteria that will biodegrade the compound of interest.

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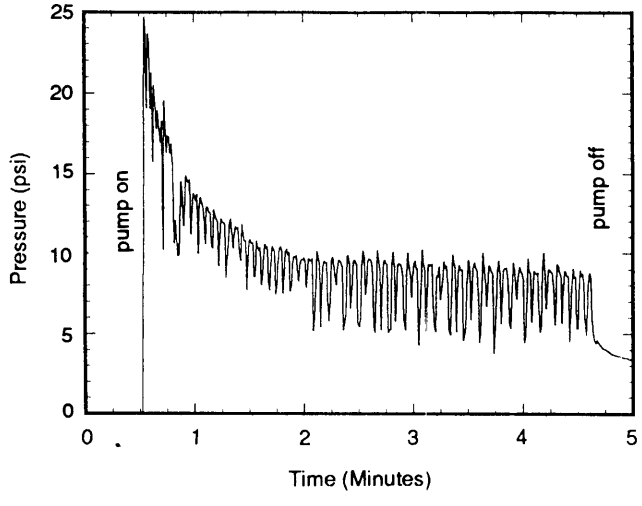
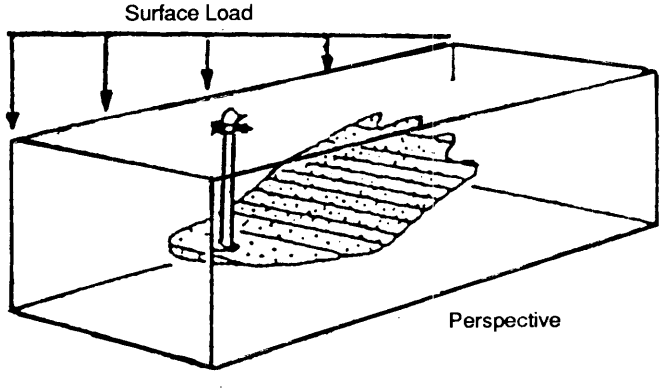
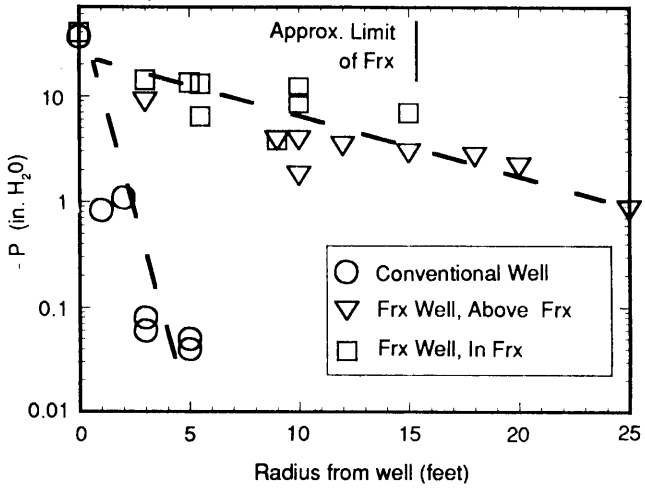
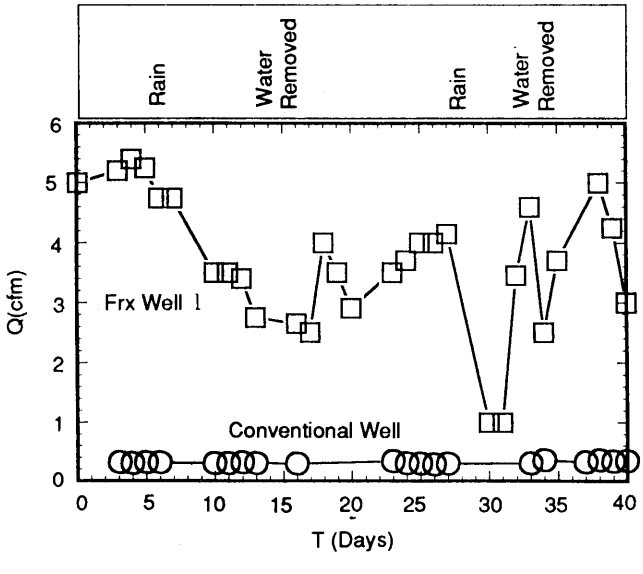


Pressure log displaying peak that marks the onset of fracture propagation.



Idealized hydraulic fracture created at shallow depths in over consolidated silty clay.





Performance comparison between fractured and nonfractured wells during vapor extraction.

Clean Products Program

Technology Description: The Pollution Prevention Act of 1990 directs the USEPA to initiate within the Agency a program to encourage the adoption of technologies and strategies to prevent pollution in all sectors. Legislative authority and guidance for the Agency's pollution prevention research activities are contained in the Resource Conservation and Recovery Act (RCRA) which authorizes programs and research that support the minimization of hazardous waste generated.

RREL serves as the lead organization within the Office of Research and Development for research related to pollution prevention. RREL's pollution prevention research program encourages the development and adoption of processing technologies and products in the United States and internationally that will lead to reducing the aggregate generation rates for pollutants entering the various environmental media. Projects within the program are supported through in-house activities, contracts with outside organizations, and cooperative agreements with universities and other governmental agencies.

One of the ten environmental problems targeted for priority attention for pollution prevention research within ORD is the production, use and disposal of consumer products. The **Clean Products Program** supports this initiative encouraging the development of cleaner products and technologies.

Status of Technology: Municipal solid waste (MSW) generation is becoming an ever increasing problem worldwide. Organizations within the United States and internationally are adopting the clean products and packaging idea as an effective tool for reducing waste generation rates.

While both industry and the general public have demonstrated interest in promoting clean products and technologies, little information is readily available to assist in making sound decisions and changes. Several projects have been initiated within RREL to assist in promoting clean products and technologies and transfer of this information.

A recent RREL publication, *Achievements in Source Reduction and Recycling for Ten Industries in the United States*, (EPA/600/2-91/051), contains twenty examples of clean technologies in ten industries in the United States. These examples have been collected from participating companies as direct efforts in reducing waste generation through source reduction and recycling.

There are currently three projects within the laboratory that are addressing the clean product side of pollution prevention:

(1) **Evaluating the Potential for Safe Substitutes** is a cooperative agreement with the University of Tennessee. It is developing a protocol for evaluating potential substitutes for products that are either toxic themselves or rely upon toxic chemicals in their production phase. This project will produce a background document in 1993 addressing safe substitutes.

(2) **Clean Products Case Studies**, a cooperative agreement with INFORM, Inc., will produce case studies of various approaches to clean products and packaging both in the United States and Europe. European initiatives are more aggressive in attacking the MSW problem. These studies will address MSW primarily, but toxic issues will also be included.

(3) **Dynamic Case Studies on Environmentally Advanced Product Design** is a project with the Resource Policy Institute, developing information on environmentally advanced product design. Areas being evaluated are construction, public utilities, and product optimization. Increased product durability, reduced production wastes, and innovative product design will be approached from studies that exemplify reduction of toxicity and volume in the MSW stream, provide economically and environmentally superior alternatives, demonstrate versatility and adaptability in the product or service and overall reduce the environmental burden to the biosphere.

Clean Products Program

All these projects are ongoing and in various stages of analysis.

Opportunities for Collaboration:

- Environmental labelling is an area being addressed by several organizations. The public seeks some confidence level in products purchased at the consumer level. However, there are conflicting groups using various criteria for product labelling and "green" consumer information. Development of a universal guide for labelling is an area needing further collaborative effort.
- Promotion of environmentally friendly packaging is an area being approached in diverse and innovative ways in the European Community. Further research into the culture and necessity of change in the European Community might provide fuel for change in the United States.
- The solid waste stream has become an enormous issue for now and the future. Understanding the issues driving the national solid waste crisis and fundamental concepts for future redemption would be an area for definitive collaboration.
- Industry is facing the massive issue of solid waste from a production and product standpoint. Cooperative efforts of packaging initiatives need to be developed and marketed to manufacturers for reducing this society's landfill dilemma.

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BCD Detoxification of Chlorinated Wastes

Status of Technology: Scientists at the Risk Reduction Engineering Laboratory have been working on detoxifying chlorinated organics for over ten years. They focused their efforts on contaminated soils, and developed three chemical treatment processes that are described as base-catalyzed dechlorination (BCD) processes. Unlike the earlier versions that use polyethylene glycol (PEG), the latest version of this technology uses no PEG, and represents new chemistry for dechlorination. This new mechanism is a breakthrough in treatment technology, and provides clean and inexpensive reaction.

Past and future applications of the BCD process are listed below:

- 40,000 cu.yds. of PCB-contaminated soil (100-600ppm) treated on a Superfund Site, Brant, NY (1991-1992).
- PCB-contaminated sediments treated at Waukegan Harbor, Waukegan, IL in 10 tph system achieving 99.9999% destruction (1992).
- Two liquid treatment systems (2000 liters) will be placed into operation in Australia (1992).
- The U.S. Navy's 1-tph/soil treatment system is scheduled to treat 5000 tons of PCB-contaminated soil (25-6500ppm) starting in October 1992.

Technology Description: The process embodies the following steps: mixing the chemicals with the contaminated matrix (such as excavated soil or sediment, or liquids, containing these toxic compounds), and heating the mixture at 320-340°C for 1-3 hours. The off-gases are treated before releasing to the atmosphere. The treated remains of the reactor are non-hazardous, can be either disposed of according to standard methods, or further processed for separating components for reuse.

Applicability: The BCD process can be used for the destruction of the following chlorinated compounds:

Halogenated Volatiles
Halogenated Semivolatiles
PCBs
Pentachlorophenol
Herbicides (halogenated)
Pesticides (halogenated)
Dioxins/Furans

Cost of Control Implications: The U.S. Navy conducted an engineering and cost analysis of processes that might be used in Guam to destroy PCBs (25-6500ppm) in 5000 tons of soil. The results from this study were:

- Secure Landfill.....$910/ton
- Off-site Incineration.....$2000-3320/ton
- On-site Incineration.....$2020/ton
- APEG Treatment.....$270/ton
- BCDP Treatment.....$245/ton

Such factors as high clay and moisture content may raise BCD treatment costs slightly, but much less so than with incineration.

Opportunities for Collaboration: The BCD technology has been licensed and commercialized in foreign countries. The BCD is being offered by RREL for licensing for commercial use in the United States. Several companies continue to show strong interest in licensing the technology.

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Fungal Treatment Technology

Status of Technology:

- Wastes generated in the wood treating industry are a major hazardous waste problem in the United States. More than 700 existing wood treating sites will eventually require some form of site remediation.
- Wood treating technology has been based on the use of three kinds of preservatives: creosote, pentachlorophenol, and copper chromated arsenite.
- Soils, surface, and subsurface waters have been contaminated with the toxic metals and organic chemicals found in the commercial procedures.
- Concentrations of pentachlorophenol found in contaminated soils can be treated in the percentage concentration level range. Few bacteria can withstand the toxicity associated with these concentrations but the lignin-degrading fungi are able to withstand very high concentrations (400-900 mg/Kg).
- The technology is now available for application at field scale. Process improvements for the inoculum preparation and application are expected in the next year.
- Application of the fungal technology to waste materials such as pesticides, town gas wastes, and munitions will be conducted in 1993.

Technology Description:

- Fungal species have shown wide versatility in degrading organic pollutants. The fungi capable of degrading lignin are among the most competent. They secrete extracellular enzymes that degrade lignin. For applications to the detoxification of hazardous wastes, these lignin-degrading fungi are superior to bacterial systems because the secreted enzymes are strongly oxidizing and non-specific.
- USEPA and USDA staff lead a team of researchers in investigating the abilities of lignin-degrading fungi to detoxify hazardous waste organic compounds. Their efforts have focused on the treatment of pentachlorophenol and other organic chemicals associated with wood preserving. The development of this field-worthy technology has proceeded through methodical investigation of growth requirements of the fungi and the evaluation of fungal treatment in soil to determine the conversion of pollutant to non-toxic end products.

Applicability:

- Treatability results derived from studies at an Oshkosh, WI, site in 1989 showed 80-85% depletion of pentachlorophenol in contaminated soil over a period of eight weeks.
- Results of a time-series treatability study conducted at Brookhaven, MS, confirmed the Wisconsin results and indicate that this technology has great field potential. SITE Demonstration Program data have shown that pentachlorophenol was depleted by 80-85% during 56 days of treatment. Polynuclear aromatic hydrocarbons that are components of creosote showed significant removal rates during the same study.
- A field scale demonstration of this fungal treatment technology will be conducted at the Brookhaven, MS, site for five months in 1992.

Cost of Control Implications: The cost of treatment of wood treating wastes is being evaluated as part of the ongoing Brookhaven SITE demonstration. Inoculation systems are under development as a cost reduction component. The process has technical advantages in application to bacterial inhibitory concentrations of organic pollutants (pentachlorophenol) and to soils with low pH.

Opportunities for Collaboration: The USEPA and USDA wish to evaluate the extension of the technology to other organic pollutant classes and complex wastes found in landfills.

Fungal Treatment Technology

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Destruction of Organic Pollutants in Water and Air by Titanium Dioxide Photocatalysis

Technology Description: RREL is actively investigating an advanced oxidation process for the destruction (decomposition) of organic pollutants and detoxification of inorganic pollutants in water and air streams. The principal objective is the optimization of a titanium dioxide (TiO_2) based photocatalytic technology which, in combination with ultraviolet radiation, produces highly reactive hydroxyl radicals. Once formed *in-situ*, these radical intermediates have been shown to cause the rapid destruction of a wide array of chemical compounds known to be present in both ground water and surface water. Many chlorinated organics can be dehalogenated by the process (rendering them less toxic) and certain problematic inorganic contaminants (e.g., cyanide) are oxidized to innocuous forms.

A novel aspect of the technology is the incorporation of a TiO_2 semiconductor material imbedded in a fiberglass mesh which lines a photolytic reactor. This material behaves as a catalyst for the oxidation process and greatly enhances the formation of hydroxyl radicals, resulting in much greater process efficiency and output. Under optimal conditions, this enhanced oxidation mechanism results in complete mineralization of substrate organic contaminants. As such, the process is an "ultimate disposal" method which leaves behind only water, carbon dioxide, and some benign halide salts.

Applicability: The hydroxyl radical advanced oxidation process has a variety of pollution prevention applications including:

- The manufacture of Ultra Pure Water for the semiconductor, nuclear, and pharmaceutical industries without the use of other process chemicals like ozone, chlorine, or permanganate.
- The purification and disinfection of Drinking Water without the production of disinfection by-products (e.g., chloroform).
- The purification of Plant Processing Water at the source (e.g., metals recovery, trichloroethylene removal).

Significant benefits from the technology are gained for those active in achieving environmental compliance. These benefits include:

- The destruction of waterborne organics at the source, which eliminates the cost and risk associated with the collection, transportation and long-term disposal of organics.
- A user-friendly technology which operates on demand that is low profile, quiet and uses readily available components and skills for operation (i.e., amenable to small community systems' requirements).
- Titanium dioxide photocatalysis is proving to be an exceptional technology for the treatment of air emissions from a variety of sources including: wastewater treatment plants, air stripping towers, incinerator off gas, municipal landfill sites, carbon regeneration facilities, dry cleaning facilities, freon-based processes, spray booths, degreasing facilities, soil venting processes, and organic chemical manufacturing plants.

Current Activities and Opportunities for Collaboration: RREL is investigating novel photochemical reactor designs which will optimize hydroxyl radical formation. Reactor geometry modeling and prototype construction are required. Stainless steel is the currently preferred reactor fabrication material though lighter, more easily assembled and inexpensive materials and components would be highly desirable. Studies of various "front-end" technologies are necessary to determine how much pretreatment of heavily contaminated water streams is required for effective photocatalytic oxidation in the final reactor stage. Off-the-shelf technologies will be evaluated first for this purpose (e.g., microfiltration systems).

Destruction of Organic Pollutants in Water and Air by Titanium Dioxide Photocatalysis

Process efficiency measurements and sensors will be required very soon. On-line water/air quality monitoring systems for low molecular weight, highly water soluble organic compounds need development and testing at field scale. Rapid microbial screening techniques need to be developed to monitor the bacterial quality (safety) of water treated for human consumption. A near-real time bacterial enumeration technique like epifluorescent microscopy may be necessary in situations where access to sophisticated laboratory measurements and expertise is unavailable.

A critical process parameter in TiO_2 photocatalysis is detection and measurement of the primary oxidant, the hydroxyl radical, HO•. We have already developed the chemistry necessary for quantitation of HO• but require a pilot/field-scale process monitor/analyzer based on our bench-scale measurement principles. This hypothetical monitor would also be extremely useful in other measurements of HO• unrelated to TiO_2 (e.g., ozone systems which produce small quantities of HO• and the study of upper atmospheric chemistry).

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Clean Technology Demonstration Program for Pollution Prevention

Technology Description: Under the Pollution Prevention Act of 1990, the EPA is empowered to champion source reduction across a spectrum of activities. Among these it is charged with identifying cleaner technologies and promoting their implementation by industry.

Current Activities: The Agency has entered into a number of activities aimed at voluntary and cooperative efforts with industry as well as incorporation of more flexible, pollution prevention approaches into any regulatory activities in the future.

The 33/50 Program is a pollution prevention initiative with the objective to reduce 17 priority pollutants 33 percent by 1992 and 50 percent by 1995 on the basis of comparing Toxics Release Inventory (TRI) values for the base year 1988 on a voluntary basis. Success is to be measured on an aggregate basis per pollutant.

Pollution prevention solutions are also being sought for the Resource Conservation and Recovery Act (RCRA) Best Demonstrated Available Technology (BDAT) problem wastes. Present emphasis is placed on Arsenic and Mercury.

The Source Reduction Review Program (SRRP) is an effort to investigate pollution prevention approaches and solutions in proposed or upcoming legislation. A list of 17 industry and pollution problem areas have been identified for study.

In these pursuits, the Pollution Prevention Research Branch (PPRB), RREL, has established two major programs, the Waste Reduction Innovative Technology Evaluation (WRITE) Program (expiring in FY 93), and a similar follow-on program called the Clean Technology Demo Program (started in FY 92), to evaluate relatively mature (pilot or full scale) new technologies on a cooperative basis with industries developing and/or using such technology.

The WRITE Program addresses priority problems identified by individual states or local governments as being high priority. Participants in the pilot program are California, Connecticut, Illinois, Minnesota, New Jersey, Washington and Erie County, N.Y.

The Clean Technology Demo Program uses the research needs identified by the 33/50 Program, the RCRA Hard To Treat Wastes and the Source Reduction Review Program (SRRP) to identify and evaluate new technologies being implemented for source reduction. Both programs are based on locating industries implementing the technologies at large- or full-scale. The cooperative effort consists of EPA providing test design, sampling hardware, sampling personnel, data analysis, reduction and report preparation. The industry provides the operating facility and data regarding releases generated by the previous operation as well as cost comparisons between the two.

Approximately 35 technologies are being evaluated under the WRITE Program over a three year period. Another 12 technology evaluations are being planned for the Clean Technology Demo Program, which is now beginning.

The technologies cover a range of industries including: electroplating and metal finishing; printing; reinforced plastic composite production; paints, coatings and adhesives. Generic types of source reduction improvements are being evaluated for a number of industries, such as cleaning, degreasing and paint removal, that replace traditional chemicals with others that are less toxic.

Other approaches are of interest that, for example, use mechanical means of cleaning, investigate procedures that maintain cleanliness as a trade-off to cleaning or refine cleanliness criteria for accomplishing objectives.

Applicability of a number of these improvements (such as cleaning improvements) is potentially extensive.

Opportunities for Collaboration: All new evaluations are seeking sites where technology is being implemented and the facility is interested in participating in an impartial test of the pollution

Clean Technology Demonstration Program for Pollution Prevention

prevention aspects of the technology as well as providing sufficient cost data to serve as comparison between old and new systems.

More detailed project plans are available and distributed under separate cover, entitled *Pollution Prevention Research Branch: Current Projects, July 1992.*

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September 1992

Floor Tile Encasement of Asbestos Fibers

Status of Technology: Unknown.

Technology Description: A tough, durable, non-yellowing, transparent coating/encapsulant is needed to cover asbestos-containing floor tile to allow layers of polish to be applied over the encapsulating coating so that normal maintenance activities (buffing) can be conducted without fear of asbestos release.

Applicability: This technology affects all asbestos-containing floor tile in hundreds of thousands of buildings and residences in the United States.

Cost of Control Implications: This technology will eliminate the necessity for removal of existing floor tiles where they are in good condition and eliminates the risk of contaminating the adjacent area when the removal is improperly done. Also, the technology eliminates the risk, both to the worker and to the building occupants, from maintenance activities such as wax removal and routine buffing operations.

Opportunities for Collaboration: EPA can provide the expertise to evaluate environmental release and worker exposure and could also provide test sites. Industry must develop products for testing.

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RREL Treatability Data Base

Status of Technology: The RREL Treatability Data Base is updated yearly with aqueous and solid treatability data.

Technology Description: To provide a thorough review of the effectiveness of proven treatment technologies in the removal/destruction of chemicals in various types of media including, but not limited to, municipal and industrial wastewater, drinking water, groundwater, soil, debris, sludge, and sediment.

Version 4.0 of the Risk Reduction Engineering Laboratory Treatability Data Base was released in February 1992 and contains 1166 chemical compounds and over 9200 sets of treatability data. The chemicals contained in the database are often those regulated under the Clean Water Act, Safe Drinking Water Act, Resource Conservation and Recovery Act, Toxic Substances Control Act, Superfund Amendments and Reauthorization Act, and other environmental laws enacted by Congress. For each chemical, the database includes: physical/chemical properties, aqueous and solid treatability data, Freundlich isotherm data, other environmental database information sources, and data references including a reference abstract. The physical/chemical properties included are those most routinely used, such as molecular weight, boiling point, melting point, etc. The treatability data summarize the treatment technologies used to treat the specific chemical; the type of waste/wastewater treated; the size of the study/plant; and the treatment efficiency achieved. In addition, each data set is referenced to sources of information, operational information on process(es) sampled and quality-coded based upon analytical methods and reported quality assurance.

Applicability:, The database is distributed to federal, state and local governments, foreign governments, academe, industry, industrial trade associations, environmental groups, law firms, and engineering firms. The database has a current mailing list of approximately 2000.

Cost of Control Implications: Not applicable.

Opportunities for Collaboration: Collaboration between ORD, Program Offices, Regional Offices, and the private sector is necessary to access the current treatability data for inclusion in the database.

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WQA/U.S. EPA Evaluation of Ion Exchange Softening on Corrosiveness of Drinking Water

Status of Project: The test pipe loop systems and ion exchange systems are currently being installed. Corrosion experiments are expected to begin in October, 1992.

Project Description: This Water Quality Association (WQA)/USEPA joint project is an outgrowth of a new program under the Federal Technology Transfer Act.

The leaching of lead, copper, and other metals from metallic materials in household plumbing systems is impacted by the corrosiveness of the distribution water. Numerous studies have been conducted and are currently being conducted to evaluate the effects of different water quality constituents on the corrosion of household plumbing materials. Although naturally soft, waters low in total dissolved solids have been shown to be corrosive, and no comprehensive studies have been conducted to determine the corrosive effect of ion exchange softening where the calcium and magnesium ions are exchanged for sodium ions to produce soft water. Additionally, little data exist on the fate of various water quality constituents that play an integral role in surface film development or the corrosion of metals as they pass through domestic water softeners.

The general goal of this project is to determine if domestic water softeners increase corrosion by-products in household plumbing systems.

The specific objectives of this research are:

1. Evaluate the impact of domestic ion exchange (IX) water softening on corrosion by-product levels of lead and copper from common household plumbing materials of waters of two different levels of hardness (~120 mg/L and 300 mg/L as $CaCO_3$).
2. Determine if domestic IX water softening produces changes in the chemical characteristics of the water that potentially results in an increase in corrosivity.
3. Determine whether domestic IX water softening can produce reversible changes of passivation surface films of domestic plumbing systems.

