

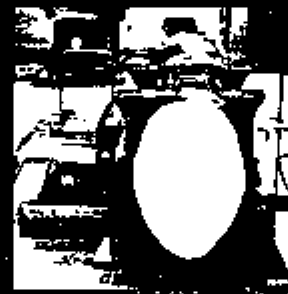
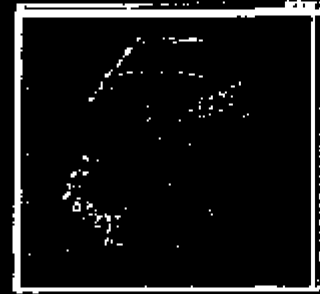
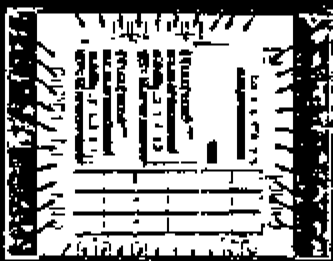
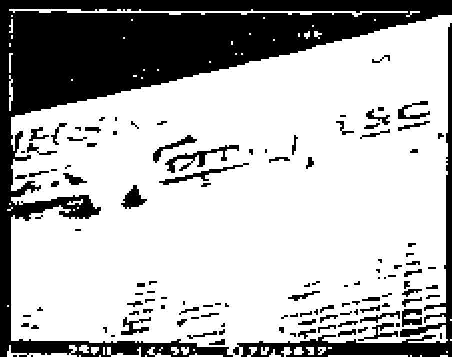
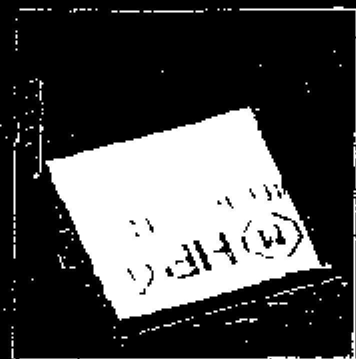
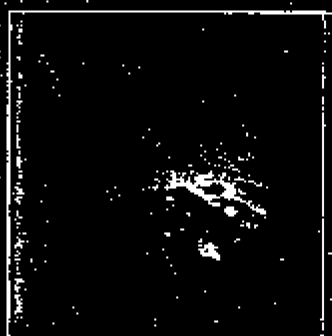
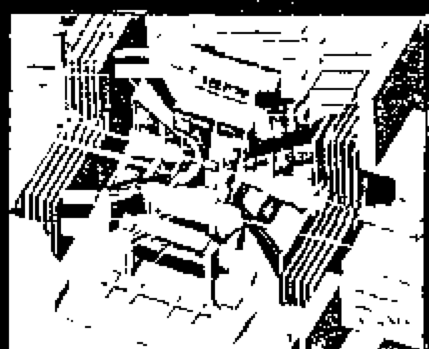
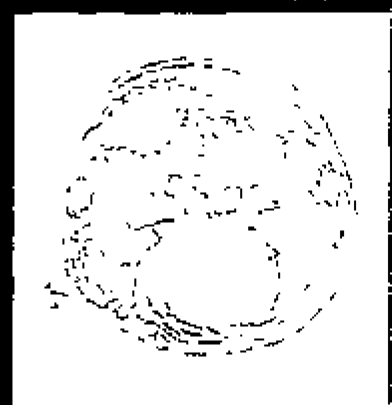
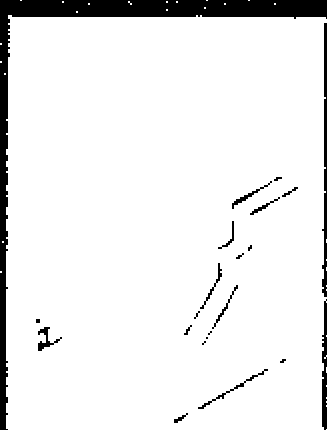

Instrumentation and Controls Division Progress Report for the Period July 1, 1994, to December 31, 1997

working together on new horizons

Working Together on New Horizons

Instrumentation and Controls Division Progress Report for the Period of July 1, 1994, to December 31, 1997

Oak Ridge National Laboratory

Managed by
Lockheed Martin Energy Research Corporation
for the U.S. Department of Energy

Prepared by Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6285
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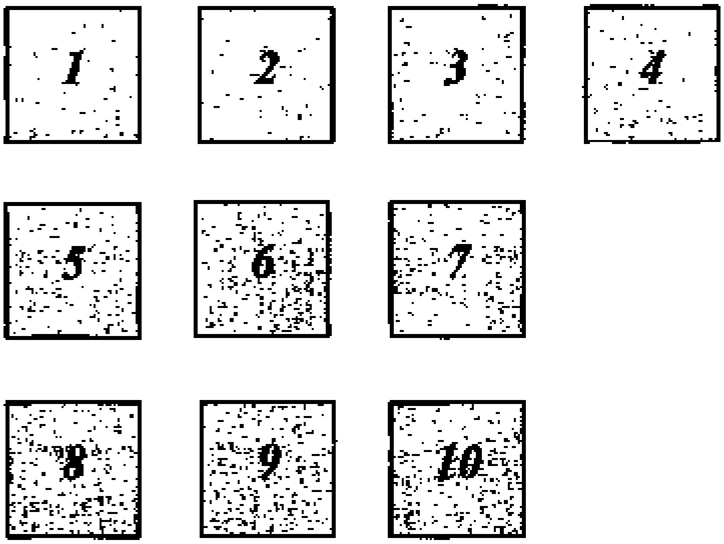
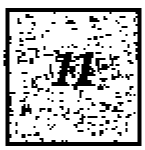
On the Cover





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Division Highlights

Mission and Vision

The Instrumentation and Controls (I&C) Division at Oak Ridge National Laboratory (ORNL) develops and maintains techniques, instruments, and systems that lead to a better understanding of nature and harnessing of natural phenomena for the benefit of humankind. We have dedicated ourselves to accelerating the advancement of science and the transfer of those advancements into products and processes that benefit U.S. industry and enhance the security of our citizens.

Key Principles

As an organization, we have a set of key principles that we use to guide our decision making and our priorities:

- We dedicate ourselves to the assured mutual success of each other.
- We keep our technology portfolio at the leading edge.
- We keep our commitments to our customers and sponsors.
- We maintain a work environment that enhances the lives of all our staff.
- We use our talent and skills to benefit the nation, its industry, and its citizenry.

Programmatic Direction

We view ourselves as a national resource. To retain that view, we strive to maintain technical excellence and relevance and the capability to respond quickly to rapidly changing national priorities. The science and technology policy of the United States in the post–cold-war era has been and continues to be a contentious issue. Charting a course for our division during these times, when even the need for the U.S. Department of Energy (DOE) is a debated issue, is not easy. Nevertheless, our staff have managed to see through this uncertainty and identify opportunities for us to continue to benefit the nation in dramatic ways. All our funding comes from the successful efforts of our staff in peer-reviewed competition within DOE or from our demonstration of capabilities not found in other federal agencies or U.S. private industry.

Our primary focus is on the advancement of science. Because many of the techniques and concepts we develop in pursuit of our science agenda are applicable to national security and industrial competitiveness, these two areas have become additional significant markets for our research. This synergy of these three markets results in a perspective and technology base that is rare, versatile, and powerful.

To focus our outside program development activities, we have identified six target areas within our three main markets. These six areas represent technical communities that have the technical challenges we are best suited to address:

- Science Markets
  —nuclear detection, measurement, and analysis
  —biological sciences

- Industrial Markets
  —industrial applications and power generation
  —semiconductor process-and-yield improvement

- National Security Markets
  —surveillance, measurement, and analysis
  —external operational facilities

Within the science market, we continue our strong heritage in nuclear physics, a long-time primary market for our division. As we complete our successful developments for the European Organization for Nuclear Research (CERN) in Geneva, the Relativistic Heavy Ion Collider at Brookhaven National Laboratory, and the High Flux Isotope Reactor at ORNL, we begin new initiatives for the JT-60 tokamak in Japan in preparation for the International Thermonuclear Experimental Reactor program. We also hope to play an important role in building and maintaining the Spallation Neutron Source at ORNL.

An important new market for us within the science arena is biological sciences, particularly in the area of functional genomics, a key initiative of the Laboratory. In the past three years, we have focused most of our efforts on educating our staff on terminology and issues and on building foundations for future collaborations.

Our industrial markets have focused on support of DOE's "Industries of the Future" Program and the U.S. semiconductor industry. A major highlight of our work in this area was the development of a system for determining surface temperature during critical stages of the production of galvanneal steel.

Our work in support of SEMATECH (SEmiconductor MAnufacturing TECHnology), a nonprofit research and development (R&D) consortium of U.S. semiconductor manufacturers, has been particularly fruitful, producing patents, licenses, and an R&D 100 Award, and creating new cooperative research and development agreement opportunities and a new project with the Defense Advanced Research Projects Agency.

In the area of national security, we have significantly expanded our role in nuclear weapons dismantlement, nonproliferation, and nuclear arsenal treaty verification technologies. These projects are based on neutron interrogation concepts developed and refined over many decades by our Corporate Fellow, John Mihalczo. Additionally, we have nearly completed our work for the U.S. Navy in providing a new and improved submarine noise characterization facility. Our role now is in operational support as the facility is used to characterize the Navy's submarine fleet and the new Seawolf submarine. We continue to work with the Navy to define other experimental research facilities where our capabilities can be applied.

Technology Frontiers

We have made significant additions to our technology base in four new areas:

- industrial wireless systems,
- optical application-specific integrated circuits,
- continuous wavelet transforms, and
- digital holography.

The first two areas, industrial wireless systems and optical application-specific integrated circuits, represent our continuous push to achieve more functionality out of silicon. We have successfully demonstrated the integration of mixed-mode, analog-digital circuitry with simple sensor technology and radio frequency signal transmission on a single chip. Our work with the signal-processing technique known as wavelet transforms was recognized with an R&D 100 Award in 1997, the second R&D 100 Award we have received for wavelet-based work. Our work in digital holography holds promise for surface metrology in many applications. Revolutionary impacts in several fields are possible.

In addition to adding these new technical capabilities, we continue to significantly enhance our capabilities in previously established areas such as image processing; low-power, high-performance electronics; and neutron-based measurement systems.

Technical Support Initiatives

In addition to our R&D responsibilities, we also have technical support responsibilities at the Laboratory. Our engineers and technical support staff have saved thousands of research dollars by providing innovative and timely solutions to research problems. We have focused on reengineering activities to support the ORNL-wide effort to reengineer research support at the Laboratory. We have relied heavily on surveying techniques to prioritize our efforts. For example, we conducted an organizational culture survey of our bargaining-unit employees and conducted several customer-based surveys. In addition, we supported two major studies on outsourcing some of our services. The overall result has been a major emphasis on increased commitment to customer service and a simplified organizational structure that encourages staff involvement and engagement.

Summary

The ORNL I&C Division was created to support DOE-funded research. We have since broadened our mission to include other sponsors as the need for our services has grown. This report summarizes some of the work we have been conducting on behalf of DOE, other federal agencies, and the private sector during the past three and a half years. Because we take on nearly 750 individual projects every year, much of our work cannot be reported in detail. We hope that these summaries are of interest and demonstrate that our work, rooted in DOE scientific and technological programs, can also benefit the nation, its industry, and its citizens in direct and tangible ways.

II. How We Benefit Our Markets

The following summaries describe how we benefit our markets. A key contact person is listed with each summary. Inquiries about the programs described here, and about other I&C Division programs, can also be directed to

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Additional information about the I&C Division can be found on the World Wide Web at *http://www.ic.ornl.gov/*.

Science Markets

Introduction

With the I&C Division's dedication to the advancement of science through engineering, it is not surprising that an important market for us has been the basic sciences. Currently, this market accounts for between 10 and 15% of the division's total budget. Since its inception more than four decades ago, the division has continually found itself playing an enabling role in the physical sciences community, providing advanced detector technologies, reactor technologies, plasma diagnostic techniques, and electronic readout systems for experimental facilities around the world. We have collaborated with the international physics community on major experiments at Fermi Laboratory, Brookhaven National Laboratory, the Large Hadron Collider at the European Organization for Nuclear Research (CERN), the Japanese Atomic Energy Research Institute, and, of course, at ORNL. Although some predict that advancements in the physical sciences will be slowing, we believe there will continue to be opportunities for I&C work generated by upgrades at existing experimental facilities and the occasional construction of new detectors and accelerator facilities such as the Spallation Neutron Source and the International Thermonuclear Experimental Reactor.

An emerging market for the us is in the biological sciences. The next century is being dubbed "the age of biology." We believe we can play an enabling role in this field also and are positioning ourselves to work with the biotechnical and biomedical community to provide advanced instrumentation systems and concepts. We have already begun such work at ORNL, which has declared functional genomics to be one of its major strategic initiatives. I&C staff are working with scientists from the ORNL Life Sciences Division to understand the issues and bottlenecks facing progress in this rapidly expanding area and to develop new approaches to addressing those issues.

