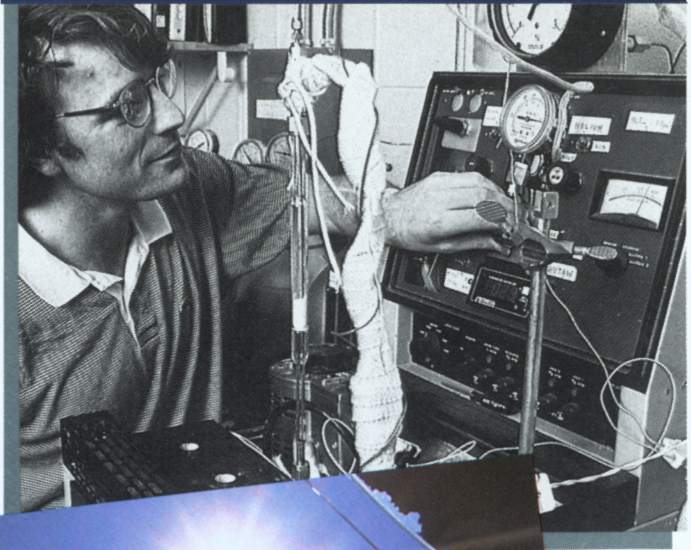
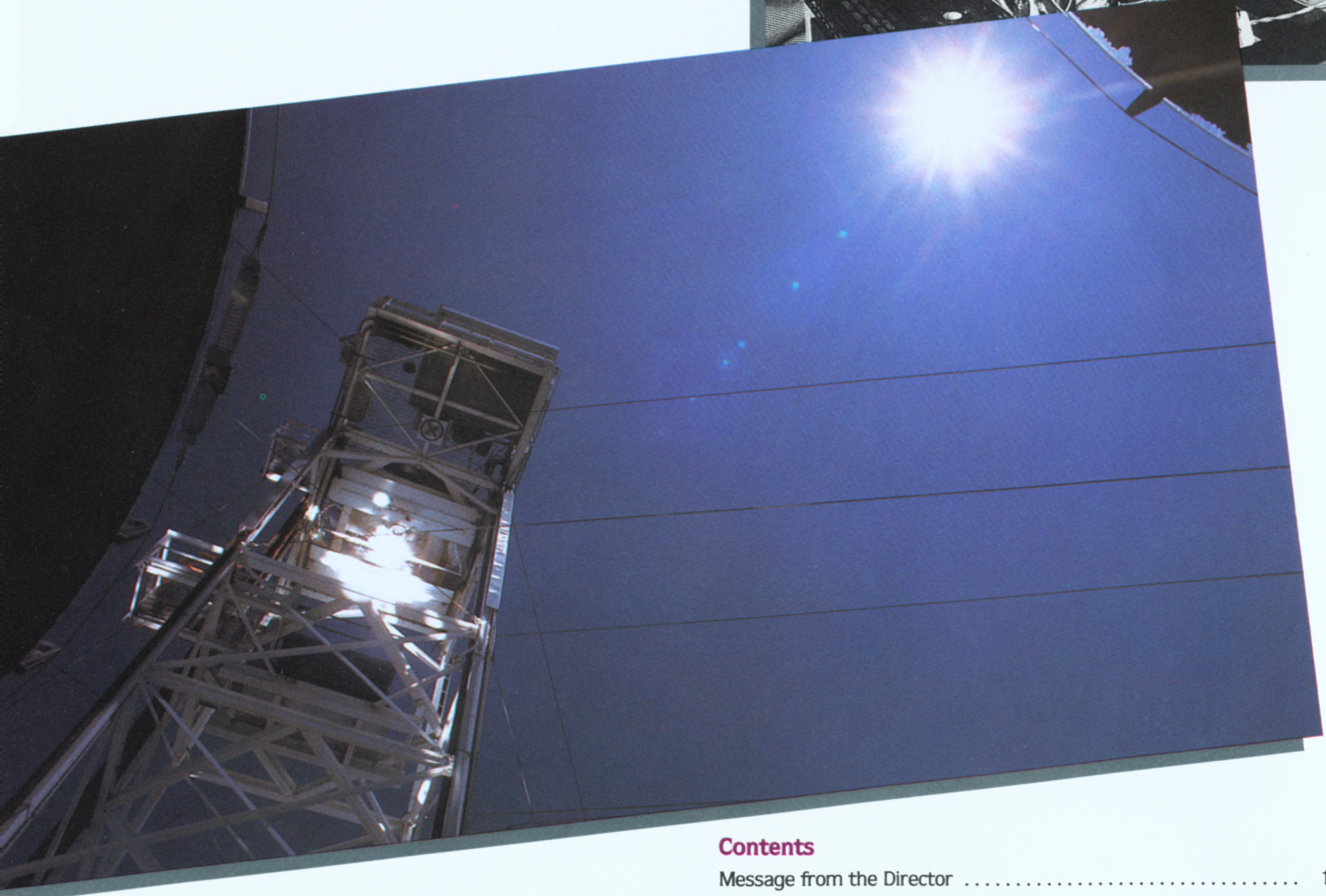
ENERGY AND MATERIALS SCIENCES LABORATORY

Georgia Institute of Technology
Georgia Tech Research Institute

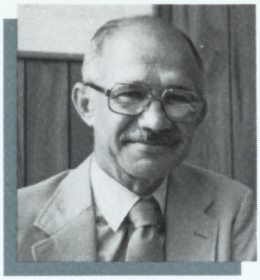




Contents

(On the cover) EMSL researchers have developed thermite reactions for the production of high-purity titanium diboride. *(Top of page)* This microreactor is used for testing new catalyst materials. *(Above)* The laboratory operates one of the country's largest solar thermal central receiver facilities.

MESSAGE FROM THE DIRECTOR



Hans O. Spauschus

We live in a time when the rapid expansion of technological horizons places an unprecedented demand upon the innovativeness and adaptability of our private and public institutions. Scientific research is the cornerstone of technological innovation, and the university affiliation of the Energy and Materials Sciences Laboratory (EMSL) of the Georgia Tech Research Institute (GTRI) places it in a strong position to make knowledgeable, unbiased contributions to leading-edge technology development.

