

## Literature for American Power Conference

## Fact Sheets

- 1) Air Toxics Being Measured More Accurately, Controlled More Effectively
- 2) NOx and SO2 Emissions Reduced by New Additive in Flue-Gas Scrubber
- 3) Enhanced Surface Condensers Improve Heat Rate
- 4) Usable Fuel Produced from Municipal Solid Waste
- 5) Cofiring Technology Reduces Gas Turbine Emissions
- 6) Trainable, Rugged Microsensor Identifies Wide Range of Gases
- 7) Long Lengths of High-Tc Superconductors Fabricated
- 8) High-Temperature Superconducting Current Leads
- 9) Vitrification of Low-Level Radioactive and Mixed Wastes
- 10) Integrated Quality Assurance Planning for Characterization, Demolition, and Disposal of Contaminated Structures
- 11) On-Line Plant Diagnostics and Management
- 12) Sulfide Ceramic Materials for Improved Batteries
- 13) Flywheel Provides Efficient Energy Storage
- 14) Analyses and Diagnostics Laboratory Fosters Advanced Battery Systems for Electric Vehicles
- 15) Polymer-Electrolyte Fuel Cells for Transportation
- 16) Solid-Oxide Fuel Cells for Transportation
- 17) Driving a Lab Around a Lab
- 18) Surface Acoustic Wave Sensor Accurately Monitors Emissions in Real-Time
- 19) DOE/Industry Competitions Advance Alternative-Fueled Automotive Technologies
- 20) Thermal & Mechanical Process (general info fact sheet)
- 21) Flow-Induced Vibration & Flow Distribution in Shell-and-Tube Heat Exchangers
- 22) Ice Slurries for District Cooling
- 23) Advanced Fluids
- 24) Compact Evaporator and Condenser Technology
- 25) Analysis of Failed Nuclear Power Station Components

**DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED  
GH

**MASTER**

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

# NO<sub>x</sub> and SO<sub>2</sub> Emissions Reduced by New Additive in Flue-Gas Scrubber

*Emissions of NO<sub>x</sub> and SO<sub>2</sub>, which contribute to acid rain and ozone pollution, are being more effectively controlled by new technologies for coal-combustion systems.*

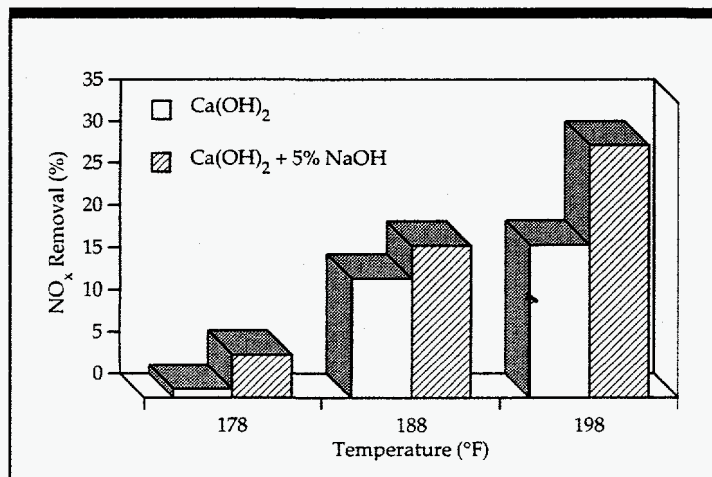
## Opportunity

More than 20 years ago, the Clean Air Act accelerated the development of pollution-control technologies for coal-combustion systems. Attention was focused on the abatement of sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and particulate-matter emissions. Subsequent concerns over the possible effects of acid rain served to strengthen that focus. In 1990, Amendments to the Act addressed acid rain controls and reinforced restrictions on other air pollutants such as ozone, which is influenced by NO<sub>x</sub> emissions. An additional concern now receiving greater attention is the safe and economical disposal of large volumes of solid wastes from air-pollution control systems. As new issues arise and emission limits are gradually reduced, there are continuing needs for engineering improvements and research into new concepts that could lead to improved processes.

Argonne's pollutant emissions research has ranged from experiments in the basic chemistry of pollution-control systems, through laboratory-scale process development and testing, to pilot-scale field tests of several technologies. Whenever appropriate, the work has emphasized integrated or combined control systems as the best approach to technologies that would offer low cost and good operating characteristics.

## Advantages

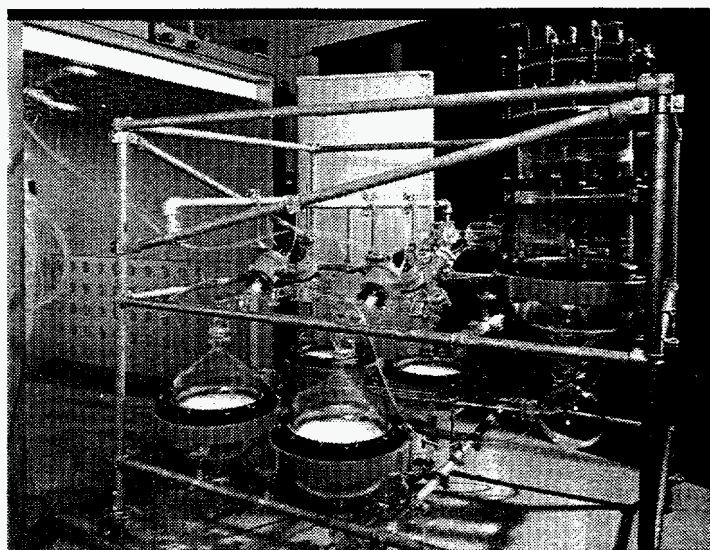
- Combined removal of NO<sub>x</sub> and SO<sub>2</sub> simplifies the pollution-control system and reduces overall costs;
- New or improved technologies for controlling emissions of NO<sub>x</sub> and SO<sub>2</sub> will enable U.S. industry to continue to compete in a cost-effective, environmentally sound manner;
- Industries that burn coal and other fossil fuels will be able to meet tougher restrictions on NO<sub>x</sub> and SO<sub>2</sub> emissions;
- Air quality can be improved in areas that are heavily industrialized.



Variation of NO<sub>x</sub> removal with temperature and NaOH addition.

## Argonne Solution

In response to the directives of the Clean Air Act and its Amendments, Argonne National Laboratory is developing new or improved pollutant control technologies for industries that burn fossil fuels. This research continues Argonne's traditional support for the U.S. Department of Energy's Flue Gas Cleanup Program.



Laboratory spray-dryer facility.

---

## Technical Approach

Laboratory facilities are available to address a variety of flue-gas cleanup problems using realistic flue-gas compositions, on-line multicomponent gas analysis, and computerized data logging. Current experimental systems include a complete wet scrubber, a unique spray-dryer/fabric-filter combination, and a fixed-bed reactor designed for investigation of dry sorbents. Additional laboratory facilities are available for supporting bench-scale research and waste characterization studies.

## Accomplishments

- Development and patenting of a  $\text{NO}_x/\text{SO}_2$  process concept based on the use of ferrous ethylenediaminetetraacetate  $\text{Fe(II)•EDTA}$  in a wet flue-gas-desulfurization (FGD) system. This concept was later tested at pilot-plant scale by Dravo Lime Co. Recent work has identified electrochemical techniques that can extend the useful life of the  $\text{Fe(II)•EDTA}$  additive.
- Performance characterization of the first commercial-scale spray-dryer FGD system operating on high-sulfur coal. This work, done onsite at Argonne, was documented in a design and operation handbook.
- Identification of chemical additives and process conditions that promote  $\text{NO}_x$  capture in spray-dryer/fabric-filter FGD systems. The techniques were successfully tested in two sets of field tests using Argonne's 20-MW spray-dryer system.

## Status

Efforts continue to emphasize combined  $\text{NO}_x/\text{SO}_2$  control. Preventing or reversing the oxidation of ferrous ions in  $\text{Fe(II)•EDTA}$  is the primary focus of the wet scrubbing research.

## Future Plans

Work on the chemical kinetics of the process will continue to improve understanding of the underlying phenomena and to guide process development. Tests of flue-gas cleanup wastes and waste processing techniques will continue in parallel with the process development activities.

## Contacts

For technical information, contact C. David Livengood, Energy Systems Division, Bldg. 362, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-3737; Fax: (708) 252-9728.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

## Enhanced Surface Condensers Improve Heat Rate

*Retubing surface condensers with commercially available enhanced tubes can lower the heat rate of a power plant by 20 Btu/kWhr or more and achieve payback times of 1 to 3 years.*

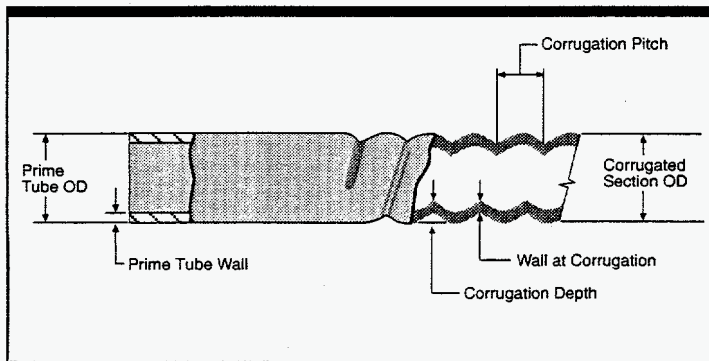
### Opportunity

Competition is intensifying in the power generation and transmission business because of gradual deregulation. With tougher competition, the heat rate of the power plant becomes a more important issue. One long-established method to reduce the heat rate is to lower the back-pressure of the surface condenser. This is accomplished by retubing existing units with commercially available enhanced tubes. This practice has been successfully used by the Tennessee Valley Authority (TVA) for the past 15 years.

### Argonne Solution

Argonne National Laboratory is working with TVA and other utilities to 1) determine the potential heat-rate reductions that are possible by retubing with enhanced tubes, 2) make utilities aware of these benefits, and 3) remove technical concerns such as tube-side fouling, tube vibrations, and eddy currents.

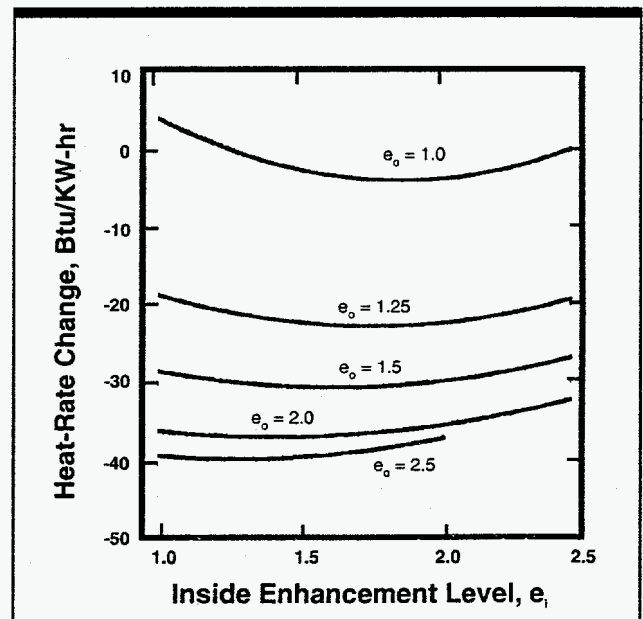
To determine the heat-rate reduction, Argonne has written a computer program that performs the lengthy thermal calculations based on information supplied by the utility. Publications in journals and presentations at conferences and meetings are being used by Argonne to acquaint utilities with the experience obtained with enhanced tubes and to address the most often-mentioned concerns.



*The spirally indented enhanced tube is the type most commonly used for power-plant condenser retubings.*

### Advantages

- Enhanced surface condensers have potential heat-rate reductions of 20 Btu/kWhr or more, resulting in payback times of 1 to 3 years;
- During the summer, when power is in greatest demand, the potential power output increases by 1-2%.



*The outside enhancement is more important than the inside enhancement. (Results obtained for Condenser #1, no tubeside fouling, and a bundle factor of 0.45.)*

### Technical Approach

The quantity of heat rejected by the tubes in surface condensers is a function of the surface area and the surface profile of the tubes. Enhanced tubes improve the thermal performance inside the tube because they 1) increase the surface area per foot of tubing, and 2) modify the flow field by increasing turbulence levels and decreasing the boundary-layer thickness. Performance improvements outside the tube depend on the particular type of enhancement—that is, the disruption or roughness shapes and manufacturing process used. These improvements are offset somewhat by an increase in tube-side pressure drop and higher fouling rates for some cooling-water types.