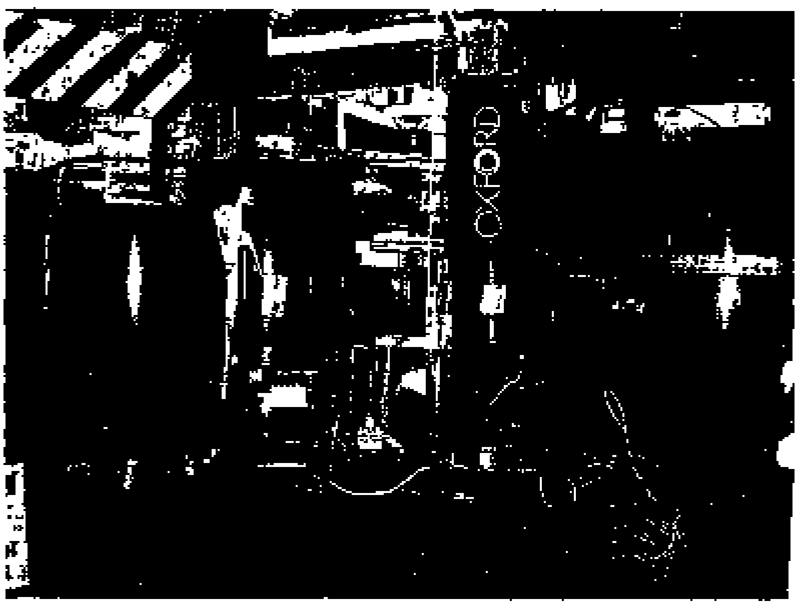
Closed-Loop, Step-Motor Control Using Absolute Encoders

We have developed a multiaxis, step-motor control system for a triple-axis spectrometer at ORNL's High Flux Isotope Reactor (HFIR) that achieves a positioning accuracy of 0.00275 degrees of rotation.

Triple-axis spectrometers are used in neutron scattering and diffraction experiments and require highly accurate positioning. To replace the aging and mechanically worn spectrometers at the HFIR, we designed a new motion-control system that seamlessly integrates new mechanical hardware with the existing computer system. The HFIR system consists of a digital VAX computer and computer-automated measurement and control modules that run the spectrometer and collect data. The new motion-control system integrates absolute encoders with step-motor drives in a closed-loop configuration. This combination of technologies provides benefits not commercially available, namely, the simplicity of open-loop stepper operation with the positioning speed, accuracy, and certainty of a closed-loop system.

Our new control system is based on a single-board, rack-mount industrial personal computer with a passive backplane. The system can handle up to 16 axes of motion. Four of these axes are outfitted with 17-bit absolute encoders. Staff who use the spectrometer like the absolute encoders because they do not require reinitialization after power failures or between experimental setups.

The axes equipped with absolute encoders are controlled with a software feedback loop that terminates the move based on real-time position information from the absolute encoders. The variable backlash of the system required a robust design that could handle moves for which the exact number of pulses needed is unknown until after the move is started. Because the final position of the axis is used to stop the motion of the step motors, the moves can be made accurately in spite of the large amount of mechanical backlash from a chain drive between the motors and the spectrometer arms. A modified trapezoidal profile, custom C software, and the industrial personal computer were used to achieve a positioning accuracy of 0.00275 degrees of rotation. A form of active position maintenance ensures that the angles are maintained with zero error or drift. Another benefit of the new system is an improved operator interface that displays status information as well as current target positions.



Multiaxis, step-motor control system in use at the ORNL High Flux Isotope Reactor

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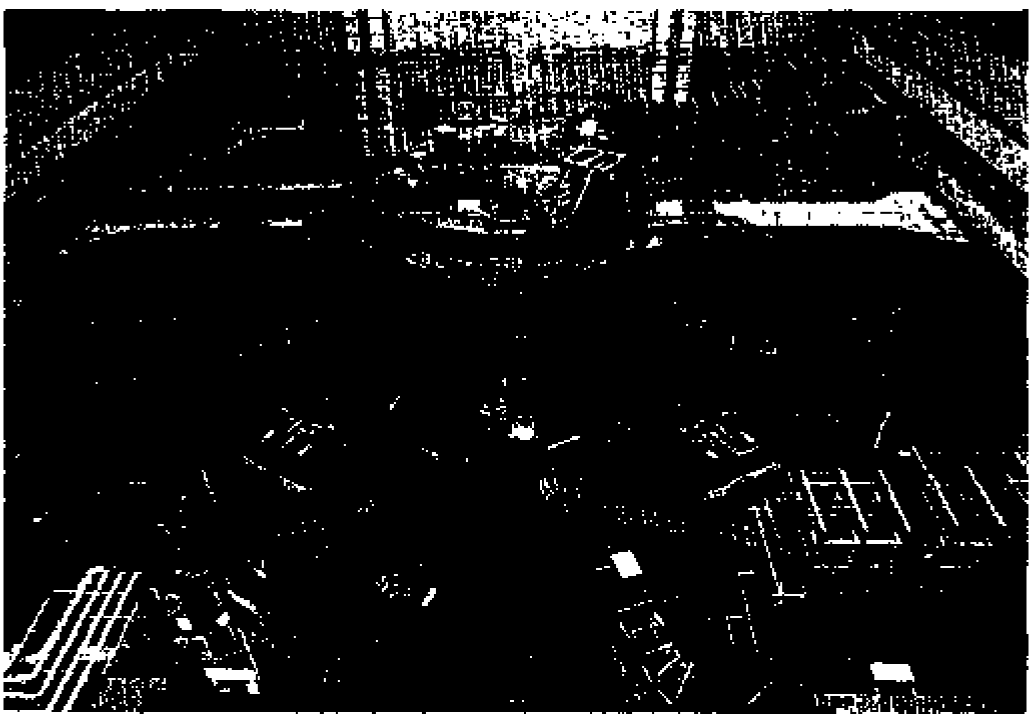
Collective Thomson Scattering for the JT-60U Tokamak

We have developed alpha particle diagnostics for use in experimental thermonuclear fusion reactors.

DOE, the European community, Japan, and the Russian Federation are designing the world's first fusion reactor, the International Thermonuclear Experimental Reactor (ITER). One purpose is to study confined alpha particles produced in the reactor by combining deuterium and tritium at high temperatures. The particles, created with an energy of 3.5 MeV, must be trapped in the magnetic field long enough (~1 second) to heat incoming cold fuel to ignition temperatures (~100 million degrees). Study of the trapping and slowing down of the alpha particles is a major goal.

We have developed a diagnostic technique to determine the density and velocity distribution of the alpha particles. This technique, called Collective Thomson Scattering, works by scattering 10-μm light generated by a high-power carbon dioxide laser from clouds of electrons surrounding alpha particles (helium ions) in a high-temperature plasma. All the atoms of the filling gas are completely ionized and will remain so if the temperature is maintained. The ions attract fast-moving electrons, but recombination into atoms is prohibited by the particles' high energy. If a probing wavelength is chosen that is comparable in size to or larger than these electron clouds, the spectrum of the scattered laser light will be characterized by the ion velocity distribution.

A proof-of-principle experiment successfully completed at the ORNL Advanced Toroidal Facility in 1991 led to the selection of our technique as one of the primary alpha particle diagnostics for ITER. We have also established a joint program with the Japanese Atomic Energy Research Institute to further develop this technique on the JT-60U tokamak in Naka, Japan, to measure the fast-ion tail in the JT-60U plasma produced by the injection of energetic negative ion beams used for plasma heating.



Exterior view of the JT-60U tokamak in Naka, Japan.

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PHENIX Detector Systems

We are developing custom integrated circuits for multicomponent photon electron new heavy ion experiment (PHENIX) detectors.

The PHENIX detector is a large, multi-component detector at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. PHENIX has approximately 425,000 channels of electronics, most of which are implemented as custom integrated circuits. The I&C Division has been heavily involved in custom mixed-mode integrated circuit development for 300,000 of the PHENIX detector channels. We are responsible for developing and manufacturing electronics for the event vertex-finding subsystem, pads tracking subsystem, electromagnetic calorimeter subsystem, and the muon tracking/identification subsystems. These various subsystems compose what is, in effect, a large image-processing system that reconstructs the origin, trajectory, and energy of the particles thrown off of the intentional collisions of various heavy-ion species. To acquire a great deal of data in the shortest possible time, we have developed an architecture that uses simultaneous read-write analog memories throughout the detector, allowing data to be taken continuously, even during event readout (a no-dead-time system). The manufacturing technologies being used range from multilayer printed circuit boards to multilayer, multichip modules.

PHENIX detector in the early assembly stage.

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Three-Dimensional Beam Profile Monitor Based on Residual Gas Ionization

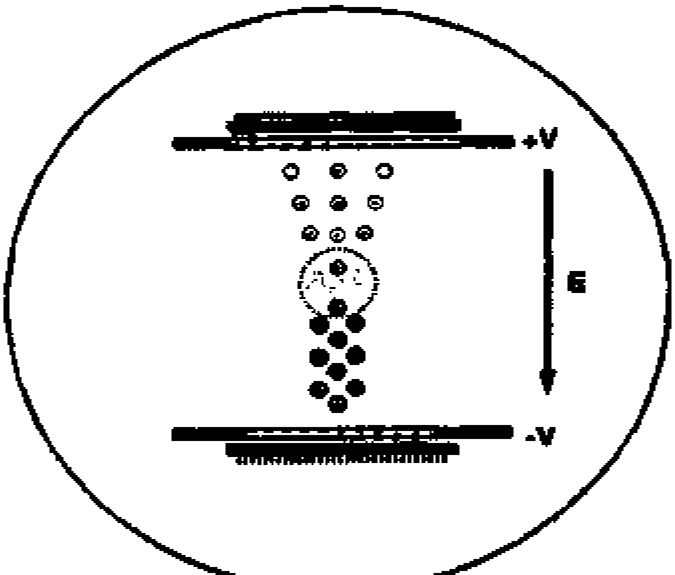
We have developed a three-dimensional beam profile monitor for use in ORNL radioactive beam facilities.

Nonintrusive beam sampling was first needed at storage rings and other facilities where high-quality, low-emitting charged particle beams had to be stored for extended periods. Devices that use residual gas ionization for beam sampling have been used for some time; however, all of these devices have various limitations, including a low sampling rate and being limited to sampling stored beams or very intense extracted beams. Our version of the monitor is based on tracking the ionization of residual gas molecules in an evacuated beam pipe and includes special features that make it possible to sample very low beam currents.

The principle of this device is based on sweeping out the electrons and the positive ions produced in ionizing collisions between the beam particles and the residual gas molecules in the evacuated beam pipe. The beam particles have large kinetic energies and continue unabated; however, the residual ions drift in the direction of the electric field (toward the negative electrode), and the knocked out electrons move in the opposite direction. The charged ions and electrons pass through the grid and are then further accelerated and amplified with microchannel detectors.

The positive ions produced in the interactions with the "stationary" gas molecule have, on average, very small velocity in the plane transverse to the electric field direction. This is precisely why they are used, as in all previous applications of this method, to infer the original position where the interaction with the beam particle occurred. By maintaining parallel field lines along which the ions are restricted to move, one can project from the position of their arrival back to the interaction region. Spatial resolution is limited in principle by transverse momentum transfer to the residual gas ion by the beam. With our device, we can also detect the electrons formed in the same interaction. The anticipated sampling rate can be estimated using calculated energy loss from gas ionization by the particle passing the sensitive region of the detector.

This device can be used in many different configurations and can be easily improved and adapted to different research needs.



Principles of the three-dimensional beam profile monitor: residual gas ion and electron pairs formed in interactions with beam particles are swept vertically in the direction of an applied electric field. Microchannel electron multipliers amplify the signals and provide timing and position signals for the positive ion hits and timing only for electron hits.

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Instrumentation and Controls Division

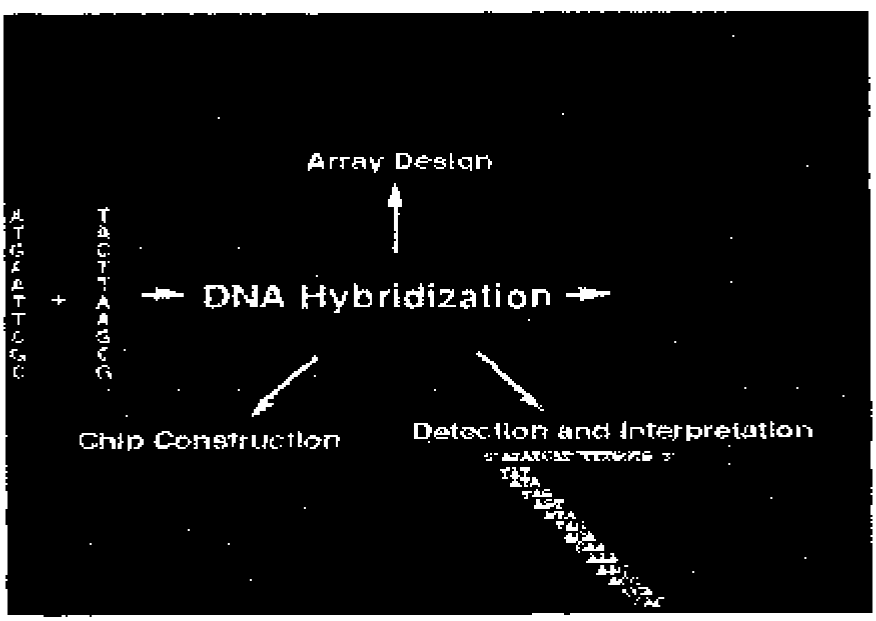
Genomic Profiling Using Flowthrough Genosensors

We are developing analytical microsystems for ultrahigh-throughput analysis of gene structure and function.

An important future trend in analytical instrumentation for biological research and clinical diagnostics will be microanalytical systems capable of analyzing large numbers of biological samples quickly and in a small space. A new technological advancement promising to greatly facilitate genome analysis is the "genosensor" or "DNA chip," a miniature array (addressable library) of surface-tethered DNA molecules.

Each site in the genosensor array contains a coating of specific DNA strands (the DNA probe), tethered at one end to the surface. The short DNA probe serves as a specific recognition/sensor element that binds to a complementary short sequence in the DNA or RNA analyte, through specific A•T and G•C base pairing. Thus, when a nucleic acid sample (the target sequence) is hybridized to the genosensor array, a pattern of binding is obtained that corresponds to the nucleotide sequence of the target strand. We have begun developing an advanced genosensor configuration in which the hybridization reactions occur within three-dimensional volumes of porous silicon dioxide or channel array glass, rather than on a two-dimensional surface.