EMSL is one of seven laboratories making up GTRI, which in turn is an integral part of the Georgia Institute of Technology. Personnel and facilities are located on the Georgia Tech campus in the heart of Atlanta. The laboratory is home for 45 professional engineers and scientists and a corps of full-time and part-time support personnel, with the latter including many Georgia Tech graduate and undergraduate students. EMSL offers R&D services to sponsors in industry and government on a not-for-profit basis, forming flexible, interdisciplinary scientific teams to address specific project goals. Interaction with other laboratories and academic staff is strong, and, when it will benefit the sponsor, EMSL augments its own pool of talent by incorporating in project teams appropriate personnel from Georgia Tech's 2,800-member faculty and staff.

As its name suggests, EMSL covers a range of research specialties. The staff has proven competence in fields as diverse as molecular sieve zeolites, anti-fouling membranes, biomass conversion, and thermoelectric power generation.

Client services vary widely and include materials synthesis and characterization, computer modeling and simulation, high-temperature material analysis and testing, prototype hardware development, and design and operation of research pilot plants.

The laboratory has access to extensive computer facilities and state-of-the-art instrumentation for materials synthesis and characterization. EMSL also conducts a variety of solar thermal energy experiments at the Advanced Components Test Facility, a 325kW central receiver test-bed on the Georgia Tech campus.

In the recent past, EMSL has strengthened and diversified its technical staff, updated its equipment and modernized assigned engineering facilities. The volume of contract research has doubled, and the sponsor base has broadened. The staff of the laboratory will continue to stress timely, cost-effective work performed in keeping with the highest professional standards.

EMSL areas of technical competence and strong research initiatives are highlighted in this booklet. We invite you to study them and contact us about your technology needs and interests. □

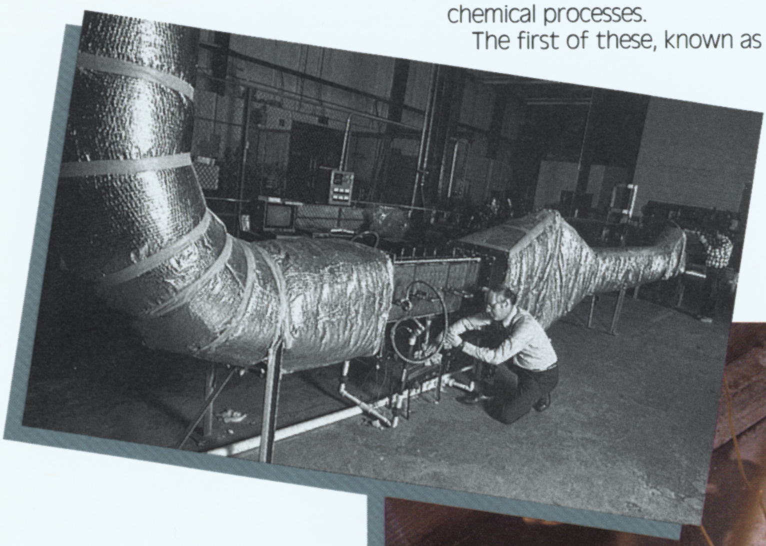
Hans O. Spauschus
Director

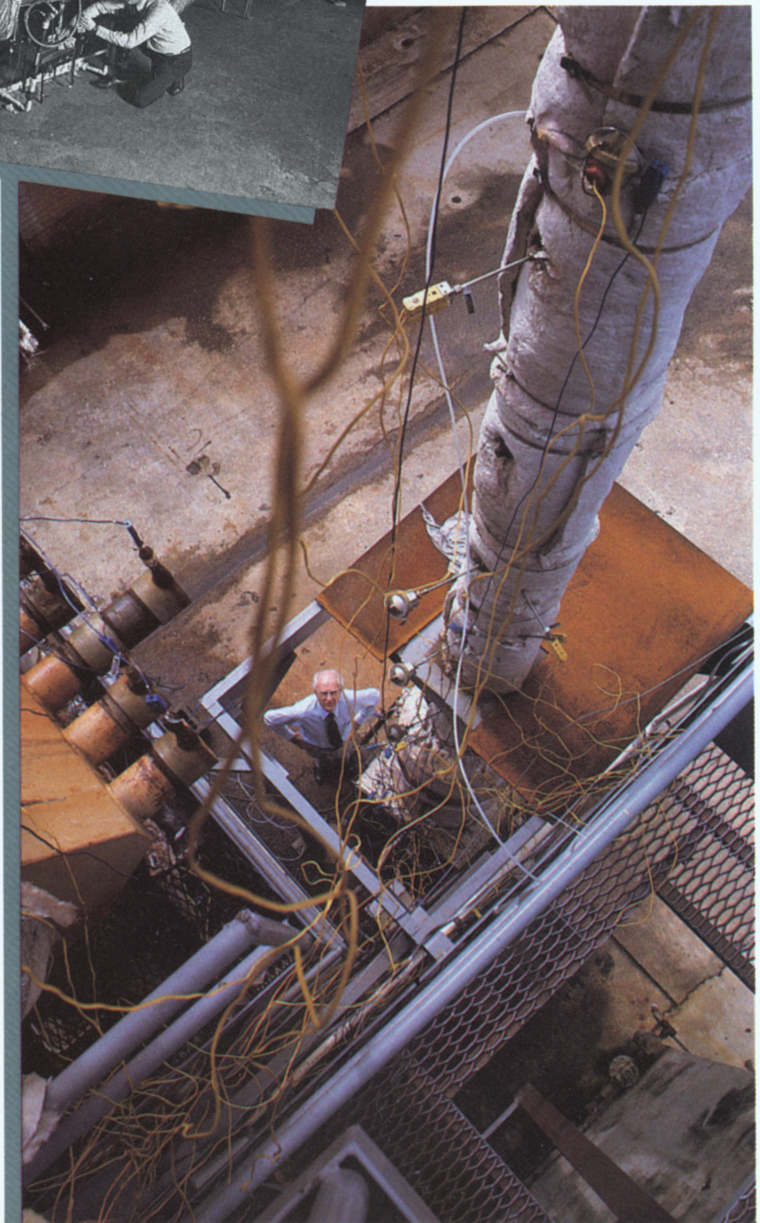
EMSL maintains facilities for characterizing a range of materials, including microelectronic devices.

ENERGY CONVERSION TECHNOLOGIES

THERMOCHEMICAL CONVERSION. Biomass, coal and other resources can be converted thermochemically to valuable fuels and chemicals. EMSL is a leader in liquefaction and gasification processing, as well as in advanced incineration technology. Recent research has led to three unique thermochemical processes.