---

A computer program was developed to calculate the heat-rate reduction that can be obtained by retubing with Korodense LPD, a commercially available tube made by Wolverine Tube, Inc. The program incorporates the thermal performance characteristics obtained by monitoring 14 operating TVA condensers that were retubed with Korodense LPD.

### **Status**

Argonne has conducted research to identify enhanced tubes that are superior in performance to Korodense LPD. Two important findings are: 1) more outside enhancement is needed through the use of low-fins, and 2) the internal disruption shapes should be more contoured. Enhanced condenser tubes of the low-fin type are now being used successfully in Japan, but not in the U.S. The profile modifications of the spirally indented enhanced tubes can be made with a larger diameter indenting tool and are being considered as a possible option by Wolverine Tube.

The following major barriers to the use of enhanced condenser tubes have been eliminated: 1) uncertainty of performance, 2) concern of excessive fouling, 3) lack of long-term successful demonstrations, and 4) low cost-effectiveness. Results of investigations to date indicate that increases of 30%-40% in the overall heat-transfer coefficient (with a cleanliness factor equal to 1.3 to 1.4) are obtained in the clean condition with Korodense LPD. Argonne is continuing to monitor the performance of these units and that of others to update these characteristics. For most river waters, the superior performance is maintained for a year or more. The new clean condition can be obtained by mechanical or chemical cleaning during shutdown or by on-line ball cleaning. Intermittent chlorination also effectively controls biofouling. The 14 retubed TVA condensers are operating successfully, one of them for 15 years. Recent studies with Argonne's computer program indicate that payback times of 1 to 3 years are possible for many utility condensers when retubing is necessary.

### **Future Plans**

Progress is being made to identify superior tube configurations for power-plant condensers. Several have been identified, and approximate prediction methods were developed. If funding is obtained, the next step will be to demonstrate these performance improvements by conducting experiments in the condenser of a host utility.

### **Contacts**

For technical information, contact Thomas J. Rabas, Energy Systems Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-8995; Fax: (708) 252-5210.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

## Air Toxics Being Measured More Accurately, Controlled More Effectively

*New technologies are being developed to reduce toxic emissions from coal combustion and to measure a wide variety of organic air pollutants.*

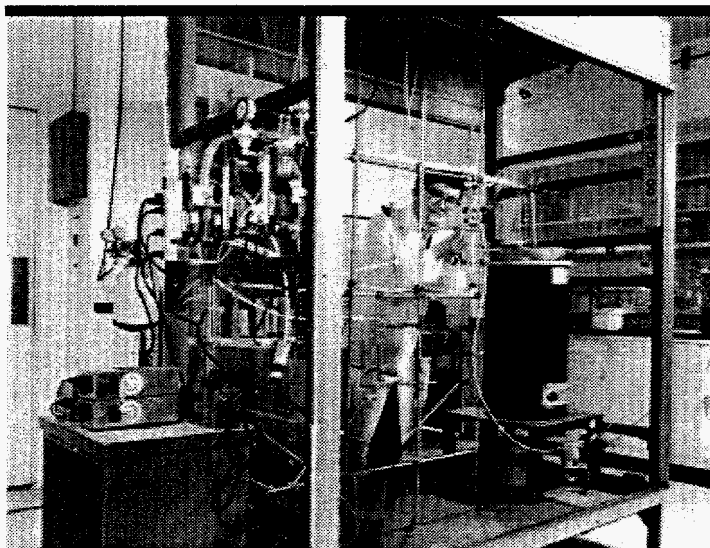
### Opportunity

Passage of the Clean Air Act Amendments of 1990 focused public attention on the toxic air pollutants emitted by various industrial processes. Nearly 200 air toxics have been targeted for regulation, many of which are produced during combustion of coal and other fossil fuels. For industry to comply with tougher restrictions on air toxic emissions in the future, engineering and research is needed on innovative concepts that lead to improved measurement and control of air toxics.

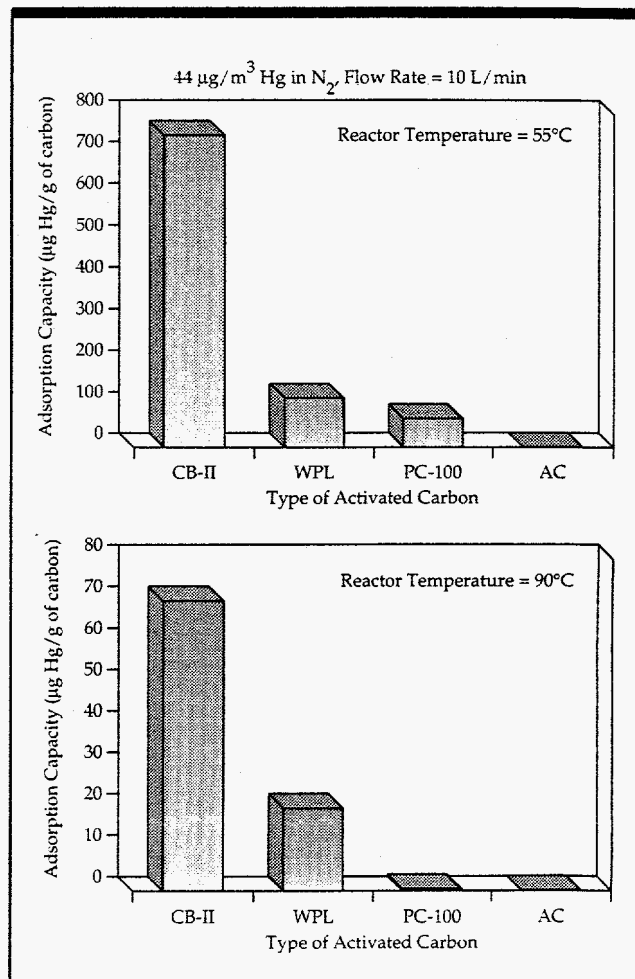
### Argonne Solution

In response to the directives of the Clean Air Act Amendments, Argonne National Laboratory is developing new or improved pollutant control technologies for industries that burn fossil fuels. This research continues Argonne's traditional support for the U.S. Department of Energy's Flue Gas Cleanup Program. Research is under way to measure process emissions and identify new and improved control measures.

Argonne's emissions control research has ranged from experiments in the basic chemistry of pollution-control systems, through laboratory-scale process development



*Photo of laboratory fixed-bed facility*



*Charts of mercury adsorption capacity at two reactor temperatures*

and testing, to pilot-scale field tests of several technologies. Whenever appropriate, the work has emphasized integrated or combined control systems as the best approach to technologies that offer low cost and good operating characteristics.

### Advantages

- New or improved technologies for measurement and control of air toxics will enable U.S. industry to continue to compete in a cost-effective, environmentally sound manner;

- Industries that burn coal and other fossil fuels will be able to meet tougher restrictions on emissions of specific air toxics;
- Air quality can be improved in areas that are heavily industrialized.

### Technical Approach

Argonne's work on air toxics is divided into two major elements:

1. Measures to improve mercury removal by existing pollution-control systems applied to coal combustion. The emphasis has been on evaluating activated carbons and other low-cost dry sorbents that can be injected into a gas stream or incorporated into a filter. In addition, modifications for wet scrubbers, including chemical additives and various types of packing, are being evaluated.
2. Development of sensors and control techniques for emissions produced by the textile industry. Formaldehyde, for example, is known to be emitted in many processes, but the amounts are not well-known, and appropriate control measures or minimization strategies have not been developed.

### Status

Although air toxics research is a relatively new area, Argonne's program has already resulted in several accomplishments, including

- Improvements to coal combustion systems and identification of promising methods of controlling emissions of air toxics
- Development and construction of an experimental research facility to evaluate dry sorbents for removal of air toxics
- Characterization of several types of plain and treated activated carbons for mercury pollution control, comparative evaluations of proprietary sorbents supplied by industrial developers, and initial development of low-cost mineral-based sorbents
- Preliminary development of a new, low-cost solid-state sensor capable of measuring a wide variety of organic pollutants.

### Future Plans

Additional testing of dry sorbents for capturing mercury and other air toxics will be conducted with the fixed-bed reactor and the laboratory-scale spray-dryer system to develop viable process concepts for large-scale tests at industrial sites. Tests of wet scrubbing for mercury removal will continue to define the potential and limits for that technology. A test facility will be established to support research on sensors and controls for various organic compounds. In parallel with these efforts, tests of gas-cleanup wastes and waste processing techniques will continue to ensure that land-based disposal can be done safely.

### Contacts

For technical information, C. David Livengood, Energy Systems Division, Bldg. 362, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-3737; Fax: (708) 252-9728.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

## Usable Fuel Produced from Municipal Solid Waste

*Recycling of solid waste into fuel reduces pollution, conserves valuable landfill space, and minimizes refuse-disposal costs.*

### Opportunity

Refuse disposal is a matter of increasing concern for municipal and state governments. As existing landfills reach full capacity and new landfills become more costly to site, the need to develop alternative disposal methods is more critical than ever. Some of the refuse now being landfilled could provide considerable quantities of energy, which would help extend supplies of traditional fuels. Also, the Clean Air Act Amendments of 1990 significantly restrict emissions of sulfur dioxide ( $\text{SO}_2$ ) and nitrogen oxides ( $\text{NO}_x$ ) from combustion facilities. Emissions from coal-fired plants could be reduced by cofiring with cleaner fuels, such as those produced from municipal refuse.

### Argonne Solution

To address these concerns, Argonne National Laboratory, with U.S. Department of Energy sponsorship, has developed a means of producing refuse-derived fuel (RDF) from municipal solid waste. When cofired with coal, RDF reduces problematic emissions and supplements coal supplies.

### Advantages

- Recycling of solid waste into RDF conserves valuable landfill space and minimizes waste-disposal costs while supplementing conventional energy resources;
- Cofiring with RDF reduces flue-gas emissions and heavy-metal concentrations in ash residues from coal combustion plants;
- Boiler operators can burn RDF in quantities up to 30% by weight without repermitting.

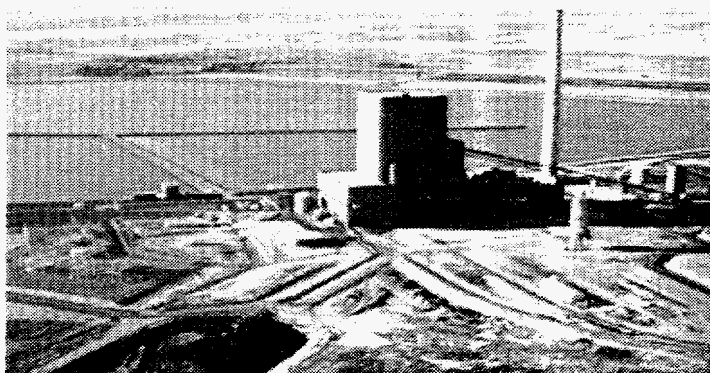
### Technical Approach

The combustible fraction of municipal solid waste is formed into cylindrical pellets that require a binding additive to remain intact during handling and storage. After investigation of about 150 candidate additives, lime (calcium hydroxide) was identified as the most useful and economically attractive binder. Lime also provides a scrubbing function, combining with sulfur in the coal and decreasing  $\text{SO}_2$  emissions.



*Argonne researchers have developed these refuse-derived fuel (RDF) pellets from municipal solid waste.*

Argonne conducted full-scale cofiring tests in the laboratory's onsite spreader-stoker unit, using about 600 tons of binder-enhanced RDF pellets blended with high-sulfur coal in varying proportions. Test burns conducted over an 8-week period included extensive flue-gas sampling and analysis. Further tests were performed, using about 1,200 tons of RDF, with the National Renewable Energy Laboratory and three industrial partners—Otter Tail Power Co., Eden Prairie Recycling, and XL Disposal Corp.—in a 440-MW cyclone-fired boiler at Otter Tail's Big Stone Plant. Researchers analyzed air emissions, ash residues, and fuel composition, and measured combustion performance for coal firing alone and for a coal-RDF mixture.