The core of the microscale instrumentation we are developing is a flowthrough genosensor, containing an arrayed library of thousands of specific DNA sequences, immobilized within microporous cells in a thin layer of silicon dioxide. When a nucleic acid sample flows through the microchannel genosensor, each porous hybridization cell serves as a reaction vessel for extraction and quantitation of specific nucleic acid sequences complementary to the immobilized DNA probe. The pattern of binding relates directly to the identity of the nucleic acid analyte. The genosensor system will include temperature-controlled fluid delivery and elution across the array; a charge-coupled device imaging system for data acquisition; and software packages for image analysis, data interpretation and output, and nucleic acid sequence database interface. Proof-of-concept for important applications of the flowthrough genosensor will be demonstrated through the ORNL mouse genetics program, including discovery and mapping of genes and profiling of gene expression. The system will also be used to acquire a comprehensive understanding of the specificity of short duplex hybridization, which is critical to successful application of genosensors in DNA diagnostics and DNA sequencing.



Conceptual operation of the flowthrough genosensor

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Instrumentation and Controls Division

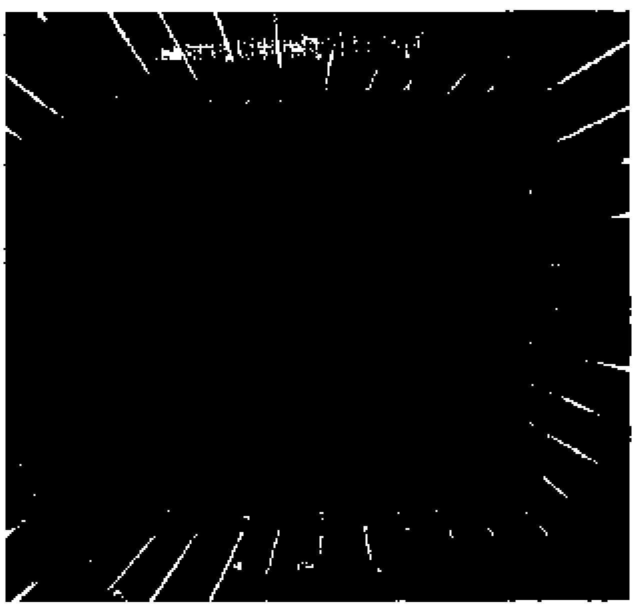
Optical Application-Specific Integrated Circuits

We have developed a technology that brings electro-optical detection capability to integrated circuit technology.

As part of a Laboratory Director's Research and Development project, we developed a technology that brings a flexible electro-optical detection capability to standard integrated circuit (IC) technology. This innovation allows us to create laboratory instruments on a chip. Our first applications have been in distributed, low-power environmental sensing and industrial photo-spectroscopy. We call these devices optical application-specific integrated circuits (OASICs). Since early in the semiconductor revolution, silicon has been the workhorse of the IC industry because (1) it readily grows a stable oxide, (2) silicon hole mobility and electron mobility are close enough to allow complementary devices, and (3) silicon is inexpensive and readily available. To make a major impact in the IC arena, we must find ways to add functionality to standard-process silicon devices. OASIC research has allowed us to do this.

First uses of the OASIC concept have been a single-chip photospectrometer and an environmental biosensor. The photospectrometer was developed by taking advantage of unused features of ICs (e.g., different depth diode junctions were used to separate long from short wavelength light; protective oxide coatings were used as thin-film interference filters). The accompanying figure shows the photospectrometer chip, useful in the near-ultraviolet, visible, and near-infrared regions, all of which are important for chemical analysis, medical diagnostics, DNA sequencing, and color imaging.

The environmental biosensor was composed of bioluminescent bacteria on an OASIC. The bacteria emit visible (blue-green) light in the presence of targeted substances such as pollutants and explosives. OASICs are small, low-power, and rugged. They can be made wireless and can be deployed in places where other devices cannot (e.g., in groundwater and on the battlefield). The bioreporters can be engineered to be specific and sensitive to a particular substance. We call these hybrid (½ living, ½ silicon) devices bioluminescent bioreporter ICs.



Photospectrometer on a chip.

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Instrumentation and Controls Division

Industrial Markets

Introduction

For the industrial market, the I&C Division develops sensors and controls for standard industrial applications, power generation, and semiconductor applications. We work with corporations in several market sectors, including the textile, glass, steel, pulp and paper, nuclear power, and semiconductor industries. We have built long-standing relationships with many customers who come to us with repeat business to develop new technologies and materials, and we often work with equipment manufacturers and suppliers to ensure that the developed technology finds its way into the commercial sector for multiple applications.

In collaboration with other ORNL divisions and our university partners, we offer a wide range of goods and services to our customers. We invent and develop new measurement and control technologies, and we apply both existing and newly developed technologies to customer needs. Capabilities that our customers value most highly include miniaturization and ruggedization of components and systems, wireless communication solutions, prototyping for demonstration and evaluation, protection system design and fabrication, system integration, testing and evaluation, and technical consulting.

Because of international competitiveness and the desire to reduce energy consumption and waste generation, U.S. industries are striving to improve measurements in harsh industrial environments, measure parameters related to product recycling, optimize dynamic and transient processes, improve process reliability and throughput to reduce costs, and reduce the costs of plant equipment upgrades. We are continually responding to these needs by providing

- temperature and other physical sensors for harsh industrial environments,
- characterization of equipment behavior under harsh and damaging conditions,
- chemical sensors for real-time process measurement based on lower-cost technologies,
- remote measurement of process parameters,
- high-speed product and process characterization using image-processing techniques,
- improved development and manufacturing processes, and
- new manufacturing methods for rapid production of prototypes and short part runs of cast-metal parts.

We have facilities where activities ranging from environmental testing of components and systems to flow calibration can be conducted. These facilities are available to our customers along with the engineering expertise to make design changes at our site as needed. Other capabilities include unique skills for miniaturization of electronics and high-temperature components; unique algorithms for feature extraction and pattern identification; and system integration experience in optics, electronics, digital signal processing, software, electromagnetic and radio frequency systems, nuclear detection, power supply, and packaging.

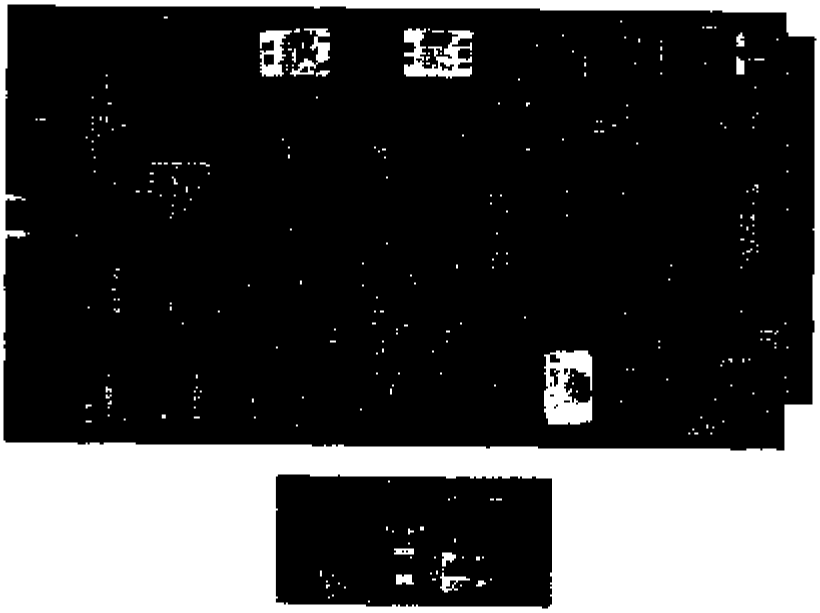
Application-Specific Integrated Circuit Design and Algorithm Development for Life Extension of Nuclear Power Plants

In collaboration with the Electric Power Research Institute, Westinghouse Electric Corporation, and the Westinghouse Owners' Group, we have designed and fabricated an application-specific integrated circuit (ASIC) for use on a circuit card to replace analog process function modules in nuclear power plants.

During the lifetime of a nuclear power plant, I&C systems need to be upgraded to replace obsolete equipment, reduce operation and maintenance costs, improve plant performance, and maintain safety. Today, most plants continue to operate with the original analog I&C equipment. An objective of the ASIC-based modules was to reduce the cost of replacing obsolete analog process function modules and the overall cost of maintaining and operating the instrumentation modules used in nuclear plants. The ASIC was also designed for use in research reactors operated by DOE.

In addition to designing and fabricating the ASIC, we developed algorithms for the ASICs that can be used to replace 28 separate analog functions. The concept of the new ASIC-based cards is that one design could be used to replace many different analog cards. This significantly reduces the spare parts inventory that a nuclear power plant operator must maintain as well as the capital expense of the inventory and the maintenance necessary to keep many different types of cards operating.

The fabricated ASICs were delivered to Westinghouse to include in printed circuit boards that are plug-compatible with the older analog cards. The ASICs and boards are currently undergoing engineering tests. When those tests are completed, the modules will be subjected to electromagnetic interference testing and qualification testing. The modules are scheduled to be tested in the South Texas Nuclear Power Plant next year.



The top image (the ASIC board) is the replacement printed circuit board for the Westinghouse 7300 analog control and protection module that is used in nuclear power plants. The large square on the left contains the ASIC developed by the I&C Division. The bottom image is one of the boards that is mounted on the ASIC board and that configures it to replace any 1 of 28 styles of analog modules.

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Computer-Aided Fabric Evaluation Project—Pick Measurement Device

We have developed an optical-based pick (thread) measurement device (PMD) for on-loom fabric inspection.

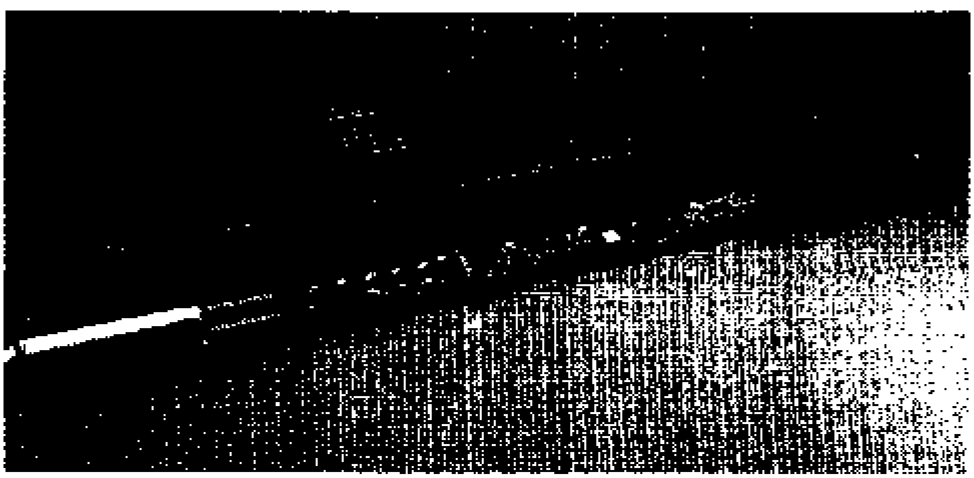
This device automatically inspects fabric, locates and identifies defects, and feeds information instantly to loom operators so that the process can be corrected while the fabric is woven. Additional analytic capabilities include resolving 30% variations in filament diameters, anomalous woven patterns, and process parameters associated with running of the weaving machine.

The PMD uses a class 3a laser and a set of cylindrical lenses in a front-lit mode to image individual picks onto a linear array. The device can also operate in a back-lit mode but requires special consideration when configured this way. The electronics and optical hardware are housed in a 72-in.-long, black anodized tube with an associated user's control panel (see figure). The system is composed of three major subsystems: the laser and cylindrical lenses, linear diode array and microprocessor, and in-line power supply and external input/output control and external connections.

The device also uses its internal processing capabilities to provide additional quality information to the user and production staff. With the proper settings available through the user's panel or network connection, plant and production information can be selectively addressed for display and control. The device can be set to provide an alarm on absolute values or changes in certain parameters, providing the ability to run the device as a closed-loop controller or as an alarm module controlling audio or visual drivers.

Since 1980, the U.S. textile industry has lost approximately 400,000 jobs to foreign manufacturers and is expected to lose another 600,000 by the year 2002. The operating cost for this device is estimated to be 1% of the cost of human inspection, the prevalent method of off-line inspection, and is more cost-effective than current inspection systems. Moreover, this device is easily integrated onto existing looms.

We have also developed three other technical innovations to support the weaving industry: camera-based, on-loom greige inspection; loom prognostics and health assessment; and color evaluation based on a tristimulus imaging colorimetry system.



Pick measurement device.

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Electromagnetic Survey Systems for Nuclear Power Plants

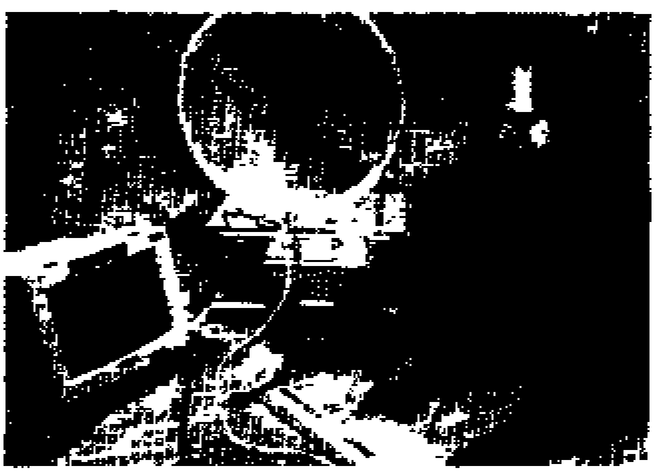
We have developed an electromagnetic measurement system (EMS) that permits long-term, automatic, unattended monitoring of ambient electromagnetic emissions while minimizing intrusion on the day-to-day operations of a nuclear power plant. We have also developed an experimental digital safety channel (EDSC) for environmental susceptibility investigations that incorporates technologies representative of proposed advanced light-water reactor safety systems. These technologies were developed while performing confirmatory research for the U.S. Nuclear Regulatory Commission.