The first of these, known as the Georgia Tech Entrained Pyrolysis Process, was developed by the laboratory and has been funded since 1980 by the U.S. Department of Energy. Experimental operations are now ongoing at a two-ton per day process research unit on the Georgia Tech campus. EMSL researchers have achieved 55% yields in conversion of hardwood feedstock to liquid fuel by a process which requires no external energy and is environmentally benign.





In an earlier development of note, the laboratory transferred the Georgia Tech Vertical Bed Pyrolysis Process to the private sector. Over a 10-year period, EMSL scientists and engineers scaled up this technology from bench tests through four pilot plant stages. Throughput capacity reached 25 tons per day. Gross energy recovery was 95% in the form of product yields based on dry feedstock.

A third significant thermochemical process resulted from development of an updraft gasifier rated at one MMBTU/hour. This gasifier incorporates an innovative air supply and a grateless, air-cooled grid design. Close-coupling to a modified natural gas burner has eliminated tar clogging. The unit is sized for pilot scale testing of burners, boilers, ovens, driers, kilns, and engines.

Related work in the laboratory has led to advances in carbon activation, drying, and pyrolytic oil stabilization and upgrading.

THERMOELECTRIC CONVERSION. Many industrial processes lose or under-utilize large amounts of low-grade thermal energy. EMSL is developing a large-scale thermoelectric generator for converting waste heat into economical electricity. Since thermoelectric conversion requires no rotating machinery, these generators are expected to be highly reliable, require minimum maintenance, and have a long operating life.

The thermoelectric generator designed and constructed by EMSL involves new concepts for integration of heat exchangers and thermoelectric modules. The first prototype, a 5 kW unit developed under contract for Omnimax, Inc., has been completed and is undergoing extensive performance tests. Larger units are planned. □

EMSL has developed: *(top left)* **a prototype thermoelectric generator for Omnimax Energy Corporation and** *(left)* **an entrained pyrolysis unit now achieving 55% yields in converting hardwood to liquid fuel.**

WASTE DISPOSAL TECHNOLOGY

In recent years, waste-disposal problems have grown more severe and regulations governing waste-disposal have become simultaneously more stringent. EMSL has broad experience in providing "high-tech" solutions to these environmental concerns.

The laboratory's research staff has developed thermochemical processes for a variety of disposal problems. Pyrolysis has been shown to be effective in disposing of explosive-contaminated materials for the military. Sludge and municipal solid wastes have been treated effectively using advanced incineration. Disposal technologies also have been studied for conversion of cotton gin trash, peanut hulls and industrial waste products to chemicals and fuels of higher value.

In addition, EMSL has evaluated and engineered several new reactor designs for the anaerobic digestion of poultry and cattle wastes. The laboratory has evaluated the Fulton County (Atlanta, Georgia) anaerobic digestion system and recommended cost-saving retrofits for the facility.

Under the sponsorship of the U.S. Environmental Protection Agency, EMSL is developing a chemical detoxification process, based on low-cost, naturally-occurring polymeric materials. As in many of the processes outlined above, energy recovery is an important consideration driving this development.

Finally, the laboratory is continuing a major study of waste control in biomass gasifiers. With funding from the Department of Energy, EMSL engineers are developing technology for safely controlling and utilizing waste streams in these gasifiers. A patent is pending on a new method of using thermochemical pretreatment of the waste tars and aqueous effluents before returning them to the gasifier as a supplementary feedstock. □

Engineers in EMSL have developed a novel technique for cleaning and recycling effluents produced in wood gasification furnaces.

SOLAR THERMAL RESEARCH

TEST FACILITIES. EMSL has been at the forefront of solar thermal energy technology since 1971. In 1977, a large, experimental solar thermal receiver was built on the Georgia Tech campus with support from the U.S. Department of Energy, and EMSL contracted to manage the facility. Today, the laboratory operates the nation's largest university-based research program in the solar thermal area.

The DOE receiver, known as the Advanced Components Test Facility (ACTF), has a field of 550 individually focused tracing mirrors (heliostats) which direct concentrated solar energy onto a 23-meter-high test platform. The resulting thermal power input to the focal zone is 325 kW at a 2,300-sun concentration.

DOE and the Department of Defense sponsor applied research at the ACTF. The facility's technical staff also tests sub-systems for private industry and other universities. Test programs provide on-line analysis of data, evaluations of safety requirements, and integrations of solar interfaces.

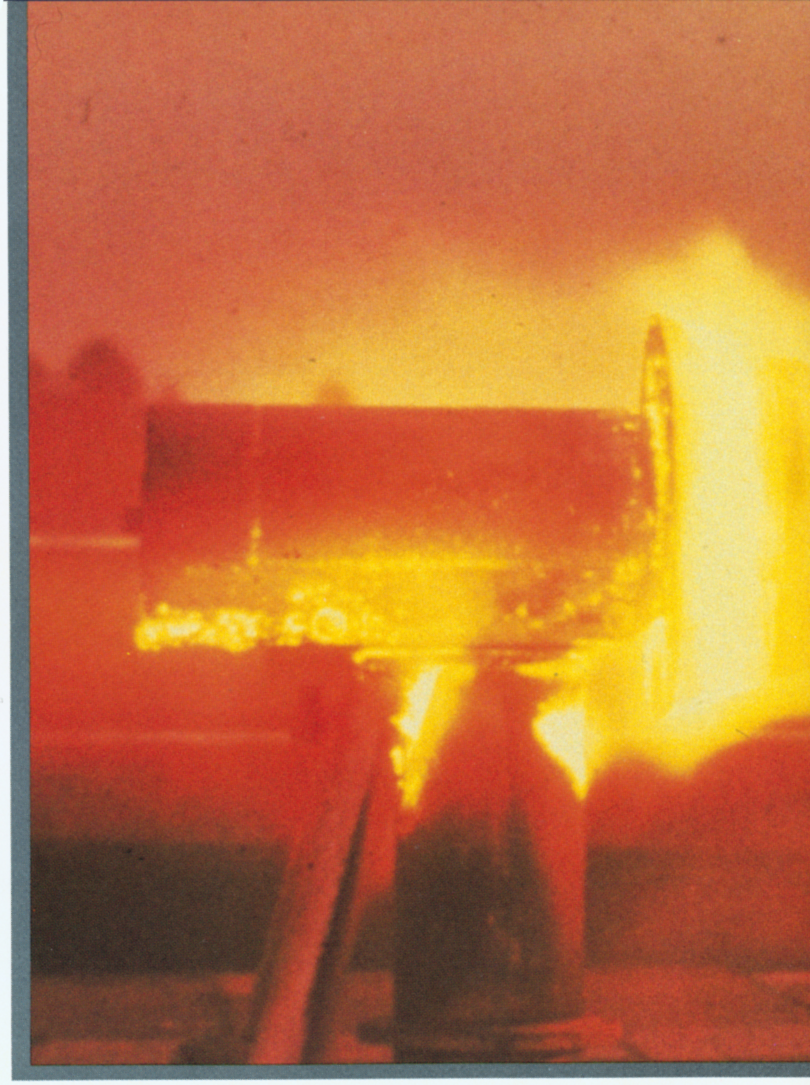
Organizations considering use of this facility should contact EMSL well in advance to schedule tests.