*The Otter Tail Power Co. plant in Big Stone, South Dakota, hosted tests on the combustion of coal with RDF pellets.*

---

## **Accomplishments**

- As a result of the Argonne facility tests, the U.S. Environmental Protection Agency now allows boiler operators to burn RDF in quantities up to 30% by weight without repermitting;
- Data from the Otter Tail tests allowed participants to understand the benefits of RDF cofiring, in terms of reductions in flue-gas emissions and heavy metal concentrations in ash residues;
- The RDF cofiring technology received a 1989 R&D 100 Award and the 1990 Federal Laboratory Consortium Award for Excellence in Technology Transfer;
- Argonne and the University of North Texas have jointly applied for two patents, and ARCH Development Corp. has negotiated licensing of the pellet-making process to Catrel, Inc.

## **Status**

Research efforts are now focused on pulverizing the RDF pellets so that the fuel can be cofired or burned alone in pulverized-coal boilers. Research with several Fortune 500 companies is also examining the potential for using industrial waste as a pellet fuel source. To overcome potential barriers to commercialization of RDF technology, Argonne is working with others to set up a trade association for waste-to-energy fuel manufacturers, equipment vendors, and potential users.

## **Future Plans**

Data from this project will be used to develop operating, technical, and financial information for the use of RDF pellets as fuel in cyclone, suspension-fired, or small spreader-stoker-fired combustors. Results will be used to provide a manufacturers' database and to help state regulatory agencies evaluate methods to permit and monitor commercial co-combustion units.

## **Contacts**

For technical information, contact Oscar O. Ohlsson, Energy Systems Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-5593; Fax: (708) 252-9281.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

# Cofiring Technology Reduces Gas Turbine Emissions

*Reducing emissions from natural-gas-fired turbines without sacrificing efficiency can help operators meet stringent new emissions controls.*

## Opportunity

Increasingly stringent emission controls have prompted investigation of alternative-firing schemes that limit the release of carbon monoxide (CO) and nitrogen oxides (NO<sub>x</sub>) from natural-gas-fired turbines. Restrictions of less than 25 parts per million (ppm) of NO<sub>x</sub> usually cannot be met without significantly increasing CO production. A method is needed for simultaneously decreasing NO<sub>x</sub> and CO emissions from gas-fired turbines while retaining or increasing system efficiency.

## Argonne Solution

Argonne National Laboratory is examining alternatives to straight natural gas firing. When hydrogen cofiring is used in tandem with steam injection, a decrease in both CO and NO<sub>x</sub> has been observed. In-process hydrogen production and premixing with the natural gas fuel are also being explored.

## Advantages

- Increased fuel flexibility
- Reduced NO<sub>x</sub> and CO emissions
- System efficiency not impacted.

## Technical Approach

Laboratory tests have been conducted in a swirl-stabilized combustor under thermodynamic and aerodynamic conditions representative of those in gas turbines. Diffusion and premixed flames were tested, and axial profiles of temperature and gas composition were measured. Exhaust levels of CO, NO<sub>x</sub>, nitrogen dioxide (NO<sub>2</sub>), oxygen (O<sub>2</sub>), and carbon dioxide (CO<sub>2</sub>) were measured. Emissions were monitored as hydrogen was added to the natural gas fuel at constant steam/fuel and combustor exit temperatures. Additional testing investigated the coincident injection of hydrogen and steam as required to meet emissions targets.

## Status

Results of laboratory tests have shown that a greater range of NO<sub>x</sub> and CO emissions targets could be achieved when hydrogen is added to steam-injection systems. However, cost estimates indicate that hydrogen production from natural gas through conventional steam

reforming would be too costly unless steam were readily available. As a result, alternative methods of hydrogen production are being explored, which could reduce the capital costs associated with hydrogen combustion.

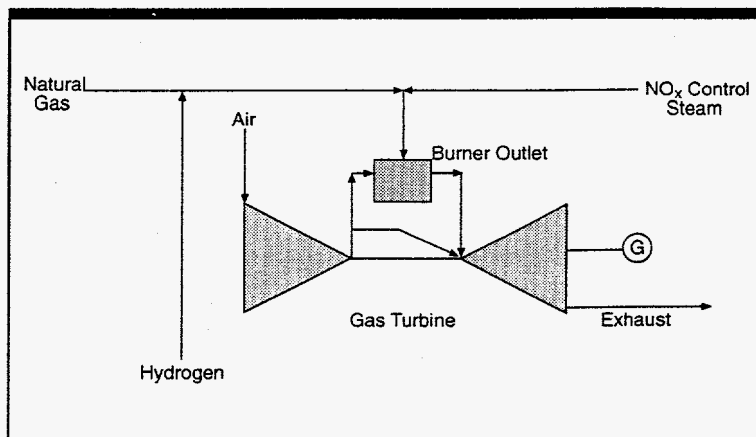
## Future Plans

Argonne's Center for Industrial Technology Systems is planning a pilot-scale demonstration of this hydrogen-cofired, steam-injection system. Negotiations are under way with the U.S. Department of Energy and industry participants to construct and test a pilot-scale gas-turbine system with auxiliary hydrogen production capabilities. The targeted start date for this work is fiscal year 1996.

## Contacts

For technical information, contact Betsy W. Curlin, Energy Systems Division, Bldg. 362, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-8071; Fax: (708) 252-9728.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.



*Schematic diagram of hydrogen cofiring in gas turbines.*

# Trainable, Rugged Microsensor Identifies Wide Range of Gases

*Argonne National Laboratory's electrocatalytic sensor, made from ceramic-metallic materials, could prove durable enough for continuous emissions monitoring of hot flue and stack gases.*

## Opportunity

Regulation of emissions from industrial plants is becoming more stringent, requiring operators of furnaces and boilers to install emissions monitoring systems, even for relatively small combustion equipment. Industrial plant operators also need to demonstrate the reductions achieved when emissions control systems are installed or industrial processes improved.

However, many available sensors for measuring gaseous emissions are too delicate to withstand the high-temperature, hostile environments found in industrial stacks and flues. These sensors can also be expensive, and their versatility and sensitivity are limited.

## Argonne Solution

Argonne National Laboratory has developed a small electrocatalytic sensor made of ceramic-metallic (cermet) materials that identifies many different gases by their electrical signatures. The microsensor relies on an innovative combination of cermet materials, cyclic voltammetry, and neural network signal processing. Work is under way to train and evaluate the sensor to differentiate gases in mixtures.

## Advantages

- The sensor's intelligent pattern recognition system would allow industrial plant operators to comply with emissions regulations by measuring a wide variety of gases;
- The microsensor is inexpensive to produce, yet may prove rugged enough to survive in high-temperature, hostile environments;
- The microsensor can be remotely cleaned and does not require electrolyte replenishment or replacement;
- Compared with conventional sensors, power requirements are lower (milliwatts).

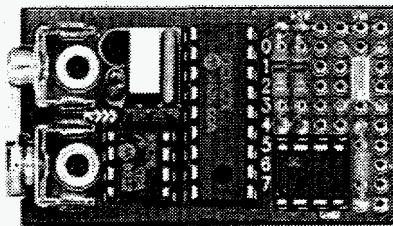
## Technical Approach

The sensors are produced using thick-film screening/firing methods (with thin-film versions still in testing). The sensing technique involves constructing sandwiched cermet layers and measuring catalytic reactions at the

sensing electrodes, which change the concentration of ions at the three-phase boundary between the gas, electrode, and solid electrolyte. This, in turn, changes the ionic current flow measured through the sensor. When a voltage is applied to measure the electrical current, the sensor produces a voltage/current "signature" that is unique for individual gases and mixtures. The sensor's intelligent signal processing uses neural networks to recognize the gas signature patterns and quantify the gases by their shape changes.



*Typical Sensor Training System (STS) and Miniature Sensor Support System (MSSS)*



*ECG Microsensor and Miniature Sensor Support System (MSSS) (Actual size shown; microsensor is small chip in upper right corner.)*

---

## **Status**

Researchers are evaluating applications for the microsensor, including monitoring stacks and flues for gaseous emissions of regulatory concern, characterizing environmental contaminants in the field, providing early fire warning, monitoring vapors inside machinery, detecting overheating computer components, and providing input information to process control systems.

## **Future Plans**

The neural network processing now fits onto a microcontroller chip, which will minimize support electronics and transfer the burden of signal generation from the sensor itself to the support electronics.

The cermet sensor research team is also developing other microsensors. For example, researchers are working to apply the new measurement techniques to tin oxide sensors and thin-film/thick-film hybrids based on various advanced materials. The team is also rebuilding the electrocatalytic microsensors to exploit a new thin-film process called metal organic chemical vapor deposition (MOCVD), which could reduce the sensor's size and improve its response time.

## **Contacts**

For technical information, contact Michael C. Vogt or Erika L. Shoemaker, Energy Systems Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-7474; or -7846; Fax: (708) 252-6407 or -5210.

For information on working with Argonne, contact the Industrial Technology Development Center, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

# Long Lengths of High- $T_c$ Superconductors Fabricated

*Long lengths of superconductors could benefit motors, generators, and transmission cables.*

## Program Objective

The basic objective of this Argonne National Laboratory program is to produce long lengths of high-quality conductors that exhibit good mechanical and physical properties for commercial operation at 35 K in a magnetic field up to 2 Tesla.

## Work Description

High-quality superconducting powders have been synthesized by using various ceramic powder-processing techniques. The powders are packed into high-purity silver tubes, swaged, drawn, and rolled to a final thickness of 0.1 mm. Desired electrical and mechanical properties are obtained by subjecting the tape to a series of thermomechanical treatments. Long lengths of conductors have been fabricated.

## Advantages

A wide variety of applications, such as motors, generators, and transmission cables, have been envisioned for high- $T_c$  superconductors. Long-length conductors are required for these applications.

## Status

Critical current densities  $>40,000$  A/cm<sup>2</sup> have been obtained in short lengths of superconducting tapes. Also, long-length conductors with comparable current densities have been fabricated, and pancake-shaped coils and test magnets have been fabricated from the long-length conductors. Recently, Argonne achieved a milestone when one of its test magnets, fabricated in collaboration with Intermagnetics General Corp., New York, generated the world's highest magnetic field (by high- $T_c$  superconductor) of 2.6 Tesla at 4.2 K. This magnet was fabricated by using  $\approx 500$  m of high- $T_c$  conductors.

Another magnet containing  $\approx 780$ -m-long high- $T_c$  wire generated a field of  $\approx 1$  T at 4.2 K and  $\approx 0.6$  T at 27 K, both in an applied background field of over 20 T.

Argonne is now producing  $\approx 1$ -km-long HTS conductors. Currently, efforts are under way to improve the mechanical properties of the superconducting tapes, either by fabrication multifilament conductors, or by using alloyed sheath material.

## Contacts

For technical information, contact U. (Balu) Balachandran, Energy Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-4250; Fax: (708) 252-3604.

For information on working with Argonne, contact the Industrial Technology Development Center, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

# High-Temperature Superconducting Current Leads

*High-temperature superconductors with low thermal conductivity and zero electrical resistance are excellent replacements for conventional conductors in current leads.*

## Opportunity

The utilization of electrical devices operating in a cryogenic environment (less than  $-150^{\circ}\text{C}$ ) is increasing on a regular basis. Such devices include superconducting magnets for medical diagnosis (MRI), magnetic separators, particle accelerators, motor/generators, and electronics. One of the major refrigeration loads of these devices is the heat input from the electrical current leads that transfer energy between the ambient and low-temperature regions. Such current leads, conventionally made from normal metal (copper) conductors, provide heat input by solid conduction from warm to cold and by ohmic heating due to current passage. A low-heat-input current lead is needed to significantly reduce refrigeration system capital equipment and operating costs.

## Argonne Solution

High-temperature superconductors (HTSs) with low thermal conductivity and zero electrical resistance are excellent materials for replacing the conventional conductors in current leads. Under the U.S. Department of Energy's Superconductivity Technology Program, Argonne National Laboratory and U.S. industry partners are developing HTS current leads suitable for various commercial applications. The work includes HTS materials development and characterization, development of application-specific designs, and the performance evaluations of commercial HTS current leads.

## Advantages

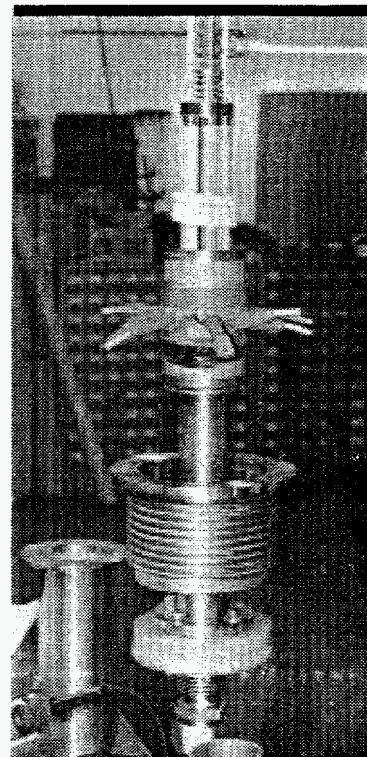
Use of HTS current leads to deliver power to devices at low temperature can reduce refrigeration requirements to values significantly below those achievable with conventional leads. Argonne estimates a theoretical best reduction to 1/10 that of a conventional lead, with specific applications-driven designs capable of a 1/3 to 1/5 reduction.