Test pipe loop systems containing copper tubing, copper pipe with 50:50 lead solder joints, galvanized pipe, lead pipe, and brass faucets will be subjected to both untreated ground water and ion exchange softened water to determine corrosivity.

Applicability: Data will be gathered that will be useful to water utilities, WQA, and the USEPA to determine the effect that ion exchange water softeners have on the corrosion of plumbing materials. These data could be used to help meet the lead and copper regulations.

Opportunities for Collaboration: The outcome of the project may be used by states, WQA (and its members) and the USEPA to help understand if water ion exchange softeners increase the corrosivity of waters. If these systems show an increase in corrosivity, then further work will be necessary to find ways to reduce or prevent the corrosion.

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Municipal Solid Waste Innovative Technology Evaluation (MITE) Program

Technology Description: This program provides waste managers with information on the cost-effectiveness and limitations of innovative municipal solid waste (MSW) management treatment and reduction methods. By doing so, the EPA hopes to foster and accelerate the development and commercialization of innovative technologies and management techniques for municipal solid waste. Through cooperative efforts with private developers, new solutions to MSW management problems can be obtained.

Eligible technologies or methodologies should meet at least one of the following criteria:

- Decrease final volume and/or toxicity of the MSW stream.
- Create a profitable and easily marketable end-product using a portion of the MSW stream as a feedstock.
- Increase the marketability of recycled goods.
- Be environmentally sound and economically favorable.
- Be of assistance to local waste managers in selecting and implementing techniques for solving their solid waste disposal problems.
- Have a reasonable potential for acceptance and commercialization.

Applicability: The cost of municipal solid waste disposal has increased dramatically due to the shortage of acceptable disposal options. There is a need to develop higher quality options for managing the wastes that are generated by our complex society. The MITE program was developed to aid this process, and will combine the talents of the participants — private entrepreneurs, local and State governments, waste management professionals, experienced scientists, engineers, and economists — to develop and implement waste management solutions.

The design and operation of the MITE demonstration is done by the Technology Developer. EPA performs the evaluation by providing a complete technical, environmental and economic analysis of the selected technology. Although the EPA is not providing funding to the developer, there are a number of advantages:

- An objective evaluation of the demonstration or process
- Useful data on equipment performance.
- Environmental analysis.
- Cost analysis.
- Published report on the evaluation, and distribution to municipal managers and others that would ultimately be users of the technology. This report serves as a marketing tool for the private developer, or is used to target further research.

Cost of Control Implications: Each individual technology will have a different cost of control. With the MITE evaluation, a thorough cost analysis is done. A summary of the regulatory and permit requirements that would be required for full-scale implementation is also provided to the technology developer.

Opportunities for Collaboration: The MITE program provides an excellent opportunity for collaboration. The chosen technologies receive a thorough evaluation including the potential of the technology to be accepted in the solid waste management industry. There is an annual solicitation for technologies in the fall.

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Toxicity Reduction Evaluations at Municipal Wastewater Treatment Plants

Status of Technology: In 1984, EPA issued a policy for developing water quality-based permit limitations to control the discharge of toxic pollutants through the nation's wastewater treatment plants. Wastewater discharges are regulated by the National Pollutant Discharge Elimination System (NPDES) under the Federal Water Pollution Control Act of 1972 (FWPCA).

Until recently, EPA relied on chemical-specific controls to limit toxic discharges from wastewater treatment plants. This approach is problematic since reliable toxicity data exist for only a few compounds likely to remain in treatment plant effluent. This problem has been mitigated by including rapid bioassays of the waste stream to provide a more comprehensive, yet cost effective, analysis of the treatment plant's ability to remove toxic substances from the waste stream.

Bioassays are used to determine whole effluent toxicity in aquatic species such as the water flea (*Ceriodaphnia*) or fathead minnow. Bioassays may be acute (48 to 96 hour survival) or short-term chronic (7 to 8 day survival, growth and reproduction). If toxicity is found in the effluent, bioassays may be used to track the toxicity back through treatment stages and the influent stream to determine the source of the toxicant. This process is called a Toxicity Reduction Evaluation (TRE).

The (TRE) Protocol for Municipal Wastewater Treatment Plants provides a systematic framework for conducting a TRE using bioassay endpoints. The TRE Protocol is designed for use by Publicly Owned Treatment Works (POTWs) in conducting TREs to meet NPDES whole effluent toxicity permit limits.

Technology Description:

The overall objectives of a municipal TRE include:

- Evaluation of the operation and performance of the POTW to identify and correct treatment deficiencies causing effluent toxicity.
- Identification of toxic compounds causing effluent toxicity.
- Tracing the effluent toxicants to the sources.
- Selection and implementation of toxicity reduction methods or technologies to control effluent toxicity.

The TRE Protocol describes the following methods and procedures:

- TRE Design.
- Implementation of a TRE plan.
- Interpretation of results and data generated during the TRE.
- A scientific and engineering basis for selection and implementation of toxicity control methods.

Applicability: EPA has applied the Municipal TRE Protocol to a number of POTW case studies to ensure the effectiveness and flexibility of the procedures. Current methods permit timely evaluation of plant performance, identification of acute and chronic toxicants, and techniques for rapid screening of treatability methods for removal of problematic toxicants.

Currently, work is underway at EPA to enhance the chronic bioassay for more refined source location and identification of specific toxicants. Improved toxicant identification facilitates location of the origin of toxic agents for source control, or design of treatment processes targeted to the removal of specific substances at the POTW.

Cost of Control Implications: Economic implications of TREs for municipal wastewater plants are site-specific and range from simple modifications of operating conditions to total plant replacement. Whenever possible, refractory toxicity should be controlled at the source through an effective pretreatment program.

Toxicity Reduction Evaluations at Municipal Wastewater Treatment Plants

Opportunities for Collaboration: Future TRE development is needed in the area of refractory toxicity assessment. This involves laboratory simulation of wastewater treatment plants to reveal the presence of toxicants refractory to removal during treatment. This technology will permit more effective analysis of separate influent sources to identify origins of refractory toxicants, and screening of potential treatment alternatives. In addition, TRE concepts should be applied to the assessment and control of bioconcentratable contaminants in wastewater using recently developed protocols.

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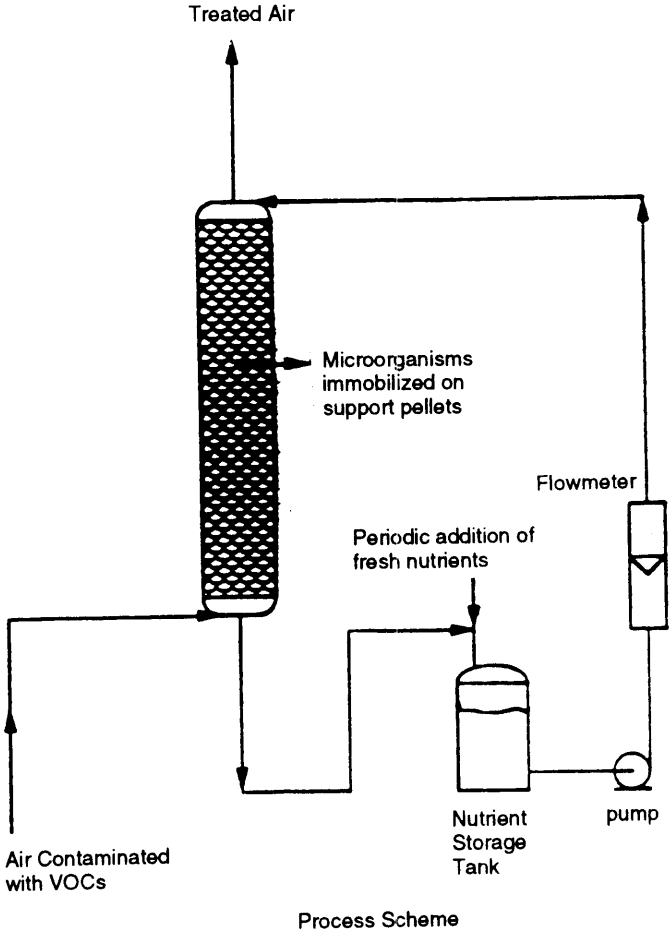
Biofilter Technology for Controlling Air Emissions of Volatile Organic Chemicals (VOCs)

Status of Technology: Current commercial VOC control technology includes two treatment approaches for low to moderate VOC concentrations: (1) isolating VOCs by adsorption on solids such as activated carbon, then destroying thermally, and (2) destroying VOCs biologically in conventional air biofilters. High concentrations of VOCs near the combustion limit can be incinerated.

Adsorption on solids such as activated carbon with sorbent regeneration is expensive.

Conventional air biofilters using peat or soil media require media replacement to prevent buildup of excess biomass and pressure drop across the filter. Thus they have not achieved major market penetration.



Process Scheme

The Risk Reduction Engineering Laboratory of the EPA, in cooperation with the University of Cincinnati, has developed gas-phase biofilters that rapidly and efficiently remove VOCs from air with low pressure drop across the filter. The filter design employs pelletized activated carbon or porous-ceramic materials as support media, and recirculated nutrient liquid to produce efficient biodegradation (Process Scheme). One reactor configuration employs straight-passage ceramic media with high surface area per volume of filter. A patent application has been filed on the improved biofilters.

Technology Description: The combined sorption-biodegradation process in the biofilter has achieved rapid (2 minutes) aerobic bioremediation of the tested VOCs. 520 ppm of toluene, 140 ppm of methylene chloride and 25 ppm of trichloroethylene were degraded (Process Performance).

The improved biofilter concept features the use of niches (regions) in the biofilter where specific microorganisms, adapted under controlled operating conditions, efficiently degrade specific VOCs. The coinventors of the improved biofilter found that the biomass on the filter achieved high cell density and rapid degradation rates. The straight-passage reactor configuration offers continuous operation without media replacement. The straight-passage reactor produces low pressure drop in the filter and permits excess biomass release from the filter.

Applicability: VOC air emissions pose potential health risks. Dominant VOC sources include direct industrial and commercial releases; contaminated

Process Performance - Pelletized, Activated-Carbon Media: Retention Time = 2 minutes

Contaminant Chemicals	Acclimated Operations (Days)	VOC Removal (Percent)
Toluene	105	100
Methylenechloride	105	100
Trichloroethylene	105	100

Biofilter Technology for Controlling Air Emissions of Volatile Organic Chemicals (VOCs)

drinking water, ground water and wastewater; and releases from Superfund and RCRA sites. VOCs are regulated by CAA, RCRA and CERCLA air emissions requirements.

Cost of Control Implications: Cost estimates using EPA costing models for alternative VOC control technologies and RREL estimates for the air biofilter reveal substantially lower costs for the air biofilter technology at VOC concentrations lower than those that permit sustained combustion. Principal costs for the biofilter are associated with the pressure drop across the filter.

Opportunities for Collaboration: The EPA plans to competitively select a private firm and develop an exclusive licensing agreement for the technology under the Federal Technology Transfer Act. The selected private firm will participate in further development and marketing of the EPA biofilter concepts for VOC control.

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September 1992

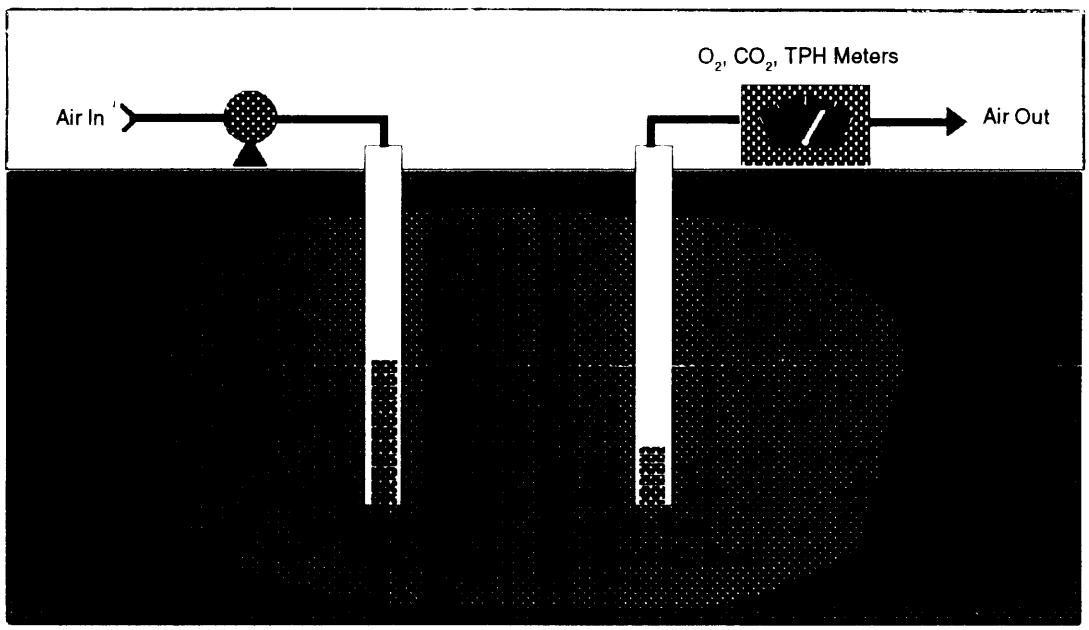
Bioventing: An *In-Situ* Bioprocess for Detoxifying Contaminated Soils

Status of Technology: Current field research in RREL is being conducted in collaboration with the U.S. Air Force (except for the Reilly Tar Site). Ongoing projects include:

- Bioventing of jet fuel in shallow soils in a cold climate. The study features evaluation of *in-situ* soil warming methods at Eielson Air Force Base, AK.
- Bioventing of jet fuel in very deep soils. The study features optimization of air flow rate to maximize biodegradation and minimize volatilization of the petroleum wastes at Hill Air Force Base, UT.
- Bioventing of PAH-contaminated soils at Reilly Tar Superfund Site, MN.
- Bioventing demonstrations at 80 Air Force sites. The data will be used in developing a guidance document for field implementation.
- Full-scale bioventing demonstration with jet fuel contamination at FE Warren Air Force Base, WY.

Technology Description: Bioventing is the process of delivering oxygen by forced air movement to contaminated unsaturated soils in order to stimulate biodegradation of hazardous organic contamination. Unlike the physical/chemical processes of soil vacuum extraction and soil venting where large flow rates of air are forced through contaminated soils to remove volatile organic compounds, bioventing employs low air flow rates that provide only the necessary amount of oxygen for biodegradation while minimizing volatilization. In its most simple form, bioventing can be implemented by either injecting air through a screened well into the plume (see figure) or by withdrawing air through a screened well, thereby drawing air into the contaminated soil from the surrounding clean soil. Depending on the spatial distribution of the contaminated area, various combinations of injection and withdrawal wells can be installed to optimize the distribution of air at a particular site.

A Simple Bioventing Configuration



Conceptual design of a simple bioventing process. Air injection and soil gas monitoring wells are shown. Dark area is plume of contaminated soil.

Bioventing: An *In-Situ* Bioprocess for Detoxifying Contaminated Soils

Applicability: The bioventing process can destroy hazardous organic wastes *in situ* in unsaturated soils. Thus, naturally unsaturated or dewatered contaminated soils can be treated with bioventing. All types of soil are potentially applicable, although highly permeable soils are favorable. All aerobically biodegradable contaminants can be treated, including petroleum-based contaminants, nonchlorinated solvents, PAHs, BTEX, and others.

Advantages of the Bioventing Process:

- An *in-situ* technology – no excavation costs.
- Contamination is destroyed – no subsequent treatment or disposal costs.
- Low operating cost.
- Treats volatile and non-volatile biodegradable organics.

Cost of Control Implications: Results from research studies have shown that, for example, jet fuel levels in sandy soils can be reduced below detection limits in 2 to 3 years, with the BTEX fraction removed in roughly 6 months. Costs depend on the site, but are likely to be between $5 and $25 per ton of soil.

Opportunities for Collaboration: Several potential areas for collaboration exist. Bioventing must be proven for situations other than highly porous soils and petroleum contamination. Thus, collaboration could entail demonstration of bioventing in low permeability soil and with other classes of aerobically degradable contaminants such as nonchlorinated solvents and low molecular weight aliphatics and aromatics. Collaborative efforts could also be directed to the development of novel air injection and withdrawal networks to optimize biodegradation and minimize volatilization.

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September 1992

EPANET Water Quality Model for Drinking Water Distribution Systems

Status of Technology: EPANET is currently in beta-testing. The final version is scheduled for completion in October 1992.

Technology Description: EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within water distribution networks. It tracks the flow of water in each pipe, the pressure at each pipe junction, the height of water in each tank, and the concentration of a contaminant throughout the network during a multi-time period simulation. Water age and source tracing can also be simulated. EPANET runs on IBM-compatible personal computers and UNIX workstations. An optional Microsoft Windows user interface allows one to interactively run EPANET and view its results in a variety of ways on a map of the pipe network.

Applicability: EPANET can be useful for calibrating network hydraulic models, designing water quality sampling programs, analyzing the loss of disinfectant residual, and performing drinking water exposure risk assessments. It can provide insight into how changes in water source utilization, pumping water storage levels, use of satellite treatment, and targeted pipe cleaning and replacement would affect drinking water quality. EPANET is currently being used to evaluate such questions at a number of water utilities throughout the country.

Opportunities for Collaboration: Establish agreements/contracts for marketing and publishing the EPANET software and for providing technical support to users.

Provide new features to the program such as a graphical user interface for Unix workstations or linkages to CAD and GIS software.

Provide new features to the program such as a graphical interface for Unix workstations or linkages to CAD and GIS software.

Apply the model in innovative ways at water utilities facing unique water quality problems and publish the results in scientific journals.

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Pollution Prevention through Process Simulation

Issue: Pollution prevention (P2) encourages the development and adoption of process technologies and products that minimize the generation of hazardous contaminants and their release into the environment. P2 research therefore involves assessing new or existing processes and products either at the initial design stage or afterwards to determine the mechanics behind contaminant generation and release. Once these mechanisms are understood, modifications ranging from simple operational changes to total process or product re-design can be implemented to optimize for minimum contaminant generation. Process simulation, or modeling of a process using state-of-the-art computer software, can be a valuable tool to a process optimization.

Process simulation is widely used in the chemical process and petroleum industries. It accurately supports pilot plant tests through characterization and simulation of technical performance, and also prediction of the influence of important process parameters. The economic advantages of simulation are that it can perform equipment size and cost calculations as well as operating cost calculations.

Despite the significant capabilities of process simulation to optimize for performance and cost, there has been relatively little effort to incorporate environmental concerns into simulation packages. It is now widely believed that process simulation can play an important role in pollution prevention research. Simulation of the wide range of industrial processes by incorporating environmental concerns would provide a cost-effective way to understand and minimize the formation and release of hazardous by-products.

Current Activities: Work is being undertaken at the EPA's Risk Reduction Engineering Laboratory (RREL) to determine how the powerful advantages of process simulation can best be incorporated into pollution prevention research and development. Current plans are to convene a workshop on this topic for December 8 and 9 of this year. Planning for the workshop is being done jointly by RREL, DOE's Office of Industrial Technologies and Pacific Northwest Laboratory, and AIChE's Center for Waste Reduction Technologies. Participants are being sought from academia, simulation package developers, process industries, design firms, and government.

The goal of the workshop is to decide on the course of action to take in using computer simulation methods to evaluate industrial process designs for pollution prevention potential. This will lead to in-house as well as extramural research that can stimulate and accelerate the evaluation of industrial process alternatives.

Opportunities for Collaboration:

- EPA is envisioning a collaborative project between government, industry, and academia to develop both general and specific (e.g., paint or electroplating) industrial process simulation packages.

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Office of Environmental Processes and Effects Research

Environmental Research Laboratory - Athens

Anaerobic/Aerobic Bioremediation

Issue: A significant fraction of our freshwater and marine sediments are contaminated with hazardous organic chemicals, such as PCBs, hexachlorobenzene, PAHs, DDT, and chlordane. Remediation of such sediments has historically involved dredging the contaminated sediment and storing it in a confined disposal facility (CDF). Storage in a CDF merely moves the problem without cleaning up the pollution. Without new technologies such as bioremediation, CDFs will continue to be the remediation method of choice.

The development of bioremediation options that can treat waste *in situ* or in the CDF is needed. Both aerobic and anaerobic technologies will be needed to degrade the variety of contaminating organic chemicals currently found in sediments. Research will have to combine a basic component that investigates the physiology of the microorganisms that degrade these compounds, a component that addresses the environmental factors and reactor characteristics that can influence the rates of degradation, a technology assessment component, and a field validation component.

Current Activities: The mission of the Bioremediation Research Program at the Environmental Research Laboratory-Athens is to advance the understanding, development, and application of anaerobic bioremediation solutions to hazardous waste problems threatening human health and the environment. The program is designed to strike a balance between basic research activities leading to a fundamental understanding of anaerobic degradation processes and engineering activities leading to practical applications of the underlying science to accomplish environmental clean-up.

The current research program stresses ten related areas.

1. Microbial Degradation of Creosote-Derived Compounds in Natural and Laboratory Environments.
2. Anaerobic Degradation of Creosote Components and Dechlorination of Chlorophenols: Microbial Interactions.
3. Effects of Nonionic Surfactants on Microbial Anaerobic Dechlorination of Hazardous Organic Compounds.
4. Decontamination of PCB-Contaminated Sediments Through the Use of Bioremediation Technologies.
5. Characterization of Microorganisms, Microbial Consortia and Microbial Processes for the Reductive Dechlorination of Hazardous Wastes.
6. Bioremediation of Soils and Sediments Contaminated with Aromatic Amines.
7. Effects of Metals on Reductive Dechlorination.
8. Anaerobic Biotransformation of Munitions Waste.

Opportunities for Collaboration:

1. Conduct field and pilot scale studies to evaluate the effectiveness of anaerobic bioremediation as a commercial process.
2. Develop engineering designs for conducting anaerobic/aerobic cycling in field operations.
3. Develop engineering designs to modify Confined Disposal Facilities to enhance the degradation of hazardous organic chemicals.

Key Publications:

Struijs, J. and J. E. Rogers. 1989. Reductive dehalogenation of dichloroanilines by anaerobic microorganisms in fresh and dichlorophenol-adapted pond sediment. Appl. Environ. Microbiol. 55: 2527-2531.

Bryant, F. O., D. D. Hale, and J. E. Rogers. 1991. Regiospecific dechlorination of pentachlo-

rophenol by dichlorophenol-adapted microorganisms in freshwater, anaerobic sediment slurries. Appl. Environ. Microbiol. 57:2293-2301.

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Environmental Research Laboratory - Corvallis

U.S. EPA Environmental Research Laboratory - Corvallis, OR

Issue: Diverse industrial, agricultural and military practices have resulted in the degradation and pollution of natural ecosystems and habitats. Ecosystem management provides a framework and essential scientific methodology for the assessment and mitigation of site specific to regional scale environmental problems. Development of revegetation strategies for restoration of given sites and habitats to acceptable levels of ecosystem structure and function are sought. Specific types of sites and habitats that are of interest include those contaminated by hazardous wastes and heavy metals, agricultural pesticides, wood preservatives or munitions.

Current Activities: The Environmental Research Laboratory in Corvallis, Oregon, has capabilities to conduct research on the effects of toxic chemicals and introduced organisms on terrestrial ecosystems.

Research interests include:

- Developing revegetation and ecosystem restoration strategies for disturbed and polluted sites
- Enhancing beneficial plant-microbial interactions to minimize and mitigate the effects of pollutants and stressors
- Assessing the effects of introduced plants and microbes on food webs, plant-herbivore interactions, species diversity and ecosystem processes
- Developing protocols to assess the effects of plant and microbial pest control and remediation agents on non-target plant, microbial and invertebrate species
- Formulating strategies to enhance or mitigate the survival and dissemination of biological pest control and remediation agents.
- Risk assessment of genetically altered microbes and plants.

Opportunities for Collaboration:

- **Development of methods and strategies** to use plant/microbe consortia to facilitate revegetation of disturbed, hazardous, or otherwise ecologically impacted sites.
- **Development of protocols for risk assessment of transgenic plants**. Methods are currently available to evaluate fate and effects of transgenic gene products.
- **Development of test kits and bioassays** to characterize sites and to develop optimal remediation, restoration and revegetation strategies for given types of pollutants, ecosystems and habitats.
- **Development of multi-species indicator tests and probes** to assess the functional status and community structure of degraded and stressed ecosystems.
- **Modeling and measurement of dispersal** of airborne particles, such as microbial remediation or pest control agents or plant pollen.
- **Microcosm and greenhouse testing** facilities for protocol development for risk assessment of plant and microbial pest control and remediation agents.