SURFACE MEASUREMENTS. Because thermocouples are unreliable in high-radiant-energy environments, it is a major challenge to evaluate the performances of solar thermal receivers under actual operating conditions. EMSL has developed a multi-spectral, solar-blind pyrometer that accurately measures both the emissivities and temperatures of surfaces exposed to intense solar flux.

REACTOR DESIGN. In direct-flux solar reactors, the high flux of visible and near-infrared radiation can drive chemical processes. EMSL has developed a direct-absorption, entrained-particle solar reactor, and tested it at the ACTF. Engineers use computer modeling of heat transfer, chemical processes, and particle scattering and absorption to produce parametric descriptions of reactor performance. □

(Far left) **550 individually focused tracing mirrors produce 325 kW of thermal energy.** *(Near left)* **An engineer works at the focal point of these mirrors, 23-meters-high.** *(Below)* **One of many experiments undertaken here was the successful mating of a Stirling engine with a solar power heat source.**

SPACE AND DEFENSE



SPACE POWER STATIONS. When the first U.S. space station goes into orbit, it will derive some of its electric power from a series of solar thermal devices. The shape that these collectors assume could depend on optical analyses made by solar researchers at EMSL. The lab is conducting computer modeling of various concentrator types to predict which could provide the best pattern of concentrated solar energy. This research will involve simulations of the space environment which are difficult to make under terrestrial conditions. NASA is considering the adoption of solar thermal collectors because they are four to five times more efficient than photovoltaic cells now in use on space satellites.

MATERIAL EVALUATIONS. Materials designed for high-temperature use often degrade much more rapidly if simultaneously exposed to high-energy radiation. Identification of the mechanisms of degradation is vital if materials are to be developed which will resist this environment. EMSL makes extensive use of computer modeling for predicting thermal, structural and chemical responses. The resulting models guide the laboratory's research on nonequilibrium properties of materials exposed to intense radiation. In addition to other candidate materials, EMSL researchers have extensively tested a wide variety of ceramic-based materials in radiation fields as high as 1,000 watts/cm^2 at temperatures in excess of 2,000° C.

SOLAR AND ELECTROMAGNETIC WINDOWS. Receivers sustain less convective and radiative losses when they have transparent windows containing reactants or absorbing media. EMSL has developed sol gel coatings to retard solar devitrification of fused quartz windows. Engineers have designed and tested mosaic window structures that can be scaled up for commercial-size solar reactors.

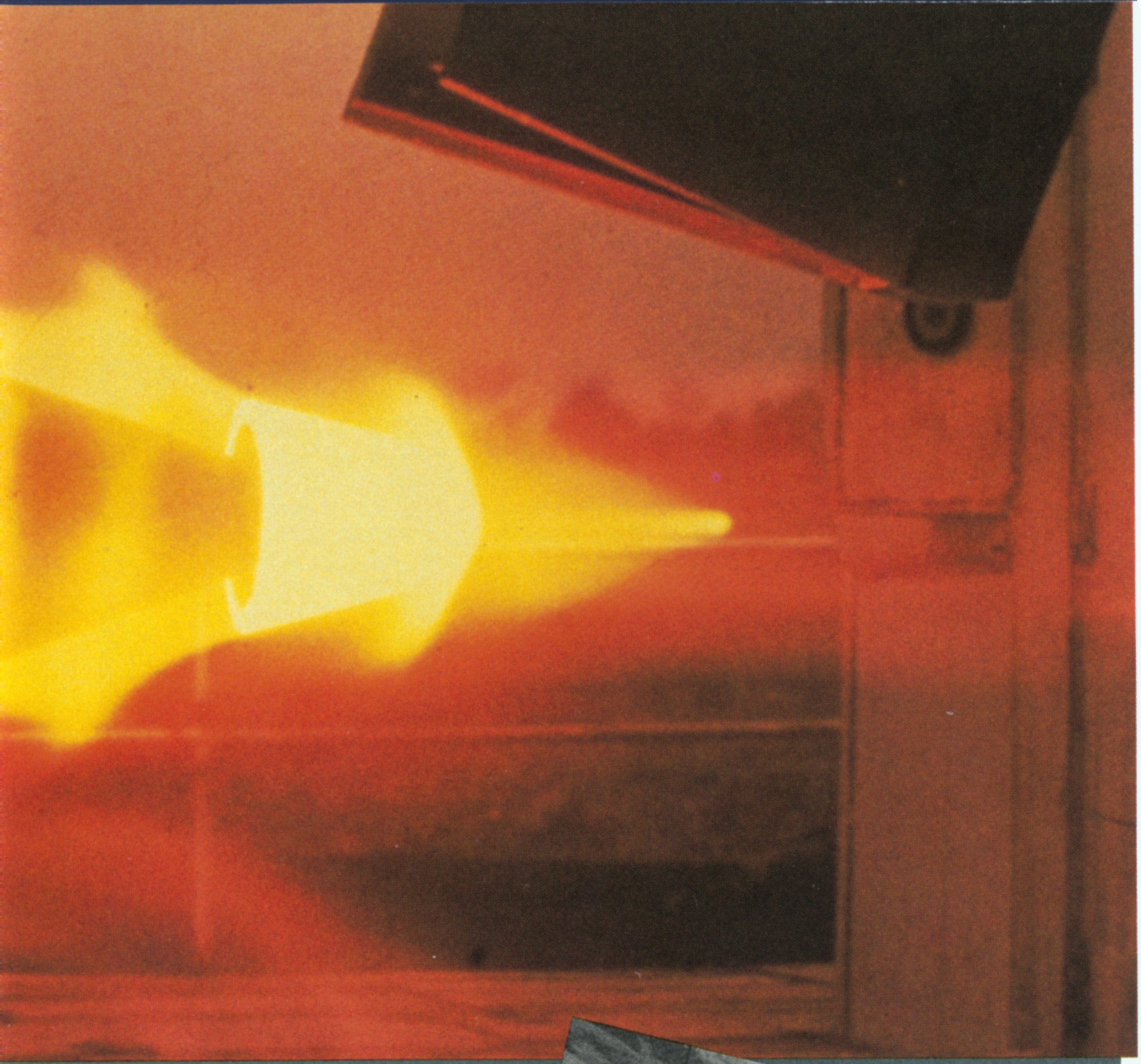
In the area of electromagnetic windows, EMSL has an internationally recognized reputation based on many years of radome development. The laboratory sponsors the biennial Electromagnetic Windows Conference held at Georgia Tech.