## Technical Concept

HTS conductors are used to replace the cold portion of the current lead. The low thermal conductivity and virtually zero electrical resistance of the HTS materials significantly reduce the heat input to the low-temperature refrigerant. In addition to good electrical and thermal performance, practical lead designs provide safety, reliability, long lifetime, manufacturability, and low cost.

## Status

In an ongoing HTS current lead project, Argonne is collaborating with Superconductivity, Inc. (SI), to develop a 1,500-A HTS lead for use in a SMES system for power quality control. The lead's features include demountable HTS components, use of a sintered Y-123/15% Ag HTS conductor rod, and capability for shielding the magnetic field from SMES magnet fields. The lead pair has been assembled and installed in a liquid-helium test dewar for the evaluation of electrical and thermal performance. Performance measurements are under way.



*Argonne is collaborating with Superconductivity, Inc. (SI), to develop this 1,500-A HTS lead for use in a SMES system for power quality control.*

---

In another collaborative project with Babcock and Wilcox Co. (B&W), a 16-kA HTS current lead for use in a 0.5-MWh SMES device is being developed. Design features include conduction cooling and use of multiple elements of PIT Bi-2223 with an Ag/3% Au sheath contained in a stainless-steel safety lead. The lead's final design is nearing completion. HTS conductor elements and a vapor-cooled 60-300K current lead are being procured from industry. Supporting research and development are being performed on the conductor elements, low-resistance electrical junctions, and the safety lead-conductor element support assembly.

### **Future Plans**

HTS materials development and characterization will continue, with emphasis on commercial HTS conductor elements. The SI and B&W lead assembly performance will be experimentally verified. Incorporation of the tested lead assemblies into actual SMES devices is planned.

### **Contacts**

For technical information, contact Ralph C. Niemann or C. Arthur Youngdahl, Energy Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-6156 or -5029; Fax: (708) 252-5568 or -3604.

For information on working with Argonne, contact the Industrial Technology Development Center, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

# Vitrification of Low-Level Radioactive and Mixed Wastes

*Argonne National Laboratory is developing glass-crystal composites that can stabilize a wide range of toxic and radioactive elements.*

## Opportunity

The U.S. Department of Energy (DOE) and nuclear utilities have large quantities of low-level and mixed wastes that must be treated prior to their disposal in near-surface repositories. Vitrification is a recognized technique for treating toxic components, because organic materials are destroyed in the vitrifier and toxic metals are stabilized in the glass. Vitrification methods for high-level wastes are available but are not always applicable to low-level mixed wastes. These contain large amounts of metals and small amounts of glass-making components. Glass materials that do not require large amounts of expensive fluxes are needed that are durable when buried in surface repositories.

## Argonne Solution

Argonne National Laboratory is developing glass-crystal composites (GCC) that can stabilize a wide range of toxic and radioactive elements. These composite materials can contain up to 70% metal oxides such as  $\text{FeO}_x$ ,  $\text{CrO}_x$ ,  $\text{ZrO}_2$ , and  $\text{TiO}_2$ , while using a minimum of expensive flux. By using contaminated soils in the formulations, 100% waste loading can be achieved. With proper proportioning of feed materials and cooling of the molten materials, toxic and radioactive elements can be contained in very stable crystalline minerals that are dispersed in a durable glass matrix.

## Advantages

A wider variety of low-level and mixed wastes can be immobilized in GCCs than would be possible with more conventional borosilicate and soda-lime glasses. A larger volume reduction can be achieved by minimizing the amounts of added flux required. The GCC waste forms can meet the most stringent requirements for low-level repositories.

## Design Concept

When metal-oxide phases crystallize from conventional glasses containing large amounts of fluxing components, the glass matrix becomes less stable and more easily dissolved in groundwater. The result is a more rapid release of radioactive and toxic elements. By tailoring the glass composition, a durable glass matrix can be maintained while the phases crystallizing from the melt are minerals that are stable in the environment.

## Status

A number of GCCs have been developed to stabilize the wide variety of DOE low-level mixed wastes. The long-term durability of these materials in repositories has been proven in accelerated corrosion tests. These techniques are based on the experience gained during the qualification of high-level waste glasses for geologic disposal.

## Contacts

For technical information, contact John Bates or David Wronkiewicz, Chemical Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-4385 or -7362; Fax: (708) 252-4771 or -5246.

For information on working with Argonne, contact the Industrial Technology Development Center, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

# Integrated Quality Assurance Planning for Characterization, Demolition, and Disposal of Contaminated Structures

*Argonne National Laboratory's integrated approach to quality planning for the demolition and disposal of contaminated buildings makes this complex process more efficient and cost-effective.*

## Challenge

Planning for the demolition and disposal of buildings and engineered structures which may be contaminated by hazardous substances is a complex process. Coordination among numerous tasks is required, including review of historical records, risk analysis, site sampling, analysis for the presence of contaminants, definition of structures, engineering and cost analyses, planning for waste disposal and land reclamation, and evaluation of regulatory drivers. Quality assurance criteria and practices among the various disciplines may differ, which can lead to regulatory problems, project delays, and rework.

## Argonne Solution

Argonne National Laboratory's integrated approach brings the quality requirements for all tasks and disciplines together into one planning document, assuring a unified application of quality principles. The functional flow diagram shown below defines some of the inter-relationships between tasks and facilitates development of quality requirements for data acquisition tasks.

## Advantages

Argonne's integrated approach to quality planning assures that all members of the project team understand the function of their task in terms of the overall project. Data quality objectives for inter-related tasks are developed jointly to ensure that objectives of both client and regulators are met in a cost-effective manner.

## Status

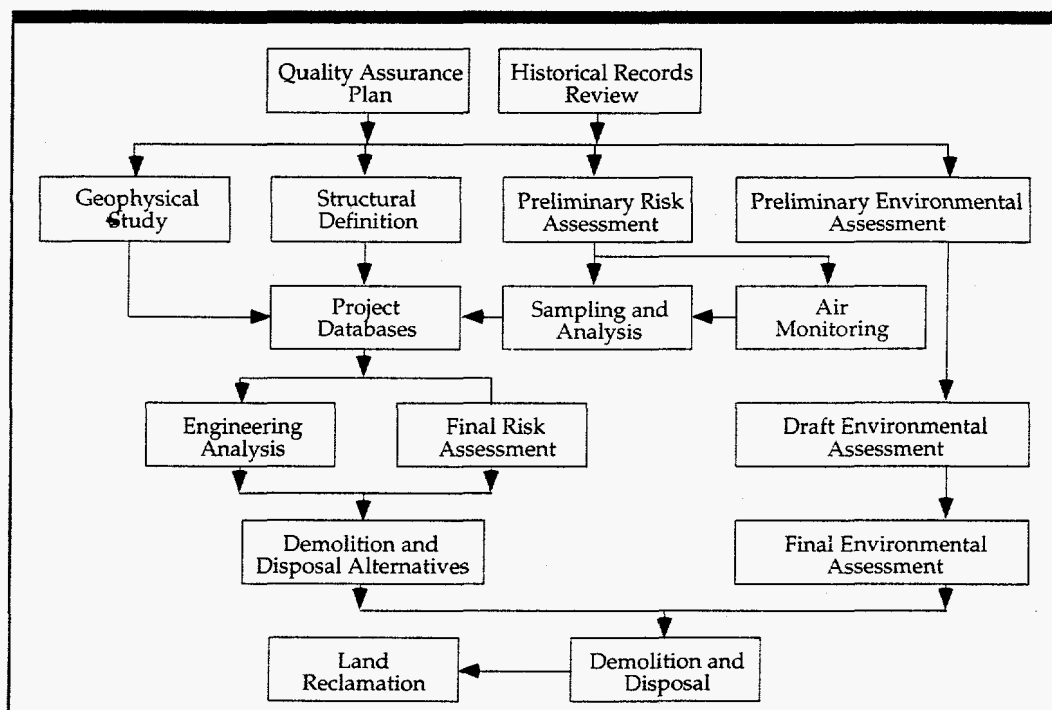
Argonne is presently characterizing a complex of buildings at the U.S. Army Aberdeen Proving Ground (APG) in Maryland. The buildings were formerly used for pilot-scale

manufacture of highly toxic chemical warfare agents and are now scheduled for demolition and disposal. An ISO-9000-type quality assurance plan covering all aspects of the project has been prepared and approved by APG. Review of historical records, preliminary risk analysis, and the structural definition have been completed. Regulatory analysis and planning for sampling and analysis are presently under way.

## Contacts

For technical information, contact R. Eric Zimmerman or John E. Parks, Center for Environmental Restoration Systems, Energy Systems Division, Building 372, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-6816 or -6725; Fax: (708) 252-6407.

For information on working with Argonne, contact the Industrial Technology Development Center, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.



*This functional flow diagram defines some of the inter-relationships between tasks and facilitates development of quality requirements for data acquisition tasks.*

# On-Line Plant Transient Diagnostics and Management

*Argonne National Laboratory's diagnostic system overcomes many of the limitations encountered with past adaptations of artificial intelligence to process fault diagnostics.*

## Opportunity

Artificial intelligence (AI) techniques in the form of knowledge-based expert systems could provide on-line decisionmaking support for plant operators during normal operating and transient conditions. However, limitations in the knowledge base hinder the use of AI to diagnose faults that occur in large-scale processes. The limitations include problems with knowledge acquisition and the event-oriented approach used for process-fault diagnosis.

## Work Description

Argonne National Laboratory has developed a real-time transient diagnostics and management system. Unlike a traditional event-oriented knowledge base, the knowledge platform used by Argonne is based on thermal-hydraulic data. Functional parameters (such as heat and mass transfer data) are used in conjunction with equipment characteristics (such as pressure-versus-flow curves that define the operating ranges of pumps and valves). Together, these provide a two-tiered approach to diagnosing process system faults.

## Advantages

Preliminary results indicate that Argonne's hierarchical diagnostic system overcomes many of the limitations encountered with past adaptations of artificial intelligence to process fault diagnostics. The highly flexible system is capable of diagnosing an unforeseen event and handling limited instrument information. It will provide comprehensive verification and validation. Although it was developed to diagnose component failures in nuclear power plants, the system has a wide range of process-industry applications.

## Design Concept

The system is a two-level, hierarchical knowledge structure. At the first level, an expert system uses thermal-hydraulic data to determine physical occurrences (i.e., water added or lost, heat added or lost). At the second level, artificial neural networks pinpoint the source of the transient by classifying the functional misbehavior of the system through specific component characteristics. The system then determines the optimal corrective action required to restore a stable configuration to the operating system.

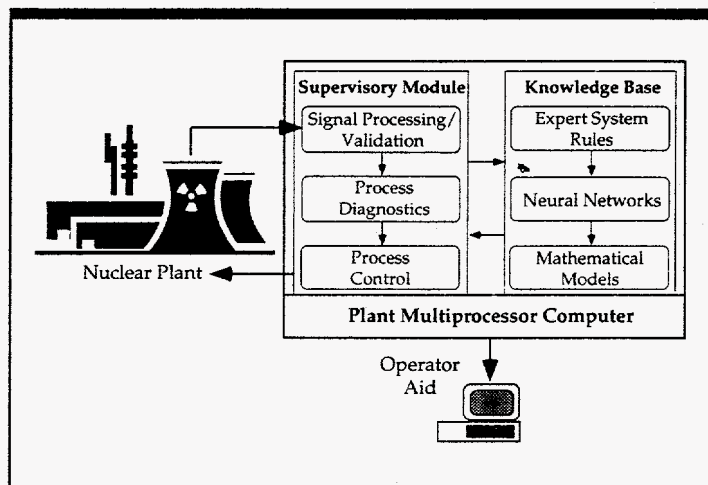
## Status

Commonwealth Research Corporation and Argonne are studying the feasibility of the system's diagnostic capabilities. Data from Commonwealth Edison's Braidwood Nuclear Power Plant full-scope operator training simulator is being used. Initial results indicate that the system is successful in diagnosing process faults in a real-time environment.