Key Publications:

Armstrong, J.L., G.R. Knudsen and R.J. Seidler. 1987. Microcosm Method to Assess Survival of Recombinant Bacteria Associated with Plants and Herbivorous Insects. Current Microbiol. 15:229-232.

Donegan, K.,C. Matyac, R.J. Seidler, and A. Porteous. Evaluation of methods for sampling, recovery, and enumeration of bacteria applied to the phylloplane. 1991. Appl. Environ. Microbiol. 57:51-56.

Donegan, K., V. Fieland, N. Fowles, L. Ganio, and R.J. Seidler. 1992. Efficacy of burning, tillage, and biocides in controlling bacteria released at field sites and the effects on indigenous bacteria and fungi. Appl. Environ. Microbiol. 58:1207-1214.

U.S. EPA Environmental Research Laboratory - Corvallis, OR

James, R.R., J.C. Miller and B. Lighthart. The Effect of *Bacillus thuringiensis* var *kurstaki* on a Beneficial Insect, The Cinnabar Moth (Lepidoptera: Arctiiade). J. Econ. Entomol, manuscript review.

Ingham, E.R., L.K. Gander, J.D. Doyle, and C.W. Hendricks. 1993. Assessing interactions between the soil foodweb and a strain of *Pseudomonas putida* genetically engineered to degrade 2,4-D. Ecological Engr., in press.

Lighthart, B. and J. Kim. 1989. Simulation of airborne microbial droplet transport. Appl. Environ. Microbiol. 55:2349-2355.

Pfender, W.F., U. Sharma and W. Zhang, 1991. Effect of water potential on microbial antagonism to *Pyrenophora tritici-repentis* in wheat residue. Mycological Research 95: 308-314.

Porteous, L.A. and J.L. Armstrong. 1991. Recovery of Bulk DNA from Soil by a Rapid, Small-Scale Extraction Method. Current Microbiol. 22:345-348

Rhodes, A.N. and C.W. Hendricks. 1990. A Continuous-Flow Method for Measuring Effects of Chemicals on Soil Nitrification. Tox. Assess. 5: 77-89.

Watrud, L.S, F.J. Perlak, M.T. Tran, K. Kusano, M.A. Miller-Wideman, M.G. Obukowicz, D.R. Nelson, J.P. Kreitinger, and R.J. Kaufman. 1985. Cloning of the *Bacillus* thuringiensis subsp. *kurstaki* Delta-Endotoxin Gene into *Pseudomonas fluorescens*: Molecular Biology and Ecology of an Engineered Microbial Pesticide, p.40-46. *In*: Engineered Organisms in the Environment: Scientific Issues. Halvorson, H.O., Pramer, D. and M. Rogul (Eds.).

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Environmental Research Laboratory - Gulf Breeze

Biotechnology

Issue: An emerging biotechnology industry is using genetic engineering techniques to develop new biological products for medicine, agriculture and environmental restoration. EPA has responsibility under federal laws to regulate commercial biotechnological products and to evaluate the environmental impact of deliberate or accidental release of microorganisms. Expertise in molecular biology, genetics, biochemistry, and microbial ecology provides the basis for environmental fate and effects studies that support the development of methods to minimize any adverse consequences from the release of an increasing number and variety of genetically engineered organisms. Factors that influence their survival and colonization in the environment and transfer mechanisms of genetic material to other environmental microorganisms are being researched.

Current Activities: The Microbial Ecology and Biotechnology Branch of the U.S. Environmental Protection Agency's Gulf Breeze Environmental Research Laboratory conducts research to predict potential risks caused by release of genetically engineered microorganisms in the environment. Research is conducted in-house and extramurally to: 1) develop methods and guidance for determining the potential risk of accidentally or deliberately released GEMs or MPCAs into the environment, 2) establish methods for the determination of the survival/colonization potential of microorganisms upon release into the environment, 3) determine the fate and effects of bioengineered organisms on stressed aquatic ecosystems using mercury as a model system (studies involve effects of these microorganisms on the structure and function of the indigenous microbial communities and the fate of added mercury), 4) determine mechanisms of genetic transfer and subsequent effects on bacterial communities, 5) determine the feasibility of developing bacterial strains (or plasmids) whereby the death of the cell can be controlled under conditions set by the investigator, 6) use of nucleic acid probes to assess changes in microbial community structure that might occur from environmental stresses, 7) establish microcosms procedures which can test the ability of a microorganism to survive and colonize in the environment (by assessing the variability among microcosms, differences between microcosms and the field, and changes that occur in microcosms/field sites over time), and 8) measure carbon and nitrogen isotope ratios in bacterial nucleic acids and field samples to determine the amount of growth substrate available in open estuarine waters and enclosed salt marshes and identify the source of organic matter available to bacteria.

Opportunities for Collaboration:

- Specific areas of research identified above.
- Field test or apply results from above research activities to proposed releases of genetically engineered microorganisms.
- Develop techniques to examine the expression and transmission of genetic information within an ecosystem and how that event affects community structure and function.
- Develop the use of 16S RNA probing techniques to determine changes in microbial community structure and its relationship to microbial community functions.
- Develop mathematical models as predictive tools and apply them to studies in environmental exposure, such as microbe dissemination and gene transfer, and environmental effects from introduced non-indigenous organisms and GEMS.
- Develop and refine methods for detection, enumeration and fate of microorganisms.
- Use stable isotopes to follow the fate of organic carbon and nitrogen in bacteria as a means of studying the effects of environment stress on trophic dynamics.

Biotechnology

Key Publications:

Barkay, T., R. Turner, A. VandenBrook, and C. Liebert. 1991. Relationships of Hg(II) Volatilization from a Freshwater Pond to the Abundance of mer Genes in the Gene Pool of the Indigenous Microbial Community. Microb. Ecol. 21(2):151-161. (ERL,GB 710).

Coffin, Richard B., David J. Velinsky, Richard Devereux, William Allen Price, and Luis A. Cifuentes. 1990. Stable Carbon Isotope Analysis of Nucleic Acids to Trace Sources of Dissolved Substrate Used by Estuarine Bacteria. Appl. Environ. Microbiol. 56(7):2012-2020. (ERL,GB 658).

Kroer, Niels, and Richard B. Coffin. 1992. Microbial Trophic Interactions in Aquatic Microcosms Developed for Testing Genetically Engineered Microorganisms: a Field Comparison. Appl. Environ. Microbiol. 23(2):143-157. (ERL,GB 708).

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Bioremediation of Toxic Chemicals

Issue: Enhanced biological removal of toxic chemicals is an inexpensive, non-destructive approach to the cleanup of hazardous waste sites (bioremediation). Biodegradation research examines how microorganisms degrade chemicals and how environmental factors effect the biodegradation processes.

One bioremediation approach involves the use of bacteria with the ability to degrade various man-made chemicals. Examples include bacteria able to degrade the cleaning solvent, trichloroethylene, a suspected carcinogen; wood preservating chemicals, such as pentachlorophenol and creosote; and oil and petroleum products. These studies provide information about the biodegradability of pollutants in aquatic and terrestrial environments. Strategies are developed to promote biodegradation at hazardous waste sites and to relate laboratory studies to conditions in the field. Field studies are also conducted to validate data obtained from laboratory studies.

Chemical analyses can not always detect degraded or transformed chemicals that are environmentally toxic, nor can they resolve synergistic or antagonistic effects of multiple contaminants. Assays based on biological criteria, however, integrate all toxicant effects, measurable or not, in a scientifically defendable, environmentally prudent strategy for assessment.

Current Activities: The Microbial Ecology Biotechnology Branch of the U.S. Environmental Protection Agency's Gulf Breeze Environmental Research Laboratory conducts research to develop and/or enhance the ability of microbes to degrade toxic chemicals in the environment and to assess the environmental safety of remediation. Research is conducted in-house and extramurally to 1) generate basic research information on microbial degradative capabilities (aerobic and anaerobic) and their enhancement to develop inexpensive and effective biological approaches for cleaning up hazardous and toxic wastes in the environment, 2) define microbiological and environmental factors that might enhance the extent and rate of biodegradation, 3) isolate microorganisms with novel and specific degradative capabilities, 4) determine the usefulness of genetically engineered microbes to detoxify hazardous waste, 5) isolate and characterize microorganisms which degrade specific problem chemicals such as trichloroethylene, PCBs, PAHs, pesticides etc., 6) determine mechanisms of pesticide biodegradation in aquatic sediments and in ground-water environments and investigate the metabolic potential of bacterial communities to degrade different structural analogs of specified pesticides, 7) determine the ability of bacteria to transform heavy metals (e.g., mercury) into forms that are not biologically available and examine environmental factors involved in modifying these processes for field applications, and 8) conduct ecological monitoring studies to gather information to minimize potential adverse ecological effects due to eutrophication as a result of nutrient additions, toxicity due to different chemical fractions and direct uptake of components by marine biota.

Opportunities for Collaboration:

- Basic research project areas identified above.
- Elucidate mechanisms responsible for the process of cometabolism. Define the conditions responsible for cometabolism and exemplify how specific growth substrates direct the routes by which a bacterial population transforms non-growth substrates.
- Evaluate microbial oxygenases for novel degradative potential,
- Perform microcosm studies to evaluate the effectiveness of adding microorganisms, nutrients, emulsifiers, etc. to contaminated sediments to enhance the rate of biodegradation of chemical contaminants.
- Apply bioremediation technologies developed through above research to field conditions and examine the rate and extent of disappearance of parent compound, the degradation products

Bioremediation of Toxic Chemicals

formed, including metabolites, and conditions for optimization of treatability.

- Develop bioassay assessment strategies to provide comprehensive and scientifically defendable toxicity data for hazardous waste sites and remediation efforts. Conduct toxicity tests to determine sensitivity of fish, crustacean, early life stages of fish, and fertilized fish eggs to chemically contaminated materials.

Key Publications:

Shields, Malcolm S., Stacy O. Montgomery, Stephen M. Cuskey Peter J. Chapman, and P.H. Pritchard. 1991. Mutants of Pseudomonas cepacia G4 Defective in Catabolism of Aromatic Compounds and Trichloroethylene. Appl. Environ. Microbiol. 57(7):1935-1941. (ERL, GB 730).

Mueller, James G., Suzanne E. Lantz, Beat O. Blattmann, and Peter J. Chapman. 1991. Bench-Scale Evaluation of Alternative Biological Treatment Processes for the Remediation of Pentachlorophenol- and Creosote-Contaminated Materials: Solid-Phase Bioremediation. Environ. Sci. Technol. 25(6):1045-1055. (ERL,GB 722).

Mueller, James G., Suzanne E. Lantz, Beat O. Blattmann, and Peter J. Chapman. 1991. Bench-Scale Evaluation of Alternative Biological Treatment Processes for the Remediation of Pentachlorophenol- and Creosote-Contaminated Materials: Slurry-Phase Bioremediation. Environ. Sci. Technol. 25(6):1055-1061. (ERL,GB 721).

Mueller, James G., Douglas P. Middaugh, Suzanne E. Lantz, and Peter J. Chapman. 1991. Biodegradation of Creosote and Pentachlorophenol in Contaminated Groundwater: Chemical and Biological Assessment. Appl. Environ. Microbiol. 57(5):1277-1285. (ERL,GB 728).

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Robert S. Kerr Environmental Research Laboratory

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The Robert S. Kerr Environmental Research Laboratory (RSKERL) serves as the Environmental Protection Agency's center for ground-water research, focusing its efforts on investigations related to the transport and transformation of contaminants in the subsurface, the development of methods and techniques directed toward the protection and restoration of ground-water quality, and evaluating the applicability and limitations of using natural soil and subsurface processes for the treatment of hazardous wastes.

The Laboratory has a long history of conducting basic and applied research related to the use of soil and subsurface media for waste treatment and the protection of surface and groundwater. In addition to its research on ground-water quality protection and restoration, RSKERL has historically been at the vanguard in developing and demonstrating cost-effective treatment technologies for municipal, industrial, and agricultural wastes.

RSKERL carries out its research responsibilities through in-house projects as well as cooperative efforts with other EPA laboratories, universities, national research laboratories, state organizations and a number of other federal agencies including the Department of Defense.

RSKERL is currently evaluating technologies which may be useful tools for site remediation: Geographical Information System (GIS)- GIS is a technology used to provide data entry, storage, manipulation, analysis, and display of geographic, environmental, cultural, statistical, and political data in a common spatial framework. GIS technology bridges the disciplines of computer science, information management, cartography, and environmental management. RSKERL is actively using GIS technology for: 1) data management and computer modeling visualization of RSKERL's large scale physical aquifers; 2) site characterization and ground-water modeling through the Technology Support Center; 3) technical support and computer modeling and visualization for EPA's Wellhead Protection Program; and 4) site characterization and modeling at field research sites.

Subsurface Remediation - RSKERL is actively researching and developing technologies designed to decrease the time frames required for remediation of contaminated sites. *In situ* bioremediation to enhance standard pump and treat technologies may be effective at lowering time frames necessary for remediation of contaminated sites. Technologies such as co-solvent and surfactant flooding are also being evaluated to increase the efficiency of standard pump and treat systems. For metal contaminants, a variety of biotic and abiotic technologies are being developed which either immobilize contaminants or increase recovery efficiencies from contaminated aquifers.

Mathematical Modeling - RSKERL scientists are developing and testing a variety of mathematical models that describe and predict contaminant transport in porous and fractured media under a variety of conditions from biodegradation to immiscible flow. From planning and evaluating remediation scenarios to identifying wellhead protection areas and permitting injection wells, mathematical modeling is becoming an increasingly important tool in Agency decision making.

Technical Assistance: In 1987, in order to make EPA's Office of Research and Development scientists more accessible to Regional decision makers, the Office of Solid Waste and Emergency Response (OSWER) provided direct funding to ORD laboratories in Las Vegas, NV, Cincinnati, OH, Athens, GA, and Ada, OK, to establish Superfund Technology Support Centers.

The RSKERL Technology Support Center consists of a Core Team of scientists and engineers supported by RSKERL in-house and extramural researchers, the RSKERL Center for Subsurface Modeling Support and technology support contractors and consultants. In addition to Superfund,

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which remains the major client, the RSKERL Technology Support Center provides assistance to Headquarters and to Regional and State personnel responsible for RCRA Corrective Action, Underground Storage Tanks, Pesticides and the Underground Injection Control Programs. These activities not only provide a "real world" testing ground for research results but aid RSKERL scientists in focusing on high priority research needs.

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Office of Health and Environmental Assessment

Environmental Criteria and Assessment Office - Cincinnati

MIXTOX Toxicologic Interaction Data Base

Technology Description: EPA has statutory requirements to conduct evaluations of exposures to environmental chemicals in terms of public health risk. Most exposures are to mixtures or multiple chemicals. The Agency's mixtures risk assessment guidelines require an evaluation of potential toxicologic interactions in order to determine the validity of the Hazard Index (the most common mixture assessment method) and the need for modifications of the Index. Single chemical information such as exists in hazard assessment documents or on IRIS is inadequate for assessing these interactions. The MIXTOX information system is the Agency's primary resource on toxicologic interaction data. This data base then facilitates site-specific modification of the general approach for assessing health risk from chemical mixtures.

The MIXTOX information system is a self-contained software package for the IBM-compatible or Macintosh personal computer. Data presentation includes summaries of specific interaction evaluations as well as summaries across studies to show degree of consistency for the same chemical pair. The data in MIXTOX are obtained from all available published studies on toxicologic interactions. The goal is to be complete, not merely representative. Exposure and toxicity are briefly described. The interaction is characterized by type (e.g., synergism, antagonism) and significance (e.g., toxicologic, pharmacokinetic).

Current Activities: The MIXTOX data base is being revised to include references through 1991. It also forms part of the Agency training on the mixtures risk assessment guidelines and is being used by risk assessors in EPA and the public sector. Currently, interaction potential is only expressed qualitatively in mixture assessments. Research is in progress to develop a weight-of-evidence (WOE) procedure for toxicologic interactions as well as quantitative indicators of consistency across studies. As these procedures develop, mechanisms will be sought to incorporate the WOE and consistency evaluations into the summary tables of MIXTOX. A Risk Assessment Forum workshop is planned on interaction data and possible uses in risk assessment. Following that workshop, methods will be investigated for incorporating information into MIXTOX from the carcinogen interaction data published by EPA's Office of Toxic Substances.

Opportunities for Collaboration:

- Develop efficient procedures for marketing and maintaining MIXTOX, including updating and quality assurance.
- Develop two related data bases on interaction mechanisms from *in vivo* studies and interaction descriptions from *in vitro* studies. These data bases will be linked to MIXTOX when they become available.
- Investigate quantitative methods for modifying or replacing the Hazard Index to incorporate toxicologic interaction potential, and modifying MIXTOX to allow Hazard Index calculation.

Key Publications:

Mumtaz, M.M. and R.C. Hertzberg. 1992. The status of interactions data in risk assessment of chemical mixtures, in press.

USEPA. 1988. Technical Support Document on Risk Assessment of Chemical Mixtures. EPA/600/8-90/064.

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Frontiers in Human Health Risk Assessment

Technology Description: Numerous federal and state agencies use risk assessments as a basis of their rules and regulations concerning environmental pollution and clean up. High interest in the science of risk assessment is also evident at the White House through the formation of an ad hoc committee on risk assessment under the Federal Coordinating Committee on Science, Engineering and Technology (FCCSET). Calls for a presidential executive order on environmental risk assessment and management policy have also been made (Federal Focus, 1991, Toward Common Measures, Federal Focus Inc., Washington, D.C.).

All of these activities are prompted, in part, by the U.S. National Academy of Sciences 1983 report on risk assessment in the federal government (NAS, 1983, Risk Assessment in the Federal Government: Managing the Process, National Academy Press, Washington, D.C.). This report frames both a fuller discussion of risk assessment activities within the United States and necessary improvements through research and rational applications. Based on the NAS framework, EPA's Office of Research and Development has improved this area of science. Listed below are opportunities for collaborative work.

Current Activities: The Cincinnati, OH, Environmental Criteria and Assessment Office **(ECAO)** is located at the Environmental Protection Agency's Andrew W. Breidenbach Environmental Research Center. ECAO is a multidisciplinary group of scientists dedicated to the advancement and under-standing of risk assessment. ECAO specializes in risk assessments of chemical mixtures and noncancer effects for humans, but also has expertise in the assessment of cancer effects for humans and ecologic effects. Programmatically, ECAO is involved in air; soil and water pollution; sludge and municipal solid waste comparative risk; recyclables, Superfund sites; Federal facilities; and combined ecologic and human health risk.

ECAO's multiple expertise and vision places it squarely in the broad range of risk assessment activities. ECAO's work defines the cutting edge of risk assessment science. ECAO has developed well over 1000 chemical- or mixture-specific risk assessments, many of which form the basis of current U.S. rules and regulations. ECAO also has over 120 risk assessment technical publications. Several of these publications have invented new areas of risk assessment and will lead to holistic new paradyms.

Opportunities for Collaboration:

- Developing and updating chemicals-biologicals-specific risk assessments for some agents of common interest to be placed on EPA's Integrated Risk Information System (IRIS); Health Risk Assessment; Guidelines, 53 FR 20162, 1988.
- Apply novel categorical regression methods for estimating human noncancer health risk above EPA's Reference Dose (RfD) and Reference Concentration (RfC) for chemicals of common interest, which are on EPA's IRIS: Hertzberg, R. C., 1989. Fitting a model to categorical response data with application to special extrapolation to toxicity. Hlth. Phys. 57(Suppl.1):404-409.
- Estimate site-specific consumption advisories for contaminated fish using information on EPA's IRIS and published EPA methods: Dourson, M.L. and J.M. Clark, 1990. Fish consumption advisories: Toward a unified, scientifically credible approach. Reg. Tox. Pharm. 12:165-172.
- Apply novel EPA methods for combining toxicity data from several studies in order to estimate cancer risk for chemicals of common interest, which are on EPA's IRIS: Dr. Rita Schoeny, U.S. EPA, 513-569-7544.
- Develop structure-activity relationship (SAR) techniques to estimate the likely range of Reference Dose (RfD) or Reference Concentration (RfC) for chemicals of common interest, which have few if any toxicity data: Ms.

Frontiers in Human Health Risk Assessment

Cindy Sonich-Mullin, U.S. EPA, (513) 569-7523.

- Apply novel benchmark dose methods for estimating RfDs and RfDs for chemicals of common interest, which are on EPA's IRIS: Dourson, M.L. *et al*, 1985. Novel methods for the estimation of acceptable daily intake. Tox. Ind. Hlth. 1(4)L23-33.
- Develop comparative risk assessment techniques for human health for municipal solid waste reuse and disposal options (i.e., recycling, composting, incineration, and landfilling): Dr. Michael Dourson, U.S. EPA, 513-569-7533.
- Develop communication strategies for risk assessment information and technology transfer capability of risk assessment techniques: Dr. Charlotte Cottrill, U.S. EPA, 513-569-7221.
- Develop common measures for ecological and human health risk assessment involving both theoretical and field work: Dr. Norman Kowal, U.S. EPA, 513-569-7584.

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Integrated Risk Information System

Technology Description: High quality, consistent human health risk assessment information is needed by risk assessors and managers to ensure the best possible risk management decisions. The information represents the best available science, data, and assessment techniques and represents U.S. EPA consensus.

The U.S. Environmental Protection Agency (EPA) is an originator and world leader in assessing human health hazards of environmental pollutants. EPA has developed the Integrated Risk Information System (IRIS) to provide Agency consensus risk information for use by risk assessors and managers. This information is accessed and utilized both nationally and internationally by federal, state and local governments, environmental consulting firms and industry.

The demand for access has increased dramatically in the past several years, not only nationally, but world-wide. IRIS has been demonstrated on four continents.

Current Activities: IRIS is a data base that summarizes human health risk assessment information on individual chemicals and substances. It currently contains information on approximately 500 substances, with approximately 50 new substances added each year. The primary information in IRIS includes inhalation reference concentrations (RfCs) and oral reference doses (RfDs) for noncarcinogenic effects, and carcinogenicity assessments. The carcinogenicity assessments include a weight-of-evidence for the substance's potential for human carcinogenicity and a quantitative risk estimate based upon slope factors.

IRIS is relied upon across the Agency when risk assessment and risk management decisions are being made. The data are developed by two Agency-wide work groups of expert EPA scientists and statisticians who meet regularly to review the risk assessments and reach agreement. Summaries of these risk assessment decisions are then loaded on IRIS. New substances and information are added monthly. In order to ensure that these assessments reflect state-of-the-art scientific knowledge and risk assessment methodologies, specific information may be reevaluated and changed.

IRIS is available on three different systems: the National Library of Medicine's TOXNET system; as simple text files on diskettes from the National Technical Information Service (NTIS); and to a limited number of EPA and state users as a PC data base (IRIS2) using a new delivery system.

IRIS2 is currently in draft form and monthly updates are downloaded by each user from EPA's main-frame computer. The user is prompted on the first of each month to update through a simple automated process.

EPA is currently working to further develop the system, focusing primarily on speed issues and refinement of updating processes.

Opportunities for Collaboration:

- Commercialize IRIS. IRIS is used by government and private organizations here in the United States, but the demand for access is greater than EPA can support. There is a wider audience that has a need for IRIS information world-wide. EPA would welcome collaboration to develop and market a commercial version of IRIS the highest quality risk system in the world.
- Integrate IRIS with other interactive data bases or systems. IRIS data are used in a larger risk characterization/management process that requires other types of information available in other data bases and systems. An integrated system that conveniently packages the diverse information needed to develop high quality risk characterizations would be of interest to a large world-wide audience.
- Translate IRIS into other native languages, Spanish, German, Chinese, etc. Other countries are faced with many of the same environmental and health problems as the United

Integrated Risk Information System

States and are desperate for high-quality risk information. Translating IRIS into one or more languages would open up an even wider audience for this information.