MODELING MATERIAL BEHAVIOR. The laboratory's extensive base of computer software programs allows experimental modeling of materials behavior in severe environments, such as those often associated with defensive weapons systems. Typical programs include:

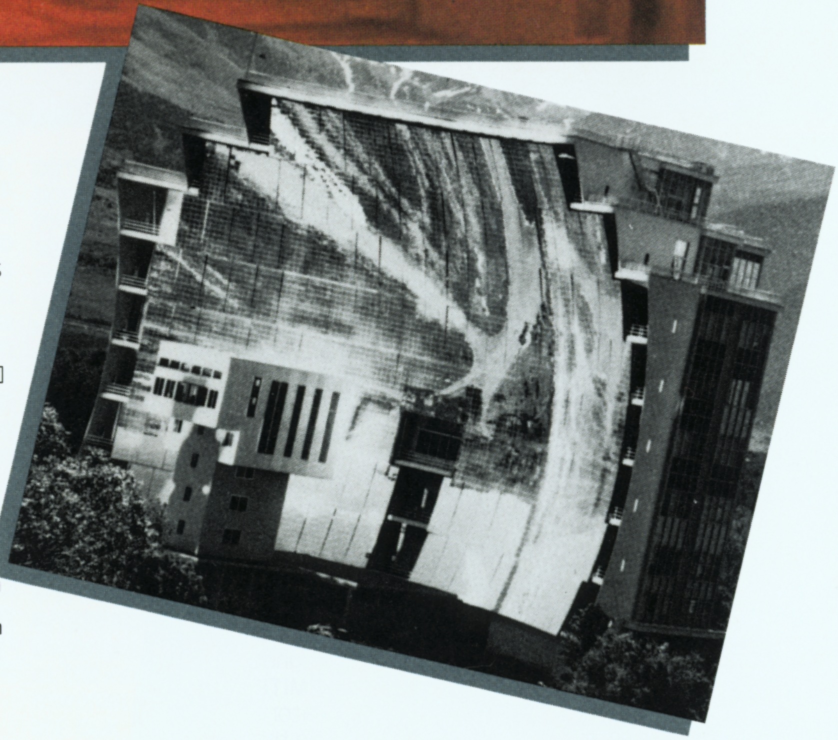
- The Georgia Tech Integrated Civil Engineering System/Structural Design Language (GTSTRUDL) for structural analysis.
- The Martin Interactive Thermal Analysis System Version 2 (MITAS II). MITAS is used to calculate temperature distributions from heat-transfer inputs.
- Optical analysis software, including geometrical optics (ray tracing) and Huygens-Fresnel surface integration. These programs analyze the flight-regime effects on missile radomes as well as the influences of blast and radiant heating on ground-based radomes.

Computer software also is available for modeling of supersonic flow fields (inviscid flow), viscous flow, aerodynamic heating and gas-dynamic/aerothermal analysis.

THERMAL PULSE EFFECTS. Computer analysis cannot adequately forecast the effects of a nuclear thermal pulse on materials near the site of an explosion. There is no substitute for actual testing, and EMSL has been using the French CNRS solar furnace since 1971 to investigate materials effects of this kind. Non-equilibrium effects and alterations in physical and optical properties which occur when materials are exposed to ultra-high heating rates have been studied. Typical materials tested are candidates for use in radomes and phased-array antennas.



A related research activity has focused on uneven, rapidly changing temperatures in radomes, which may cause bore-sight errors in missile trajectories. EMSL analytically predicts bore-sight errors from calculated temperature variations of radomes, experimentally verifying these predictions. □



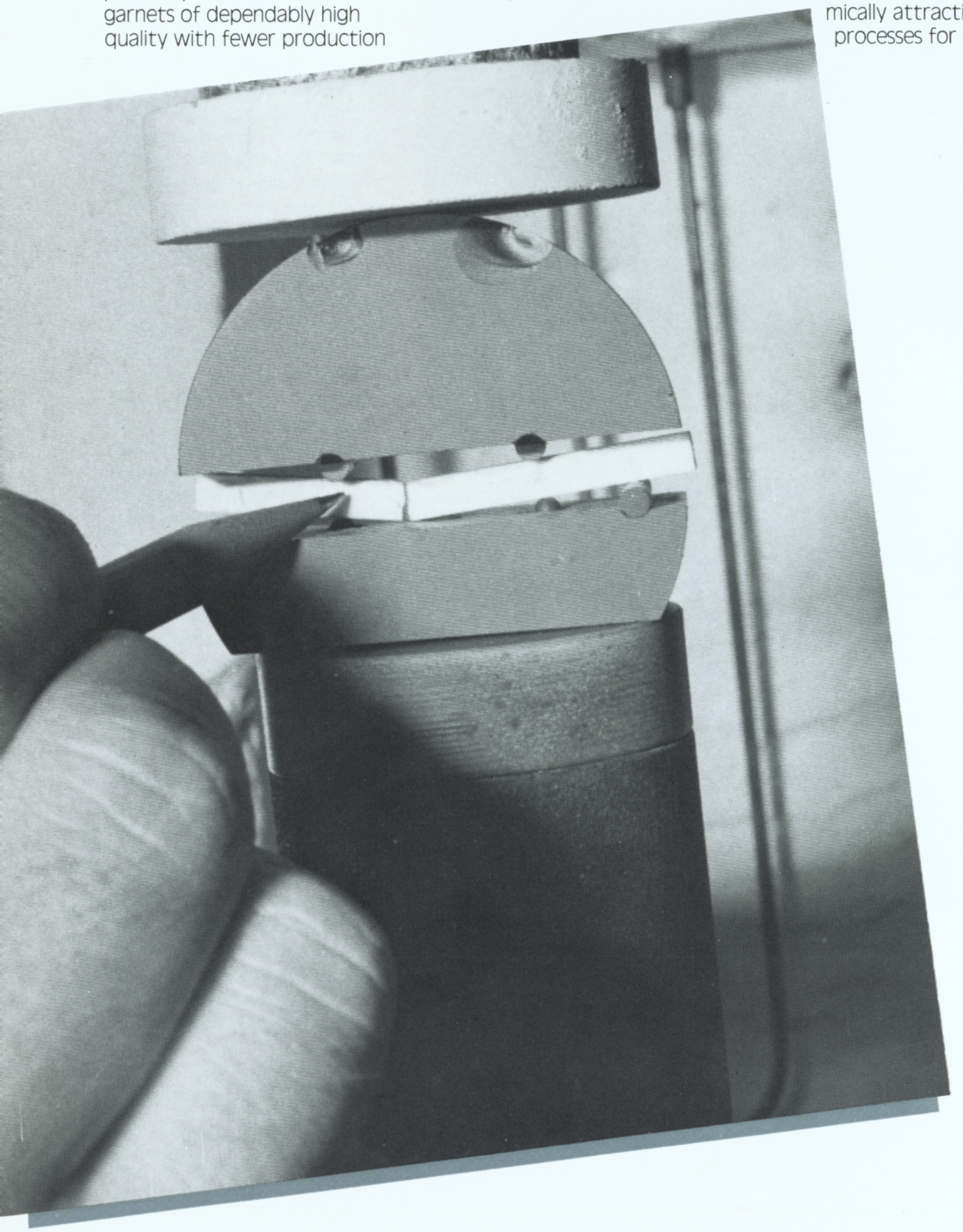
(Above) **A radome is tested under severe aerothermal conditions by EMSL engineers.** *(Right)* **Since 1971, laboratory researchers have conducted high temperature materials studies at the Centre National de la Recherche Scientifique (CNRS), a major solar test facility in southern France.**