## Contacts

For technical information, contact Thomas Y. C. Wei, Reactor Engineering Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-4688; Fax: (708) 252-4780.

For information on working with Argonne, contact the Industrial Technology Development Center, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.



Argonne's real-time transient diagnostics and management system.

# Sulfide Ceramic Materials for Improved Batteries

*A new class of materials offers unique properties for a variety of different engineering applications. Among them could be an efficient, long-lasting battery for electric cars.*

## Opportunity

The newly developed sulfide ceramics hold great promise for many specialized engineering applications where great strength is needed for bonding to other materials, often in highly corrosive environments. Their use is envisioned in such diverse areas as batteries, aluminum production, and nuclear waste processing.

## Argonne Solution

Argonne National Laboratory researchers have based these new sulfide ceramics on nontransition metals (so called because of their place in the periodic table) rather than on conventional oxides, nitrides, or borides. These sulfides contain such nontransition metals as silicon, aluminum, lithium, calcium, and sodium. Their melting points range from 700°C to 1100°C, which makes them suitable for use between 400°C and 700°C.

So far, the primary application of sulfide ceramics has been in coupling metal components in electrically insulating arrangements for service in severely corrosive, high-temperature environments. Historically, development of new electrochemical devices and processes has been hampered by the inability of known ceramic sealants to fulfill these requirements. One of the first successful uses for sulfide ceramics was as a sealant for the first rechargeable bipolar lithium metal sulfide battery.

## Advantages

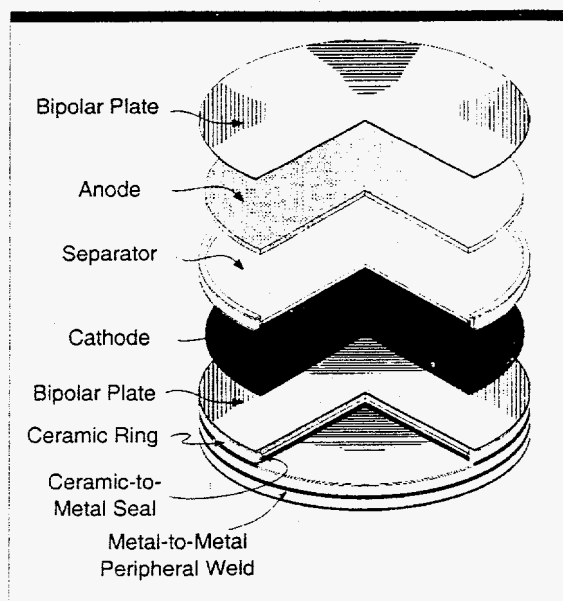
Sulfide ceramics can be used in structural ceramics, porous ceramic frits (partially fused or calcined compounds), corrosion-resistant coatings, and electrically conductive ceramic coatings. For example, they can be used as porous ceramic bodies within batteries or as substitutes for expensive metal components through the use of low-cost protective coatings. They can also be used with the molten-salt or molten-metal heat exchangers typically found in nuclear reactors or solar energy converters.

Sulfide ceramics are also promising for probes and electrical feeds for producing and refining metals, such as aluminum and lithium, and for metallic products such as nuclear fuel. Components made from sulfide ceramics improve both the safety and efficiency of such processes.

## Technical Concept

As bonding and sealing agents, the sulfide ceramics form a strong reaction bond with a broad range of metal components. The sulfide ceramic melts, aggressively wets, and attacks the metal surface to bond interlocking "fingers" of metal and ceramic.

As structural components, sulfide ceramics are a composite of a fusible material enveloping solid aggregates such as oxides and other sulfides. The aggregates dictate the resulting physical properties (for example, thermal expansion, toughness, and fusion temperature flow). Other aggregate materials can change the electrical properties of the ceramic. Structural ceramics can also be engineered to reduce stresses at metal/ceramic interfaces. Finally, seals with dramatically larger diameters have been fabricated than were ever thought possible.



*Four-cell six-volt lithium/iron disulfide bipolar stack*

---

## Status

Argonne researchers have developed the first rechargeable bipolar lithium metal sulfide battery—an accomplishment impossible without the ceramic bonding made possible by sulfide ceramics. The bipolar configuration has by itself doubled or tripled this battery's power. Such batteries could potentially power a car for about 250 miles before needing to be recharged and could last for 100,000 miles before needing to be replaced. With its high power capability, this battery could accelerate a car from 0 to 60 miles per hour in 8 seconds. It could also provide up to 5 times as much energy per pound as current battery technology while lasting 10 times longer.

## Future Plans

Argonne is a partner in a three-year, \$7.3 million cooperative research and development agreement (CRADA) to develop a new generation of batteries for electric vehicles. The research is funded by the U.S. Department

of Energy's Office of Energy Efficiency and the U.S. Advanced Battery Consortium, a partnership of Chrysler Corp., Ford Motor Co., and General Motors Corp. with the Electric Power Research Institute. Argonne is working closely with Saft America, Inc., which has a separate contract to develop a commercial version of the bipolar battery.

## Contacts

For technical information, contact Thomas D. Kaun, Chemical Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-5605; Fax: (708) 252-4176.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

# Flywheel Provides Efficient Energy Storage

*A flywheel energy storage system can cut costs, save energy, reduce pollution, and minimize the need for new power plants.*

## Opportunity

New research could result in this highly efficient energy-storage device, significantly changing the way energy is produced and supplied.

## Argonne Approach

Researchers from Argonne National Laboratory and Chicago's Commonwealth Edison utility have scored a major breakthrough in the age-old battle against friction, setting a world record for the least friction created in a magnetic bearing. Friction is the force that robs engines and other machinery of their power and efficiency.

The jointly developed bearing has ten times less friction than its closest competitor. The bearing is the essential component of a highly efficient flywheel energy-storage device that economically stores and releases energy.

## Advantages

Flywheels enable load leveling in electrical generation or industrial applications. Coupled to a suitable electric motor/generator, utilities and other heavy users of electrical power can balance the peaks in electrical demand by using flywheels to alternately store and release needed electricity.

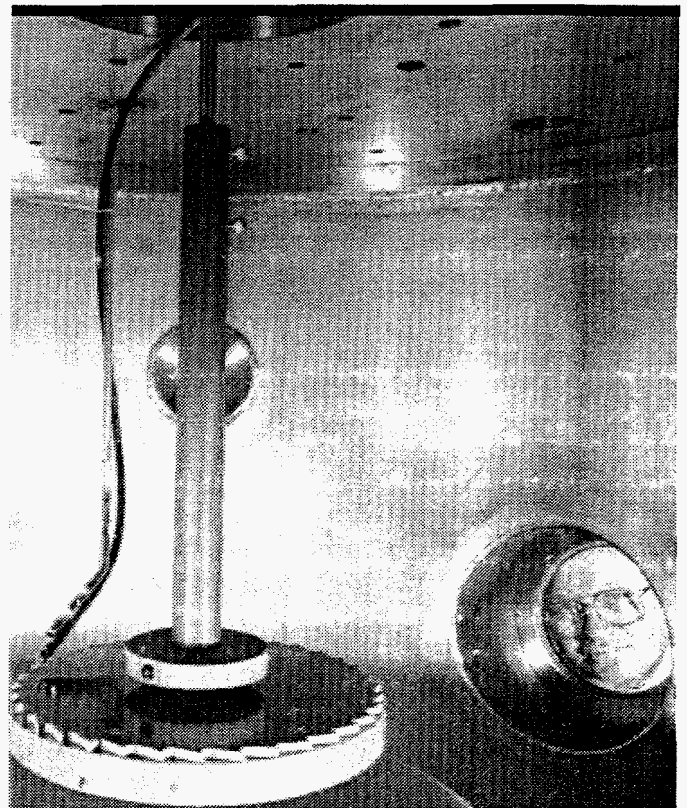
In an electric vehicle, flywheel energy storage can be used with regenerative braking. By feeding power back into the motor/generator attached to the flywheel, the vehicle's braking energy is converted into energy in the flywheel instead of being wasted. In addition, one or more on-board flywheels in a vehicle could be spun up during off-peak electrical generation periods, storing energy for later use.

## Technical Concept

To store a large amount of energy, the flywheel must spin at high rotational speeds. These speeds are achieved most reliably with flywheels made of high-strength, graphite fiber materials. Argonne scientists are working with academic researchers to examine the use of fiber-wound composite rotors, which can be spun at much higher speeds than conventional metal rotors.

Any practical flywheel must be supported on very low-friction bearings to avoid energy loss. The Argonne/Commonwealth Edison bearing uses a permanent magnet trapped and suspended in a magnetic field above an array of high-temperature superconductors—materials that lose all electrical resistance when cooled by liquid nitrogen. The magnetic bearing supports the flywheel as it moves at 1,100 yards (1,000 meters) per second—about three times faster than the speed of sound. Part of the bearing is attached to the bottom half of the flywheel.

The bearing's other half is an Argonne-made high-temperature superconductor. When the superconductor is cooled to minus 321 degrees Fahrenheit, it generates a magnetic field that causes the magnet/flywheel assembly to float above the superconductor. The two surfaces never touch.



*Highly efficient flywheel energy storage systems, such as the one shown here, could revolutionize the way energy is produced and supplied to consumers.*

---

## **Status**

A vacuum chamber called the Flywheel Energy Storage Test Apparatus permits many different system configurations and operating conditions to be tested. A motor/generator unit is being designed to work with this test chamber to demonstrate efficient power input/output. Researchers are still determining the best method to transfer energy in and out of the flywheel.

Tests are presently being conducted on a 15-inch (38-centimeter) flywheel that weighs 27 pounds (12 kilograms). These flywheels are expected to store one to two kilowatt-hours, or enough to power ten 100-watt light bulbs for two to five hours. Researchers are developing a commercial product that eventually will weigh up to 40 tons and store five megawatt-hours of electricity.

## **Future Plans**

Researchers are continuing magnetic bearing and flywheel energy storage system development. A field test of a 50 kW-hr energy storage unit is planned for 1995.

## **Contacts**

For technical information, contact John Hull, Superconductivity Applications Section, Energy Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-8580; Fax: (708) 252-5568.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

## Analyses and Diagnostics Laboratory Fosters Advanced Battery Systems for Electric Vehicles

*Advanced battery systems for electric vehicles will improve vehicle performance and range, while reducing maintenance and downtime.*

### Opportunity

An electric vehicle's battery weight limits its range and payload. Current technology is best suited for a range of under 50 miles between battery chargings. A partnership involving America's "Big Three" automobile manufacturers (General Motors, Ford, and Chrysler), the Electric Power Research Institute, and the U.S. Department of Energy (DOE) was created to accelerate development of advanced battery systems for electric vehicles. Created in 1991, this partnership was named the U.S. Advanced Battery Consortium (USABC).

### Advantages of Battery R&D

Advances that increase range and decrease battery weight will improve the operational performance of electric vehicles.

### Primary Goals and Objectives

To achieve such advances, Argonne National Laboratory is working with the USABC and industry battery developers to form battery R&D teams and to define the work to be performed by Argonne and each of the industrial partners. Argonne's Analysis and Diagnostics Laboratory (ADL), established by DOE in 1976, is being used to study advanced battery systems. Advanced battery candidates are being evaluated to quantify their performance and life characteristics, assess their developmental status, and identify their operational limits and deficiencies for electric vehicle applications.

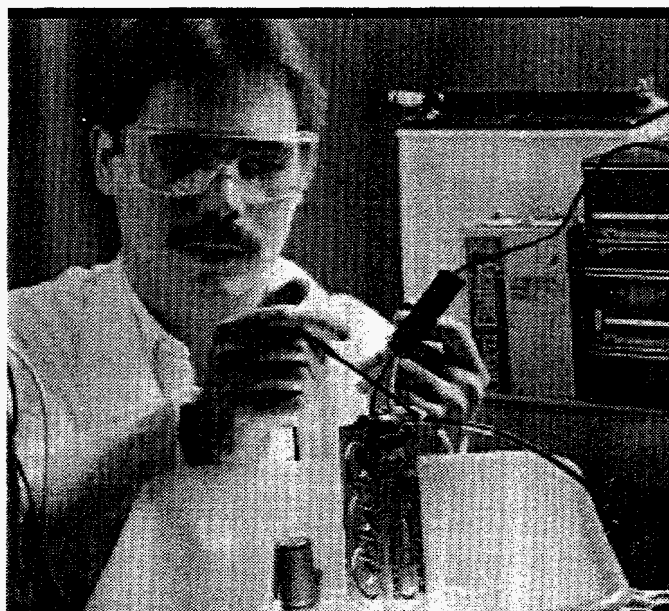
### Facility Description

Argonne's ADL houses two laboratories: a versatile computer-operated test laboratory and a post-test analysis laboratory. In the test laboratory, researchers subject cells, multicell modules, and full-size battery systems fabricated by industrial firms to performance and lifetime testing that simulates electric vehicle applications. Then, in the post-test laboratory, researchers analyze failed cells (in a protected atmosphere, if needed) to assess component reliability and correlate operational performance with material changes.