The EMS was developed during research to support development of a regulatory guide that addresses methods to establish electromagnetic compatibility for digital safety-related I&C systems. This research has led to recommendations for design, testing, and installation practices that help minimize the electromagnetic susceptibility of I&C equipment and that control growth in ambient electromagnetic conditions at a site. The EMS was developed to take long-term plant measurements to characterize electromagnetic emission profiles at selected nuclear power plants. The EMS consists of two instruments:

- the magnetic spectral receiver, which measures radiated magnetic fields or conducted electromagnetic interference (EMI) in the range of 305 Hz to 5 MHz, and
- the electric spectral receiver, which measures radiated electric fields in the range of 5 MHz to 8 GHz.

Development of the EMS resulted in several instrument innovations that are incorporated in the magnetic spectral receiver (which simultaneously captures the time-localized peak magnetic field strength present in each frequency octave during each sampling cycle) and that received an R&D 100 Award.

The EDSC was developed during research to support development of a regulatory guide that addresses methods for environmental qualification of safety-related, microprocessor-based I&C systems. As part of this research, the potential failure modes and vulnerabilities of distributed digital systems under environmental stress were investigated. The EDSC is a valuable tool for experimentally investigating failure mechanisms characteristic of digital systems under environmental stress and for assessing the potential consequences of degraded performance for microprocessor-based, safety-related I&C systems. Stressors investigated in this research included EMI and radio-frequency interference (RFI), temperature, humidity, and smoke exposure.



Electromagnetic measurement system

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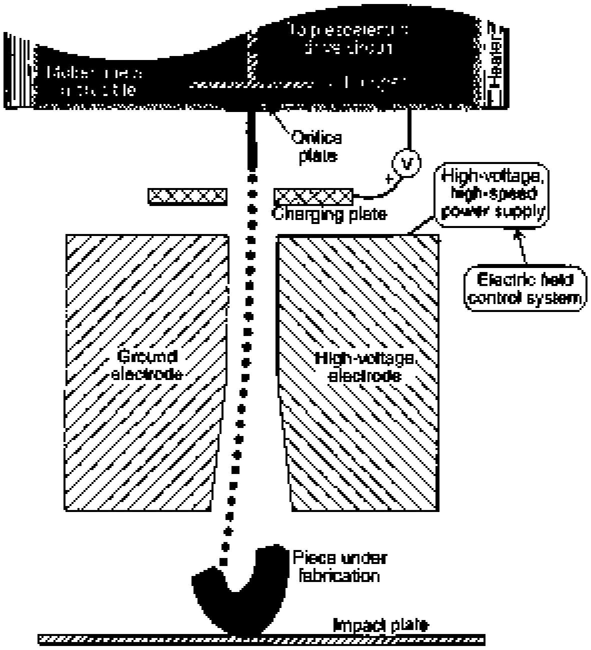
Net Shape Metal Forming Using an Electrostatically Directed Droplet Stream

We have developed a novel technique for free-form fabrication of net shape metallic parts.

The goal of this project was to demonstrate a novel technique (at a proof-of-principle level of sophistication) for free-form fabrication of net shape metallic parts. The major technological focus of the project was on developing and demonstrating a system for creating a columnar jet of uniformly charged and sized molten metal droplets, electrostatically directing that jet, and evaluating the properties of the pieces formed from the accumulation of the droplets. A primitive version of the technology was successfully created.

We undertook this project because of the significant benefits to energy science and technology that would come from the capability to fabricate quality metallic parts from high-temperature engineering alloys. The transportation, utility, and industrial sectors are replete with requirements for precisely shaped parts of novel, high-temperature–tolerant, corrosion-resistant, structural alloys. Our technique produces virtually no waste stream and is much less energy intensive than competing technologies for producing similar parts.

In the first process step, metal is melted in a crucible (see figure) with a precisely sized and located orifice. Metal jets out of the orifice when a pressure head is applied to the molten metal. A piezoelectrically driven plunger placed in the melt creates a time-varying pressure wave in the jet, destabilizing the jet. The frequency of the pressure wave is set to a natural harmonic of the laminar jet, resulting in a controlled, systematic breakup of the jet into a stream of uniformly sized droplets. As the metal jet approaches the charging plate below the droplet orifice, charge accumulates at the tip of the jet and is retained on the droplets as they break off. Because the uniformly sized droplets break off from the jet at a consistent spot in the electric field gradient, they have a uniform charge-to-mass ratio. The droplet stream is steered electrostatically with an electrode array to impact a surface at prescribed locations, forming the desired shape. The droplet stream cools rapidly as it travels through a controlled atmosphere, achieving a specified semisolid state before impact.



Electrostatically directed droplet stream technique.

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Instrumentation and Controls Division

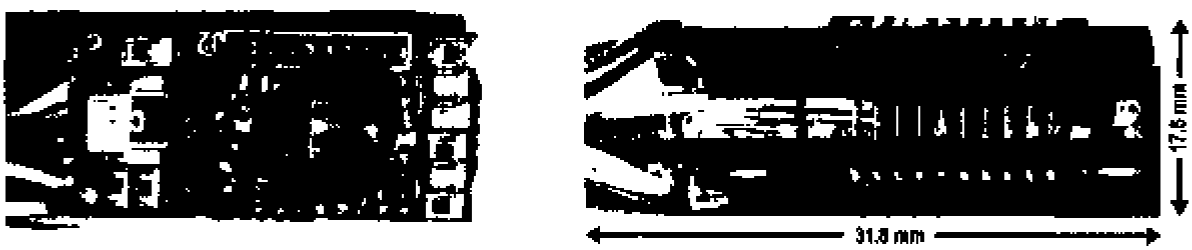
Rugged Incipient Failure Monitoring Module for Use in Oilfield Drill Bits

We have developed physical parameter measurement and logging instruments that will serve as the core of an implantable incipient failure monitor for use in oilfield drill bits.

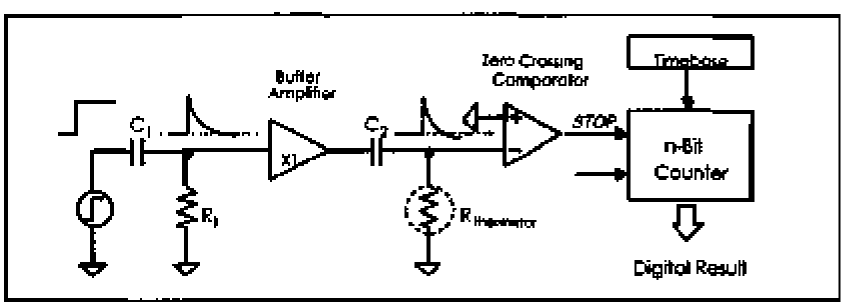
We developed this system through a cooperative research and development agreement among ORNL, Hughes Christensen Company, and the Houston Advanced Research Center. The system is the first measurement electronics ever directly implanted into oilfield drill bits. This monitoring instrument helps ensure the affordable availability of petroleum to the U.S. market by lowering the cost of exploration and production.

The first generation of the measurement electronics was designed to measure temperature. The unit includes two custom, application-specific integrated circuits: (1) an analog chip that performs the measurement and (2) a mixed analog and digital chip that controls the system and logs the measurements. The entire unit fits within a 17.5- by 31.8-mm cylinder and uses two stacked, six-layer printed circuit boards that have components loaded on both sides. The system is highly rugged, operating in temperatures up to 150°C, and is tolerant of both vibration and mechanical shock.

This instrument incorporates a novel temperature-measurement method (patent pending) that uses a sensor whose resistance varies with temperature in a known manner and whose digital output is proportional to temperature. The method relies on performing a zero-crossing time measurement of a step input signal that is double-differentiated using two time constants, only one of which varies with the sensor temperature. This method has several advantages over standard resistance and thermocouple temperature measurements for applications in which the measurement electronics are not in a controlled environment: no requirement for a temperature-stable, high-gain amplifier; tolerance to voltage supply variation; monolithic compatibility; and direct digital output. In addition, the system can operate at very low power levels, making it ideal for battery-powered applications.



Temperature measurement electronics module (unpotted)—front and side views.



Temperature to digital result conceptual diagram.

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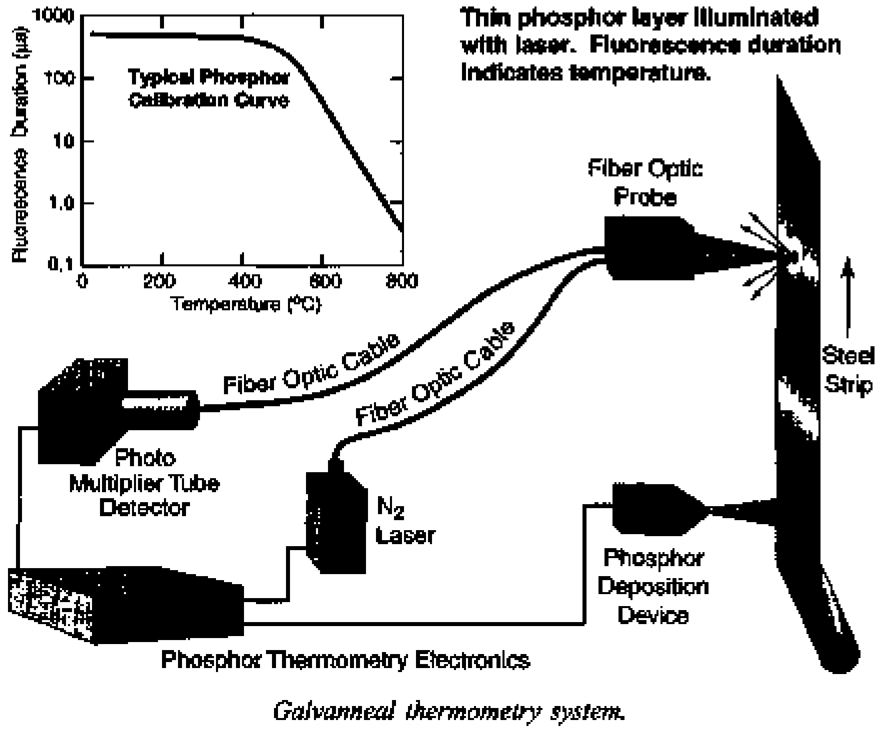
Thermometry for the Steel Industry

We have helped develop a technique for determining surface temperature during critical stages of the production of galvanneal steel.

Cars today don't rust the way older vehicles do because the steel industry uses a "galvannealing process" of adding zinc to produce corrosion-resistant sheet metal now used in virtually all automobiles. However, ensuring that the molten steel surface is always at the right temperature for formation of the best galvanneal coating has long been a problem for the steel industry, a problem that ORNL is helping to solve. We have devised a method to accurately measure the temperature of galvanneal steel as it forms the zinc iron layer. This information can be instantly relayed to steel producers so they can adjust furnace operation to get the right temperature and hence the best product.

Our device uses a thermal phosphor method and has a demonstrated accuracy of better than 3°C, independent of production settings. A phosphor-deposition device applies the phosphor under command from a control computer. This deposition takes place several feet below the temperature measurement equipment, allowing time for the thin phosphor layer to become equilibrated in temperature with the galvanneal surface. Through an optical fiber, an ultraviolet laser illuminates the phosphor. Another optical fiber conveys the fluorescence signal to a remotely located photomultiplier tube detector, which converts this optical signal to its electrical analog. The data analysis system operates on a personal computer using both commercial and ORNL-designed hardware and software. Temperatures are displayed in real time on the monitor. A prototype galvanneal temperature measurement system is now operating at National Steel's Midwest Plant.

Bailey Engineering Inc. is commercializing this technology, and a product will soon be available to the steel industry. Annual savings could be as much as $7.2 million. This approach may be adaptable to measuring temperature in other steel industry processes such as reheat ovens and rolling mills.



Galvanneal thermometry system.

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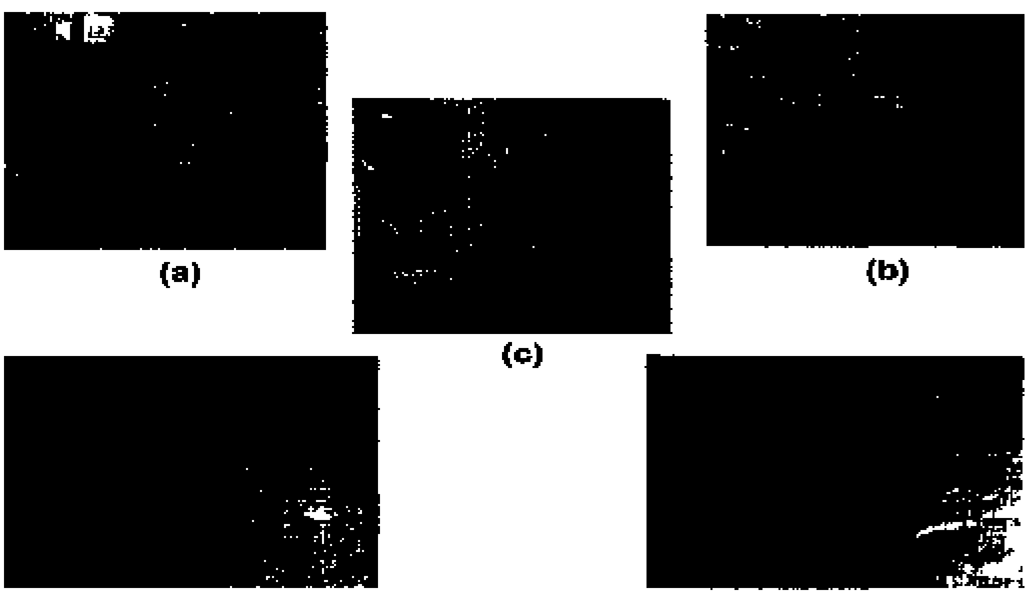
Instrumentation and Controls Division

Wet-End Characterization of Paper Web

We are developing an intelligent, vision-based apparatus for the paper industry that provides better control of the papermaking process.