MATERIALS RESEARCH AND DEVELOPMENT

FERRITE SYNTHESIS. The magnetic properties of ferrites and garnets must be precisely controlled for phased-array radar systems to function properly. EMSL's patented process yields ferrites and garnets of dependably high quality with fewer production steps than required with traditional procedures.

CERAMIC COMPOSITES. Ceramic fiber reinforcement of refractory glasses and ceramics greatly increases their toughness. EMSL's novel fabrication techniques allow large, complex composite shapes to be formed at reasonable cost. Applications include high-temperature gas turbines, adiabatic diesel engines, radomes and electromagnetic windows.

THERMITE SYNTHESIS. The laboratory has developed unique thermite reactions for synthesis of refractory materials like borides and carbides, which are otherwise difficult or impossible to obtain. EMSL research has resulted in unique and economically attractive processes for forming a number of materials with melting points above 2,000° C. For example, the laboratory produces titanium diboride as a fine, sinterable powder and as a composite with alumina. Methods for fabricating titanium diboride powder into fusion cast plates are under investigation.



COMPLEX CERAMIC SHAPES. Georgia Tech has patented a novel process developed by EMSL for fabricating complex geometric shapes from reaction-bonded silicon nitride. One application for this technology would be multi-bladed automotive turbine rotors.

MATERIALS DEGRADATION. EMSL has studied the effects of acid rain on marble and limestone, two materials frequently found in cultural monuments. Researchers also have investigated reactions of fluorocarbon coolants with the constituents of electrical transformers.

POLYMERS. High technology processes make increasingly stringent demands on material performance. To meet these requirements, EMSL is investigating the suitability of polymeric materials for diverse engineering applications, focusing on known variations in mechanical, thermal, electrical, morphological, rheological and optical properties. Researchers place special emphasis on the creative modification of the structures and behaviors of commercially available polymers. They often achieve design goals by generating new blends, alloys and composites.

Using as a foundation the known thermodynamic behaviors of polymers in composites, EMSL is designing for the Department of Energy thermal-energy storage materials with heat capacities above 30 cal/g.

Under an Environmental Protection Agency contract, the laboratory is characterizing a pristine lignin polymer derivative that will capture and concentrate hazardous chemicals in waste streams. This process may become competitive with activated carbon adsorption.

COATINGS. The Materials R&D Branch of EMSL has improved formulations and techniques for applying coatings to magnetic video cassette tapes, low-observable infrared cloth and bridge steel. Researchers also are developing guidelines for increasing coating reliability and minimizing premature failure.

SEPARATORY MEMBRANES. Membrane-based processes can make many industrial separations and concentrations more economical and energy-efficient. EMSL researchers perform specialty modifications of membrane surfaces for quantum improvements in selectivity by deposition of single oriented molecular layers (LB layers) of selected materials. Modification can optimize selectivity for a variety of feeds and render the surfaces nonadhesive to foulants without changing the basic separatory action. Anti-Fouling Technology (AFT) is now patented, and EMSL is seeking to extend it to numerous other permeable and impermeable systems.

INTERFACE SCIENCE. Many important phenomena occur at the interfaces between materials rather than within the bulk. EMSL's Interface Science Program focuses on these important regions and the special nature of the physical and chemical events taking place there.

In one industrially sponsored program, the laboratory is studying the influences of the surfaces of thermoplastic polymers on their usefulness as investment molding patterns. Another research project focuses on the effects of soluble refrigerants on the lubricating action of oils in vapor compression refrigeration systems.

Of special interest to EMSL researchers is the practical application of the special properties of LB layers. These have promise in lubrication of outer-space structures and in the development of highly specific sensors and electronic devices. □

(Left) **Flexure testing of toughened ceramic composites for high-temperature structural applications.** *(Above)* **Reverse osmosis and ultrafiltration membranes are tested in this high-pressure cell.**

CHARACTERIZATION OF MATERIALS

A variety of industrial clients and governmental agencies rely on EMSL's expertise in materials characterization for optimizing new processes and solving materials problems as they arise. The following are some of the materials characterized at EMSL and the evaluations that typically are performed on them:

- Catalysts — The size, distribution and chemistry of active metals and contaminants are critical to the activities and selectivities of given catalysts. EMSL analyzes these by: scanning electron microscopy (SEM), which yields information about the dispersion and segregation of the elements; secondary ion mass spectroscopy (SIMS), which identifies trace levels of elements and molecular species; and X-ray photo-electron spectroscopy (ESCA), which pinpoints the oxidation states of many surface species.
- Minerals — The sizes, shapes and purities of mineral particles at all stages are critical to the efficiency of additional processing and to the success of subsequent applications. EMSL uses bulk techniques such as X-ray diffraction (XRD) and X-ray fluorescence (XRF) to quantify the proportions of various mineral phases. Microscopic examinations yield information about the sizes and morphological distributions of different species in relation to varying processing conditions.
- Fibers and particles — The laboratory routinely uses SEM and microprobe data to identify particulates and to generate information about relative sizes and populations of each particle species. Particle sizing is done automatically by computer processing of SEM data, directly by a Coulter counter, or by examination of transmission electron microscopy (TEM) micrographs.
- Structural materials — EMSL researchers work with materials such as metals, composites and polymers, using thin sectioning and replication with TEM to characterize samples. The laboratory differentiates and identifies phases, precipitates, inclusions, contaminants and thin-film compositions. Quantitative analyses are carried out in the SEM and electron microprobe for regions as small as one cubic micrometer. Films as thin as one atomic layer are quantified by EMSL surface analytical equipment. Crystalline phases less than one micrometer in diameter are identified by electron diffraction. Phases substantially smaller than one micrometer in diameter are differentiated with backscattered electron detection in the SEM. The same techniques are useful for bulk analyses, with the results compared to those of bulk XRD and XRF, optical microscopy, and thermal analysis.
- Thin films and electronic devices — EMSL compares thin film thicknesses at resolutions of 10 to 20 angstroms while at the same time identifying and quantifying the elemental compositions of the films, down to the parts per billion level. Electronic devices are powered in the microscope itself to generate voltage contrasts for detection of submicroscopic metallization failures. In this setting, researchers are also able to observe corrosion products and unplanned migration.

In its electronic and device characterization programs, EMSL works closely with Georgia Tech's Microelectronics Research Center. □

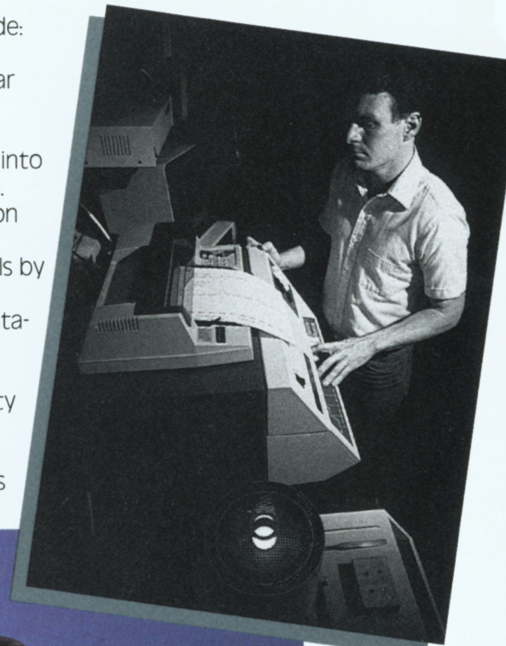
MOLECULAR SIEVE ZEOLITES

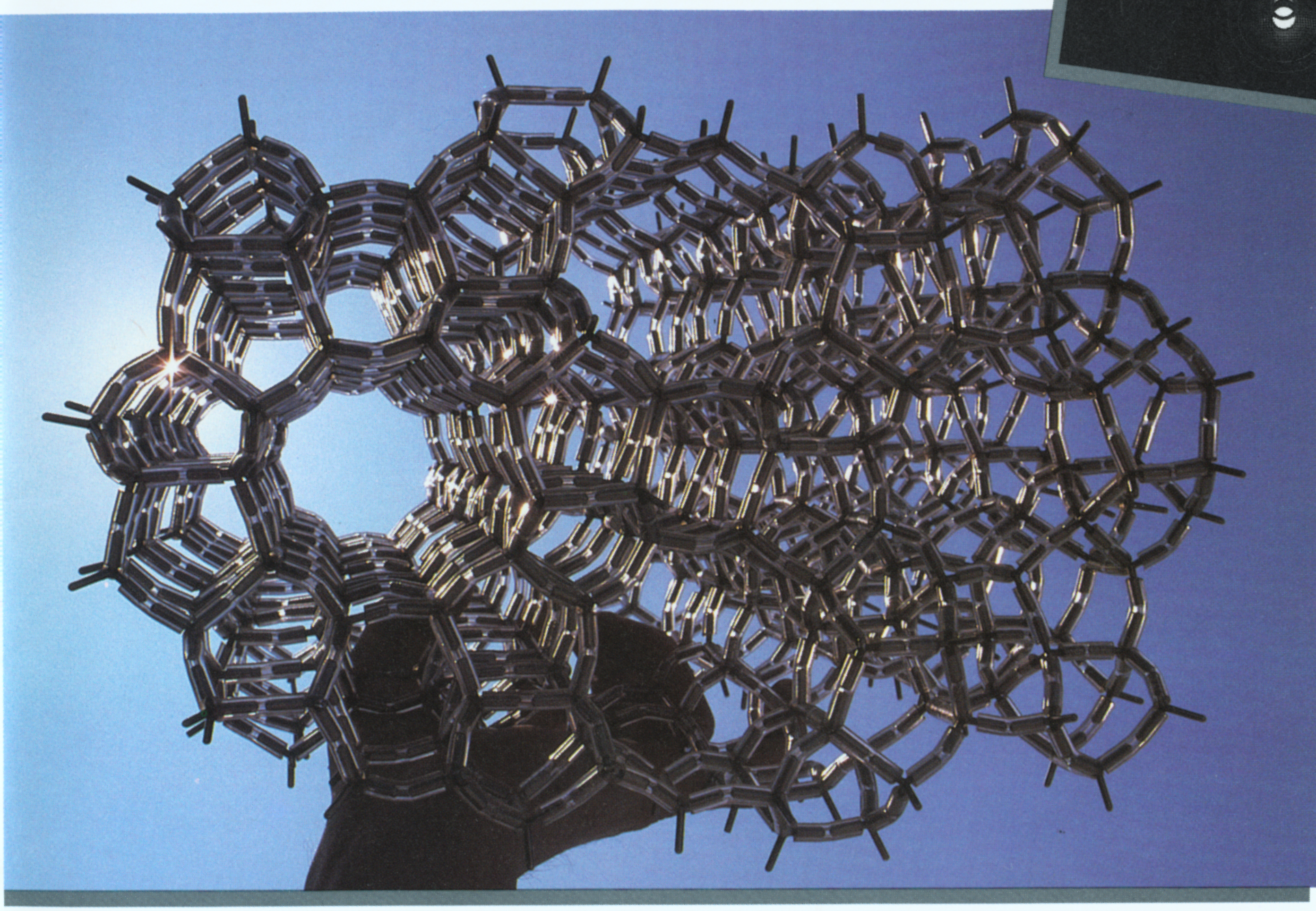
EMSL has established the only comprehensive, non-industry research program focusing on molecular sieves and zeolites. New, useful molecular sieve materials are being synthesized and characterized by X-ray diffraction, adsorption, infrared, and physical methods. Catalytic behavior of new molecular sieve materials are being evaluated by methods such as acid catalyzed cracking of butane.