In this facility, researchers apply unbiased tests and analyses, thereby creating a common basis for evaluating battery performance and life. For example, the information gained from the performance and lifetime tests, together with the post-test evaluations, provides benchmarks of technical progress. More importantly, scientists can identify specific changes in design or construction materials that could lead to improved battery performance.

### Staff Expertise and Experience

During its 18 years of operation, researchers associated with the ADL have acquired considerable expertise in the technology and methodology of measurement and control of battery test conditions. The ADL presently has more than 50 person-years of battery testing and analyses experience in projects for both the government and private industry. This expertise, along with the versatility of the ADL test system, has allowed a variety of units to be evaluated and analyzed. These range from small, individual cells to large battery systems. Also of interest have been electrolyte flow and high-temperature systems.



*An Argonne researcher measures the voltage on a test battery.*

---

## Results and Accomplishments

An excellent relationship has been established between the ADL and battery developers, manufacturers, and sponsors. More than 4,000 cells, ranging from individual 4-Wh cells to 22-kWh batteries, have undergone performance and lifetime evaluations for electric vehicle, utility load-leveling, and standby power applications. These evaluations covered more than 12 technologies from more than 18 battery developers. The following are among the more significant contributions made in the areas of battery development, testing, and application:

- Different sizes and types of battery systems can now be compared on an equivalent basis because of data normalization techniques developed at the ADL;
- Batteries can now be evaluated more economically because the ADL demonstrated that electric vehicle range projections based on laboratory test data can accurately predict the ranges measured in vehicle tests; and
- R&D needs have now been better defined as a result of identifying component failure mode and reliability issues and demonstrating that battery power losses are predictable when based on battery internal resistance and heating.

## Contacts

For technical information, contact Kevin Michael Myles, Electrochemical Technology Program, Chemical Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-4329; Fax: (708) 252-5528.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

# Polymer-Electrolyte Fuel Cells for Transportation

*Fuel cells are strong candidates to replace the internal combustion engine because they are energy-efficient, fuel-flexible, and clean. With polymer electrolytes, useful power can be drawn at room temperatures.*

## Opportunity

Transportation accounts for approximately one-fourth of all energy consumed in the United States and two-thirds of U.S. petroleum use. As domestic oil production declines, more efficient power systems are needed for transportation vehicles, especially those that use alternative fuels. Meanwhile, the internal combustion engine is a major cause of urban air pollution. Developing fuel-cell power systems might resolve both problems.

Use of fuel cells could dramatically lower both petroleum consumption and "tailpipe emissions" if applied to transportation vehicles. Operating efficiencies in the 35% to 50% range are expected for transportation applications, compared with about 20% for internal combustion engines. Because fuel cells operate far below the combustion temperature of an engine, a fuel-cell-powered vehicle would have near-zero emissions.

## Fuel Cell Technology

Fuel cells are electromechanical devices that convert the energy of a chemical reaction directly into electricity. In a typical system, hydrogen and oxygen from air react to produce electricity, heat, and water. The hydrogen fuel may be in the form of a stored gas, or it may be processed from a hydrogen-rich fuel, such as natural gas, methanol, or coal.

## Argonne Approach

Argonne National Laboratory is pursuing fuel-cell transportation R&D along several technical paths. One approach is based on a fluorocarbon ion-exchange membrane as the electrolyte of the fuel cell. This type of membrane can carry higher current densities than electrolytes now in use.

## Advantages

Using a solid polymer electrolyte instead of a liquid simplifies sealing and reduces corrosion. But the greatest advantage of the technology is its ability to operate at temperatures below 100° C. Useful power can be drawn from the cell at room temperature, which means faster, easier start-ups.

## Technical Concept

A drawback of the low operating temperature is the fuel-cell's limited tolerance for carbon monoxide, a byproduct of hydrogen manufacture. Argonne is investigating alternative electrocatalysts that are less susceptible to fuel impurities.

## Status

Using fundamental scientific principles and electrochemical characterization techniques, Argonne is exploring binary and ternary metal alloys as potential new catalysts.

## Future Plans

Improved catalysts will be provided to fuel-cell manufacturers.

## Contacts

For technical information, contact Michael Krumpelt, Chemical Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: 708/252-8520; Fax: 708/252-4176.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: 708/252-5230.

## Solid-Oxide Fuel Cells for Transportation

*Fuel cells are strong candidates to replace the internal combustion engine, but their size and weight need to be reduced greatly before they are commercialized. Ceramic technology can help accomplish this by eliminating the cumbersome external reformer.*

### Opportunity

Although the internal combustion engine—a mature technology, surely—has been under constant development for over 100 years, it is largely responsible for much of the air pollution associated with urban America. Clearly, in the face of declining domestic petroleum production and increased reliance on foreign energy resources, alternative fuels and unconventional power systems are high priorities for transportation research.

Fuel cells represent an important new technology to dramatically lower both petroleum use and “tailpipe emissions,” if applied to transportation vehicles. Operating efficiencies in the 35% to 50% range are expected for fuel cells, compared with about 20% for internal combustion engines. Because fuel cells operate far below the combustion temperature of an engine, fuel-cell-powered vehicles would have near-zero emissions.

### Fuel Cell Technology

Fuel cells convert chemical energy directly into electricity. In a typical system, hydrogen and oxygen from air react to produce electricity, heat, and water. The hydrogen fuel may be in the form of a stored gas, or it may be processed (reformed) from such hydrogen-rich fuels as natural gas (methane), methanol, or coal.

### Argonne Approach

Argonne National Laboratory is pursuing several paths in fuel-cell transportation R&D. One approach is to develop a solid-oxide (ceramic) fuel cell. Because they operate at higher temperatures, solid-oxide fuel cells do not need platinum or other precious metals as catalysts. They are also much more tolerant of fuel impurities (e.g., carbon monoxide) than are lower temperature systems.

### Advantages

A solid-oxide power system has relatively few components. Because the system comprises all-ceramic structures, solid-oxide fuel cells may need less maintenance and be less expensive than other fuel-cell approaches. Most important, the solid-oxide system needs no reformer to split off elemental hydrogen from the hydrogen-rich fuel. The necessary reforming is internal to the

system. This means potentially large weight savings and a more compact system.

### Technical Concept

Argonne is developing materials and fabrication methods for a ceramic fuel cell that would fit into a passenger car. The new materials will improve the power density of the fuel cell and allow rapid start-up.

### Status

Development of this new solid-oxide fuel cell is still in the laboratory phase, but it may gain momentum under the Partnership for a New Generation Vehicle.

### Future Plans

The next step in this development is building a prototype that is large enough for system demonstration.

### Contact

For technical information, contact Michael Krumpelt, Chemical Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: 708/252-8520; Fax: 708/252-4176.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: 708/252-5230.

## Driving a "Laboratory" Around a Lab

If your home can be your castle, then perhaps a car can be a laboratory. In fact, Argonne National Laboratory employees driving test vehicles at Argonne's Illinois site are working in moving laboratories. The employees are participating in an experiment to evaluate cars and trucks running on fuels other than gasoline.

With 55 vehicles, Argonne's Center for Transportation Research is the nation's largest alternative-fuels fleet demonstration center. Included are vehicles powered by methanol (alcohol derived from natural gas or wood), ethanol (alcohol made from grain), and natural gas.

Alternative fuels are one way to minimize exhaust emissions (hydrocarbons, carbon monoxide, and nitrogen oxides) that contribute to air pollution and global warming. Federal law requires that alternative-fueled vehicles be included in government automobile fleets beginning in 1997 and in private fleets beginning in 1998.

Argonne employees use the cars powered by alternative fuels in their daily work, which is as varied as hauling equipment and driving to meetings. The information gathered about the daily performance of the cars aids not only federal agencies that will purchase these types of cars, but car makers and others as well. The information will be available to researchers through a computer data base.

Argonne's alternative-fuels fleet includes mid- and full-sized sedans, burning either ethanol or methanol, and vans and trucks using natural gas. Gasoline-powered vehicles of the same type are used to gather comparison data. The experiment runs for three years.

Most of the flexible-fuel vehicles use methanol during the experiment, but they can use any mix of gasoline and alcohol without modifications. Several flexible-fuel cars use ethanol and gasoline only.

Drivers log mileage and performance for each trip taken. These data and vehicle fuel economy and maintenance records are compiled. Argonne is analyzing additional information on performance, average outdoor temperatures, and emissions for a more precise evaluation of various vehicles and types of fuels and weather.

In an earlier study, Argonne drivers logged more than 1 million miles in methanol-fueled vehicles.

### Contacts

For technical information, contact Bob Larsen, Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-3735; Fax: (708) 252-3443.

For information on working with Argonne, contact the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.



*Argonne's alternative-fueled demonstration fleet includes mid- and full-sized sedans, vans, and trucks. Shown here is a Chevrolet natural gas-powered truck.*

## DOE/Industry Competitions Advance Alternative-Fueled Automotive Technologies

Since 1987, the U.S. Department of Energy (DOE) has sponsored 21 different college and high school engineering competitions through Argonne National Laboratory that give students the opportunity to design and build a wide range of alternative-fueled vehicles. Approximately 5,400 students have benefited from the program since its inception. In 1993, more than 2,000 students took part in building approximately 100 competition vehicles. DOE's investment has been under \$750,000, and the cost per student for six to nine months of hands-on engineering experience has been less than \$350.

DOE's objectives in funding the student vehicle competitions are as follows:

### Technical Objectives

- Advance the state of the art in fuel systems and powertrains and document student designs and vehicle accomplishments.
- Support innovations and ongoing research resulting from involvement in these competitions. Examples include:
  - Northwestern University developed a gas quality sensor, Old Dominion University developed a gaseous fuel injector, and other teams developed several complex emission-control systems.
  - Four universities were awarded \$1.1 million in research grants on the basis of their competition experience.
  - Three university hybrid-electric vehicles were used to help validate the draft Society of Automotive Engineers Hybrid-Electric Vehicle Emissions Procedures.
  - At least eight student design documents and five nonstudent design documents have been published.

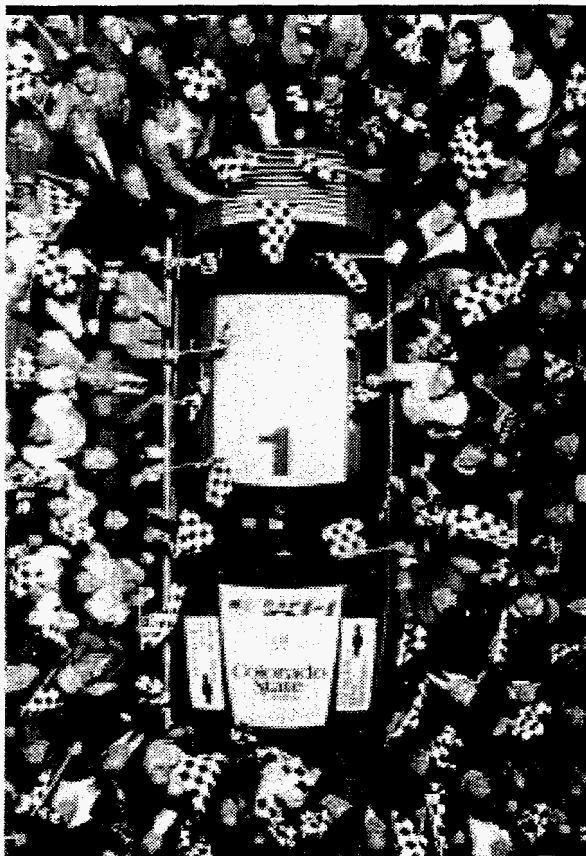
### Educational Objectives

- Increase students' engineering knowledge through work on "real world" problems outside of the classroom.
- Provide students with hands-on experience, which often results in opportunities for automotive industry employment.