- Expand the scope of IRIS. Opportunity exists to collect and disseminate additional information useful in conducting risk characterizations. This may include federal and state regulations, chemical-specific exposure parameters, and chemical and physical properties.

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Lead Uptake Biokinetic (UBK) Model

Technology Description: Over 40% of the Superfund sites on the National Priority List contain lead as the primary pollutant. Because of their susceptibility, children are at greatest risk to the toxic effects associated with exposure to lead. Young children are highly sensitive to lead in general with potential decrements in neurobehavioral indices (lowered IQ, muscle coordination). Children and adults have often been observed with hematopoietic disorders and cognitive dysfunctions resulting from lead exposure. There is no safe level established for lead exposure.

In 1988, ECAO-Cincinnati developed an issue paper on the non-cancer health risk assessment of lead. This effort evolved into the development of an approach and modelling alternative to the traditional RfD used in IRIS. The result was the development of a Technical Support Document for Lead and a user-friendly PC Lead Uptake Biokinetic Model with accompanying Users Guide. In 1991, EPA recommended the use of the UBK model as a tool for evaluating potential adverse health impacts to individuals exposed to lead at Superfund sites. (See "OSWER Directive on Soil Lead Clean-up Levels".)

Current Activities: New data are now being collected and analyzed in collaboration with the Regional Superfund Program to help resolve two controversial issues:

1. the bioavailability of lead in various soil/dust matrices from various sources, such as those found at urban and rural sites, and
2. site-specific population variances in the distribution of blood lead levels may be greater than the national average.

An expanded version of the model (version 5), which contains additional features that allow the user to produce a series of model runs for site-specific assessment, is currently undergoing review at Superfund sites. A Guidance Manual is under development for the use of the lead UBK model at Superfund sites and is currently being revised to reflect comments of the Agency's Scientific Advisory Board.

Opportunities for Collaboration:

- The development of the lead UBK model was feasible and scientifically credible because of the strong data base on lead. Collaborative efforts to produce such data for other chemicals (including non-metallics) are essential. Specifically, information on the absorption of contaminants from multiple routes is necessary.
- The Agency is currently evaluating new data and seeking additional data to enhance the preliminary maternal-to-fetal model for lead.
- Collaborative efforts are necessary on the utilization/application of the model for site-specific use to determine its usefulness and validity.
- Feasibility of the application of components of the current modelling procedure to other metal contaminants (e.g., Cu, As, Hg) need evaluation.

Key Publications:

Choudhury, H., Peirano, W.B., Marcus, A., Elias, R., Griffin, S., and DeRosa, C.T., 1992. "Utilization of Uptake/Biokinetic (UBK) Lead Model to Assess Risk in Contaminated Sites," *Superfund Risk Assessment in Soil Contamination Studies, ASTM STP 1158*, Keith Hoddinott and G. Daniel Knowles, Ed., American Society for Testing and Materials, Philadelphia.

DeRosa, C.T., H. Choudhury, and W.P. Peirano, 1991. An Integrated Exposure/Pharmacokinetic Based Approach to the Assessment of Complex Exposures; Lead: A Case Study, Toxicol. and Ind. Health 7(4):231-248.

USEPA, 1992. OSWER Directive on Soil Lead Cleanup Levels, in press.

Lead Uptake Biokinetic (UBK) Model

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Office of Health Research

Health Effects Research Laboratory

Health Effects Research Laboratory

Technology Description: In the past 20 years, major environmental legislation has given the U.S. EPA several of the regulatory tools it needs to protect our environment and public health. Environmental protection, however, requires more than legislation; appropriate regulatory decisions based on those laws must be founded on scientific data concerning the scope and magnitude of health risks associated with the environmental hazards to which the public is exposed.

While the chemical and physical compositions of environmental agents differ significantly, the evaluation of their health effects must address a common set of issues. They are (1) exposure (how and to what extent humans are exposed to the pollutants in the environment), (2) dose (the relationship between the exposure and the dose of the pollutant received at the site of toxic action within the body), and (3) effect (the health impact of the pollutant dose). Research on the relationships among exposure, dose, and effect provides the scientific basis for conducting health risk assessments that, in turn, enable regulators to make sound decisions.

Current Activities: The Health Effects Research Laboratory (HERL) in Research Triangle Park, NC, is the center of the U.S. EPA's efforts to investigate and understand the human health effects of environmental agents, both chemical and biological. HERL's mission is to conduct research that will improve EPA's ability to assess environmental health risks, focusing on both short-term applied research of regulatory significance and long-term basic research.

Current research to improve the scientific base for risk assessment is focused in four areas:

- exposure research
- hazard identification research
- dose-response research
- chemical-specific research

HERL's efforts in the area of exposure research involve developing and validating biomarkers of exposure, effect, and susceptibility in human populations. Hazard identification research develops, refines, and validates methods for identifying potential human health hazards, focusing on developing techniques that are faster, more accurate, less expensive, and more reliable than current options. HERL's dose-response research focuses on developing biologically- or physiologically-based models relating exposure to dose at the site of toxic action and to biological effects. Such models will improve the ability to predict pollutant effects and to extrapolate across species, time and dose in order to assess human health risk. Finally, the laboratory also fills specific data gaps by conducting research on environmental agents that, for regulatory reasons, are of particular interest to the Agency.

HERL is unique in that it has the facilities and expertise to pursue its research efforts in these four areas through the combination of animal toxicology, human studies, and research on predictive models. HERL's investigators represent a broad range of scientific disciplines and can conduct analyses at all levels of biologic organization, from molecular events to human populations.

Opportunities for Collaboration:

- HERL's staff and facilities provide unique capabilities that could help industry find a solution to a technological problem. For example, HERL possesses state-of-the art inhalation facilities for humans and animals that provide researchers the mechanism for exposing subjects to a variety of air pollutants.
- HERL develops methods for evaluating and characterizing actual or suspected health effects due to environmental agents, including exposure to workplace chemicals or to products for which the public or regulatory organizations have expressed concern.
- The state-of-the-science research performed at HERL often requires the development or adaptation of instruments, software, etc., in order to meet new research objectives. Per-

fecting those items for the sake of efficiency and reliability is in the interest of both the regulator and regulated community, and in the interest of the provider of those devices and services. Such opportunities include the automation of a large number of bioassays developed or refined by HERL, and required as part of EPA Testing Guidelines, or other assays which are likely to be included in Testing Guidelines once perfected and validated. Some examples of HERL's interest include:

- Automation of DNA extraction and sequencing
- Improved radioanalytic imaging systems
- Enhanced automation of cell/tissue preparation and management systems.
- Software for special purpose instrument control, instrument interface, data management, etc.

Key Publications:

Reiter, L.W. and K. Sexton, *Strategy for Environmental Health Research at EPA*, USEPA/ ORD, EPA/600/9-90/053

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Office of Modeling, Monitoring Systems, and Quality Assurance

Atmospheric Research and Exposure Assessment Laboratory

VOC Emissions Reactivity and Mutagenicity Measurements

Issue: Chemical production facilities often emit large quantities of volatile organic compounds (VOCs). Many of these are photochemically reactive and contribute to the formation of photochemical smog (ozone, reduced visibility, eye irritation, etc.). Many of these emissions are also toxic or can produce toxic and hazardous products after undergoing atmospheric transformations. Therefore, proper identification/quantification of these emissions is necessary.

Current Activities: AREAL personnel have expertise in studying the photochemical reactivity of ambient levels of VOCs. Over 100 emission sites have been studied since the 1960s. Our present technology employs a gas chromatograph (GC) and a gas chromatograph/mass spectrometer (GC/MS) capable of quantitatively identifying pollutants at 0.12 ppb and has a minimum detection limit of 0.04 ppb. The VOCs analyzed range from C_2-C_{12} carbon numbers. Samples are taken around the facility in pressurized electropolished stainless steel canisters. These canisters are returned to the central laboratory and are analyzed for the VOCs. Normally the analysis involves the trapping of known volumes of air with the use of a cryogenic trap cooled by either liquid oxygen or argon liquid. The trap is then heated with hot water and the sample is introduced into the GC equipped with a capillary column and a FID detector. A GC/MS is employed when the compounds cannot be identified using previously recorded retention times. The reaction products can be tested for toxic/mutagenic effects by exposing them to bacteria, such as *Salmonella typhimurium* (Ames test). Past studies on wood smoke and auto exhaust have shown that these emissions can produce high levels of ozone and that the reaction shows high mutagenicity after undergoing atmospheric transformations. However, although some separation of the mutagenic compounds has been achieved, most of these compounds have not been positively identified. This is largely due to poor resolution of the preparatory GC columns employed in these studies. A large amount of material is needed for the salmonella tests and separation is difficult with large samples. Collaboration would entail the development of better GC columns and/or new bioindicators.

Additional research is needed in this area to establish the relationship between airtrak smog indicators and the airshed model predictions.

Opportunities for Collaboration: There are several opportunities for collaboration under this area of research. Some of these could involve access to cooperator facilities to evaluate emissions at the sources within the facility, rather than downwind after mixing and dilution. Possible advantages to the cooperator include the development of: better methods for determining leaks; better and more cost-effective emission controls, due to a better understanding of the emissions; and a better understanding of the toxicity and mutagenicity associated with facility emissions, thus leading to better safety procedures. The possible advantages to the Agency include: a more accurate inventory of emissions; a more accurate determination of emission factors and reactivities; a better assessment of the role played by the emissions in the production of photochemical smog; a better assessment of the toxicity and human risks associated with the emissions; and the possible opportunity to develop and evaluate new mutagenicity tests.

Key Publications:

T.E. Kleindienst, P.B. Shepson, D.F. Smith, E.E. Hudgens, C.M. Nero, L.T. Cupitt, J.J. Bufalini, and L.D. Claxton, "Comparisons of Mutagenic Activities of Several Peroxyacyl Nitrates," Environ. and Molecular Mutagenesis, 16, 70-80 (1990).

W.A.Lonneman, R.L. Seila, "Speciated Hydrocarbon and NO_x Comparisons at SCAQS Source and Receptor Sites," 82 Annual AWMA Meeting, Anaheim, California, Paper Number 89-152.3, 1989.

VOC Emissions Reactivity and Mutagenicity Measurements

R.L. Seila, W.A. Lonneman, S.A. Meeks, "Determination of C_2 to C_{12} Ambient Air Hydrocarbons in 39 U.S. Cities from 1984 Through 1986," U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA/600/3-89/058, March, 1989.

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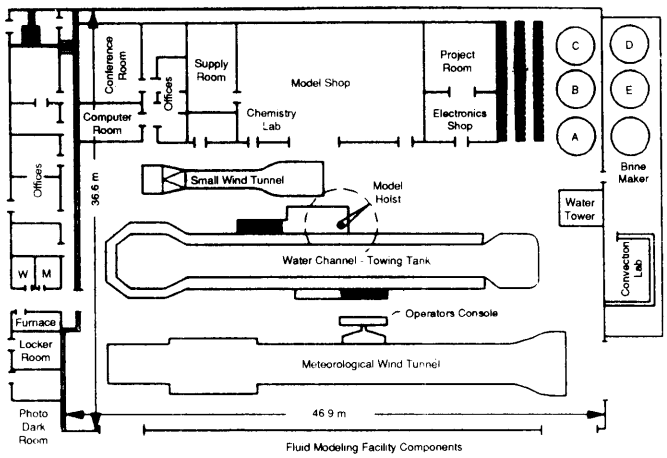
Atmospheric Diffusion Modeling

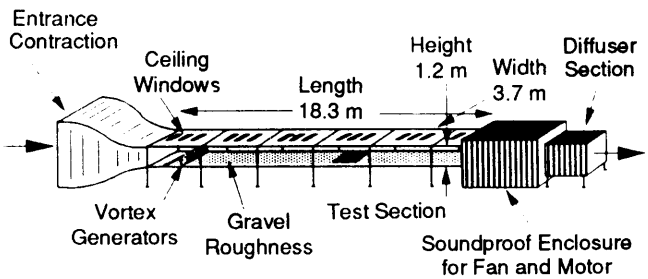
Issue: The Environmental Protection Agency's interest in the modeling of atmospheric diffusion processes is an outgrowth of the establishment of National Ambient Air Quality Standards, which are the maximum levels of a given pollutant that are permitted in the ambient air. The dispersal of pollutants to and at ground level depends on atmospheric diffusion and transport. Mathematical models, field programs and fluid models are the three methods available to predict the likelihood of exceeding an air quality standard concentration at ground-level. Fluid models appear to work best where mathematical models fail (i.e., where obstructions such as buildings and hills block wind flow). Fluid models also show great promise for simulating surface-induced airflows such as heat island circulation and mountain valley winds. Atmospheric conditions can be programmed into a fluid model so that years of field study time can be reduced to a few weeks. Fluid model studies can reduce the resources required for field studies and facilitate the development of better mathematical models.

Current Activities: The AREAL Atmospheric Characterization and Modeling Division's Fluid Modeling Branch is a fluid mechanics laboratory that specializes in the simulation of transport and diffusion of atmospheric pollutants. An effective method of characterizing atmospheric diffusion involves placing a carefully constructed physical model of a pollutant source in AREAL's unique wind tunnels or water-channel towing tank facilities.

The main facilities are a large meteorological wind tunnel used to simulate neutral flow conditions, a salt-water-stratified towing tank for simulation of nighttime stable stratification, and a convection tank where a heated floor is used to simulate afternoon convection in the full-scale atmosphere. Examination of the effects of these artificial atmospheres on pollutant emissions provides researchers with a greater understanding of the interaction of meteorological factors and air pollution.



Fluid Modeling Facility Components



Schematic diagram of the Meteorological Wind Tunnel

Opportunity for Collaboration: The facilities of the AREAL Fluid Modeling Branch are available for use in joint or shared research in the areas of flow structure and dispersion from sources in the vicinity of buildings, dense-gas dispersion, flow structure and dispersion in neutral and stratified conditions in complex terrain, and convective processes such as plume penetration of elevated inversions, top-down versus bottom-up diffusion, and nonhomogeneous and nonstationary surface heating. These may range from fundamental studies attempting to gain understanding of basic fluid dynamic and dispersion processes to applied studies attempting to obtain rules-of-thumb for use by air pollution meteorologists. The stratified tow tank was recently used in a joint venture with the Georgia Institute of Technology under a Federal Technology Transfer Act - Cooperative Research and Development Agreement to simulate the rise of buoyant wastewater plumes from the bottom of

Atmospheric Diffusion Modeling

Boston Harbor — to aid in the engineering design of the Boston Wastewater Outfall.

Key Publications:

Briggs, G.A., Thompson, R.S. & Snyder, W.H. 1990. "Dense Gas Removal from a Valley by Crosswinds." J. Hazard. Materials, 10, 1-38.

Castro, I.P., Snyder, W.H. & Baines, P.G. 1990. "Obstacle Drag in Stratified Flow." Proc. Roy. Soc., A 429, 119-40.

Snyder, W.H. 1990. "Fluid Modeling Applied to Atmospheric Diffusion in Complex Terrain." Atmos. Envir., 24A, 2071-88.

Snyder, W.H., Khurshudyan, L.H., Nekrasov, I.V., Lawson, R.E. Jr. & Thompson, R.S. 1991. "Flow and Dispersion of Pollutants within Two-Dimensional Valleys." Atmos. Envir., 25A, 1347-75.

Snyder, W.H. & Lawson, R.E. Jr. 1991. "Fluid Modeling Simulation of Stack-Tip Downwash for Neutrally Buoyant Plumes." Atmos. Envir., 25A, 2837-50.

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September 1992

Automated Gas Chromatographs for Analysis of Volatile Organic Compounds

Issue: The implementation of the Clean Air Act Amendments of 1990 provides a new impetus for monitoring methods development. Under the Title I provisions, "enhanced" ozone monitoring is mandated in ozone non-attainment areas. As a result, EPA guidelines for the monitoring of ozone, NO_x, and carbon-containing ozone precursors (hydrocarbons and aldehydes) have been prepared to assist state agencies in establishing the required monitoring capability. The guidelines provide for the monitoring of 55 hydrocarbons and NMOC (non-methane organic carbon) as well as aldehydes. The monitoring schedule is customized for each site depending on the degree of ozone non-attainment. A common requirement is a three hour monitoring schedule for hydrocarbons and NMOC and a one day sampling schedule for aldehydes. Title III provisions imply the need for instrumentation to characterize the ambient air for individual toxic volatile organic compounds (VOCs).

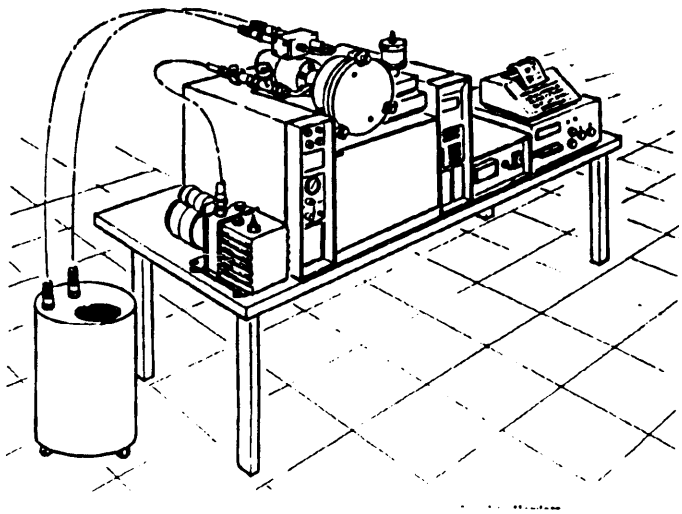
Speciation of hydrocarbons and toxic VOCs is now typically done in the laboratory after collecting a sample in the field in canisters or the equivalent. AutoGCs have recently been operated in the field at monitoring network stations to obtain this type of data (i.e., updates every 1-3 hours by sampling directly from an ambient air manifold); however, the sample must be preconcentrated by use of cryogenic nitrogen before the analysis can detect typical ambient concentrations. AutoGC design for cost-effective, reliable and stand-alone operation has become an issue.

Current Activities: The methods development program at the Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC (AREAL-RTP) has pioneered the use of automated gas chromatographs for speciation of volatile organic compounds. Recently, in support of the Office of Air Quality Planning and Standards, AREAL has demonstrated a second generation autoGC that operates free of liquid cryogen that is typically used for sample preconcentration. This successfully avoids the inconvenience and cost associated with the delivery of commercial liquid cryogens. This advantage coupled with features such as automated calibration and reliability of components has improved the prospects for widespread use of the autoGCs.

Additional development efforts are warranted in order to pursue the use of closed cycle coolers for autoGCs and real-time formaldehyde monitors. AREAL-sponsored research and development successfully demonstrated new instrumentation in both these areas.

Opportunities for Collaboration: Having demonstrated the feasibility and viability of new types of instrumentation for use in enhanced ozone and toxic VOC monitoring, AREAL is interested in collaborating with outside parties to develop commercial prototypes of these systems or new approaches to these measurements.

In particular, the realization of a commercial closed cycle cooler design for sample concentrators will require an engineering design that avoids



Automated Gas Chromatographs for Analysis of Volatile Organic Compounds

the occurrence of hot-spots during the thermal desorption part of the cycle.

The development of a commercial prototype formaldehyde monitor appears to be simply a matter of using the results of AREAL-sponsored research as a guide. A research prototype monitor for formaldehyde has been fabricated and operated in the field. Evaluation has included instrument characterization with respect to merit parameters such lower detection limit, interference equivalents from other gases, and reliability of operation.

The extension of autoGC application to toxic polar VOCs involves careful design with respect to sample integrity. Sample inlets and sample conditioning are crucial factors if the sample is to be delivered to the GC column without alteration. AREAL is proceeding to develop new sample introduction systems to address this problem. At the same time, the commercial interest in this area is obviously high and new ideas abound. This should be a fertile area for collaboration.

Key Publications:

T.J. Kelly, R.H. Barnes and W.A. McClenny, "Continuous Indoor and Outdoor Formaldehyde Measurements with a Novel Fluorescence Technique," Proceedings of the 1989 EPA/ A&WMA International Symposium on the Measurement of Toxic and Related Air Pollutants, May 1989, Raleigh, NC.

W.A. McClenny, J.L. Varns and J.V. Daughtridge "The Emergence of Automated Gas Chromatographs as Air Quality Network Monitors for Volatile Organic Compounds," Proceedings of the 84th Annual Meeting and Exhibition of the Air & Waste Management Association, June, 1991

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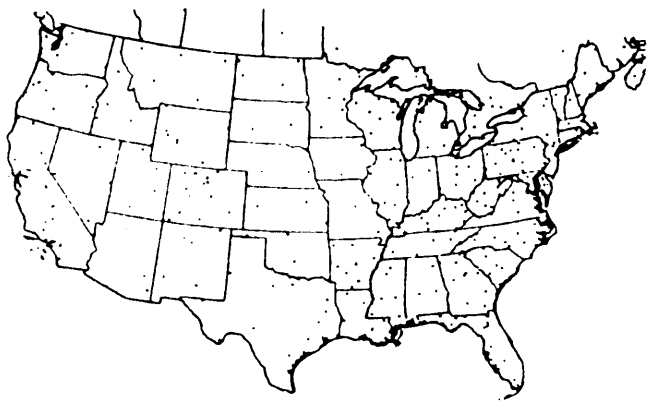
Clean Air Status and Trends Network Research and Development

Issue: The Atmospheric Research and Exposure Assessment Laboratory has recently initiated the Clean Air Status and Trends Network (CASTNET) for the purpose of collecting and interpreting several different types of atmospheric data. The CASTNET program, in addition to collecting data to serve the Agency's purposes, will serve to coordinate the efforts of several different data collection networks including ambient and ecosystem data. The primary purpose of this data will be to provide the current status and trends in air quality data. This data will be used by AREAL and other Offices within the Agency to perform assessments of the impact of the implementation of Clean Air Act regulations on atmospheric contaminants. Among the major areas of concern are acid deposition, rural ozone, air toxics, and visibility. It is intended that these data not only be tied to changes in the related air quality, but may also be used for interpreting information collected on sensitive ecosystems to determine the impact of programs designed to reduce the concentrations of atmospheric pollutants on these ecosystems.

Current Activities: A major activity within the Air & Deposition Research Monitoring Branch is the collection and interpretation of atmospheric data particularly as it relates to acid deposition and atmospheric transformation products that lead to the formation of acidic components. The Atmospheric Research and Exposure Assessment Laboratory has been long involved in a multi-agency (Federal, State, and local) program for the collection and interpretation of this type of information. This program, the National Acid Deposition Program/National Trends Network, has as cooperators, many industry groups which collect and provide to agencies, relevant information regarding atmospheric concentrations and acid deposition. These industry groups have been a valuable participant in this program. Maps indicating the current wet and dry deposition network sites are shown.



Wet Deposition Monitoring Sites

Dry Deposition Monitoring Sites

Opportunities for Collaboration: There is the opportunity to develop new instrumentation and data collection hardware that will greatly enhance the operation of the networks. Acid rain monitoring is in its infancy. Automated instruments that eliminate the need for taking precipitation samples to the laboratory for analysis would better preserve the integrity of the samples. The measurement of dry deposition is an evolving technology. Methods to measure the flux of SO_2, HNO_3, O_3, and other pollutants are now at a very basic stage. Visibility measurements are another area where new technologies are needed. Currently, these measurements are being made at airports on a routine basis; however, they are far less accurate and

Clean Air Status and Trends Network Research and Development

precise than what is now needed in the air monitoring community. Collaboration on the development and testing of these new technologies, and the establishment of new dry and wet deposition monitoring sites is desired.

Key Publications:

Bigelo, D.S. 1984. Instruction Manual: NADP/NTN Site Selection and Installation. Natural Resources Ecology Laboratory, Colorado State University; Fort Collins, CO. Environmental Sciences and Engineering, Inc. 1990. National Dry Deposition Network. Project Work Plan. Gainesville, FL.

USEPA/Canada Ontario Coordinated Committee on Annex 15. IADN Implementation Plan. 1990.