The paper industry has had a long-standing need to better understand and robustly control its papermaking process upstream, specifically, in the forming section (also known as the wet end). We are developing a unique state-of-the-art vision system that automatically measures and interprets pertinent paper web parameters at the wet end. Unlike currently available sensing systems that are intended to operate downstream, our vision system provides timely measurements of important web parameters at the crucial stage of paper formation. Having this capability can create both short-term and long-term changes in the paper industry and can dramatically affect product quality and production yield. In the short term, the ability to characterize the web at the wet end will provide machine operators with the necessary feedback they need to make definitive adjustments to the headbox [figure (*a*)] and hence minimize the undesirable effects of formation variations. In the long run, the industry can expect significant advances in headbox design and control as their researchers use this same capability to better understand and quantify headbox flow dynamics.

The wet-end characterization of the paper web by our vision system involves a four-dimensional measurement of the slurry (fiber and water mixture) in real time. These measurements include the two-dimensional spatial information, intensity profile, and depth profile of the slurry. To infer the pertinent web parameters from these measurements, the system employs a suite of sophisticated image-processing and pattern recognition algorithms. Automatically inferred parameters, such as homogeneity of the web and location and topography of the web streaks, are then used to quantify paper formation characteristics or to monitor production events (e.g., table activity and web breaks). One of the subsystems of this apparatus has been designed and tested in a paper mill for on-line evaluation. The overall system is expected to be completed by the end of fiscal year 1999.



(a) (b) (c) (d) (e)

The top two images depict the wet end of a paper machine, the headbox (a) and the press section (b). Image (c) shows the subsystem deployed to capture high-quality, on-line images of the slurry; two such images are shown at the bottom. Note the distinct structures present in the images, (d) water beads and (e) web streaks.

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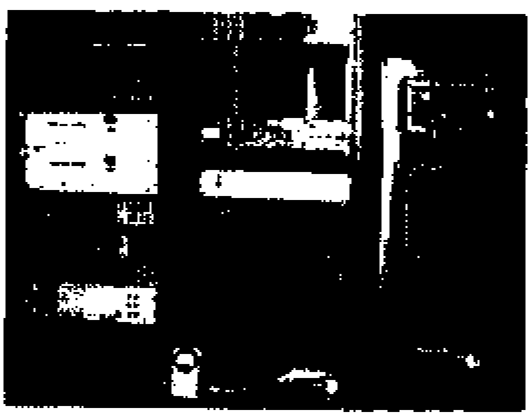
Large-Area Plasma Facility with Real-Time Control

ORNL has built a large-area, inductively coupled plasma facility with real-time control to help the semiconductor industry prepare for the transition to 300-mm wafers.

Unlike simple feedback control systems, the ORNL plasma control system uses model-based, nonlinear controls for active control, including startup and shutdown transients, to improve cycle time and prevent wafer damage. Our control system approach for the inductively coupled plasma source includes real-time feedback of critical process variables and a control law structure based on an accurate process model. Although these two key elements have been incorporated into control strategies for applications in other fields, they have not been incorporated into plasma processing because sensor data from the antenna/coupler and process plasma have not been included in the feedback control law. In addition, accurate models of these components have not been synthesized into a form suitable for designing a control strategy. Such model-based control methodology is key to our project. With sensor data from all components of the system and their corresponding process models, we are developing a more precise (e.g., stable) control system. The control strategy we are implementing includes several elements of advanced control theory:

- *nonlinear control*—plasmas are highly nonlinear and can exhibit chaotic dynamic behavior;
- *model reduction*—because plasmas are distributed parameter systems, the dynamics must be finitely dimensioned and then further reduced for real-time control;
- *robust control*—the stability of the plasma is sensitive to operating parameters and must be tightly controlled despite these uncertainties.

Key innovations in our ongoing work on 300-mm plasma systems include use of models for the power amplifier, plasma, and transmission line and matching components within an integrated system control model; improved sensors to optimize control response; and active control during startup and shutdown to minimize cycle time and destructive transients. Although this approach for the overall system is new, we are also implementing ideas for improved operation within each system (e.g., stabilizing certain classes of instabilities in electro-negative plasmas by introducing deliberate mismatches).



Real-time control system.

Large-area plasma processing test bed.

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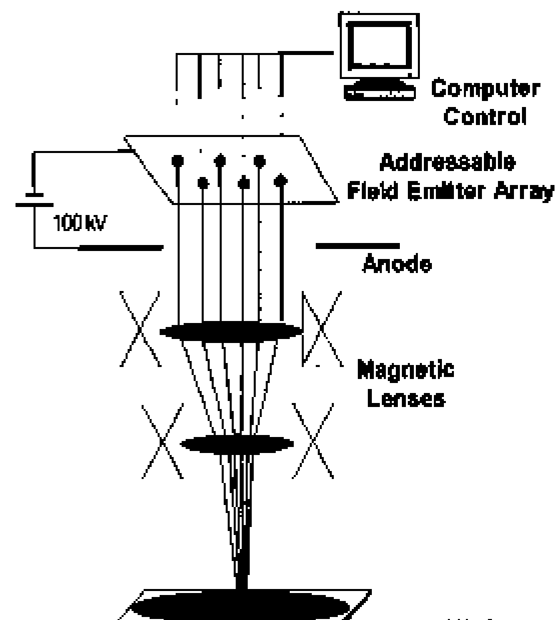
Instrumentation and Controls Division

Massively Parallel, Digital, Direct Electron-Beam Lithography for 0.1-Micron and Smaller Structures

We are developing massively parallel, digital, direct electron-beam (e-beam) lithography to extend semiconductor lithography beyond the foreseeable optical limit of 0.1 microns.

It is well known that optical lithography for semiconductor wafer production is limited by the wavelength of light. At any particular wavelength of light, diffraction limits the capability to focus a point to a circle approximately equal to the wavelength of light used for imaging (phase masks improve this by a factor of two or so). Electrons also have a wavelength and a theoretical diffraction limit, but the electron wavelength is so short that lens aberrations limit the resolution. This makes e-beam technology a strong candidate for lithographically produced semiconductor devices beyond the reach of current optical lithography techniques, with line widths on the order of 100 nm and below.

The concept we are developing allows simultaneous writing with millions of e-beams in an easily programmable field emitter array (FEA), potentially writing an entire 1-cm chip, with 0.1-micron line widths, in the order of 1 second. FEAs are two-dimensional arrays of miniature cathodes used for e-beam sources. We propose using custom-made FEAs with addressable amorphous diamond emitters for direct writing of lithographic patterns on semiconductor wafers coated with suitable resistant material. An electrostatic acceleration structure accelerates the emitted electrons to a voltage on the order of 100 to 200 kV to avoid aberrations caused by stray magnetic fields. A magnetic lens assembly consisting of a telecentric magnetic lens system and correction lenses demagnifies the field-emitted beam array onto the target wafer. The individual beam from each emitter cathode is addressable, enabling patterns to be programmed into the addressable FEA before being written onto the target wafer. "Turn on" and "turn off" of the entire array is achieved by switching the bias grid from positive to negative. This concept also has the advantage of a digitally programmable "mask" with no moving parts, which can be reprogrammed for new layers within milliseconds.



The digital e-beam lithography concept is a layered design that includes: (1) a source with transistor-controlled electron field emission arrays, (2) an electrostatic acceleration layer to accelerate the electrons to 100 kV to avoid magnetic aberrations, (3) a magnetic lens system that demagnifies the field emitted beam array (by 10) onto the final layer, and (4) a target wafer, where the original pixels are demagnified to ~20 nm pixels and are imaged onto the wafer.

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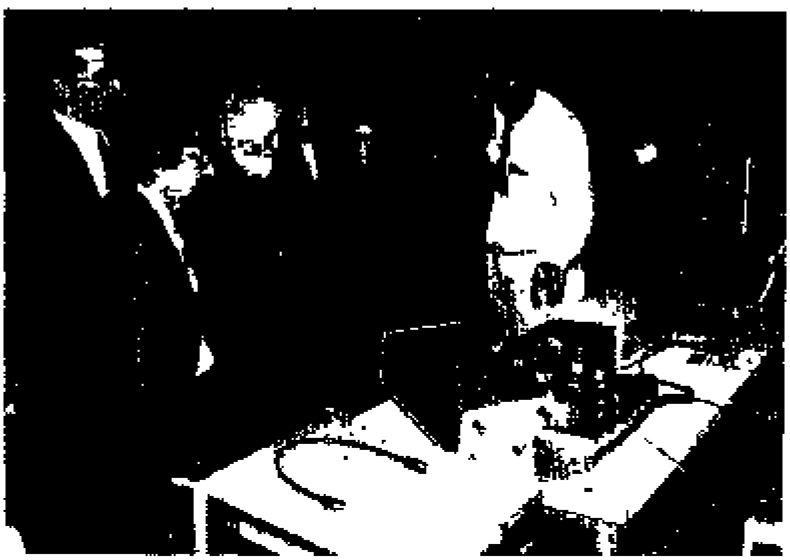
Radio Frequency Power Measurement and Control

We have developed a way to measure and control radio frequency (rf) power levels for making computer chips.

As prices of computer chips fall and costs of chip-processing equipment rise, the U.S. semiconductor industry seeks to become more competitive. Its goals are to pack more circuits onto semiconductor wafers and to produce more high-quality wafers per day. One way to achieve these goals is to better control the plasma etching of wafers. In this process, hot ionized molecules, such as a gaseous compound of fluorine, etch integrated circuit patterns many times smaller than a human hair.

One of the keys to producing a uniform etch is accurately controlling the rf power that generates the plasma. The rf energy is used to break down the gas and ionize the etch gaseous compound. Neutral atoms then fall out of the plasma onto the wafer, etching the surface chemically. Our rf system controls delivered power to plasmas at least 10 times faster and more accurately than systems routinely used throughout the industry. This novel system offers the potential for improved yield and increased throughput of high-quality wafers from plasma etch equipment.

The measurement technique uses two highly unobtrusive sensors that determine whether the impedance (resistance and capacitive reactance) in the plasma and the rf generator match. The sensors take data on impedance mismatches in equipment and cables that carry the rf power and feed the data to a microprocessor that controls a novel electronic rf power-matching network with no moving parts. In a few milliseconds, the controller tunes the rf matcher so that rf impedance matches the changing electrical impedance of the plasma in the etch equipment. The controller also rapidly adjusts the rf power level of the generator to compensate for power losses along the delivery path to maintain constant delivered power to the plasma. The combination of accurate sensing and rapid controlling of rf power offers better plasma control, fewer wafer-to-wafer variations, and increased production throughputs with higher yields.



ORNL's Tony Moore (in white shirt) points out features of the rf matcher. The small device at the back of the table is an ORNL-developed sensor for the rf system for accurately measuring and controlling rf power levels in plasma-processing equipment used to produce semiconductor chips.

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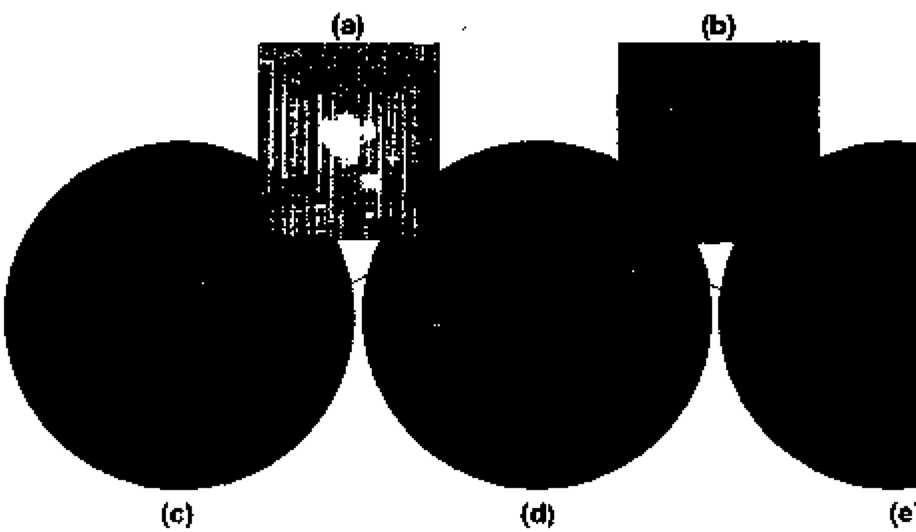
Instrumentation and Controls Division

Semiconductor Yield Improvement Through Spatial Signature Analysis

In partnership with SEMATECH, Austin, Texas, we have developed a system, called Spatial Signature Analysis (SSA), that automatically analyzes in-line manufacturing data from inspection equipment to assist the engineer in rapid, root-cause diagnosis of defect-generating mechanisms.

In 1965 when Gordon Moore pointed out the future exponential growth of semiconductor device capacity, little consideration was given to the fact that the volume of data required to manage the manufacturing process would follow suit. Accommodating this growth required that a rapid reduction in process data be achieved through its conversion to useful process control information. SSA has helped address this data-reduction issue by applying an image-processing–based, fuzzy classifier system to automate a tedious and time-consuming manual inspection process. The technique uses data collected from current in-line inspection tools to interpret and rapidly identify characteristic patterns, or "signatures," that are uniquely associated with the manufacturing process, such as those shown in the accompanying figure. The SSA system then alerts fabrication engineers to probable yield-limiting conditions that require attention.