- Excite students about careers in science. The high school events have interested many students in science careers.
- Inform and educate the public about alternative-fuel technologies.

### Institutional Objective

Obtain industry participation to improve the relationship between DOE and industry, other government agencies, the Society of Automotive Engineers International, and academia.



*Since 1987, the U.S. Department of Energy (DOE) has sponsored 21 alternative-fueled vehicle competitions—involving thousands of students—through Argonne National Laboratory. The competitions provide students with hands-on experience and help bring advanced transportation into today's marketplace.*

# Surface Acoustic Wave Chemical Sensors Accurately Monitor Emissions in Real-Time

*Chemical sensors offer sensitivity, ruggedness, and compact size for environmental emissions monitoring.*

## Opportunity

Sensors that reliably monitor emissions and detect toxic chemicals can aid air-pollution measurements and industrial and automotive emissions monitoring.

## Argonne Approach

Argonne National Laboratory is developing various surface acoustic wave (SAW) chemical sensors for environmental emissions monitoring and toxic chemicals detection. Researchers are studying thin-film technology, coating techniques, and surface chemistry. Artificial neural networks are being evaluated and applied to pattern recognition for sensing gas mixtures. Special coating materials for sensing radionuclides are also being assessed.

## Advantages

Chemical sensors offer many attractive features for emissions monitoring, including sensitivity, ruggedness, and compact size. In addition, these sensors are relatively inexpensive and provide on-line, real-time, and in-process monitoring.

## Technical Concept

A surface acoustic wave chemical sensor consists of two arrays of interdigital transducers (ITD) deposited on a piezoelectric substrate, a ST-quartz or a lithium niobate crystal, and a chemical selective coating bonded on the surface between the ITDs. The sensing principle is based on the mass-loading effect on SAW propagation velocity. When a chemical under detection is absorbed by the coating, the SAW propagation velocity, and thus, the SAW frequency established between the two ITDs, will be altered. The amount of change in frequency or velocity gives a quantitative measure of the chemical. Because the frequency change is proportional to the square of the operating frequency and the chemical mass, a SAW sensor increases its detection sensitivity when the operating frequency is raised.

The selectivity of a SAW sensor depends on the application of the proper coating material. This has been demonstrated in detection of trace gases such as carbon monoxide (CO), methane, and  $\text{SO}_x$ . The SAW sensor can be applied to gas mixture detections by using an array-sensor

design coupled with pattern recognition algorithms.

## Status

Argonne researchers are focusing on thin films that can sustain high-temperature environments and are chemically sensitive to the targeted gases, including  $\text{NO}_x$ , CO, carbon dioxide, and hydrocarbons. In the initial phase of the program, researchers will work on the basic configuration of a SAW chemical sensor and the basic design of a flexural-plate-wave chemical sensor. (See figures.)

## Contacts

For technical information, Shuh-Haw Sheen, Energy Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (708) 252-7502; Fax: (708) 252-3250.

For information on working with Argonne, the Industrial Technology Development Center, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439. Phone: (800) 627-2596; Fax: (708) 252-5230.

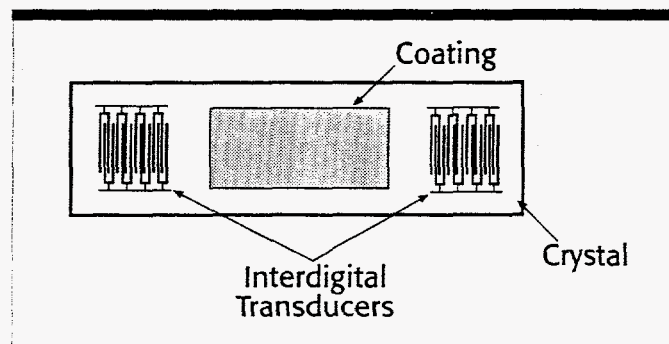


Figure 1: The basic configuration of a surface-acoustic-wave chemical sensor.

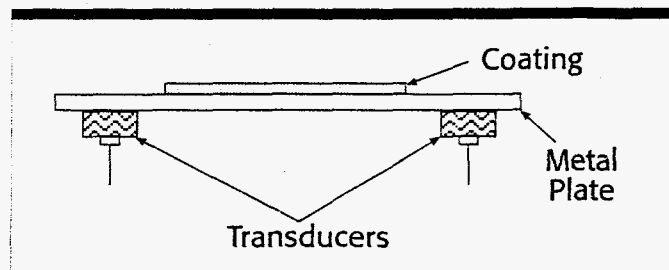


Figure 2: The basic design of a flexural-plate-wave chemical sensor.

# Industrial Thermal and Mechanical Processes

Argonne is a multiprogram research and development laboratory operated by the University of Chicago for the U.S. Department of Energy. Applied research is performed within the Thermal and Mechanical Sciences Section of the Energy Technology Division. Current program areas include compact evaporators and condensers for the process and transportation industries, ice slurries for district cooling, advanced fluids for improved heat transfer and reduced pressure drop, flow-induced vibration and flow distribution in shell-and-tube heat exchangers, and dynamics and control of maglev systems. In general, the objective of the research is to extend the technology base in each of these areas and to facilitate its application in solving problems of importance to U.S. industries and utilities. This is accomplished by developing validated design correlations and predictive methods.

The staff of the Thermal and Mechanical Sciences Section have extensive experimental and analytical experience in heat transfer, multiphase flow, structural dynamics and control, fluid/structure interaction, transient flow and mixing, thermally driven flows, and flow visualization by ultra-high-speed video. Large general-purpose test facilities and smaller single-purpose test apparatuses are available for experiments and evaluation of component design. A world-class capability in the study of flow-induced vibrations is available within the Section.

The U.S. Department of Energy encourages Argonne to work with industry in order to transfer technology developed at the Laboratory to industry, and contribute to the development of new and/or improved components and processes. Such industrial interaction is expected to improve the competitiveness of U.S. industry in world markets and to create jobs. Various arrangements for working with industrial companies are available. These include Cooperative Research and Development Agreements, or CRADAs (parties share the cost of research and the company may elect ownership of resulting intellectual property); Work for Others R&D (the company pays full costs and retains commercial rights to intellectual property), and Personnel Exchange (typically six months to one year, with the company paying its share of costs).

For general information on the programs and capabilities of Thermal and Mechanical Sciences, and to learn of opportunities for industry to work with the Section on problems in the research areas described above or on related problems of specific interest, contact: Dr. Martin W. Wambsganss, Manager, Thermal and Mechanical Sciences Section, (708)252-6144 FAX:(708)252-5568. For information on technology transfer working arrangements, contact the Industrial Technology Development Center, (800)627-2596.

*Individual fact sheets are available on currently active research program areas and related facilities. Each fact sheet provides the name of the principal investigator as a contact.*

Compact evaporators  
and condensers



Ice slurries for district  
cooling



Advanced fluids



Flow-induced vibration  
in shell-and-tube heat  
exchangers



Dynamics and control  
of maglev systems



Experimental and  
analytical capabilities



Extensive test facilities



Working with industry  
CRADAs

Work for Others R&D  
Personnel Exchange



# Industrial Thermal and Mechanical Processes

## Flow-Induced Vibration & Flow Distribution in Shell-and-Tube Heat Exchangers

*Energy Technology Division*

### Features

- Eliminate unexpected maintenance cost.
- Extend useful life.
- Reduce construction cost.
- Increase efficiency.
- Reduce risk in nuclear power plants.

### Applications

- Conventional heat exchangers.
- Steam generators.
- Boilers and condensers.
- Heat transfer equipment in process industries.
- Aerospace, civil, and undersea technology.

### State of the art

- Flow-induced vibration continues to be an operational problem resulting in extensive unexpected maintenance and replacement cost.
- Excitation mechanisms are now understood.
- Flow-induced vibrations cannot be predicted completely.
- Design guidelines are available to avoid major detrimental flow-induced vibration.
- Techniques are available to identify the root cause of flow-induced vibration.
- Effective and reliable computer codes for flow distribution in heat exchangers are not commercially available.

### Argonne research program

#### *Objectives:*

Develop analytical models and measure necessary fluid forces; develop general guidelines to identify root cause after the problems occur; predict and avoid detrimental vibration in design stage.

#### *Work Scope:*

- Mathematical models of fluid/structure interaction and excitation mechanisms in energy systems, including subcritical vibration, instability, parametric resonance, lock-in resonance, and chaotic vibration.
- Experiments to characterize response of tube arrays in crossflow and to validate mathematical models based on the unsteady flow theory.
- Measurement of motion-dependent fluid forces.
- Characterization of flow field and its relationship to motion-dependent fluid forces and fluid/structure interaction phenomena.

# Industrial Thermal and Mechanical Processes

## Argonne test facilities

- 500 and 8000-gpm water loops.
- Water channel.
- Heat Exchanger Test Facility.
- Electrodynamic vibration exciters.
- Computer-based data acquisition and processing.

## Selected publications (available upon request)

"Flow-Induced Vibration of Circular Cylindrical Structures," S. S. Chen, Hemisphere Publishing Co. (1987).

"Flow-Induced Vibration of an Array of Cylinders, Part 1 and Part 2," S. S. Chen, The Shock and Vibration Digest, Vol. 23, pp. 3-9 (1991) and Vol. 24, pp. 3-11 (1992).

"A General Theory for Dynamic Instability of Tube Arrays in Crossflow," S. S. Chen, J. Fluids and Structures, Vol. 1, pp. 35-53 (1987).

"Vibration of Nuclear Fuel Bundles," S. S. Chen, Nuclear Engineering and Design, Vol. 35, pp. 399-422 (1975).

Guidelines for the Instability Flow Velocity of Tube Arrays in Crossflow," S. S. Chen, J. Sound and Vibration, Vol. 93, pp. 439-455 (1984).

## Industrial interaction

U.S. DOE encourages its National Laboratories to promote technology transfer and to work with industry to increase competitiveness in world markets and to create jobs.

## Working arrangements

- Cooperative Research and Development Agreement.
- Work-for-Others contract.
- Personnel exchange.
- Licensing program.
- Technical consulting.

## For further information

Dr. Shoëi-sheng Chen  
Principal Investigator: Thermal and Mechanical Sciences Section  
(708)252-6147 FAX:(708)252-5568



# Industrial Thermal and Mechanical Processes

## Ice Slurries for District Cooling

*Energy Technology Division*

### Features

- Ice slush made in central cooling plant.
- Slurry of 5 to 30% ice crystals in water piped to distributed users; warm water returned to plant.
- Users no longer need chillers; they utilize slurry directly in air handler or store for load shifting.
- High energy content of ice slurry allows significant reductions in size of pipes, pumps, and storage tanks and reduces pumping, air handling, and chilling costs over conventional chilled water systems.
- Greatly facilitates load management, reduces peaking problems, and enhances switch to environmentally safer refrigerants, reducing costs to individual users.

### Applications

- Central city locations for cooling offices, factories, shopping facilities, or government complexes tied together by a common slurry-delivery piping network.
- Large food-processing and industrial complexes such as petrochemical plants where load management and cost reductions by elimination of many separate smaller chillers are possible.

### State of the art

- Argonne in its test facilities pioneered the concept of ice slurry cooling and established that ice slush could be pumped as easily as water.
- Various manufacturers are developing ice slush makers.
- Argonne, Northern States Power, and EPRI designed and built a small-scale (80 ton) first-of-its-kind demo in Minneapolis.
- Argonne is developing plans for a first-of-its-kind commercial-scale demonstration (>500 ton) at its site near Chicago, together with a utility and equipment manufacturers.

### Argonne research program

#### *Objective:*

Develop correlations and predictive methods that will facilitate the design and optimization of ice slurry district cooling systems and their components; foster the technology and facilitate its transfer to the private sector.

#### *Work scope:*

Ice slurry flow and heat transfer experiments conducted in large-scale pipes, heat exchangers, pumps, storage tanks and other equipment such as slush makers.

#### *Sponsors:*

U.S. DOE Office of Energy Efficiency and Renewable Energy (Advanced Utility Systems), and Electric Power Research Institute.

# Industrial Thermal and Mechanical Processes

## Argonne test facilities

- Flow and Heat Transfer Test Facility, capable of up to 2000 gpm flow over a wide range of computer-controlled thermal-hydraulic conditions simulating steady and unsteady loading of energy system equipment.
- Plans are being developed for a large commercial-scale ice slurry cooling system to be built at Argonne for use in demonstrating and further developing technology relative to optimal hardware, controls, and operating philosophy.