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September 1992

Development of Integrated Methods for Measuring Aerosols in Indoor and Ambient Air

Issue: The Aerosol Physics and Methods Branch (APMB) is primarily responsible for developing, evaluating, testing, improving, and standardizing methodology and systems for measuring small particles suspended in air (aerosols) in indoor and ambient air. The Branch has the aerosol research expertise and unique facilities and equipment for conducting applied and basic research associated with the measurement of aerosol particles. These facilities and expertise are applicable to cooperative problem solving with industries that utilize aerosols in their chemical processing or have particle pollution or exposure problems.

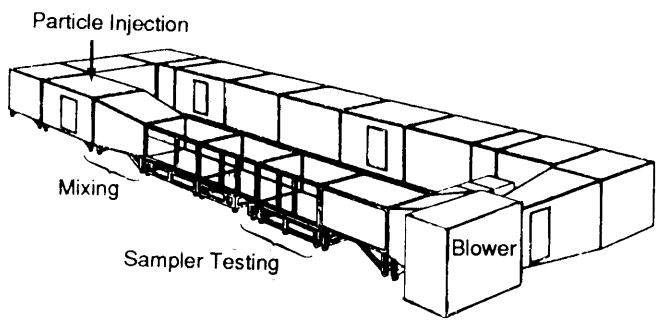
APMB responds to the methodology needs and requirements of both existing and anticipated air quality standards for PM-10 (respirable and inhalable suspended particulate matter), fine particles and acid aerosols. During the past several years efforts in this area have been concentrated on methodology for supporting the National Ambient Air Quality Standards (NAAQS) for PM-10. Current and future efforts are focused on improving these methods and developing and evaluating new methods for measuring aerosols.

The APMB operates a state-of-the-art Aerosol Test Facility (ATF) that is used to develop new techniques for particle sampler evaluation and to implement basic research addressing sampler design and aerosol mechanics (the study of the motion of particles in air). The ATF low velocity wind tunnel (2 to 48 km/hr) has primarily been used for performance testing of EPA approved inlets (PM-10). Performance data have been collected for new techniques such as the tapered element oscillating microbalance (TEOM), beta gauges, optical particle sizing instruments, and indoor and personal impactors. These techniques allow for the measurement of particle size, mass, number, and distribution in real time.

Current Activities: The Branch has developed the Wide Range Aerosol Classifier (WRAC) which, among other ambient particle sampling instruments, is available for studies of temporal and spatial aerosol distributions. The WRAC is a large ambient sampler that representatively collects and provides size distribution information for very large suspended particles (>200 μm) to very small (<0.1 μm) in the ambient atmosphere. The WRAC is used to evaluate the distribution of particles and to provide reference information for comparison with other samplers.

A new aerosol exposure laboratory has been constructed for the study of the nature of personal and indoor (microenvironmental) aerosol measurements and their relationship to human exposure. Characterization studies evaluate the use and performance of personal samplers to assess aerosol exposure. Hygroscopic growth of particles (the change in particle size with humidity) is being studied using a state-of-the-art acoustic phase doppler particle sizing technique. The technique allows us to non-invasively measure particle growth in real time. Our microbiology laboratory supports field studies and indoor air investigations for the purpose of risk determination and physical characterization of biological suspended particles (viable and non-viable).

In addition to the experimental work listed above, numerical models of inlet flow fields are being generated to assist in the development of advanced sampler designs. Experimental validation studies are being performed in our laboratory utilizing technologies such as optical phase doppler anemometry and hot film anemometry.



EPA Aerosol Test Facility

Development of Integrated Methods for Measuring Aerosols in Indoor and Ambient Air

Opportunities for Collaboration: The APMB is well equipped for all aspects of aerosol and bioaerosol evaluation. The staff holds expertise in sampling instrument development, evaluation, and operation. They are familiar with current and developing sampling technologies. The APMB has been involved in numerous field studies with such varied objectives as assessing human exposure, quantifying biological contamination of ambient and indoor air, evaluating sampler performance, and quantifying ambient aerosol concentrations. Thus, the APMB is experienced in the development of sampling methodologies for studies with diverse objectives. Opportunity exists to collaborate on sampling instrument development, utilizing the expertise of the APMB personnel, the aerosol test facility, and supporting equipment at the EPA. Field studies may be undertaken to integrate outside methods into EPA monitoring programs. Other opportunities include joint efforts in addressing a unique exposure situation, drawing on the staff's field experiences, knowledge of current sampling technologies, and expertise in sampling methodologies. Also, sampling systems developed by the EPA are available for commercial applications.

Key Publications:

Russell W. Wiener and Charles Rodes, in press. "Indoor Air and Exposure Studies." Chapter Number 31, *Aerosol Measurement*, ed. K. Willeke and P. A. Baron, Van Nostrand Reinhold, New York.

Rodes, C. E., Kamens, R.M., and Wiener, R.W. 1991. "The Significance and Characteristics of the Personal Activity Cloud on Exposure Assessment Measurements for Indoor Contaminants." Indoor Air, 2:123-145.

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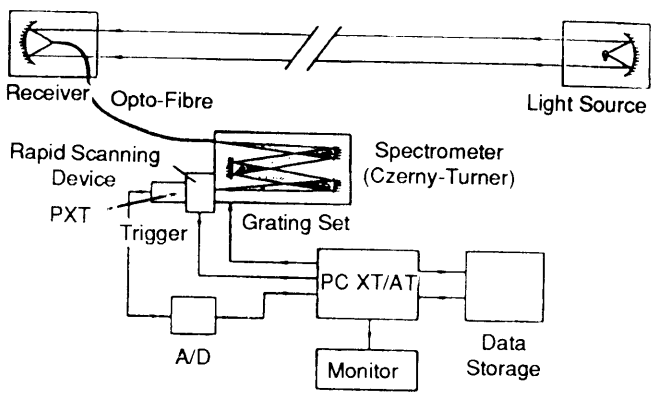
Open Path Monitoring with the Differential Optical Absorption Spectrometer

Issue: The Atmospheric Research and Exposure Assessment Laboratory (AREAL) of the U.S. EPA has a commercial version of a Differential Optical Absorption Spectrometer (DOAS) manufactured by OPSIS, Inc. The DOAS can be configured to measure multiple pollutant concentrations over multiple open paths in near-real time. The system is computer controlled, and concentrations of species of interest are calculated automatically using software and calibration files supplied by the manufacturer.



Schematic of the DOAS System

Current Activities: The U.S. EPA performed a preliminary evaluation of this system between October 1991 and March 1992 in RTP, NC. This evaluation consisted of a comparison of long-path DOAS measurements with Federal Reference Method (FRM) point measurements for SO_2, O_3, NO_2, and NO. Results indicated a high level of correlation for SO_2, O_3, and NO_2. A similar DOAS system had been field tested in RTP, NC, during September and October of 1989. In this comparison, the DOAS and FRM measurements were highly correlated (r 0.94) for SO_2, O_3, and NO_2. Their average concentrations also compared well. A DOAS system was operated in Atlanta, GA, during July and August of 1990 as part of a U.S. EPA study of ozone and its precursors. In this study, the DOAS demonstrated its capacity to measure the concentrations of a multitude of gaseous air pollutants over several open paths in near-real time. Comparisons between FRM's and the DOAS for O_3, NO_2, and NO showed good correlations (r = 0.85-0.96) but some differences in average concentrations, most notably for NO.

Opportunities for Collaboration: Plans for AREAL's DOAS system include the following: (1) Characterize the system and optimize it for the analysis of criteria pollutants and key organic pollutants; (2) Compare the results obtained with the DOAS to results obtained with more standard methods; (3) Devise monitoring strategies for using the DOAS to support the apportionment of chemical species measured in the ambient air to their sources; (4) Devise monitoring strategies for using the DOAS to measure dry deposition in near-real time; (5) Develop DOAS long-path methods to monitor aromatic emissions from area sources such as oil refineries and gas and oil tank farms; (6) Develop methods for combining these measurements of area source emissions with meteorological data to estimate emission factors.

The system is currently configured to calculate concentrations automatically using manufacturer-supplied software. Details of this calculation procedure are known only to the manufacturer and are not under operator control. An approach to optimizing the system for species of interest would be to modify or replace the existing software so that the DOAS can operate as a research tool under operator control. A multi-path optical cell for making calibration spectra and investigating potential spectral interferences should be purchased or constructed. Data from conventional sampling/monitoring equipment (canisters and GC analysis for organic pollutants and FRM monitors for criteria pollutants) could then be obtained concurrently with the DOAS measurements. Measurements would be made of gases in the ambient air and in the calibration cell. These data would be compared with pollutant concentrations measured with the DOAS using correlations and other statistical techniques to evaluate the DOAS operation. Preliminary studies have shown mea-

Open Path Monitoring with the Differential Optical Absorption Spectrometer

surements of organic pollutants with the DOAS to be problematic. Work planned with the calibration cell, as well as development of software to permit operator control of the analysis, should help to solve these problems. Once the system has been adequately characterized, optimum monitoring strategies for gathering data with the DOAS for apportioning pollutants to their sources can be devised, as well as procedures for measuring near-real time dry deposition. Likewise, expertise from the areas of long-path monitoring and pollutant dispersion can be merged to develop methods for estimating emission factors of area sources using long-path monitoring.

Key Publications:

C. P. Conner, B. W. Gay, Jr., W. E. Karches, and R. K. Stevens. "Open Path Ambient Measurements of Pollutants with a DOAS System," in Proceedings of the 1992 EPA/AWMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC, May 4-8, 1992.

R. K. Stevens, R. J. Drago, W. T. McLeod, J. P. Bell, R. P. Ward, Y. Mamane, and H. Sauren. "Evaluation of a Differential Optical Absorption Spectrometer as an Air Quality Monitor," in Proceedings of the 1992 EPA/AWMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC, April 30 - May 4, 1990.

T. L. Conner and R. K. Stevens. "Air Quality Monitoring in Atlanta with the Differential Optical Absorption Spectrometer," in Proceedings of the 84th Annual Meeting and Exhibition, Vancouver, B.C., Canada, June 17-21, 1991.

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September 1992

Human Exposure Research: The Need for a State-of-the-Art Pump for High-Flow Personal Monitoring

Issue: Research within the last 10-15 years has shown that measurements of air contaminants vary considerably between those made personally and those made remotely, such as ambient or microenvironmental based sampling. Moreover, personal measurements generally exceed those made remotely and have been shown to be more closely linked with health effects. The value of person-based exposure measurements has been well established in industrial hygiene and has resulted in the development of pumps suitable for personal monitoring in the industrial environment. Pumps developed for workplace applications are ill-suited for environmental personal sampling due to limitations in power, excessive noise, and comfort considerations of size and weight. These limitations are especially severe when sampling for air contaminants that are at trace levels in the environment (e.g., polycyclic aromatic hydrocarbons, particles, dioxins, metals, pesticides). Since there is no commercially available pump suitable for high-flow sampling to assess human environmental exposure, implementation of person-based exposure monitoring by researchers at the EPA and other institutions across the country has involved retrofitting industrial hygiene pumps that are commercially available. This need for pump retrofitting delays study implementation and results in unstandardized sampling systems that are unreliable, expensive, and difficult to maintain.

Current Activities: Awareness of the importance of person-based sampling (as well as requests for the technology) in assessing risk to environmental contaminants is increasing among the research community as well as among local, state, and federal agencies mandated to protect human health (in this country and abroad). Development of a readily available state-of-the-art personal pump suitable for the collection of environmental samples has broad application. The development of such a pump is also likely to establish a new standard for industrial hygiene applications and present appeal for this market.

Opportunities for Collaboration: EPA's primary contribution will be providing detailed design requirements that reflect the experience and expertise of the Agency in conducting human exposure research. Design considerations will include cost, power, performance, noise, and comfort. These considerations will reflect the current and future perceived needs of EPA human exposure scientists and the university and contractor researches with which they work. The contribution desired from the private sector is in advising the Agency as to what technology is available, the limitations of the technology, the production of a prototype personal pump, and eventually the commercial availability of a new state-of-the-art personal exposure pump suitable for environmental applications.

Key Publications:

L. Wallace, E. Pellizzari, T. Hartwell, et al. "The influence of personal activities on exposure to volatile organic compounds," *Environmental Research*, 50:37-55 (1989).

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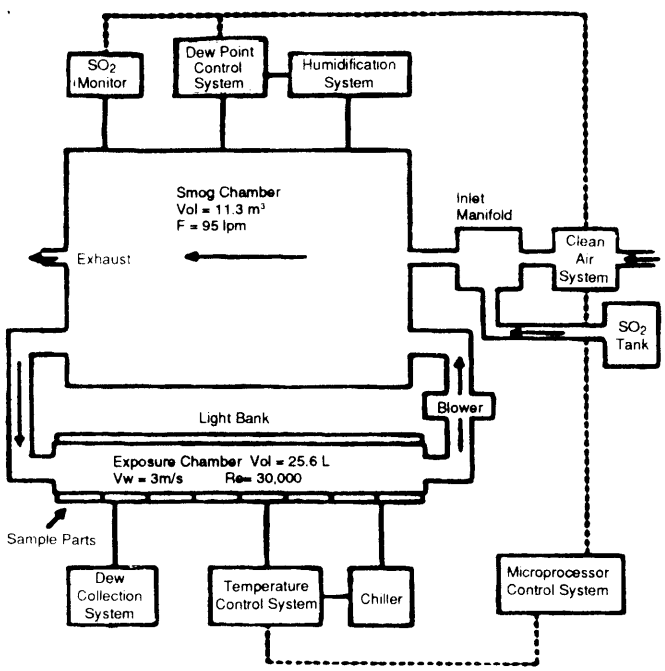
EPA Laboratory System for Accelerated Weathering Studies

Issue: All materials exposed out of doors are subject to weathering by heat, moisture, sunlight and by pollution. The gas phase pollutants, sulfur dioxide, ozone, oxides of nitrogen, and hydrocarbons; atmospheric particulates; and acid dew, fog, and precipitation can all, in principle, accelerate the weathering of materials of construction and those of historic and/or artistic significance. Forecasting weathering rates is critical for improving basic product design; selecting the appropriate product for a given environmental condition; establishing product lifetimes; and, determining maintenance procedures and schedules.

Until recently, methods for addressing these issues have been limited mainly to outdoor exposure studies and weatherometer laboratory studies. Although outdoor studies provide weathering data for particular locations, it is difficult to translate the findings to other environmental conditions. Weatherometer studies employ harsh conditions that prevent accurate extrapolation to ambient conditions. Methods are needed for inducing damage under realistic conditions to afford ready extrapolation to real-world environments.

Current Activities: The Atmospheric Research and Exposure Assessment Laboratory (AREAL) is conducting laboratory exposure studies to determine the damage to materials. The research is centered around a unique exposure chamber, designed by AREAL scientists to carry out material exposures so that the damage data can be extrapolated to ambient conditions. The material exposure system consists of a large flow reactor coupled to an exposure chamber. Hydrocarbons, oxides of nitrogen, and sulfur dioxide are added into the flow reactor in an air stream that upon irradiation generates atmospheric mixtures that are similar in many ways to those occurring under ambient conditions. The flow reactor serves as a reservoir for complex air mixtures for conducting exposure studies in the exposure chamber. Test panels, including those of polymeric and metal-based materials, can be exposed to the mixture under dry conditions and in the presence of surface moisture. The moisture system can be cycled, generating condensation/evaporation periods. The laboratory system is fully equipped so that gas and particulate chamber concentrations can be measured, thus providing AREAL researchers the necessary information for extrapolating chamber damage to that expected under ambient conditions. Analytical methods have also been developed for determining the surface concentrations of pollutants that cause damage.

The laboratory system served as the basis for much of material damage studies conducted under the United States Congress-mandated National Acid Precipitation Assessment Program. The chamber was used to develop a damage function for predicting the atmospheric lifetimes of galvanized steel structures and generated important data on the environmentally induced damage to organic coatings. More recently, the system was employed to conduct research for Ford Motor Company on the impact of acid rain on automotive finishes. The research, conducted under the Federal Technology transfer Act (FTTA), involved using the exposure chamber to develop test methods for determining the key chemical and physical parameters that cause contaminated precipitation to damage



Flow Chamber System

EPA Laboratory System for Accelerated Weathering Studies

coatings. Over 60 coatings were evaluated during the program. AREAL has also just completed a FTTA research program for Dow Corning Corporation where the laboratory system was used to predict the performance of new products developed by Dow Corning.

Opportunities for Collaboration: Scientists at the Atmospheric Research and Exposure Assessment Laboratory have developed a unique exposure chamber that can provide important information on issues related to product performance. AREAL is interested in continuing their work with industry and other government institutions in material damage investigations. By initiating these types of studies, AREAL can furnish, in a cost-effective manner, the resources for conducting these unique laboratory exposure experiments as well as environmental data necessary to interpret the results for given environments. In particular, AREAL is interested in entering into agreements with those organizations that have advanced techniques for evaluating damage to materials. It is the merger of this unique laboratory exposure facility with advanced techniques for quantifying damage on a microscopic level that will most rapidly advance our ability to predict product performance.

Key Publications

Edney, E.O., D.C. Stiles, J.W. Spence, F.H. Haynie, and W.E. Wilson. 1986. A laboratory study to evaluate the impact of NO_x, SO_x, and oxidants on atmospheric corrosion of galvanized steel, pp 172-193. In: R. Baboian, ed. Materials Damage Caused by Acid Rain. Amer. Chem. Soc., Washington, DC.

Edney, E.O., D.C. Stiles, J.W. Spence, F.H. Haynie, and W.E. Wilson. 1986. Laboratory investigations of the impact of dry deposition of acidic species on the atmospheric corrosion of galvanized steel. Atmos. Environ. 20:541-548.

Baedecker, P.A., E.O. Edney, P.J. Moran, T.C. Simpson, R.S. Williams, R.P. Hosker, G. Kishiyama, D. Langmuir, E.S. McGee, V.G. Mossotti, M.J. Pavich, M.M. Reddy, K.J. Reimann, R. Schmiermund, C.A. Sciammarella, E.C. Spiker, M.L. Wesley, and C.A. Youngdahl. 1990. G neva ch- nology, National Acid Precipitation Assessment Program, Washington, DC.

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Calibration and Audit Methods Development

Issue: The need for simple and rapid methods to field calibrate and audit monitors used for volatile organic pollutants increased dramatically with the passage of the 1990 Clean Air Act Amendments (CAAA). The present practice of using compressed gas cylinders for these purposes is now logistically awkward, technically inadequate and prohibitively expensive because the CAAA requires more than 50 new volatile organics to be regulated.

Current Activities: The Quality Assurance and Technical Support Division (QATSD) conducts research to improve quality assurance in association with methods development and applications and prepares appropriate guideline and technical assistance documents for AREAL, Program and Regional Offices, state and local air pollution agencies, and the air pollution monitoring community. The Division prepares guidance on how to manufacture, transport, store, and use reference and QC materials. QATSD develops and improves reference and QC materials and determines their suitability for the air medium and for commercialization. The Division also coordinates the development of the QA requirements for EPA regulations dealing with the air medium.

Opportunities for Collaboration: The Analytical Materials and Support Branch (AMSB) has been investigating the use of commercially available hollow fibers as potential devices to serve as vehicles for delivering calibration and audit gases to pollutant monitors and as a means for sampling process streams for a very diverse spectrum of pollutants. Enough is known about the basic chemical physics of these fibers to begin evaluation of the more advanced and practical considerations required for system engineering design. Opportunity exists for those knowledgeable about the physical characteristics of these hollow fibers, engineering design or pollution measurement/control to work with AMSB to design/test practical devices based on these fibers and investigate their practical use in these areas. Commercial availability of these devices hopefully would reduce the cost of ensuring that good quality data are collected from environmental compliance monitoring and air quality assessment activities. While the direct savings due to the adoption of these devices may be small, the value of the mitigation decisions based on such data ensures demand for such devices will be substantial.

Key Publications:

Westover, L.B., Tou, J.C., and Mark, J.H., "Novel Mass Spectrometric Sampling Device — Hollow Fiber Probe," Anal. Chem., 1974, 46, April 1974.

Calvo, K.C., Weisenberger, C.R., Anderson, L.B., and Klapper, M.H., "Permeable Membrane — Mass Spectrometric Measurement of Reaction Kinetics," Anal. Chem, 1981, 53, 981-965.

LaPack, M. A., Tou, James C., and Enke, C.G., "Membrane Mass Spectrometry for the Direct Trace Analysis of Volatile Organic Compounds in Air and Water," Anal. Chem. 1990, 62, 1265-1271.

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Remote Sensing of Trace Gases for Air Quality Analysis of Volatile Organic Compounds

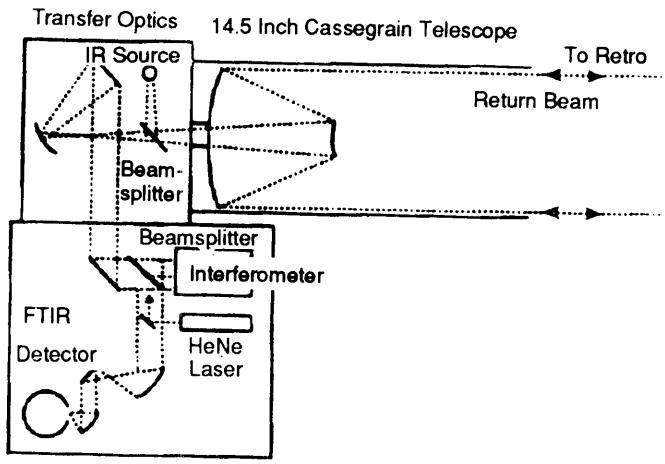
Issue: The prospect of using remote sensing for air quality measurements is intriguing to environmental scientists since it is a more comprehensive and potentially more accurate monitoring tool than traditional point monitoring. Remote sensing includes a wide variety of techniques, using radiation and sound as probes. The methods development group within AREAL has historically been concerned with the subset of techniques referred to as open path monitoring (OPM) of selective radiation absorption in situations where the equipment is used in a ground-based mode. These techniques include FTIR-based bistatic monitors, UV-based bistatic monitors, and ground-based DIAL (Differential Absorption Lidar) systems.

Applications of remote sensing are expanding to take advantage of features unique to remote sensing such as the space-time averaging over kilometer size grids, the absence of storage stability problems, and the ability to obtain spatial resolution and vertical burden information.

The issue has become the identification of applications in which remote sensing is a cost-effective means or unique means to obtain air quality data.

Current Activities: The recent methods development program within AREAL has included the development and field evaluation of FTIR-based commercial-prototype OPMs and of UV-based commercial OPMs. Continual interaction with commercial suppliers of this type of equipment has led to significant reduction in the method detection limits and to a better understanding of potential spectral interferences. Symposium presentations and journal articles originating from AREAL on the comparison of point monitors and OPMs, and on the features of path monitors have added significantly to our information base. Recently, field testing of OPMs at two Superfund sites, the Shaver's farm site in Georgia and the French Limited site in Texas, have helped to establish the relevancy of the technique to practical problems.

Refinement of the FTIR-techniques to treat the problems of water vapor and carbon dioxide interference and the determination of reference spectra is underway at our new OPM evaluation range. Two commercial systems are being evaluated based on experience over the past three years. A guidance document is being prepared for the operation of FTIR-based systems in field studies. This document contains the technical detail that is lacking in existing literature in order to optimize field performance.



FTIR OPM Schematic

Opportunities for Collaboration: AREAL is continuing to develop remote sensing methods with an even broader scope to address such problems as the measurement of emission flux from extended sources, the use of DIAL techniques to obtain concentration profiles of plumes from localized sources, and the use of FTIR systems to detect fugitive emissions.

One important aspect of the development is that of data processing software and specifically the customizing of this software to deal with the sophisticated solutions involving the use of reference libraries and spectral subtraction. The treatment of data processing, especially for FTIR-based systems, is far from satisfactory.

Remote Sensing of Trace Gases for Air Quality Analysis of Volatile Organic Compounds

New and improved remote sensing techniques involving SONAR and new pulsed laser sources are of interest. New and innovative remote sensing solutions to air monitoring problems posed by the 1990 Clean Air Act Amendments are needed on a priority basis.

The OPM monitoring range and in-house expertise provides a basis for collaboration on both instrument design and instrument evaluation.