Validation testing of the technology at Digital Equipment Corp., Intel, and Texas Instruments has proved SSA to be effective for application-specific integrated circuit and random access memory (DRAM and SRAM) products. Texas Instruments, Rockwell International, Motorola, IBM, Advanced Micro Devices, Intel, and National Semiconductor have licensed SSA for use in their own fabrication facilities. Applied Materials, Defect and Yield Management, ADE Software, KLA-Tencor, Inspex, and Knights Technology, all manufacturers of yield management and inspection systems, have also licensed the software for integration into their existing commercial defect data management systems or to develop new commercial products.



A spatial signature is defined as a unique distribution of wafer defects originating from a single manufacturing problem. (a) High-resolution optical defect image. (b) High-resolution scanning electron microscopy defect image. (c) Single wafer containing scratch signatures. (d) Superimposed stack of wafers highlighting a subtle systematic particle contamination problem. (e) Single wafer showing a spin-coater streak pattern.

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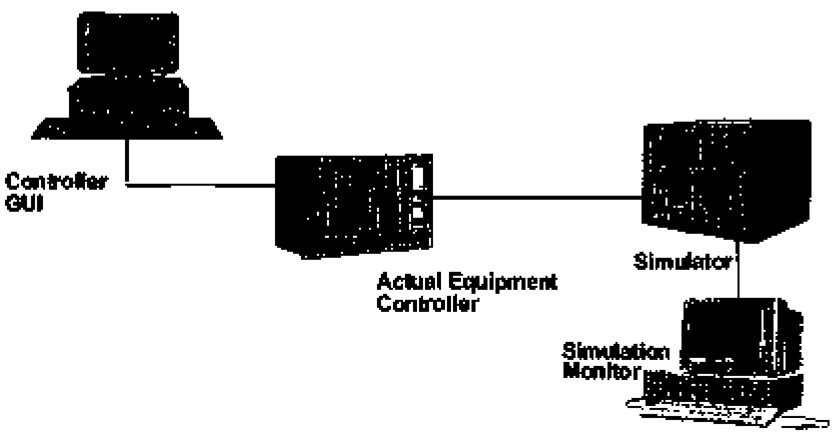
Simulator-Based Control System Testing

We are developing simulator-based control system testing for SEMATECH and the semiconductor industry to improve the unreliability of many process tools.

Semiconductor equipment, in general, suffers from poor reliability. Unscheduled downtime runs about 15%. Up to 40% of failures are attributable to control system software failures. A SEMATECH study shows that many of the root causes of these failures could be alleviated using simulator-based testing. This method of testing has already proved effective in industries such as the aerospace and automotive industries.

Unlike the typical tool-development process in which control software is developed last (after the tool hardware has been manufactured), the simulator-based method uses a model of the equipment so that software can be developed and tested in parallel with and independent of tool hardware fabrication. The basis of this methodology is building and loading a model of the manufacturing equipment into a simulator; the controller is connected to the simulator rather than the actual equipment. The controller is then tested against the simulator.

Currently, our work is at the strategic level: demonstrating to the semiconductor community the benefits of this approach. We have written case studies of successful uses of this methodology. We have also documented simulator requirements from semiconductor equipment suppliers and have conducted a survey of commercial simulator providers. Our goal is to point out the existing capabilities of simulator products to the semiconductor community and to point out the requirements from the semiconductor community that commercial simulator providers should build into their future products. We hope to undertake a tactical-level project by using this technique on a semiconductor manufacturing tool and documenting the benefits.



Conceptual drawing of simulator-based control system testing.

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National Security Markets

Introduction

The I&C Division markets for national security and safety and for external research and development facilities are clustered around ORNL's national defense mission. Acting alone as well as in collaboration with other ORNL divisions, we have developed relationships with the U.S. Department of Defense (DOD) and other federal organizations, matching our capabilities to their needs for advanced tools in measurement and control technologies. Over the years, we have led and participated in interdisciplinary collaborations for the U.S. military and other security organizations. In recent years, we have expanded our traditional customer base of DOD and DOE to include international organizations, national law enforcement agencies, and federal intelligence agencies.

Our expertise in nuclear detection techniques, long a mainstay of the division, now serves the missions of nuclear nonproliferation and treaty verification for DOE, DOD (Defense Special Weapons Agency), and U.S. Department of State programs. Subcriticality measurements, in particular, are being applied to nuclear disarmament and weapons dismantling programs in the United States and Russia. In fiscal year 1997, 20% of the division's funding was devoted to nuclear detection technology. We expect national and international needs in this area to continue for the next 10 years.

Many of our core capabilities have been applied to other important international and national interests. I&C's long-standing core competency of nuclear reactor controls and safety analysis continues to serve nuclear reactor safety assessment needs for DOE, DOD, and international organizations. Through the Y-12–based National Security Program Office, our division attracts many federal and state law enforcement customers who are interested in surveillance, detection, and recognition technologies. Using image-processing techniques, we have even helped law enforcement personnel solve crimes at the local level. Our staff are currently serving on a team led by the Defense Advanced Research Projects Agency that is working to advance the state of the art in landmine detection.

An important new project is the development of a miniaturized mass spectrometer for rapid detection of chemical and biological agents, a multiorganizational effort for the U.S. Army. We are actively pursuing opportunities for our advanced light detection and ranging technologies, for which there are many military, environmental, and commercial aircraft applications. In addition, we have recently completed a highly successful large-scale system for the Navy (the Acoustic Measurement Facilities Improvement Program, or AMFIP II) to measure and certify radiated acoustic signatures of the new Seawolf submarine and the entire submarine fleet.

Chemical-Biological Mass Spectrometer

ORNL is developing a chemical-biological mass spectrometer (CBMS) that will provide faster, more reliable detection and identification of chemical and biological warfare agents in the field.

Historically, detection of chemical warfare agents in the field has been unreliable because of the chemically complex background of exhausts from weapons and engines. The detection of biological warfare agents (toxins, viruses, and pathogenic bacteria) is even more difficult. The Chemical Biological Defense Command of the U.S. Army selected ORNL to design and construct prototypes and to oversee the construction of preproduction models of the next series (Block II) of the CBMS. The next-series instrument must be smaller, lighter, faster, cheaper, more sensitive, easier to maintain, and able to detect and distinguish among a wider variety of chemicals and microorganisms, airborne and on the ground, than existing instruments. The five-module instrument will be about the size of a desktop computer and monitor.

The heart of the Block II CBMS is an ion trap mass spectrometer. To detect biological agents, the CBMS samples air and classifies and concentrates micron-sized biological agents such as anthrax spores or bacterial toxins. In the ion trap mass spectrometer, the biomarker molecules are ionized, selectively accumulated, separated in an electric field, and detected. Bacteria are identified by their phospholipid fatty acid content, and toxins and viruses are identified by their protein pyrolysis profiles. Sophisticated identification algorithms are required to detect and identify biological agents in a background that may include naturally occurring microorganisms, pollen, mold, and fungus.

To detect chemical agents, the CBMS uses an air sampler and a pair of ground wheel samplers that swing from the base of a vehicle traveling cross-country, picking up surface contaminants and sending them to the CBMS inlet. When an agent is detected by the ion trap mass spectrometer, the probe is lowered to the ground for a low-speed, higher-resolution "sniffing" to map areas of contamination. Because it will be deployed on various military platforms, the CBMS must be ruggedly built to withstand vibration, physical shock, temperature extremes, fluctuating voltage, and nuclear irradiation.

Innovations to the Block II CBMS include advanced electronics and instrumentation and self-diagnostics. Should a malfunction occur, the embedded computer will tell the operator which module should be replaced. In addition to the electronics, we are developing the data acquisition software and operator display systems for the Block II CBMS.

The Block II CBMS will be deployed on several different military platforms such as the Biological Integrated Detection System shown here.

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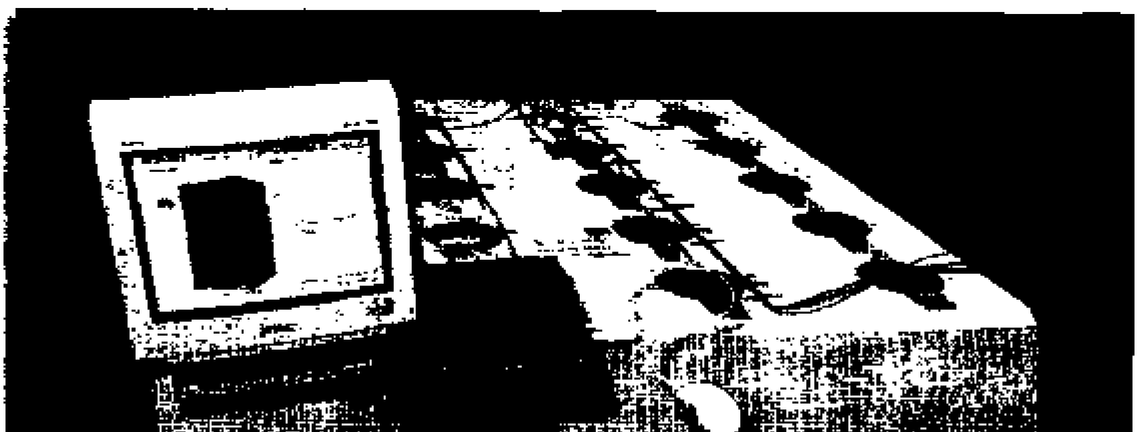
Continuous Automated Vault Inventory System

We have developed electronics and sensors for a cost-effective, automated system for inventorying special nuclear material (SNM).

Traditional SNM accountability systems have relied on physical measurements with specialized equipment and intermittent audits performed by highly trained personnel. These systems, although effective, are labor intensive and highly procedural. Such inspections are slow, put personnel at risk, and detect anomalies only after they have occurred. The Y-12 Continuous Automated Vault Inventory System (CAVIS)™ was developed to automate the process of inventorying stored enriched uranium. Unlike manual inventory methods, CAVIS minimizes the required human labor and, hence, the radiation exposure typically associated with SNM inventories. The I&C Division developed the electronics and sensor support for this system.

CAVIS uses an integrated set of fiber-optic sensors to continuously and passively monitor the status of stored nuclear (radioactive) materials. Weight and radiation attributes can be quickly obtained from individual items in the inventory. The basic concept is to provide a scintillator material for each item to be monitored that converts neutrons or gamma rays to photons (light energy). The photons are then coupled into a fiber-optic cable and transmitted to a location outside the vault area. Signals from the fiber-optic cables are fed to a module consisting of a two-dimensional photomultiplier tube and associated electronic processing circuitry. The circuits were implemented as application-specific integrated circuits, minimizing the cost and size of the module and maximizing the reliability of the detector. The absence of active components (such as power supplies and amplifiers) inside the vault that require periodic maintenance minimizes the need for human intervention.

We have also developed a variety of other materials for use in alpha-, beta-, gamma-, and neutron-sensitive scintillator detectors. We have developed new sensor materials capable of measuring weight, temperature, and source location.



Conceptual drawing of CAVIS in use at the Y-12 Plant in Oak Ridge, Tennessee.

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Instrumentation and Controls Division

Enclosed Space Detection System

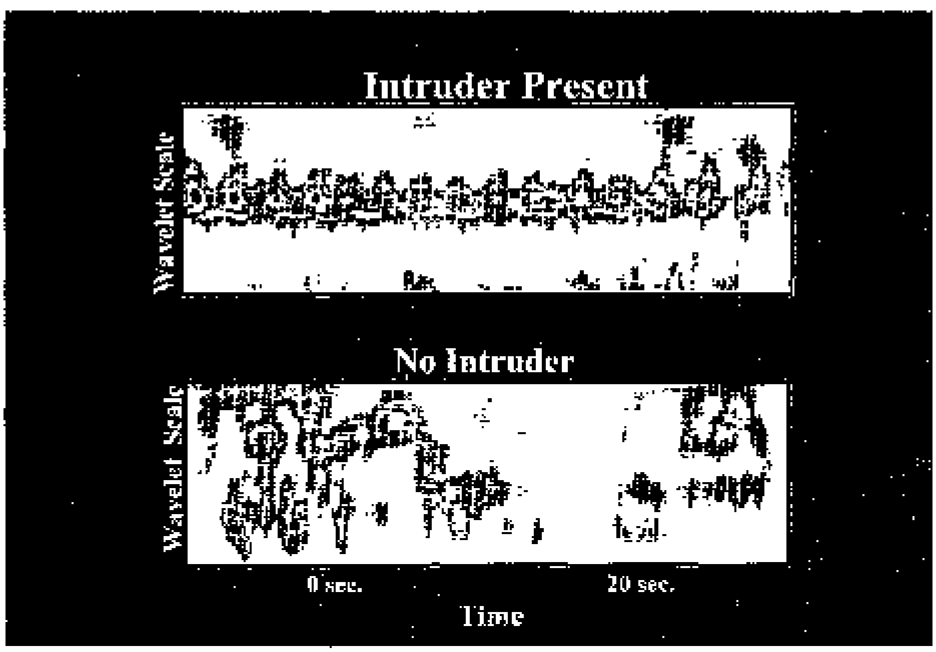
We have developed an essential algorithm for a heartbeat detector that is a breakthrough in security systems.

The scene is all too familiar from TV shows like *America's Most Wanted*: law enforcement has mounted a massive, expensive manhunt for a convicted criminal who has hidden in a laundry truck and slipped through the prison sally port without the guards ever noticing.

The ability to detect concealed passengers is critical for security at vehicle portals at DOE's nuclear facilities. Several years ago, a team of engineers at the Y-12 facility in Oak Ridge, Tennessee, began developing a heartbeat detector, originally for DOE's "Portal of the Future." This system uses a variety of sophisticated devices and methods to quickly inspect trucks passing through vehicle portals at key facilities. Key to the success of the heartbeat detector is a fast continuous wavelet transform algorithm developed by the I&C Division. The heartbeat signal is captured outside the vehicle by a geophone (a device used to detect small disturbances in the earth). The sensor signal is fed into the wavelet algorithm, producing the kind of information shown in the accompanying figure. The heartbeat stands out of the background noise as a series of easily recognized blobs.