Researchers in the program are evaluating the effect on molecular sieve activity of post-synthesis thermal and hydrothermal treatments. They have shown, for example, that hydrothermal treatment of ferrisilicate molecular sieve leads to a significant increase in hydrogenation activity.

Program interests include:

- Developing synthesis methods for new molecular sieves.
- Studying the effects of isomorphous substitution into molecular sieve structures.
- Understanding adsorption properties.
- Modifying these materials by thermal and/or chemical treatments to improve catalyst and adsorbent performance.
- Studying shape selectivity and its effect on catalytic reactions.
- Tailoring molecular sieves and zeolites for special applications.





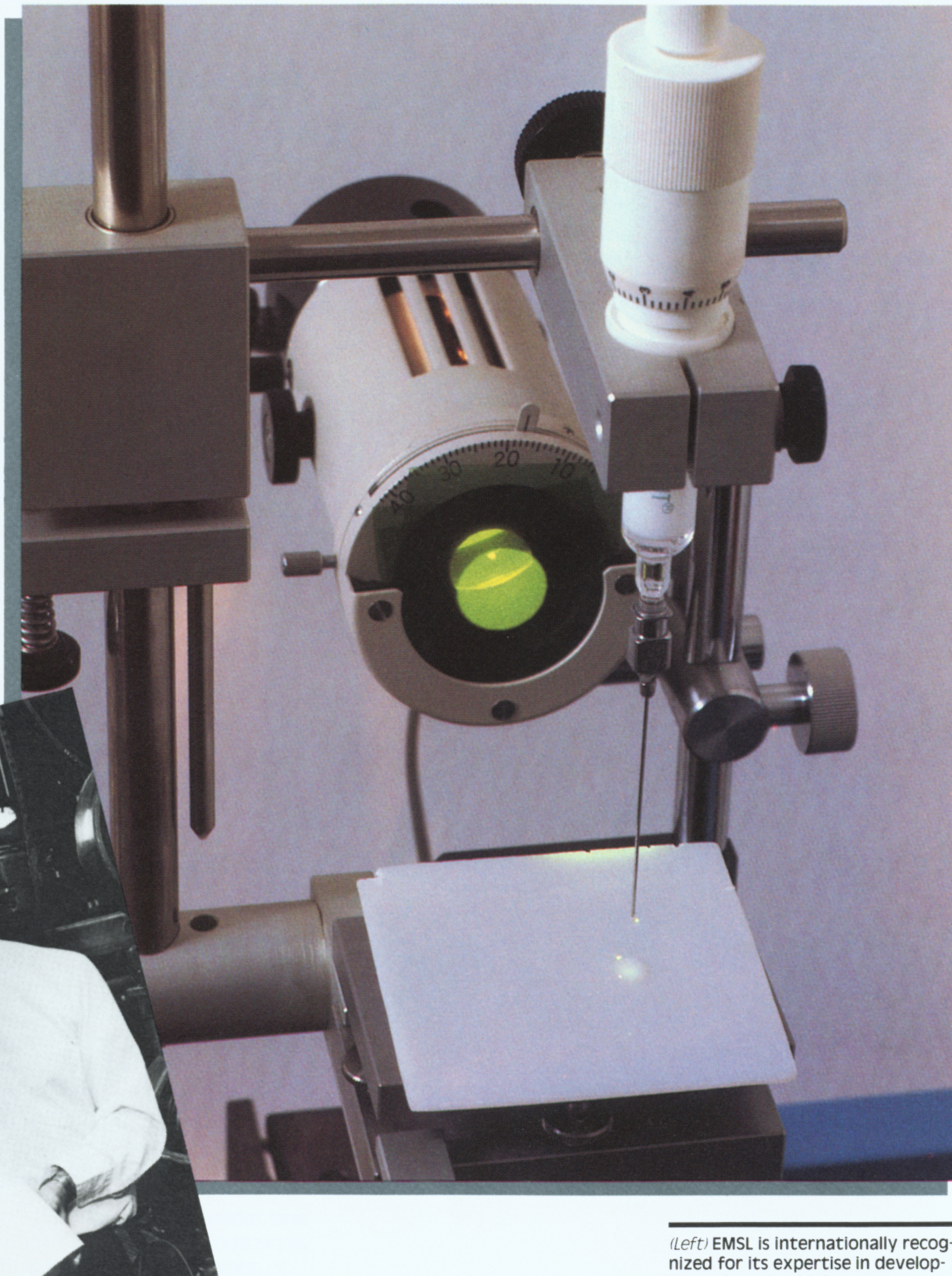
In addition to fundamental research, the Zeolite Research Program at EMSL is increasingly involved with proprietary R&D contracts for industrial firms. □

(Left) **This distribution of aluminum and titanium in a sample was produced with EMSL's energy dispersive X-ray spectrometer on a scanning electron microscope.** *(Top of page)* **Tests made with this differential thermal analysis unit are useful for a variety of materials characterization requirements, including molecular sieve zeolite research.** *(Above)* **A model of a molecular sieve zeolite.**

EMSL SUMMARY

The Energy and Materials Sciences Laboratory conducts applied research in advanced engineering and physical sciences directed toward energy production, the development of new materials, and the resolution of environmental problems. The laboratory has national and international repute in several areas of specialty.

Both proprietary and non-proprietary R&D programs are conducted on a contract basis within specified budgets and time limitations. The Georgia Tech Research Corporation, a non-profit corporation, handles contractual relations, copyrights, and patent procedures associated with the performance of sponsored research projects. □



(Left) **EMSL is internationally recognized for its expertise in developing and testing high temperature radomes.** *(Above)* **This precision contact angle goniometer measures surface energies and wettabilities.**

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