Key Publications:

G.M. Russwurm, *et al.*, "Long-path FTIR Measurements of Volatile Organic Compounds in an Industrial Setting," JA&WMA, 41(8), 1062-1066, 1991.

R.K. Stevens, *et.al.*, "Evaluation of a Differential Optical Absorption Spectrometer as an Air Quality Monitor, "Proceedings of the 1990 EPA/A&WMA International Symposium on Measurement of Toxic and Related Air Pollutants, Raleigh, NC, April 30, 1990.

Proceedings of the Symposium on Optical Remote Sensing and Applications to Environmental and Industrial Safety Problems, 6-8, April 1992, Houston, TX. Available from the A&WMA.

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Climate, Remote Sensing and Geographic Information Systems

Issue: The Atmospheric Research and Exposure Assessment Laboratory conducts research to address assessment and decisions which are sensitive to climate and climate variations. The research utilizes both *in-situ* observations and remotely sensed data in the analyses. Geographic Information Systems are primary tools in analysis and display of information. Applications include assessment for decisions related to ecosystems, air quality and other environmental issues.

Current Activities: Major products include geographically resolved climate indices which are regionally aggregated to reflect climate forcing on selected ecosystems (forests, estuaries, agroecosystems). The geographic extent of the current assessment of forest ecosystem (Cooter and Truppi) shown in Figure 1 depicts a climate index directed to assess ice damage. Satellite indices of vegetation (derived from the NOAA polar orbiting Advanced Very High Resolution Radiometer, U.S. Geological Survey, EROS) and associated surface climate parameters are being analyzed for input into agroecosystem assessment.

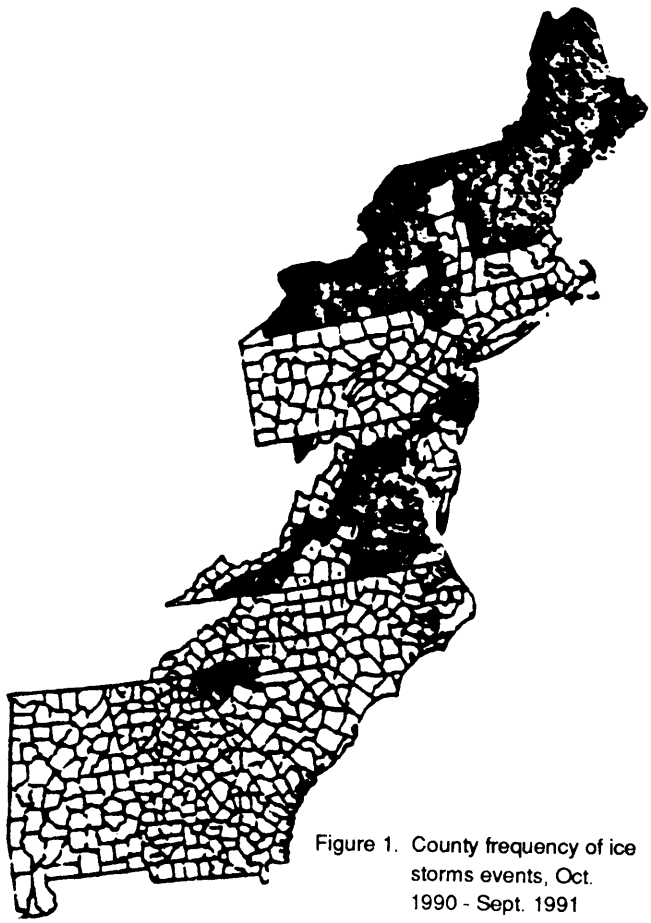

Figure 1. County frequency of ice storms events, Oct. 1990 - Sept. 1991

The link between climate and ozone (surface and tropospheric) is being addressed for the Eastern United States with plans to extend efforts globally. Homogeneous regions with respect to surface ozone are displayed in Figure 2. Satellite derived (TOMS and SAGE) estimates of tropospheric ozone are being compared to other physical atmospheric parameters at the surface and in the troposphere.

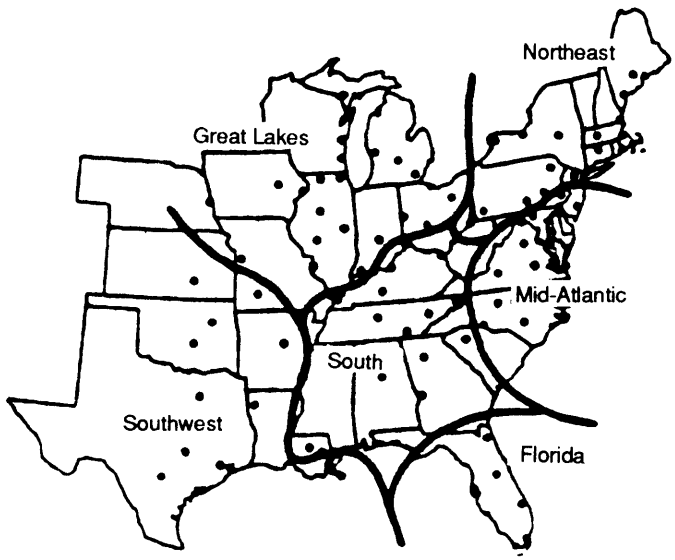

Figure 2. Homogeneous O_3 concentration regions

Climate and the atmosphere are factors which determine the demand for energy (for air conditioning). The atmosphere is also a determining factor in the supply side of the energy equation when photovoltaics are included. Photovoltaics are environmentally acceptable but have not been efficient enough in the past to be economically feasible. Technology is improving the efficiency and reducing the cost. Climate data on surface temperature, humidity and wind can estimate cooling needs by time of day. The ability of

Climate, Remote Sensing and Geographic Information Systems

photovoltaics to provide expensive peak load energy generation can be estimated from satellite data (Figure 3). Cost benefit studies of this problem for various distribution systems (Figure 4) in the United States for a representative period of record would allow determination of year-to-year variability and payback period.

Opportunities for Collaboration: The implementation of geographically resolved climate information, including remotely sensed data, to address assessment and decision making, offers many opportunities for AREAL scientists to cooperate with external groups. Climate data and remotely sensed data are of limited value when used alone, but have strong relationships with many sectors of society, economy and industry. These relationships can be utilized. AREAL is receptive to external groups interested in identifying and improving the application of *in-situ* or remotely sensed climate information through:

1. advanced visualization techniques;
2. development of faster and friendlier computer interacitve capability;
3. analytic capability designed to facilitate assessments and address uncertainty in the information used by decision makers.

The applications of interest are broad and include agriculture, forests, estuaries, air quality, energy demand for air conditioning (cooling and heating) and energy supply for atmospherically driven renewable resources (solar and wind).

Key Publications:

Eder, B.K., J.M. Davis and P. Bloomfield. "A Characterization of the Spatiotemporal Variability of Non-Urban Ozone Concentrations over the Eastern United States," in review.

Cooter, E.J. and L. Truppi. "Chapter 6. Selected Climatic Data Summaries." *Forest Health Monitoring Statistical Summary*, (K. Riitters, B. Conkling, eds.), EPA, in review.

Justus, C.G. and J.D. Tarpley. Atlas of Satellite-Measured Insolation in the U.S. , Mexico, and South America. Nov. 1984.

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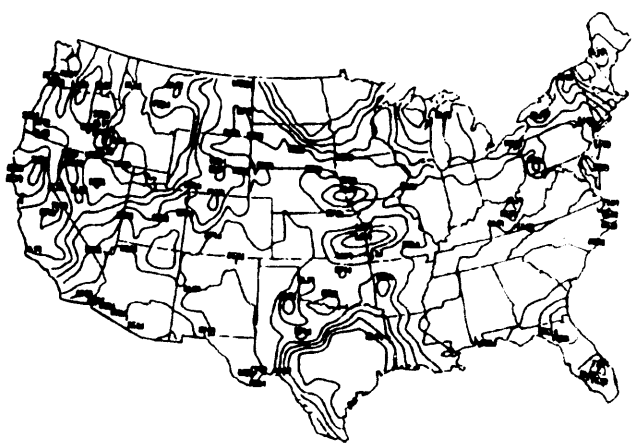

Figure 3. Daily total insolation estimated from GOES data, Mar. 13, 1983.

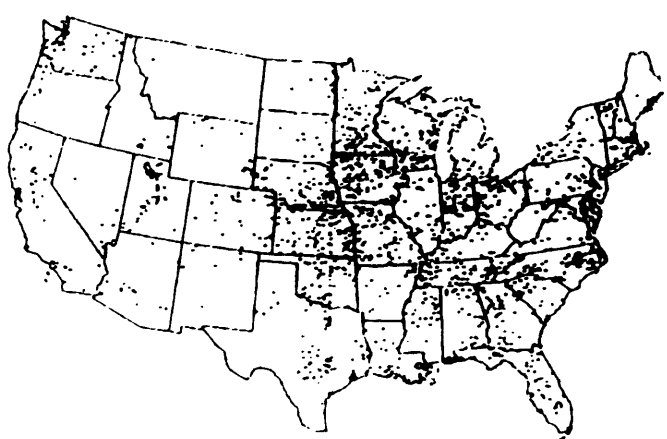

Figure 4. Municipal utilities in the U.S.

Development of a Continuous Emission Monitor for Total Gaseous Nonmethane Organic Carbon

Issue: The present method for measuring Total Gaseous Non-Methane Organic Carbon (TGNMOC) is by EPA Method 25, a Manual method for stationary source sampling and analysis for several industrial source categories. Many laboratories have experienced difficulties in performing the method. The method has several drawbacks including the level of detection (50 ppmC) and the fact that it is not continuous.

EPA's Office of Air Quality Planning and Standards (OAQPS) has expressed a need for a Continuous Emission Monitor (CEM) for TGNMOC in addition to Method 25 for assessment of the reduction of stationary source emissions from several of the industries regulated under the Clean Air Act Amendments (CAAA) of 1990, Title III. For this purpose they have defined continuous as providing a value every 10 minutes or less.

Current Activities: The Source Methods Research Branch has been assessing new procedures for possibly replacing Method 25 with a more reliable procedure. We have been evaluating a new detector that is sensitive to organic carbon with good results. The detector is the Catalytic Flame Ionization Detector (CFID) with a detection limit of <1ppmC.

We are in the process of developing and field testing a CEM based on the CFID with a response time of 10 minutes or less. The field testing will probably be in the first quarter of 1993.

A successful CEM will provide EPA's regulatory offices with the methodology to assess the reduction in stationary source emissions from newly installed control devices. It will allow the industries to maintain control of their processes, and could be used as a part of their process regulation.

Opportunities for Collaboration: There is a need to demonstrate that the CEM coupled with CFID can be successfully packaged and installed on stationary sources. Another approach would be to develop a system that will provide the same results in terms of TGNMOC. Any system used to demonstrate compliance with the Clean Air Act Amendments of 1990, Title III must be compatible with the requirements of the CAAA and conditions encountered at stationary source monitoring sites.

Key Publications:

Jackson, Merrill D., Joseph E. Knoll, M. Rodney Midgett, Samuel C. Foster II, James F. McGaughey, and Raymond G. Merrill, Jr., Development of an Analysis Method for Total Nonmethane Volatile Organic Carbon Emissions from Stationary Sources, Proc. of the 1992 EPA/AWMA International Symposium on Measurement of Toxic and Related Air Pollutants, Durham, NC, May 3-8, 1992, In Press.

Jayanty, R., S. Tompkins, R. Fuerst, T. Logan, and D. Von Lehmden, Performance Audit Results Using EPA Method 25 During Source Complacence Tests. JAPCA, Vol. 40, No. 1, pp 38-41, 1990.

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Mobile Source Emission Research and Development

Issue: Motor vehicle emissions contribute significantly to most urban air quality problems, including ozone, CO, and toxics. Estimates suggest the contributions to be nearly 50% of ozone precursors and toxics, and 90% of CO. Further, there continues to be uncertainty about the accuracy of models used to estimate the magnitude of the mobile source emissions inventory. Recent roadway studies suggest that MOBILE 4.1 (EPA's motor vehicle emissions model) and other similar models may underestimate the emission rates of motor vehicle HC and CO by factors of 2 to 3.

The 1990 Clean Air Act Amendments have initiated a number of programs to decrease the impact of motor vehicle emissions on non-attainment of urban air quality standards. Included are programs to reduce emissions from new motor vehicles; programs to introduce new potentially more environmentally benign fuels, such as reformulated gasolines, methanol, ethanol, compressed natural gas, low pressure gas (propane), and electricity with associated compatible vehicle technologies; and programs to more effectively identify and repair malfunctioning consumer owned motor vehicles.

Current Activities: Research programs of the Mobile Source Emissions Research Branch, Atmospheric Research and Exposure Assessment Laboratory (AREAL), located in Research Triangle Park, NC, include activities to support the development of new motor vehicle emissions regulations, to characterize emissions from emerging alternatively-fueled motor vehicles under a variety of operating conditions, and to characterize "real world" vehicle emissions making contrasts with predictive models and determining the source of differences. Activities to support new regulation generally take the form of developing necessary analytical procedures for emission rate measurements. As permitted emission rates are reduced, the limits of analytical accuracy and precision must be extended, and as fuel compositions are changed, the array of compounds that must be measured is expanded. Characterization of emissions from emerging vehicle and fuel technologies generally involves chassis dynamometer examination of prototype vehicles and fuels as made available by the associated industries.

Emission characterization includes all regulated compounds and a large number (>> 200 compounds) of unregulated compounds to estimate the potential implication of the technology for such complex air quality problems as urban ozone. Study of "real world" vehicle emissions generally involves performing field studies in cooperation with industry and academia. These studies examine emissions at remote roadway sites by collecting and analyzing samples taken at the roadway edge and by using remote sensing instrumentation to provide real time tail-pipe emission rates. Such rates are used to identify unusually high emitters which can be examined to characterize the reasons for high emissions. With the cooperation of the vehicle owner, a malfunction can be diagnosed by experts, and the emission rates characterized with standard dynamometer procedures (transportable chassis dynamometer).

Opportunities for Collaboration: As the new technologies emerge, numerous opportunities exist for collaborative evaluation of their performance and implications for air quality. Collaborative development of test procedures, (including dynamometer procedures, emissions sampling and analytical procedures, and associated quality assurance procedures to provide necessary accuracy and precision) and collaborative laboratory dynamometer and roadway studies of vehicle emissions will be required to provide the data necessary to estimate the effectiveness of the varied emissions control activities. Numerous vehicle and fuel technologies will require examination under the widely variant operating conditions known to influence emission rates (vehicle speed, acceleration-deceleration, road grade, ambient temperature, altitude, etc.). The characteristics of "real-world" motor vehicle emissions

Mobile Source Emission Research and Development

need to be understood and appropriate strategies to manage these emissions developed.

Key Publications:

Gabele, P.A., Characterization of Emissions from a Variable Gasoline/Methanol Fueled Car, J. Air Waste Manage. Assoc., 40(3), 296-304, 1990.

Stump, F.D., Knapp, K.T., Ray, W.D., Burton, C., and Snow, R., The Seasonal Impact of Blending Oxygenated Organics with Gasoline on Motor Vehicle Tail-pipe and Evaporative Emissions, SAE 902129, Society of Automotive Engineers, Warrendale, PA, 1990.

Knapp, K.T., Dynamometer Testing of On-Road Vehicles from the Los Angeles In-Use Emissions Study, J. Air Waste Manage. Assoc, in review, 1992.

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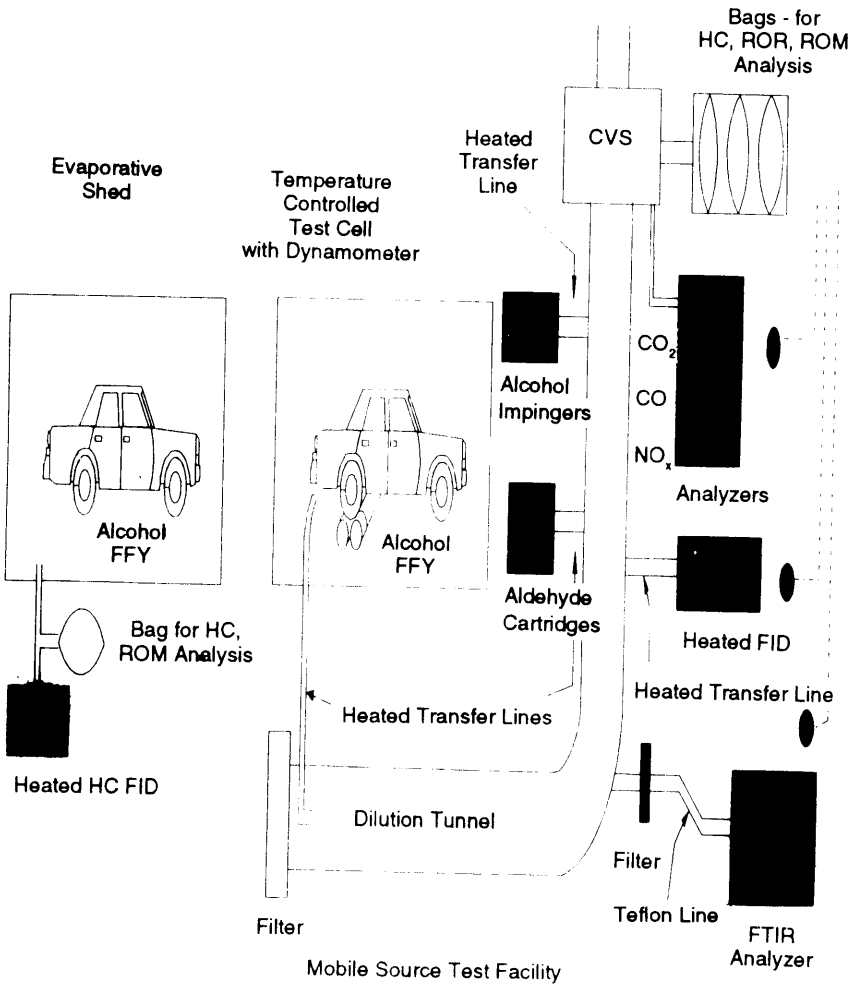

Environmental Monitoring Systems Laboratory - Cincinnati

Aquatic and Terrestrial Animal Facility

Description of Facility: At the Andrew W. Breidenbach Research Center in Cincinnati, Ohio, the Environmental Monitoring Systems Laboratory (EMSL-Cincinnati) maintains a unique, well-equipped facility to conduct ecotoxicological research with aquatic and terrestrial animals. The facility consists of 26 single module rooms (240 sq. ft. each), three double module rooms, and one triple module room. Of these, seven are hazard rooms equipped with fume hoods. Other specialized rooms within the animal facility for support of animal research consist of one necropsy room (480 sq. ft.), one surgery room (400 sq. ft.), one cage/equipment cleaning room (960 sq. ft.), and food storage room (240 sq. ft.). Two rooms are equipped with large flow-through fish tanks, and an additional five modules are devoted to culture of smaller fish. One group of modules is set up for invertebrate culture, and there is a small breeding colony of white-footed mice. The facility is accredited by AAALAC.

Current Activities: Research in the facility is conducted by personnel with expertise in carcinogenesis, mutagenesis, reproductive and developmental toxicology, physiology and ecology. The Ecological Monitoring Division of EMSL-Cincinnati performs research designed to detect and quantify responses in aquatic and terrestrial organisms exposed to environmental stressors and to correlate the exposure with effects on chemical and biological indicators. Biochemical and molecular markers are being developed in ecologically relevant species that can be used to document exposures, elucidate stressor-induced effects, and establish causality in ecosystems. Modern toxicological assessment techniques being used include computer-assisted sperm motion analysis, image-analysis-based histopathology, fish clinical and histopathological markers, and molecular biology. Organisms involved in current research include fish, tadpoles, clams, field mice, earthworms, and plants and laboratory rodents.

Opportunity for Collaboration: EMSL-Cincinnati is interested in collaborative efforts to:

- Assist in biological evaluation of remediated matrices.
- Develop new assays and markers needing toxicological support and testing.
- Compare the response of feral and laboratory species to single and interacting stressors.
- Develop cause and effect links between stressor responses at different levels of biological organization.

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Chemical Analytical Methods

Issue: The Chemistry Research Division of the Environmental Monitoring Systems Laboratory - Cincinnati is responsible for developing laboratory analytical chemical methods that are incorporated into Agency monitoring and regulatory programs. In some Agency programs, these methods are mandatory and required for monitoring to demonstrate compliance with environmental regulations.

The analytical methods are detailed, step-by-step instructions for laboratory analysts and technicians. The methods are written in a "cookbook" style to provide trained analysts/technicians with all information necessary to complete acceptable laboratory analyses of environmental samples. Included are sections on needed equipment and supplies, sample collection and preservation, sample processing and preparation, instrument calibration, analyte separation and measurement, data interpretation and presentation of results, quality assurance and control, waste disposal and prevention, and references to other sources of background information.

These analytical methods are used or cited in numerous Agency programs but most often in the Safe Drinking Water Act regulations and the Clean Water Act regulations (Nation Pollution Discharge Elimination System permits). Therefore, these methods are in great demand by the regulated community, Federal, State, and local government agencies, private laboratories, and industry. These analytical chemical test methods are also used as models for methods incorporated into many other Agency monitoring and regulatory programs including regulations under the Resource Conservation and Recovery Act (RCRA), the Superfund site investigation and remedial action program, and the Environmental Monitoring and Assessment Program (EMAP).

Current Activities: Since December 1988, 35 analytical methods have been carefully documented and distributed in a series of three methods manuals. Another 30 new or revised methods are planned for the next several years. In addition, analytical methods must be updated regularly as new techniques, instruments, and procedures are developed.

Opportunity for Collaboration: These analytical methods are distributed primarily through the National Technical Information Service (NTIS) in Alexandria, VA. The NTIS provides photocopies of methods manuals, which usually contain 7-13 methods, and estimates six weeks for delivery. Nevertheless, 1026 copies have been sold by the National Technical Information Service (NTIS) for a return of over $40,000 to the government.

An additional publication and distribution conduit is desirable to serve the needs of the regulated communities and various levels of government. One approach would be an agreement between EPA and a private publisher for publication and sale of the methods manuals prepared by EPA. EPA could assist the publisher, who would be selected through open competition, in preparing the documents for publication. The publisher would produce and market the manuals at its own expense. This effort would be consistent with the purpose of Executive Order 12591, which states that "The head of each Executive department and agency shall ... (2) identify and encourage persons to act as conduits between and among Federal laboratories, universities, and the private sector for the transfer of technology developed from federally funded research and development efforts; (3) ensure that State and local governments, universities, and the private sector are provided with information on the technology ... available in Federal laboratories".

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Ecotoxicology and Bioassessment Capability

Issue: Many Federal and State regulatory and monitoring programs are now using biological measures to demonstrate compliance with statutory requirements or to determine the status and trends of ecosystem integrity and health. For example, EPA's Superfund program is using sediment, ambient water column, and soil ecotoxicity tests to determine the impacts of hazardous waste on aquatic and terrestrial ecosystems and to evaluate treatment alternatives.

The move toward using bioassessments and ecotoxicity testing for determining ecological integrity and impairment is a logical one. These techniques form the most cost-effective and relevant approach for evaluating ecosystem impairment caused by contamination, eutrophication, physical habitat alteration, or some combination of these stressors. Demand for more sensitive, cost-effective, and technologically advanced ecotoxicity and bioassessment methods is ever increasing.

Current Activities: Scientists at the Environmental Monitoring Systems Laboratory, in Cincinnati, OH (EMSL-Cincinnati), are responsible for developing, standardizing, and publishing biological methods for EPA's regulatory and monitoring programs. They also develop indicators for Environmental Monitoring and Assessment Program (EMAP) activities. Two new programs will be underway in FY93: (1) development of metrics to develop biocriteria for bays and estuaries of the Great Lakes and (2) development of rapid biological assessment techniques for ecological assessments.