The heartbeat detector is the first practical electronic alternative to human or canine inspection of vehicles for hidden passengers and is superior to both. A heartbeat detector can check a vehicle in less than one minute; a physical search by trained guards is unfeasible in most settings, can take hours to complete, and may require dismantling the vehicle. A first-class canine security operation has been an appealing (and a photogenic) option, delivering a reliability rate of about 80%; however, a heartbeat detector can be used for about 3% of the cost and is significantly more reliable.

The wavelet-based heartbeat detector has been recognized as a breakthrough in security technology. After independent testing, the detector was commercialized in 1996 and is now available to any security operation that needs it. It won an R&D 100 Award in 1997.



The top image shows the heartbeat of a concealed person in the vehicle. The bottom image shows no concealed persons in the vehicle.

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Fingerprint Processing for the FBI

Our unique skills in human-machine interfaces, network programming, image processing, and pattern recognition are contributing to an upgrade of the Federal Bureau of Investigation's (FBI's) Electronic Fingerprint Image Print Server (EFIPS).

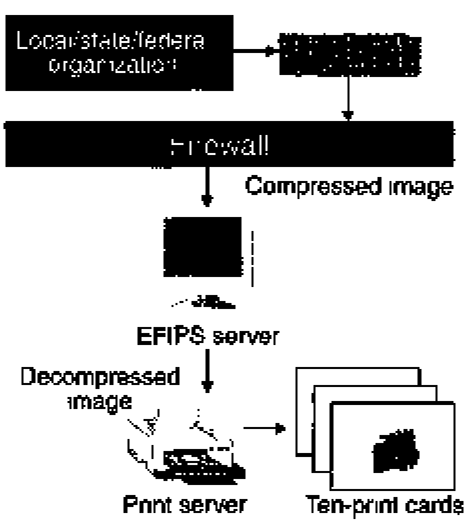
The I&C Division is working with Lockheed Martin Energy Systems to develop version III of the EFIPS for the FBI. EFIPS allows agencies to electronically submit fingerprint data for processing rather than sending paper fingerprint cards by standard mail.

Fingerprints are scanned by means of an inkless "live-scan" device and are stored electronically at a local police department, for example. These fingerprint images are then forwarded to the State Identification Bureau, which is connected to the EFIPS system via the FBI's wide-area network. EFIPS checks each submission for security privileges, completeness, and conformance to system standards. If the fingerprint submission is deficient in any way, EFIPS immediately notifies the originating agency through e-mail.

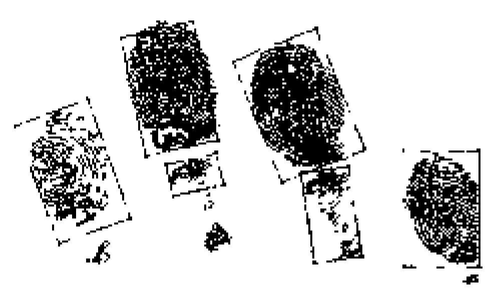
Successful submissions are decrypted, decompressed, and sent to a computer-based, graphical user interface that allows FBI employees to perform quality control and fingerprint classification tasks, all within a paperless environment. Currently, a card is also printed on a standard FBI ten-print paper card for final processing. The FBI plans to have a completely paperless fingerprint process by the year 2000.

The EFIPS system allows faster processing of both criminal and civil requests. The first suspect's fingerprints submitted by the Boston Police Department were identified within two hours, and the suspect's criminal record was available before the bail hearing. This identification would have taken several days using standard mail.

Fingerprint images that are electronically submitted to EFIPS occasionally suffer from two problems. First, poor-quality images (e.g., smeared or low-contrast prints) may result from prints being improperly scanned at the police station, for example. Second, fingerprints are often recorded out of sequence. Because EFIPS may receive up to 10,000 cards per day, detecting these image problems automatically and notifying the contributor before FBI employees manually process the images would greatly enhance efficiency. We are developing techniques to automatically assess the image quality of electronic submissions so that contributors can be notified immediately if poor-quality or out-of-sequence images are detected.



Processing fingerprints using the EFIPS



Four-finger image used for automated sequence check.

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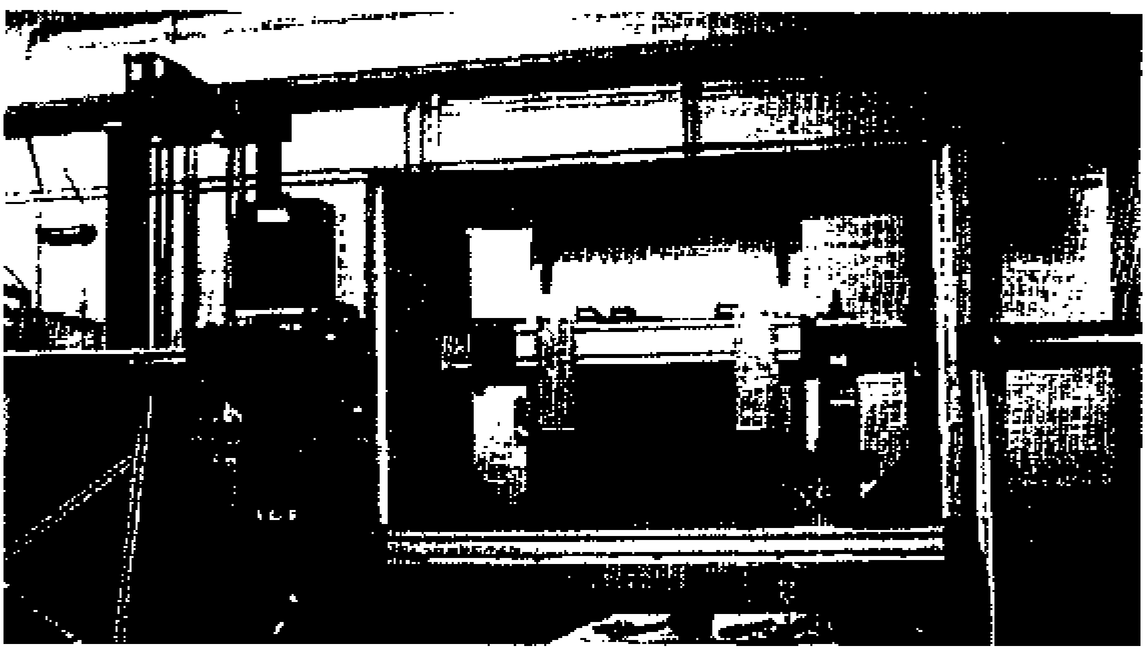
Fissile Mass Flow Monitoring System

We have developed a nonintrusive fissile mass flow monitoring system for installation in Russian nuclear fuel–blending facilities as part of an agreement to transfer 500 metric tons of weapons-grade uranium from the Russian Federation to the United States after it is converted to reactor-grade fuel. The agreement requires the United States to install equipment to continuously monitor the blend-down of highly enriched uranium (HEU) to low-enriched uranium (LEU).

The monitor we have developed is composed of a modulated neutron source and a gamma ray detection system. Neutrons from a source induce fission in a stream of gaseous or liquid fissile material. The gamma rays resulting from the decay of the fission fragments are detected downstream from the point of activation. The elapsed time between activation and detection provides a measure of the flow velocity. The amplitude of the correlated detector count rate is related to the fissile mass. This information, combined with the dimensions of the piping and gas properties, provides a measure of mass flow rate. The blending is accomplished by flowing a stream of HEU and a stream of LEU into a blending tee. The resulting LEU product can then be used as reactor fuel. Known activation in the HEU process stream and correlated gamma ray detection in the product stream provide material traceability throughout the blending operation.

In this monitor, a small ^{252}Cf neutron source is contained within a polyethylene source modulator assembly that is positioned around the process piping. This arrangement and the moderation of the neutrons increases the probability of fission in the process stream. The movement of a shutter that contains regions with and without a neutron-absorbing material modulates the injection of neutrons into the process stream. Downstream is a detector assembly consisting of a set of bismuth germinate gamma ray detectors. The source modulator and detector assemblies are connected to a computer-based control and information-processing/display unit.



Detector and source modulator assemblies mounted on process pipe section.

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Gas-Cooled Reactor Safety Analysis

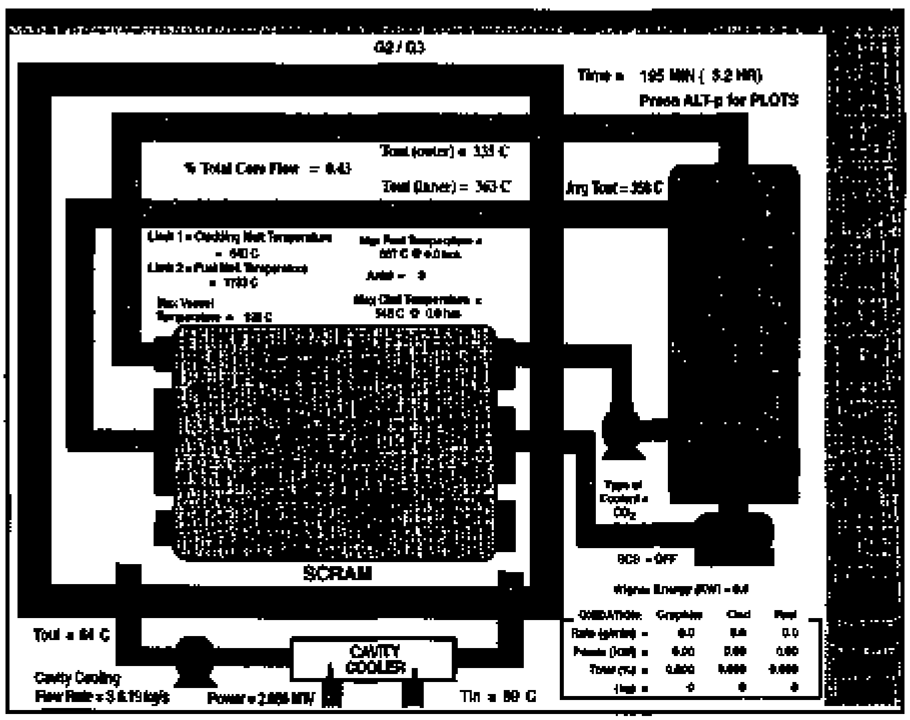
We have developed graphite reactor severe accident code (GRSAC) for use in gas-cooled reactor (GCR) safety analysis.

Recent developments in GCR technology, particularly improvements in cost and safety, have heightened interest in various high-temperature GCR concepts. Capabilities developed within the I&C Division over the past 20 years for analyzing GCR dynamics and safety characteristics are now being enhanced and applied in several different areas.

We developed the general-purpose GCR GRSAC accident simulator for the U.S. Department of Defense as a way to assess the effects and consequences of potential accidents at all of the world's nuclear facilities. GRSAC is a fast-running, user-friendly, interactive workstation simulator with unique capabilities for investigating severe GCR accidents. It includes three-dimensional thermal hydraulics coupled with models for material oxidation and fission product release, along with a neutronics package to study cases of anticipated transients without scram. GRSAC also has provisions that allow the operator to change plant design features, enabling alternative design studies and operational testing.

The GRSAC code has played a key role in International Atomic Energy Agency (IAEA) activities to study the safety characteristics of decay heat removal from a GCR in accident scenarios. Benchmarking calculations by ORNL and representatives from six other participating countries have been applied to several reactor types, including the HTTR (Japan), HTR-10 (China), and GT-MHR plutonium burner (General Atomics, U.S. and Russia). We also plan to be involved in another IAEA initiative to develop testing programs and analyze data from HTTR and HTR-10 operation, also making use of the GRSAC code.

On the basis of the GRSAC HTTR simulation capabilities, one of our staff was invited to participate in the Japan Atomic Energy Research Institute's "Foreign Researcher Inviting Program," through which GRSAC was applied to initial reactor startup conditions and safety test predictions.



GRSAC accident screen.

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MEMS Sensors for High-Sensitivity Measurements

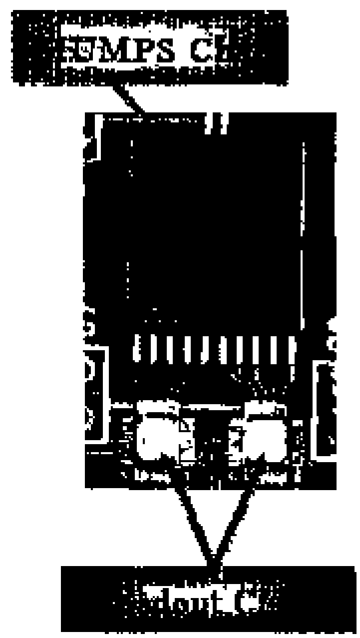
We are developing selectively coated cantilevers for chemical and biological sensing. These cantilevers are capable of sensing parts-per-trillion concentrations for certain species, exceeding that of other electromechanical devices. One of our primary areas of interest is chemical sensing for environmental applications. Toward this end, we are developing electronic readout of a coated cantilever array having ten cantilevers in a one-dimensional array.

Our research has focused on developing arrayable, electronically read cantilevers in a commercial microelectromechanical systems (MEMS) process. We ultimately want to put a variety of cantilevers with many different coatings onto a single chip to detect many different compounds. We are now proceeding to develop systems that employ electrically readable microcantilevers in a standard MEMS process and standard complementary metal-oxide semiconductor (CMOS) processes.

The process we chose for custom fabrication was the MultiUser MEMS ProcesS (MUMPS) from the Microelectronics Center of North Carolina. This is a surface micromachining process that shows promise for fast-turnaround processing. The figure on the right shows a representative cantilever set (MUMPS chip) and the custom CMOS readout chips developed for this array. The beam is pi-shaped with the coating areas on the beam legs. As the coating reacts with the vapor being sensed, the change in stress causes a deflection of the beam, thus changing the spacing between the upper and lower plates.