## Selected publications (available upon request)

"Ice Slurry Cooling: Development and Field Testing," by K. E. Kasza, J. Hietala, R. D. Wendland, and F. Collins, *Proc. International District Heating and Cooling Assn.*, 229-235 (1992).

"Impact of Advanced Fluids on Costs of District Cooling Systems," by U. S. Choi, D. M. France, and B. D. Knodel, *Proc. International District Heating and Cooling Assn.* (1992).

"Advanced Energy Transmission Fluids for Heating and Cooling Systems," by K. E. Kasza, U. S. Choi, and J. Kaminsky, *ASHRAE Transactions*, Vol. 93, Part 2, Jan. (1988).

"Measurement of Pressure Drop and Heat Transfer In Turbulent Pipe Flows of Particulate Slurries," by K. V. Liu, U. S. Choi, and K. E. Kasza, *Argonne National Laboratory Report ANL-88-15*, May (1988).

"Assessment of Impact of Advanced Energy Transmission Fluids on District Heating and Cooling Systems (Phase D)," by K. E. Kasza and M. M. Chen, *Argonne National Laboratory Report ANL-87-21*, Sept. (1987).

"Improvement of the Performance of Solar Energy and Waste Heat Utilization Systems by Using Phase-Change Slurry as an Enhanced Heat-Transfer Storage Fluid," by K. E. Kasza and M. M. Chen, *ASME J. of Solar Engineering*, Vol. 107, 229-236, Aug. (1985).

"Development of Enhanced Heat Transfer/Transport/Storage Slurries for Thermal Systems Improvement," by K. E. Kasza and M. M. Chen, *Argonne National Laboratory Report ANL-82-50*, June (1982).

## Industrial interaction

U.S. DOE encourages its National Laboratories to promote technology transfer and to work with industry to increase competitiveness in world markets and to create jobs.

Northern States Power.

Commonwealth Edison Company.

ITT Fluid Handling Division.

## Working arrangements

- Cooperative Research and Development Agreement.
- Work-for-Others contract.
- Personnel exchange.
- Licensing program.
- Technical consulting.

## For further information

Dr. Kenneth E. Kasza

Principal Investigator: Thermal and Mechanical Sciences Section

(708)252-5920 FAX:(708)252-5568



# Industrial Thermal and Mechanical Processes

## Advanced Fluids

### *Energy Technology Division*

#### Features

- Drastically reduced pressure drop.
- Improved heat transfer.
- High energy-carrying capacity.
- High energy-storage density.
- Environmentally safe materials and methods.

#### Applications

- Building hydronic heating and cooling systems.
- Industrial process heating and cooling in petrochemical, textile, pulp and paper, chemical, food, and other process plants.
- Utilities: power plants and district heating/cooling systems.
- Transportation industries (vehicular and avionics cooling systems).
- Cooling of advanced electronic packages.
- Other applications that require small and light thermal systems with high heat transfer rates.

#### State of the art

- Conducted proof-of-concept tests of advanced fluids that resulted in significant energy savings, size/weight savings, and thermal system performance enhancements.
- Demonstrated merits of using liquid nitrogen in microchannels with characteristic dimensions of less than 0.1 mm.
- Developed innovative microchannel cooling technology for applications in the Advanced Photon Source and high-temperature superconducting magnets.
- Developed concept of environmentally safe friction-reduction methods.
- Developed the concept of nanofluids for advanced industrial heat transfer fluids.

#### Argonne research program

##### *Objective:*

Develop energy efficient and cost-effective advanced fluids for a variety of industrial applications.

##### *Work scope:*

Rheological characterization of advanced fluids and pressure drop /heat transfer experiments.

##### *Research partner:*

Argonne's Materials Science Division.

##### *Sponsors:*

U.S. DOE Offices of Energy Efficiency and Renewable Energy (Utility Systems Division) and Energy Research.

# Industrial Thermal and Mechanical Processes

## Argonne test facilities

- Non-Newtonian flow and heat transfer test loop.
- Pilot-scale heating and cooling system simulator.
- State-of-the-art rheological instrumentation.

## Selected publications (available upon request)

Cha, Y. S., J. R. Hull, and U. S. Choi, "Cryostabilization of High-Temperature Superconducting Magnets with Subcooled Flow in Microchannels," *IEEE Trans. Appl. Superconductivity*, Vol. 3, No. 1, pp. 172-176, 1993.

Choi, U. S., C. S. Rogers, and D. M. Mills, "High-Performance Microchannel Heat Exchanger for Cooling High-Heat-Load X-ray Optical Elements," *Micromechanical Systems*, eds. D. Cho, J. P. Peterson, A. P. Pisano, and C. Friedrich, The American Society of Mechanical Engineers, New York, DSC-Vol. 40, pp. 83-89 (Nov. 1992). Also presented at ASME Winter Annual Meeting, Anaheim, CA, Nov. 8-13, 1992.

Choi, U. S., Y. I. Cho and K. E. Kasza, "Degradation Effects of Dilute Polymer Solutions on Turbulent Friction and Heat Transfer Behavior," *J. Non-Newtonian Fluid Mechanics*, Vol. 41, pp. 289-307, 1992.

Choi, U. S., D. M. France, and B. D. Knodel, "Impact of Advanced Fluids on Costs of District Cooling Systems," *Proc. 83rd Ann. Int. District Heating and Cooling Assoc. Conf.*, Danvers, MA, June 13-17, 1992, The Int. District Heating and Cooling Assoc., Washington, DC, pp. 343-359, 1992.

Choi, U. S. and T. N. Tran, "Experimental Studies of the Effects of non-Newtonian Surfactant Solutions on the Performance of a Shell-and-Tube Heat Exchanger," *Recent Developments in Non-Newtonian Flows and Industrial Applications*, eds. D. A. Siginer and M. N. Dhaubhadel, The American Society of Mechanical Engineers, New York, FED-Vol. 124, pp. 47-52 (Dec. 1991). Also presented at the ASME Winter Annual Meeting, Atlanta, GA, Dec. 1-6, 1991.

## Industrial interaction

U.S. DOE encourages its National Laboratories to promote technology transfer and to work with industry to increase competitiveness in world markets and to create jobs.

## Working arrangements

- Cooperative Research and Development Agreement.
- Work-for-Others contract.
- Personnel exchange.
- Licensing program.
- Technical consulting.

## For further information

Dr. Stephen U.-S. Choi  
Principal Investigator: Thermal and Mechanical Sciences Section  
(708)252-6439 FAX:(708)252-5568



# Industrial Thermal and Mechanical Processes

## Compact Evaporator and Condenser Technology

### *Energy Technology Division*

#### Features

- High surface area density ratio ( $>700 \text{ m}^2/\text{m}^3$ ).
- Small size.
- Low weight.
- Reduced fluid inventory.
- Design flexibility (multiple streams).
- Pure counterflow.
- Low-temperature approaches.
- Uniform-temperature heating and cooling.

#### Applications

- Widely used in transportation industries (*vehicles, aircraft, space*)
- Process industries (*petroleum, chemical, food processing, pulp & paper, textiles*) are very energy-intensive; thus, potential exists for significant energy/cost savings with high-performance heat exchangers.
- Process industries have shown considerable interest in compact heat exchangers (CHEs) for select applications—for example, where clean fluids are involved, and size, weight, large surface area, or fluid inventory are of critical importance.

#### State of the art

- Advances in manufacturing and fabrication greatly extend the range of CHE application.
- Established design technology and accompanying data bases are nearly nonexistent for phase-change applications.
- Design advancement is typically on the basis of experience and experimentation on prototype units.
- Validated design correlations and industrial standards are lacking, thus impeding further application.

#### Argonne research program

##### *Objective:*

Develop correlations and predictive methods to facilitate design and optimization of compact evaporators and condensers for process-industry applications, leading to industry standards.

##### *Work scope:*

Multiphase flow and phase-change heat transfer experiments with small circular and noncircular channels representative of CHEs.

##### *Research partner:*

University of Illinois at Chicago, Department of Mechanical Engineering.

##### *Sponsors:*

U.S. DOE Offices of Energy Efficiency and Renewable Energy.  
and Energy Research, Laboratory Technology Transfer Program.

# Industrial Thermal and Mechanical Processes

## Argonne test facilities

- Small-channel flow boiling test apparatus.
- Small-channel condensing test apparatus.
- Two-phase gas/liquid flow test apparatus.
- Computer-based data acquisition and processing.

## Selected publications (available upon request)

"Two-Phase Flow Patterns and Transitions in a Small, Horizontal, Rectangular Channel," by M. W. Wambsganss, J. A. Jendrzejczyk, and D. M. France, *Int. J. Multiphase Flow* **17**(3), 327-342 (1991).

"Frictional Pressure Gradients in Two-Phase Flow in a Small Horizontal Rectangular Channel," by M. W. Wambsganss, J. A. Jendrzejczyk, D. M. France, and N. T. Obot, *Exp. Thermal and Fluid Science* **5**, 40-56 (1992).

"Two-Phase Flow and Pressure Drop in Flow Passages of Compact Heat Exchangers," M. W. Wambsganss, J. A. Jendrzejczyk, and D. M. France, *SAE Transactions*, **101**(5), pp. 482-491 (1992).

"Boiling Heat Transfer in a Horizontal Small-Diameter Tube," M. W. Wambsganss, D. M. France, J. A. Jendrzejczyk, and T. N. Tran, *Trans. of the ASME, J. Heat Transfer* **115**, pp. 963-972 (1993).

"Boiling Heat Transfer in a Small, Horizontal, Rectangular Channel," T. N. Tran, M. W. Wambsganss, D. M. France, and J. A. Jendrzejczyk, *Heat Transfer-Atlanta, AIChE Symp. Series* **89**(295), pp. 253-261 (1993).

"Determination and Characteristics of the Transition to Two-Phase Slug Flow in Small Horizontal Channels," M. W. Wambsganss, J. A. Jendrzejczyk, and D. M. France, *Trans. of the ASME J. Fluids Engineering* **116**, pp. 140-146 (1994).

## Industrial interaction

U.S. DOE encourages its National Laboratories to promote technology transfer and to work with industry in order to increase the competitiveness of U.S. industry in world markets and to create jobs.

Compact condenser research is conducted under a Cooperative Research and Development Agreement (CRADA) with Modine Manufacturing Company of Racine, WI.

## Working arrangements

- Cooperative Research and Development Agreement.
- Work-for-others contract.
- Personnel exchange.
- Licensing program.
- Technical consulting.

## For further information

Dr. Martin W. Wambsganss  
Manager, Thermal and Mechanical Sciences Section  
(708)252-6144, FAX: (708)252-5568.



## **Analysis of Failed Nuclear Power Station Components**

For more than 15 years, the Energy Technology (ET) Division at Argonne National Laboratory has provided failure analysis of nuclear power plant components to several electrical utilities. In that time, the ET Division has developed considerable experience in the failure analysis of both nuclear and nonnuclear components and has established extensive facilities to handle and examine radioactively contaminated materials. Broad expertise is also available in the ET Division in areas such as metallurgy, ceramics, corrosion, mechanical deformation, fracture mechanics, stress analysis, and nondestructive examination. Moreover, Argonne is not directly associated with any nuclear-equipment vendor or electrical utility.

### **Facilities, Capabilities, and Experience**

Decontamination is typically the first step in analyzing a failed component; the aim is to reduce the associated radiation field and remove loose activity that could unnecessarily contaminate facilities and equipment used in subsequent analyses. The ET Division maintains complete physical and chemical decontamination facilities that allow handling of relatively large components (up to several feet in size). Decontamination can be modified or omitted if it would affect subtle surface features of interest in the analysis. An associated service—available as needed—is disposal of nontransuranic radioactive waste from the analysis. For inspection and flaw detection in failed components, several nondestructive examination techniques can be used: these include conventional

and microfocused high-resolution X-radiography, gamma radiography with a 100-Ci iridium gamma source, ultrasonic inspection, conventional and fluorescent dye-penetrant examination, dry and fluorescent magnetic particle inspection, and eddy-current inspection. Certified Level II and III inspectors are available to conduct examinations. (Details of facilities and equipment are given on the reverse side.)

The facilities described here are operated by experienced professional staff or by trained technicians under staff supervision. Members of this professional staff are also available to provide technical assistance in the interpretation of analytical results, identify failure causes, and develop remedial actions.