Aquatic ecotoxicity tests being developed or standardized or currently in use are acute and/or chronic sediment toxicity tests using an amphipod, *Hyalella* azteca; a chironomid, *Chironomus tentans*; an aquatic vascular plant, *Lemna minor* (duckweed); and a fathead minnow embryo/larval teratagenicity test. Acute and chronic ambient water column ecotoxicity tests being used for EMAP, Superfund, NPDES, and other evaluation programs involve *Pimephales promelas* (fathead minnow), *Ceriodaphnia, Daphnia magna, D. pulex,* duckweed, and rainbow trout.

Also under development is the use of artificial stream mesocosms to detect impacts of mine wastes on periphyton community integrity. Ten mesocosms have been constructed at the EMSL-Cincinnati Newtown Facility. Artificial periphyton substrates are colonized in the field, brought back to the laboratory, and placed in the mesocosms. After a 28-day acclimation period in laboratory-modified ground water, a representative subsample of the periphyton substrates is collected. Community metrics, chlorophyll A, ash-free dry weight, and enzyme assays are performed on these subsamples to establish baseline conditions. Then 28-day exposures to single metal, metal mixtures and mine wastes are performed in the mesocosms. The goal is to use mesocosms to establish periphyton indices of biotic integrity and to determine relationships between metal(s) and toxicity. Mesocosms will be used to study other stressors (e.g., eutrophication, light, and temperature) to determine cause-and-effect relationships.

Bioassessment collection methods, multivariate and single- vs. multi-metric assessment techniques for fish, macroinvertebrate, and plants are being evaluated and standardized in seven ecoregions and used at three Superfund sites. Functional assessment methods (e.g., sediment metabolism) are also being investigated to evaluate ecosystem dysfunction. An index of biotic integrity is being developed for application in EPA Region 3.

More advanced planned studies deal with development of electronic biological detection and identification techniques. Techniques under consideration are electronic systems that combine acoustical, image analyses, and computer interfacing that can detect and taxonomically identify fish and other aquatic organisms. The goal is to develop non-lethal electronic biological surveillance techniques to determine biological integrity.

Opportunity for Collaboration: The key to developing cost-effective and ecologically relevant ecotoxicity and bioassessment methods is access to

Ecotoxicology and Bioassessment Capability

test sites, mesocosms, and a network of long-term indicator monitoring stations along with a multidisciplinary team that is familiar with statutory requirements. With the Newtown facility testing capabilities and access to off-grid and on-grid experimental monitoring stations, opportunity exists to undertake cooperative field studies. These monitoring activities provide an opportunity for comparison of electronic biological surveillance systems with more conventional bioassessment techniques.

Key Publications:

USEPA, 1990. "Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters." Office of Research and Development, Environmental Monitoring Systems Laboratory, Cincinnati, OH. EPA/600/4-90/030.

USEPA, 1992. "Draft Fish Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters." Office of Research and Development, Environmental Monitoring Systems Laboratory, Cincinnati, OH. EPA/600/R-92/111.

USEPA, 1992. "Final Draft: Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms." Office of Research and Development, Environmental Monitoring Systems Laboratory, Cincinnati, OH. EPA/600/4-91/022.

USEPA, 1992. Final draft of "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Marine and Estuarine Organisms." Office of Research and Development, Environmental Monitoring Systems Laboratory, Cincinnati, OH. EPA/600/4-91/021.

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Gene Probes to Detect Microorganisms

Issue: Classical methods for isolation and identification of hazardous microorganisms in environmental matrices are often time-consuming and difficult. For example, analysis of potable water or cooling tower water for *Legionella pneumophila* requires approximately five to seven days for growth of the organisms on the initial isolation medium and another five to seven days to confirm the identity of these organisms. Opportunistic pathogens of the *Mycobacterium avium* complex grow even slower and require two weeks for initial isolation.

Current antibody-based methods to detect the protozoan parasites, *Giardia* and *Cryptosporidium*, in environmental samples are cumbersome to perform and prone to both false-positive and false-negative results. These methods also do not allow identification at the species level and do not differentiate between viable and non-viable cysts.

Fungi that cause health effects in indoor air environments are both slow-growing and difficult to identify. Most of the diagnostic tests rely on morphological observations and require considerable expertise to perform, and very few individuals in the entire nation possess this expertise.

A serious concern is that existing standard plaque assay methods for virus detection in environmental waters underestimate the quantity of viruses or produce false negatives when viruses are actually present in the waters, leading ultimately to inadequate protection of the American public. Existing standard methods are time-consuming and cannot detect the Hepatitis A and Norwalk viruses responsible for most waterborne viral outbreaks. The time required to perform these assays also precludes their use as a means of determining the source of contamination for most outbreaks.

Biotechnology methods based on DNA hybridization probes and/or polymerase chain reaction (PCR) technology circumvent all of the problems listed above. These methods are rapid and highly specific, allowing identification of hazardous microorganisms at the species and even the subspecies level. The PCR method can be used to identify an organism within a single day and can be made sensitive enough to detect a single cell. These methods are also simple to perform and require less training than is required for many of the current methods.

Current Activities: The molecular biology program in the Microbiology Research Division at the Environmental Monitoring Systems Laboratory in Cincinnati, OH (EMSL-Cincinnati) is developing gene probe methods for a variety of microorganisms that have public health significance. A chemiluminescent gene probe method is under development to allow detection of *Shigella* in wastewaters, sludges and recreational waters. Both colony probe methodology and PCR-based methodology are being tested. Gene probe methods are also being developed to detect *Giardia* and *Cryptosporidium* in these same matrices. The question of assessing the viability of *Giardia* and *Cryptosporidium* spores is being addressed at the molecular level.

A battery of DNA primer sets and DNA hybridization probes is being developed for PCR identification of fungi commonly found in indoor air. The gene coding for small subunit ribosomal RNA (rRNA) is being sequenced and the sequences are being analyzed comparatively to determine specific sequences that can be used in species identification. A battery of broad-specificity oligonucleotide primers has been developed to allow PCR amplification and subsequent rapid sequencing of large segments of the fungal small subunit rRNA genes.

A program to develop gene probes for detection of waterborne viruses encompasses development of PCR primers and hybridization probes for amplification and identification of key enteric viruses. Methodology to use primers for Hepatitis A, Norwalk virus, rotaviruses, enteric adenoviruses, as well as polioviruses, coxsackieviruses, and

Gene Probes to Detect Microorganisms

echoviruses, has been developed. These new biotechnology methods have been shown to detect viruses at levels similar to the standard plaque assay in one to two days. Methodology to use PCR with many different types of environmental samples is currently being developed. These methods will be extensively field tested in a national ground water monitoring study that will begin this fall.

Also being developed are methods for extracting nucleic acids from large volume environmental samples for PCR analysis. Problems that need to be overcome include co-extraction of substances that inhibit gene amplification. A variety of physical and chemical separation approaches are being evaluated.

Opportunities for Collaboration: Resources at EMSL-Cincinnati include an Applied Biosystems Model 381 DNA synthesizer, an Applied Biosystems Model 373A automated DNA sequencer, and two Perkin-Elmer thermocyclers. These instruments and researchers with expertise in DNA sequencing and synthesis of gene probes and primer sets are available for rapid development of gene probes for any specific microorganism or group of microorganisms of interest to environmental scientists.

Some specific development opportunities are:

- Gene probe kits for opportunistic pathogens that are becoming increasingly more important, such as some of the nontuberculosis mycobacteria.
- Gene probes for *Legionella* based on potential pathogenicity rather than species.
- DNA hybridization kits to identify the various fungi that occur in indoor air.
- Biotechnology-based methods to distinguish between viable and non-viable cysts of *Giardia* and *Cryptosporidium.*
- Molecular detection methods for other parasites with established public health significance, such as *Entamoeba histolytica and Blastocystis hominis.*
- Virus detection kits that can be used by field personnel with no virology and little molecular biology training.

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New Membrane Filter Medium for Simultaneous Detection of Total Coliforms and *Escherichia coli* in Drinking Water

Issue: Total coliforms have been used for many years to indicate fecal pollution in drinking water, effectiveness of treatment processes, and deterioration of the water quality in distribution systems. More recently, there has been a shift toward monitoring for *Escherichia coli* in drinking water because this organism is always found in feces and is, therefore, a more direct indicator of fecal contamination.

Drinking water regulations under the Final Coliform Rule require that total coliform-positive drinking water samples be examined for the presence of *E. coli* or fecal coliforms. Current approved membrane filter methods necessitate serial analyses or confirmation procedures using several different types of media and two different incubation temperatures. These procedures can take up to 72 hours. Use of a rapid, sensitive, and specific medium that simultaneously detects both types of microorganisms in a single drinking water sample will simplify laboratory compliance with the Final Total Coliform Rule, eliminate the additional time, labor and expense of procedures that can delay detection of contaminated drinking water, and obviate the need for a second incubator.

Current Activities: Scientist at the Environmental Monitoring Systems Laboratory in Cincinnati, OH (EMSL-Cincinnati), have developed a sensitive, selective, and specific membrane filter method for simultaneous detection of total coliforms and *E. coli* on the basis of enzyme activity. The method has been shown to be superior to currently used membrane filter media for a variety of water samples, including drinking water. A study of the recovery of chlorine-stressed or damaged organisms is in progress and a collaborative study is planned.

Opportunity for Collaboration: An opportunity is available to collaborate with EMSL-Cincinnati scientists in development, production, and commercialization of this new medium for drinking water. Other potential uses for the medium are recreational and surface waters, groundwater, treatment plant effluents, water from drinking water distribution lines, bottled water, foods, pharmaceuticals, veterinary and human clinical specimens, and other environmental samples (e.g., aerosols, soil, or sludge).

A second opportunity exists in preparation of the sterile ampouled antibiotic solution used in the medium. In addition, because of its specificity for *E. coli* and other coliforms, the medium has the potential for use in clinical and veterinary labs and may be used to separate *E. coli* transformants from non-transformants in cloning work utilizing the *lac* and/or *GUS* genes.

Key Publications:

Brenner, K.P., C.C. Rankin, Y.R. Roybal, G.N. Stelma, Jr., and A.P. Dufour. 1992. New Medium for the Simultaneous Detection of Total Coliforms and *Escherichia coli* in Water. Manuscript is currently under review before planned submission to the journal, *Applied and Environmental Microbiology.*

Brenner, K.P., C.C. Rankin, Y.R. Roybal, and A.P. Dufour. Patent application entitled "Membrane Filter Medium for Detection of Total Coliforms and *E. coli*" was filed 11-18-91.

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Research Containment Facility

The U. S. Environmental Protection Agency's first self-contained, freestanding, high-hazard research facility is located adjacent to the Andrew W. Breidenbach Research Center in Cincinnati, Ohio. It is dedicated to performing research and development with toxic or hazardous materials that cannot be handled in conventional buildings. The Research Containment Facility was designed with maximum safety features to prevent exposure of workers in the building and contamination of the surrounding area. Building access is strictly controlled through card-activated door locking mechanisms, and entry and egress are monitored continually. Samples are received at a specially-designed area that incorporates an air-lock system so that delivery personnel have no need to enter the facility.

The building features a one-pass air system with air locks to ensure a negative air pressure differential throughout the entire containment area. All exhaust air from the building is treated and monitored through a three-stage filtering system before being discharged. The first and third stages consist of high-efficient particle filters, and the second stage is a high-efficiency vapor filter. Two exhaust treatment systems are installed in tandem to allow uninterrupted operation during malfunctions or maintenance.

This facility provides about 7000 sq. ft. of floor space for laboratory-scale experimental studies on high-hazard, non-radioactive materials in a setting designed for maximum safety and control. Several analytical instruments are currently in service, and equipment is modified as necessary to accomplish research projects.

Through a cooperative agreement with the Environmental Monitoring Systems Laboratory in Cincinnati, OH, the private sector could use this facility to conduct research and development involving hazardous substances. In toxic treatability studies, liquid and solid wastes could be studied to characterize, destroy, or detoxify materials containing toxic chemical contaminants, such as polychlorinated dibenzodioxins (dioxins), dibenzofurans, and biphenyls (PCBs).

Examples of Collaborative Opportunities:

- Removal of Asbestos from Surfaces — Using a glove box in a controlled, negative pressure atmosphere, the effectiveness of various techniques (vacuum, chemical, wet dusting, and electrostatic) for cleaning carpets, furniture, walls, and ceilings can be assessed.

- Stored Drum Treatment Tests — The effectiveness of sequential chemical and biological treatment for destroying organic contaminants can be determined using small scale reactors.

- Lead Removal from Contaminated Soil — A small-scale furnace and scrubber can be used to determine the feasibility of pyro-metallurgical extraction of lead.

- Biokinetics of Toxic Compounds — Kinetic parameters and inhibitory effects related to biodegradation of RCRA and CERCLA compounds can be determined with respirometry apparatus and measurement units.

- Hazardous Waste Treatment — Lab-scale reactors, chemostats, and respirometers can be used to study the biodegradability of complex toxic wastes in both aerobic and anaerobic systems.

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Frontiers in Ecological Monitoring

Issue: Federal and state laws mandate monitoring and characterization of natural resources in association with effluent discharge permits, environmental monitoring programs, Superfund activities, and ecological risk assessment. Consequently, practical tools are needed to economically and efficiently perform these activities. Although specific chemical characterization has played a major role in this arena, biological evaluation is not only relevant, but also can provide cost effective alternatives to identification of chemical analytes.

Biological endpoints have the advantage of being sensitive to multiple stressors, detecting actual exposure and effect not just the presence of compounds, detecting rapidly metabolized contaminants, sometimes acting as a record of pulsed events, and integrating contaminant distribution for mobile organisms in their home range. Furthermore, because biological changes occur before organism death or disease, they can act as a barometer of change, before permanent damage to the ecology occurs or as a record of improved condition following remediation.

Current Activities: The Ecological Monitoring Research Division conducts research to develop methods to evaluate the health of ecosystems using biochemical, cellular and organismal responses to stressors. Methods are developed for monitoring, assessment and diagnosis of likely causes of altered or attenuated biological integrity and robustness. Ecological, epidemiological and laboratory controlled data are used in methods development. Studies are conducted to perfect methods for practical application to field-collected samples, to demonstrate dose response relationships between environmental exposure and biological responses and to establish meaningful relationships between stressors and their ecological effects. Developed tools are integrated with existing monitoring and evaluative methods of ecological characterization and assessment.

Current research is focused in the development and demonstrations of methods using 1) gene probes, 2) immunoassays, 3) image analysis, 4) flow cytometry, 5) spectrophotometric and fluorometric analyses, 6) high performance liquid chromatography and 7) DNA fingerprinting. Some analyses are being used for the evaluation of reproductive and physiological condition, genetic diversity, immunocompetence and damage to genetic material. Emphasis is placed on developing tools that use samples with a practical storage life and assays that are relatively easy to perform and are low cost. A number of tests have been developed using automated systems or modifying technologies, developed by human clinical laboratories, for wildlife use.

Opportunities for Collaboration:

- Develop methods to measure the exposure of wildlife to environmental stressors and correlate these findings with effects on the physiological condition or community structure and function. For instance, assays for polyaromatic hydrocarbon and halogenated compound-inducible enzymes have been correlated with fish community indices.
- Commercialize technology in the form of methods publications and assay kits that can be used for the estimation of risk to wildlife or diagnosis of cause at impacted sites. One example is an automated method that has been developed to measure the free radical scavenging capacity of cell extracts.
- Adapt methods to automated systems or specific analytical equipment and supporting software for application to the assessment of wildlife health and risk assessment. Human clinical blood chemistry kits have been adapted for use with fish plasma.
- Use biomarkers and biocriteria to evaluate potentially impacted sites, effluents or remedial efforts. Worm toxicity tests have been

used to evaluate the fungal remediation of creosote contaminated soils.

- Publish a scientific journal especially dedicated to biological monitoring and assessment and special issues or books dedicated to step-by-step instructions in selection and performance of standard EPA methods.

Key Publications:

Cormier, S. M. and R. N. Racine, 1990. "Histopathology of Atlantic Tomcod: A Possible Monitor of Xenobiotics in Northeast Tidal Rivers and Estuaries". In: *Biomarkers of Environmental Contamination*, Ed. J. F. McCarthy and L. R. Shugart. Lewis Publishers, Boca Raton, FL. pp. 59-72.

Cormier, S. M. and R. N. Racine. In press. "Biomarkers of Environmental Exposure and Multivariate Approaches for Assessment and Monitoring. In: *Ecological Indicators*. Elsevier Applied Science Publ., Barking, Essex, England.

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Development and Evaluation of Immunochemical Methods for Environmental Monitoring

Issue: Monitoring and characterization of hazardous waste sites are essential under the Superfund Program. The number of sites requiring cleanup under Superfund is increasing and likely to continue to increase. Unavoidably, the accompanying sampling requirements and analytical costs will increase as well.

The EPA is considering the inclusion of immunochemical methods in newly proposed regulations on farm worker safety. Under the Toxic Substances Control Act, the EPA is also required to assess exposure to other potentially hazardous chemicals including products of biotechnology, such as genetically engineered microorganisms.

Site characterization and effective implementation of regulations require analytical methods that are applicable to widely different classes of compounds ranging from small molecules to complex protein products. There is a need to develop rapid and cost-effective field screening methods to meet these requirements. Ideally, methods should provide data in a timely manner to protect human and environmental health. These methods must also be cost-effective, sensitive, and capable of high sample throughput. Immunochemical methods often can fulfill these requirements and have broad applications for a wide variety of environmental contaminants. The potential for applying immunochemical methods to environmental measurements is just beginning to be realized.

Current Activities: The immunochemistry program at the EMSL-LV encompasses the development of: (1) immunologic reagents, (2) immunoassays for pesticides in environmental and food samples, (3) immunoassays for industrial wastes and by-products, (4) immunologic-based personal exposure monitoring devices, (5) immunoaffinity chromatography systems, (6) robotics, (7) training and instructional programs, (8) the integration of immunochemical techniques into instrumental methods and (9) laboratory and field evaluations.

EMSL-LV has an active program to develop haptens, immunogens and antibodies for a diversity of pollutants, e.g., nitroaromatics, polychlorinated biphenyls (PCBs), pentachlorophenol, carbaryl, parathion, various pyrethroids and other pesticides, and BTX (benzene, toluene, xylene).

These reagents are then used in the development of simple, field-portable methods for environmental monitoring. Quantitative laboratory methods that have a high sample capacity and rapid throughput are also formatted. Robotic methods are being investigated to automate immunoassays, sample preparation procedures, and confirmatory analysis.

We have developed the first reported immunochemical technique for the direct sampling of vaporous analytes. These immunologic-based dosimeters are under development for applications to farmworker health and safety such as determining safe reentry into pesticide-treated fields. Other workplace monitoring and indoor air studies are also possible.

Laboratory evaluations and field demonstrations are conducted for immunochemical methods that have potential for use in environmental monitoring studies. Evaluations already completed include those for alachlor, pentachlorophenol, and gasoline components.

Opportunity for Collaboration: Opportunity exists to participate in ongoing immunochemistry research at the EPA Environmental Monitoring Systems Laboratory, Las Vegas (EMSL-LV) in the following areas: chemical synthesis, immunologic reagent development, field-portable and laboratory-based immunoassays, immunologic-based personal exposure monitoring dosimeters, immunoaffinity chromatography, robotics, laboratory evaluations, field studies, and development of antibodies to specific analytes .

The key to developing a particular immunochemical method is the availability of specific immunologic reagents. The development of these reagents can oftentimes be technically demanding. However, once suitable reagents are obtained, they can be used in a wide variety of applications. EMSL-

Development and Evaluation of Immunochemical Methods for Environmental Monitoring

LV personnel have extensive experience in developing immunochemical methods ranging from hapten design and synthesis to final assay evaluations. Collaboration may also include the use of the EMSL-LV immunochemistry laboratories, which are equipped with state-of-the-art instrumentation. A dedicated robotic system is available to automate immunoassays, sample preparations and confirmatory analysis. The EPA is also interested in the development of new immunoassay formats and their potential for environmental measurements.

Immunoassays that have been developed for hazardous compounds must be evaluated using real-world environmental samples. Such evaluations determine the potential applications of the method and facilitate acceptance and implementation. EMSL-LV conducts evaluations to characterize and test individual immunochemical methods. Evaluations are conducted on commercially available immunoassay methods which are intended for general widespread use such as characterization of hazardous waste sites. Evaluations are also conducted on immunoassay methods that are intended to support registration and re-registration of chemical products. Opportunity exists to undertake field and laboratory studies for integration of methods within monitoring programs. The EPA can provide authentic environmental samples as well as access to contaminated sites. Evaluations are conducted following EPA guidelines for testing new methods. The cost of these studies is shared by the developer and the EPA. When appropriate, studies are published in the peer-reviewed literature and presented at national meetings.

Key Publications:

Van Emon, J.M. and Lopez-Avila, V. "Immunochemical Methods for Environmental Analysis" Analytical Chemistry, 64 pp. 78A-88A, 1992.

Van Emon, J.M.; Seiber, J.N.; and Hammock, B.D. "Immunoassay Techniques for Pesticide Analysis" in: Analytical Methods for Pesticides and Plant Growth Regulators, Vol. XVII Advanced Analytical Techniques, J. Sherma, ed. pp. 217-263, 1989.

Related Patents: Antibody development for ivermectin and paraquat.

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Computerized Environmental Information Management

Issue: Traditionally, EPA has provided guidance and technical information in the form of printed reports. The widespread use of personal computers and the increasing use of hypertext, expert systems, and CD-ROM technology provide a basis for doing this electronically. Documents may be captured and distributed on CD-ROMs using conventional computer programs and databases. Electronic management and dissemination is likely to be cheaper, faster, more efficient, and therefore preferable to conventional methods. Furthermore, it will reduce paper consumption.

Current Activities: EPA is pursuing three areas: CD-ROM technology, expert systems, and conventional computer programming. Current emphasis is focused on identification of materials in the Superfund program for conversion to CD-ROM format. A prototype CD-ROM will be developed to test market acceptance and developmental costs. An expert system is being developed for soil sampling with the Windows-based PC platform in mind. Standardization of soil terminology has been completed and a format for exchanging information between modules of the expert system has been proposed. The first module being developed is for standard description and characterization of hazardous waste sites. Conventional computer programming has included the production of: GEO-EAS, a geostatistical software package; SCOUT, a multivariate statistics package; ASSESS, a program for calculating variability in the sampling and measurement of contaminated soils, and Geophysics Advisor Expert System.

Opportunity for Collaboration: Development and distribution of computer programs to assist professionals in addressing complex environmental problems is a growth area. Opportunities exist to assist in the development of CD-ROMs, expert systems, and conventional software. EPA offers standards and guidance for the development of the software. Private industry supplies the tools to incorporate that guidance into useful computer software.

Other Information:

- Environmental Software from EMSL-LV, EPA/600/8-91/044
- Information Exchange Format for Environmental Expert Systems: Preliminary Analysis, EPA/600/X-91/119
- A Rationale for the Assessment of Errors in the Sampling of Soils, EPA/600/4-90/013
- Guide to Site and Soil Description for Hazardous Waste Site Characterization - Volume 1: Metals, EPA/600/4-91/029
- Description and Sampling of Contaminated Soils: A Field Pocket Guide, EPA/625/12-91/002

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Soil Sampling

Issue: Volatile organic compounds (VOCs) are common contaminants encountered at Superfund and other hazardous waste sites. As much as 80% of the total error associated with the analysis of a contaminated soil sample can be attributed to improper sampling. It has been reported that up to 99% of the VOCs are lost during sampling and sample handling. EPA research is focusing on techniques to help control and quantify the errors associated with sampling. This research will satisfy the needs of the RCRA and Superfund programs as well as for any monitoring program in which this type of sampling is involved.

Current Activities: We are beginning work to identify factors influencing the collection and analysis of VOCs. Additionally, we are designing a novel sampling device for VOCs in which atmospheric exposure is extremely limited, thereby controlling losses of VOCs. Experiments to improve the use of internal standards and matrix and surrogate spikes for QA/QC purposes are also underway.

A revised and updated report describing various soil sampling techniques and strategies has just been submitted for printing. It presents critical analysis on geostatistics, quality assurance, particulate sampling theory, field analysis, and sample handling as they relate to soil sampling.

We also have begun work in conjunction with the American Society for Testing and Materials (ASTM) to develop standards that will support the revisions under way to Chapters 9 and 10 of the SW-846 Methods Manual. Examples include drum sampling and sampling from waste piles.

Opportunity for Collaboration: Two areas of opportunity are readily available. These are (1) working with the EPA and ASTM to develop sampling standards using their professional experiences in the area, and (2) eventual production and sale of a modified VOC sampler after development and testing are completed.

Other Information:

Publications:

1. Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies, EPA/600/R-92/128, July 1992.
2. Soil Sampling Quality Assurance User's Guide, Second Edition, EPA/600/8-89/046, March 1989.
3. Investigations of Method 8240 Modifications for Analysis of Volatile Organic Compounds in Soils: Matrix Modification. In review.
4. Investigations of Method 8240 Modifications for Analysis of Volatile Organic Compounds in Soils: Analytical Method. In review.
5. Correct Sampling Using the Theories of Pierre Gy. Technology Support Center Fact Sheet, EMSL-LV, Las Vegas, NV.

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Ecological Indicators

Issue: EPA's Environmental Monitoring and Assessment Program (EMAP) will provide unbiased information on the condition and trends of the nation's ecological resources. The key to EMAPs success is development of ecological indicators appropriate for large-scale, long-term, monitoring. This will require: instrumentation to measure ecological parameters in the field; innovative ways to measure and characterize the condition of ecological systems; and identification of economically feasible means of operating a continuous large-scale field sampling and ecological monitoring program.

We are developing and testing ecological indicators in support of EMAP. This has not been done before across multiple resource types (agricultural, forest, lakes, streams, etc.) on a regional or national scale. EMSL-LV is coordinating these activities for arid, forest, and agricultural ecosystems in conjunction with other federal agencies.

Current Activities: One of our primary activities is the development of indicators (ways to evaluate or represent condition) for ecological resources (soil, water, wildlife, vegetated systems) appropriate for use over regional or national scales. Also, the development of capabilities in other support areas vital to a large-scale field monitoring program is under way, including 1) data management, 2) statistics and analysis, 3) application of remote sensing and Geographic Information System technology, 4) instrumentation and methods for ecological measurements, 5) quality assurance of data and field data collection activities, and 6) the planning and management for implementation of large scale field data collection programs.

EMAP is organized around resource groups (Agroecosystems, Arid Ecosystems, Forests, Great Lakes, Near Coastal, Surface Waters and Wetlands), and crosscutting-support activity areas (Information Management, Implementation and Logistics, Quality Assurance, Statistics and Design, Integration and Assessment, Indicators, and Landscape Characterization and Ecology). Each resource group develops protocols for implementation of a field monitoring program in conjunction with input from the cross-cutting groups. The monitoring design and strategies are written and peer-reviewed before each group is allowed to conduct field sampling. Once sampling programs are ready to be initiated, indicators are tested in the field on a small scale (pilot level). When indicators and field implementation designs prove to be successful, each group scales up their program to sample larger areas, until full national coverage is achieved.

Opportunity for Collaboration: Our primary interest in collaboration is in the area of research and development of technology designed to support ecological field sampling and monitoring. Opportunities for collaboration at EMSL-LV exist for developing and testing 1) ecological indicators for soils, vegetation, wildlife, benthos of lakes and streams, and trophic state of lakes, 2) instrumentation designed for ecological measurements, 3) computer software supporting field data collection and analysis of environmental information, 4) Quality Assurance measures for field sampling programs and ecological data, and 5) cost effective, efficient and dependable means of implementing large scale field sampling programs.

Other Information:

Hunsaker, C.T. and D.E. Carpenter, eds. 1990. Ecological indicators for the Environmental Monitoring and Assessment Program. EPA/600/3-90-606. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.

This report is a compendium of indicators from all resource groups.

The following reports provide specific plans for each resource group.

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Arid Ecosystems:

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Agroecosystems:

Heck, W.W., C.L. Campbell, R.P. Breckenridge, G.E. Byers, A.L. Finkner, G.R. Hess, J.R. Meyer, T.J. Moser, S.L. Peck, J.O. Rawlings, C.N. Smith. 1991. Agroecosystem Monitoring and Research Strategy-Environmental Monitoring and Assessment Program (EMAP). EPA/600/4-91/013. U.S. Environmental Protection Agency, Washington, D.C.

Surface Waters:

Paulsen, S.G., D.P. Larsen, P.Kaufmann, T. Whittier, J.R. Baker, D.V. Peck, J. McGue, R. Hughes, D. McMullen, D. Stevens, J. Stoddard, J. Lazorchak, W. Kinney, A.R. Selle, R. Hjort. 1991. Surface Waters Monitoring and Research Strategy, Fiscal Year 1991-Environmental Monitoring and Assessment Program (EMAP). EPA/600/3-91/022. U.S. Environmental Protection Agency, Washington, D.C.

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Development and Evaluation of Geophysical Methods for Environmental Monitoring

Issue: The purpose of the Superfund Program is to clean up the nation's uncontrolled hazardous waste sites and spills or releases of hazardous substances to the environment. The Resource Conservation and Recovery Act (RCRA) requires ground-water monitoring programs at hazardous waste treatment, storage and disposal facilities. Rapid and effective site characterization techniques are essential for supporting these programs. Geophysical methods have proven effective in delineating subsurface contamination and characterizing soil and aquifer properties. A number of new geophysical instruments and techniques recently have been developed. The capabilities of these techniques have not been fully evaluated for hazardous waste site investigations. Further work needs to be conducted in a controlled field and laboratory environment to study instrument responses and evaluate the methods.

Current Activities: The geophysical program at the EMSL-LV involves several areas, including development of new instrumentation and software, evaluation of existing techniques for environmental applications, and technology transfer. Current developmental activities include a high frequency, high resolution electromagnetic device, and a three-dimensional shear-wave source for shallow, high resolution seismic work. Research is taking place to evaluate geophysical techniques in fractured bedrock, and to evaluate methods appropriate for the location and delineation of chlorinated solvents. Technology transfer developments include a user friendly expert system computer program which advises hazardous waste site managers as to which geophysical methods could be useful at their particular site.

Opportunity for Collaboration: Opportunity exists to collaborate with EPA's Environmental Monitoring Systems Laboratory, Las Vegas (EMSL-LV) on developmental projects to further advance the use of geophysical methods for environmental monitoring. EMSL-LV personnel have a wide range of expertise in the development and evaluation of geophysical methods. Areas of special interest include geophysical response to chlorinated solvents, and two-dimensional and three-dimensional inversion modeling for transient electromagnetic methods. The EPA is also interested in field and laboratory studies for the development of new methods and the integration of existing methods within monitoring programs. The EPA can provide authentic environmental samples as well as access to actual hazardous waste sites. The outcome of any such projects is published in an EPA report, which is distributed to EPA personnel responsible for implementing site characterization and monitoring programs. When appropriate, studies are published in peer-reviewed journals and presented at national conferences.

Key Publications:

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Supercritical Fluid Extraction (SFE): Pollution Prevention in the Chemical Analysis Laboratory

Issue: Conventional means of extracting and concentrating analytes from environmental samples require the use of solvents, some of which are toxic. Supercritical fluid extraction (SFE) offers an opportunity to avoid many of the undesirable consequences of traditional analysis. It combines the advantages of gases (better and faster solid penetration and mass transfer than liquids) with the advantages of liquids (greater solvent power than gases). Compared with conventional sample preparation methods, SFE has many advantages, including (i) greater versatility; (ii) shorter extraction time; (iii) reduced solvent use (notably chlorofluorocarbons), which leads to lower cost, improved occupational safety, and less waste solvent that must be disposed of.

Of the possible supercritical fluids to use for SFE, CO_2 is the most attractive because it is supercritical at a relatively low temperature (31°C) and pressure (73 atm); relatively nontoxic and noncorrosive; chemically inert (reduces chance of analyte transformations during extraction); and inexpensive.

Current Activities: Near- and long-term research for SFE is being planned and coordinated from EMSL-LV. Recently, EMSL-LV completed work on the Agency's first SFE method for chemical analysis. This method (for petroleum hydrocarbons in solids) was accepted for inclusion in the EPA SW-846 Methods Manual. In the United States alone, conventional analysis requires that nearly 200,000 petroleum-contaminated samples per year be extracted with Freon-113. This new SFE method (Method 3560) could help to eliminate nearly 30,000 L of Freon-113 that is used in the conventional laboratory analyses.

Although this SFE method represents an historic first step, the advantages of SFE can be fully realized in its application to environmental analysis only after a number of fundamental studies are completed. These include investigations into (i) *mechanisms governing kinetics and recoveries*: variables governing desorption kinetics (temperature, pressure/density, dipole moment, matrix, water and organics content of sample); effects of "modifiers"; relative importance of solubility, desorption, and diffusional limitations for solids; and (ii) *effects of instrument design on kinetics and recoveries*: sample size versus flow rate; extraction cell shape, orientation, and void space; static versus dynamic modes of extraction; off-line collection efficiencies as a function of collection solvent, solvent volume, collection vial shape, flow rate, external cooling, restrictor type, restrictor heating.

Planned exploratory SFE studies include: effect of ultrasound application on extraction efficiency; effect of macroscopic pressure fluctuations on extraction efficiencies and rates; combination of portable SFE with ELISA (enzyme-linked immunosorbent assay) for rapid on-site analyses; feasibility of SFE extraction for specific inorganics, such as chromium and other toxic elements, using complexing agents such as crown ethers; feasibility of extracting high-molecular-weight and polar compounds from solid matrices; feasibility of SFE for on-line sample cleanup; and enhancement of SFE extraction efficiencies for refractory matrices (e.g., fly ash, weathered oil spill samples) by use of various pretreatment methods.

Opportunity for Collaboration: In the chemical analysis laboratory itself, a major effort will be required in minimizing and eliminating both the use of hazardous or toxic reagents and the generation of organic solvent waste. The opportunity exists to share our facilities and expertise by collaborating in any of the following activities in which you share an interest.

We are pursuing several approaches for minimizing laboratory wastes, most of which focus on alternative techniques for sample extraction and clean up. These new extraction technologies (for example, solid-phase extraction, SPE; thermal extraction; azeotropic and vacuum distillation) offer many technical, performance advantages

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over conventional liquid extraction methods, especially when applied to heterogeneous matrices such as soils, sludges, and tissues. Moreover, they enable tremendous savings in reducing the use of organic solvents (and possibly in eliminating the use of chlorofluorocarbon extractants). Methods such as these, when combined with robotics, could also greatly minimize occupational exposure to hazardous reagents and solvents.

One of the most promising emerging extraction technologies — supercritical fluid extraction (SFE) — uses supercritical fluids (especially non-polluting supercritical carbon dioxide) to replace organic solvents. The private sector (especially instrument manufacturers) could have a large influence in the advancement of SFE technology and in its eventual acceptance as a routine laboratory technique.

Key Publications:

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Specialized Gamma-Ray Detection Systems

Issue: Federal law requires agencies that manage Federal facilities where radioactive hazardous substances have been released into the environment to comply with requirements for site assessments and hazard ranking procedures. In addition, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) requires that the responsible agencies sample, monitor, and assess exposure to determine the necessity for and proposed extent of remedial action.

The effectiveness of a characterization depends on the timeliness and accuracy of analytical results. Until recently, the sophisticated equipment required for radioactive analysis has been limited to stationary laboratories, and has required extensive sample preparation. It is now possible to acquire reliable *in situ* analytical results.

Adaptation of analytical equipment for field use is technically challenging. However, the capability to obtain accurate results in real-time, without sample preparation, presents a potential for large savings in many site characterizations.

CURRENT ACTIVITIES: The gamma-ray analysis program at the Environmental Monitoring Systems Laboratory, Las Vegas (EMSL-LV) is responsible for the routine analysis of several types of samples. This includes monitoring concentrations of gamma-ray emitting nuclides on and around the Nevada Test Site, and other sites previously used for nuclear activities.

Research activities include the development of an ultra low-level counting system to increase the signal-to-noise ratio and reduce required analysis times, and the characterization of fractionated soils suspected of plutonium contamination.

EMSL-LV has an active program to characterize surface conditions at several locations away from the Nevada Test Site by the use of portable semiconductor detectors. The objective of the project has been to quantify nuclides in surface soil and the resulting dose rate.

Opportunity for Collaboration: Advances in semiconductor technology and the ruggedization of portable detector systems have made *in-situ* evaluation of contaminated sites an important part of the characterization process. Electronic shielding techniques used for reduction of background signal help produce more sensitive analytical results than those of more conventional systems, and can allow increased sampling by reducing the required analysis time.

There is an opportunity for collaboration with EPA to develop specialized detection equipment for use in field evaluations. Specifically, there is a need for the further development and testing of systems to accurately ascertain the concentrations and types of radionuclide contaminants in surface soils. The ability to reliably map the horizontal and vertical distributions of radionuclides would greatly simplify the excavation and decontamination phases of a clean up operation. Additionally, there exists a need for nonintrusive detector systems to monitor underground pipelines and storage tank facilities.

Key Publications:

Faller, S.H., In-Situ Gamma-Ray Site Characterization of the Tatum Salt Dome Test Site in Lamar County, Mississippi. Health Physics, 62, pp.571-575, 1992.

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Radiological Contamination Measurement Program

Issue: Site characterization, including analysis for radiocontaminants, is an essential requirement of the Superfund Program. A growing number of sites on the National Priorities List are suspected of being radiologically contaminated. Full radiological characterization may be required in many cases, even in the absence of known contamination. There is a need to develop the most cost-effective and efficient radiation detectors and screening methods, including underwater systems suitable for accurate location and identification of submerged radioactive waste and debris.

Current Activities: The environmental radioactivity monitoring program at the Environmental Monitoring Systems Laboratory, Las Vegas (EMSL-LV) consists of 1) statistically-based sampling network design, 2) operation of air, water, milk, vegetation, dosimetry, and animal bioassay networks, 3) radioanalytical method and radiation quality assurance research, 4) data analysis using Geographic Information System (GIS), and 5) radiation dose modeling and assessment.

The Laboratory is a leader in sampling and network design, using the latest statistical techniques and software. Environmental monitoring is conducted by collecting air, water, milk, vegetation and tissue samples and analyzing them in a fully equipped radiochemistry laboratory. Data is analyzed for trends, using state-of-the-art computer hardware and modeling software, which also permits calculation of radiation dose estimates and safety assessments based on analytical data.

Opportunity for Collaboration: EMSL-LV provides radiological site assessment, using its extensive inventory of field survey equipment, trained sampling personnel, and in-house radioanalysis laboratory. Opportunity exists for industry to cooperate with EMSL-LV, utilizing its expertise in environmental radioactivity characterization, nuclear chemistry, nuclear physics and radiological risk assessment. Collaborative opportunities may include development of improved sampling systems, environmental radiation sensors and recorders, or portable automated monitoring stations suitable for use in areas surrounding EPA and Department of Energy sites or off-shore nuclear waste disposal areas.

Key Publications:

Yearly reports of EMSL-LV radiological monitoring activities: "Offsite Environmental Monitoring Report: Radiation Monitoring Around United States Nuclear Test Areas, Calendar Year 1990." EPA/600/4-91/030.

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Vacuum Distillation Instrument

Issue: Pollution measurement necessitated by the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and other regulations requires accurate, rapid chemical analysis. Current methods have severe limitations in dealing with high organic content samples like tissue, oil and sediments. These limitations include low recoveries and poor precision. However, studies indicate samples of these difficult matrices as well as water can be analyzed routinely and successfully by the novel application of vacuum distillation.

The U.S. Environmental Protection Agency (EPA) Environmental Monitoring Systems Laboratory-Las Vegas (EMSL-LV) has developed a prototype vacuum distillation apparatus to separate organic volatile and semi-volatile chemicals from a variety of matrices prior to analysis by gas chromatography. Laboratory studies indicate that this device is superior to conventional techniques in fully extracting analytes from difficult samples. It is amenable to automation, which is highly desirable for commercial applications. As vacuum distillation is quick, sensitive (ppb) and does not require solvents, it represents a very attractive option to the laboratory community.

We expect an adaptation of this method to be proposed as Method 5032 in the Third Update of the Second Edition of "Test Methods for Evaluating Solid Waste Physical/Chemical Methods" (SW846). Method 5032 was introduced to the laboratory community at the 8th Annual Waste Testing & Quality Assurance Symposium held July 1992.

Current Activities: The research focusing on volatile analytes is being concluded. Final studies assessing method performance on tissue samples are completed.

Experiments are now being designed to evaluate semi-volatile analytes distillation efficiencies, mass balances, and method performance. The development of this method is of interest as it would not require organic solvents. Such a method may also provide both semi-volatile and volatile analyses on the same sample aliquot which would be very advantageous when dealing with limited sample mass.

Opportunity for Collaboration: We are seeking License Agreements under the terms of the Federal Technology Transfer Act of 1986 (FTTA) to automate and manufacture the vacuum distillation device for which EPA has a patent.

Volatile analytes have been the focus of EMSL-LV research to date. Preliminary evidence indicates that semi-volatile compounds are also potential analytes using the device; however this has not been a focus of rigorous studies to date. The use of this device to determine semi-volatile compounds would have an additional advantage over present methods in that environmentally undesirable solvents currently used are not required. Presently the EPA is intent on the investigation of the additional analytes and would also be interested in collaborating with successful licensees.

Other Information: EPA has announced the availability of U.S. Patent Number 4,600,559 for licensing through the Federal Technology Transfer Act and is seeking interested parties. There is a U.S. Patent Pending for stream-lining modifications to the invention, which are described in draft Method 5032. The technology has been documented in the peer-reviewed scientific literature and presented at national scientific conferences. Further information is available upon request.

Key Publications:

M.H. Hiatt, Anal. Chem. 53 (1981) 1541-1543

M.H. Hiatt, Anal. Chem. 55 (1983) 506-516.

Vacuum Distillation Instrument

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Experimental Room for Indoor Air Studies

Issue: Concern for indoor air quality is growing nationally. The Environmental Monitoring Systems Laboratory at Las Vegas (EMSL-LV) has an experimental room constructed to resemble a residential indoor environment. It was constructed under a previous Cooperative Research and Development Agreement (CRADA), the objective of which was to investigate the relative efficiency of five different airborne microbial samplers, detail the effect of various human activities on the retrieval of microorganisms, and test the efficiency of an antimicrobial agent. Airborne microorganisms are known to cause adverse human health effects such as allergic and asthmatic reactions, hypersensitivity pneumonitis, and infectious disease. Threshold limit values (TLVs) for exposure to airborne microorganisms, however, have not been established, and monitoring for airborne microbes in indoor environments has not been standardized. Information on sampling methods, sources of indoor microorganisms (e.g., air handling components, carpet, ceiling tiles, wall coverings), and mitigation strategies can be obtained in this controlled experimental room resembling indoor environments to assist the Agency in establishing standardized protocols and exposure TLVs.

Current Activities: The contribution of fungal-contaminated fiberglass and bare metal duct to microbial contamination in the indoor environment and the measurement of airborne glass fibers released from fungal-contaminated rigid fibrous glass ducting are future issues to be evaluated in the experimental room. Negotiations are ongoing with industries to utilize the room for studies to determine growth and dissemination of microorganisms on fiber glass and metal air handling system ductwork. The purpose of this approach will be to define the conditions under which ductwork may be a potential source of microbial contamination for indoor air. Industry has already set aside resources for this investigation and the research protocols and experimental design are being developed. It is anticipated that a formal CRADA utilizing the microbial experimental room in FY93 and 94 will be submitted to the Agency shortly.

Opportunity for Collaboration: The experimental room is available to interested cooperators. The unique characteristics of this 13 x 13 x 7.5 ft room include: 1) computerized monitoring and/or control of temperature, humidity, air turnover rates, and air exchange rates, 2) ability to change internal physical characteristics, including carpets, paint, wallpaper, furniture, etc., 3) ability to modify air handling system characteristics including ducting (rigid fibrous glass, fiberglass-lined, bare metal, etc.) use of in-line HEPA filtration or by-pass, 4) entrance to the room through a HEPA filtered air shower anteroom, 5) availability of the latest aerobiological monitoring equipment including aerodynamic particle sizer (laser), 6) a viewing window for observation or video taping, and 7) sampling ports for remote monitoring of room or ductwork. Microbial contamination (fungal spores, bacterial cells, etc.) can be introduced through the air handling system, room building materials, and furnishings. With these features, the experimental room can simulate a variety of indoor environmental conditions. The data are obtained under controlled conditions minimizing uncertainty encountered with survey data.

Other Information (Publications):

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Design of Optimum Sampling Plans for Hazardous Waste Sites

Issue: Characterization of hazardous waste sites typically involves soil sampling at various locations, in varying numbers, and in various ways. Logical and objective strategies for collecting the samples are needed to ensure that the contaminated and uncontaminated areas of a site are defined at the lowest cost with the greatest possible certainty. Improperly characterized sites can lead to unacceptable risks, excessive costs, and loss of confidence in the methodology used to assess and clean up contaminated sites. Computer software offers the opportunity to develop consistent, statistically-sound strategies for determining the number and location of samples needed to characterize contamination of soil at a site.

Current Activities: EMSL-LV is currently developing the algorithms and computer software to build a Sampling Design Optimization Methodology and Software called SAMPLAN (for SAMpling PLANner). The key statistical logic of the method is a conditional (spatial) simulator algorithm. This statistical procedure estimates many realizations of the whole site from the information (semi-variogram) obtained from initial sampling of the site. (A small number of samples from a pilot study is sufficient to estimate probable distributions of contaminants at a site). The proposed sampling design for a more detailed investigation of the site is simulated with a personal computer on these realizations over the range of a design parameter of interest, such as sample size, sample method (random or grid), etc.. From runs on a computer, a cost (of remediation) and loss (cost of mis-classification) curve is generated as a function of the parameter of interest (number of samples) and the optimum number of samples can be chosen as the abscissa of the minimum cost plus loss point on the curve. The end result is a recommendation of the number and location of samples necessary to characterize the site at low risk of error and least cost.

The methodology when implemented by PC software will be a tool for Superfund Remedial Project Managers, On Scene Coordinators, and RCRA Permit Writers.

Opportunity for Collaboration: Software development (including beta-testing of the initial software, distribution, and maintenance) is an opportunity for collaboration with geostatisticians and professionals at the EPA.

Other Information:

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Englund, E.J., et. al., 1992, "The Effects of Sampling Design Parameters on Block Selection," Mathematical Geology, v. 24, No.3.

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Messner, M.J., *et. al.*, 1990, "Retrospective Design Solutions for a Remedial Investigation," Hazardous Materials Control, v. 3, No. 3.

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Geostatistics for Soils Studies

Issue: Estimating concentrations of contaminants in soil often is time consuming and costly. Geostatistical algorithms can greatly facilitate this process. However, frequently they are not used because of the perceived complexity and lack of familiarity by the environmental scientist. Those charged with remediation of RCRA and Superfund sites need better tools for characterizing contamination. We expect the use of geostatistical software to improve the delineation of contamination at hazardous waste sites, which will result in more cost-effective remedial actions.

Current Activities: The Geostatistics Project at the Environmental Monitoring Systems Laboratory in Las Vegas has developed and distributed a program called Geostatistical Environmental Assessment Software (Geo-EAS), which consists of a collection of interactive software tools for performing two-dimensional geostatistical analyses (kriging) of spatially distributed data. Other geostatistical algorithms need to be developed in like manner to make them readily useable and accessible; these techniques include co-kriging, multivariate kriging (vector kriging), and conditional simulations (spatial simulation). As the use of these techniques becomes widespread and better understood, they will be incorporated widely into environmental decision-making processes.

Opportunity for Collaboration: Software development (including beta-testing of the initial software, distribution, and maintenance) is an opportunity for collaboration with geostatisticians and professionals at the EPA. Geo-EAS has been developed by EMSL-Las Vegas as public-domain software at a price that covers only the cost of distribution. This has made it the tool of college and government researchers nationally and internationally. Thousands of copies have been distributed within the United States and to over forty-five countries. A goal is to provide low-cost, easily-obtainable, easy-to-use software to environmental scientists to assist them in performing better, more consistent evaluations of contamination in soil.

Other Information:

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