To date, we have been highly successful in sensing three different species—mercury vapor (sensing parts-per-billion concentrations), hydrogen gas, and alkane-thiols. Successful sensing of alkane-thiols is particularly important because they are similar in structure to mercaptans, the additives that give natural gas its distinctive smell.

Prototype microcantilever.



MUMPS chip and CMOS readout chips.

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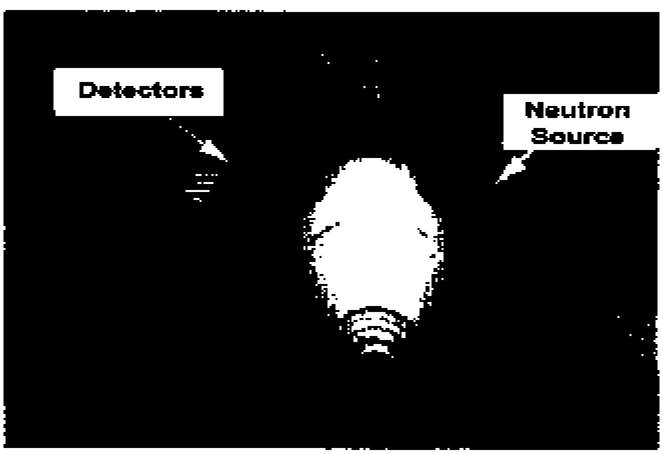
Nuclear Weapons Identification System

A nuclear weapons identification system (NWIS) has been developed for characterizing special nuclear materials.

Since 1984, the I&C Division has been developing an NWIS that analyzes neutrons and gamma rays emitted from an excited nuclear source to generate a signature of nuclear materials or components. The signatures can be used to identify or quantify stored nuclear weapons or materials. Because NWIS signatures are sensitive, robust, and multidimensional, they are difficult to defeat. NWIS can be made nonintrusive so that it does not reveal weapons design information, making it a useful verification technology for enforcing arms control agreements.

The system uses an active neutron and gamma ray interrogation method, the ^{252}Cf-source-driven noise method, and employs both time and frequency analyses to generate signatures of nuclear weapons and components and containers of nuclear materials. The system employs unique methods to accomplish the identification process. Neutrons are used to excite a chain multiplication within the fissile assembly. A set of detectors sensitive to the resultant gamma and/or neutron radiation is used to obtain signal information. This information constitutes a signature of a particular assembly configuration. Because the correlated information comes only from the region between the source and detectors, nearby materials do not present a problem, simplifying the use of NWIS in storage configurations. Comparing the NWIS signatures of nuclear materials with reference signatures or standards allows a user to identify or quantify fissile material configurations for accountability, identification, security, and safety. A prototype of NWIS is currently in use at the Oak Ridge Y-12 Plant for verification of nuclear weapons components in storage. Other uses include process plant monitoring and control, criticality safety applications, and warhead dismantlement.

The frequency content of the signal arises from statistical fluctuations in the source, the scattering, and fission chain multiplication processes. The frequency spectra are used much as acoustic signatures are used to identify voices or naval vessels. For time-domain measurements, the time distribution of neutrons and gamma rays is measured with respect to the time of emission of ^{252}Cf neutrons or to previous events in either particle detector. The advantage of frequency-domain measurements is that in the cross-power spectral densities between detectors, the uncorrelated (background) information averages to zero after many data samples. Therefore, meaningful measurements can be made when the ratio of correlated to uncorrelated components of a signal is as low as 10^{-3}.



NWIS source and detectors deployed near a fully assembled B83 (strategic nuclear bomb) for obtaining signatures at various positions along the weapons system.

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Instrumentation and Controls Division

High-Gain Acoustic Measurement System

We have developed key components and technologies for the High-Gain Acoustic Measurement System (H-GAMS), which measures and certifies the radiated acoustic signatures of ultraquiet submarines.

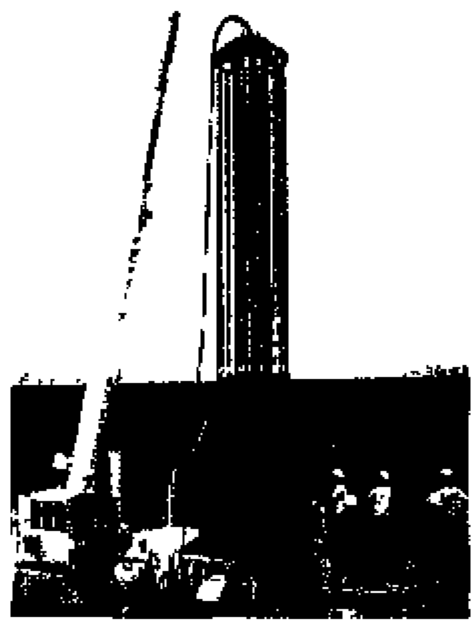
Part of a larger Navy program called the Acoustic Measurement Facilities Improvement Program (AMFIP), the H-GAMS is a unique high-performance measurement system developed to take precise acoustic measurements of devices that make very little noise. Unlike conventional underwater acoustic measurement technologies, our development provides accurate and calibrated spatial signal enhancement over predefined angles and over large regions of frequency. The system was put into service in 1997 by the Naval Surface Warfare Center. The SSN-21 Seawolf, the quietest undersea attack submarine in the world, was tested with this technology for six weeks and was determined to meet design goals.

The H-GAMS uses cylindrical hydrophone arrays, a massive suite of electronics, and sophisticated computer-based noise suppression algorithms to form high-gain acoustic beams. The system is the result of developments in new methods for array construction, underwater telemetry, and high-speed parallel digital signal processing.

This technology was strenuously tested under many different sea conditions and with many different calibrated acoustic sources and actual submarines to certify performance and accuracy of the system's capabilities. During this period, a number of important system enhancements were completed to improve performance and operational flexibility.

Our main contribution to the effort was the development of the telemetry electronics and the signal-processing elements of the high-gain array measurement system. Many other organizations were also involved to develop the target-tracking subsystem, data warehousing and database manager, the overall shipboard local area network, and operator interfaces. During certification of these new technologies over the past two years, several deficiencies were identified in the overall system. Although not directly involved with the deficient subsystems, we were able to solve several of their problems by augmenting the way in which the ORNL portions of the system operate. The end result was improved performance, higher reliability, and lower costs to the sponsor.

The SSN-21 Seawolf, the quietest submarine in the world



High-gain array of hydrophones about to be deployed off the bow of the USNS Hayes

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Instrumentation and Controls Division

The ORNL Market

Introduction

Support of research activities and facilities at ORNL represents a major portion of the budget for the I&C Division. Our engineers provide the I&C systems that ensure the effectiveness, safety, and security of research conducted at the Laboratory. For almost four decades, we have worked alongside individual researchers, constructing and maintaining the numerous unique systems that make up the Laboratory's complex operating and research infrastructure. Because of their knowledge of ORNL resources and their familiarity with the unique needs of the Laboratory, our staff have found innovative ways to provide timely, economical I&C support that has saved thousands of research dollars.

Our engineers provide ground-level design and development of prototype and other special instruments. They also modify complex research, facility monitoring, and process instrumentation systems to adapt them to the requirements of individual projects. By repairing and modifying damaged, abandoned equipment, our staff developed an automated thermal fatigue cycling test system at a fraction of the cost of a new system.

Our technical support staff provide the advanced expertise and innovative methods required for fabrication, testing, installation, maintenance, and calibration of I&C systems. Several recent projects involved developing and fabricating I&C systems, sampling systems, and on-line data acquisition systems for use in environmental cleanup and decommissioning activities. We also provide radiological metrology support for research activities in which these systems are used.

Another way we support research needs is by integrating individual systems into comprehensive testing facilities. We have developed our own environmental effects and mass flow development laboratories, which provide on-site, economical testing capabilities for ORNL staff as well as for visiting scientists.

In addition to supporting research at the ORNL site, our engineering and technical support staff often collaborate with other institutions and agencies to develop systems for one-of-a-kind facilities and projects. For the 1996 Olympic Games in Atlanta, we were part of a multiorganizational team put together to develop and test an intelligent transportation advisory system. I&C Division staff helped design the displays and develop the computer software for this project.

Our staff's enthusiasm and expertise has provided them with insight into what researchers want and need in their facilities. Because the support we provide is applicable to almost all scientific disciplines, we answer requests from almost every ORNL division. In the future, we intend to continue to support existing programs as well as new projects such as the Spallation Neutron Source.

Environmental Effects Laboratory

We designed the Environmental Effects Laboratory to provide ORNL researchers with low-cost, high-quality testing and evaluation capabilities on site.

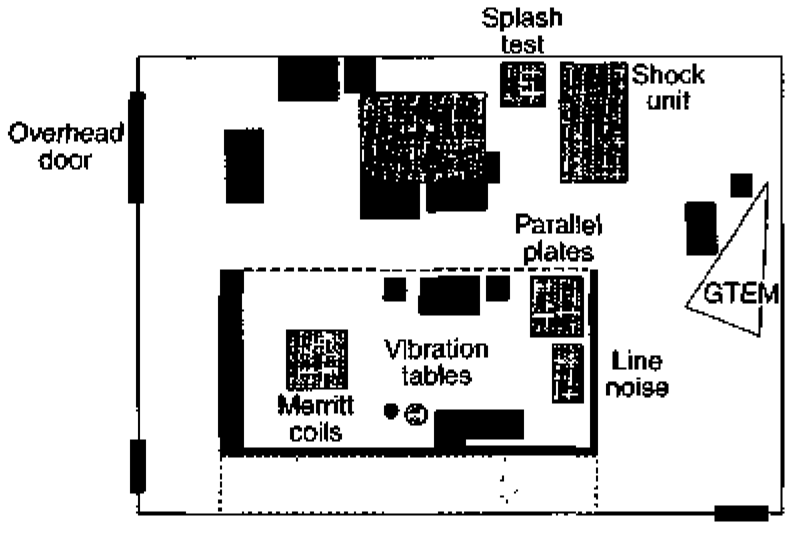
The Environmental Effects Laboratory was originally set up to evaluate radiation protection instruments to make sure they were appropriate for use at ORNL. Integrated within the laboratory were both existing and newly acquired test and evaluation capabilities from various disciplines within the I&C Division. Laboratory equipment allows us to perform complete temperature, humidity, electromagnetic interference, radiological, and mechanical evaluation services, which provide our researchers with low-cost, high-quality evaluations. Unlike similar DOE facilities, the Environmental Effects Laboratory enables immediate design or technology evaluation without the costs and delays associated with sending equipment to other locations and with gathering equipment from various locations for assembling and testing.

The manager of the Environmental Effects Laboratory is a recognized U.S. expert on radiation instrumentation and is a delegate to the International Electrotechnical Commission (IEC), Technical Committee (TC) 45, "Radiation Instrumentation." He is also a member of the technical advisory group to IEC TC 104, "Environmental Conditions, Classifications, and Methods of Test." This on-site expertise has allowed laboratory staff to be aware of changes in standards-based testing and to direct and contribute to the techniques used for testing operations. Information obtained from radiation protection instrument evaluations and about our capabilities is available on the World Wide Web at *http://www.ic.ornl.gov/centers/ite/testinfo.htm*.

Equipment available at the Environmental Effects Laboratory includes:

- Russells environmental chamber
- M B Dynamics vibration tables
- Parallel plate cell
- Splash test cell
- Electric Research and Management Merritt coil set
- KeyTek line noise system
- Electro-Mechanics Company Gigahertz Transverse Electromagnetic (GTEM) cell
- Shock test unit

Each unit has either an approved or a draft operation and verification procedure and has computer controls to ensure safe, reliable, and reproducible operation.



Environmental Effects Laboratory layout.

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Mass Flow Development Laboratory

In conjunction with the semiconductor industry, we have been working to improve process gas measurement and control accuracy and reliability in the semiconductor industry. This effort led to creation of the Mass Flow Development Laboratory, a DOE National User Facility.

Materials processing is at the heart of semiconductor manufacturing. To make today's advanced integrated circuits, silicon wafers are subjected to over 200 process steps. To achieve the quality and performance required in the microdevices, accurate measurement and control of the hazardous and corrosive gases used is essential. The Mass Flow Development Laboratory features standardized test methods developed to characterize and benchmark the performance of mass flow controllers (MFCs), the method of choice for monitoring and controlling gas delivery. Baseline testing was performed along with development of a unique mass flow instrument, the gravimetric calibrator.

A fully contained process gas test bed was constructed for calibrating MFCs with hazardous, toxic, corrosive, and flammable gases typically used by the semiconductor industry. The test bed is used to evaluate MFC accuracy, linearity, repeatability, hysteresis, and dead band and was designed to safely handle a wide variety of gases, including pyrophorics. An innovative new calibration standard has been developed for this facility that allows precision calibration of hazardous and corrosive gases to accuracies exceeding 0.5% of reading throughout a wide range of flows. The test bed and its process-gas calibrator are double-contained, and all exhaust gases are treated through a remediation system. Operation is highly automated to ensure facility safety and data accuracy and consistency.

During the past two years, more than 25 users have used this facility and have worked with its flow instrumentation experts to develop and improve the state of the art in mass flow controllers. Inaccuracies associated with calibration-factor use have been significantly reduced for several important semiconductor process gases, opening the door for improved semiconductor process yields, reduced energy and waste, and improved products. The facility has also been important in evaluation of hydrogen gas detectors for the National Hydrogen Initiative.

Hazardous and corrosive process gases may be safely handled in the laboratory's fully contained calibration test bed.

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Instrumentation and Controls Division

Cesium Removal Demonstration

We have designed and fabricated a controls system and remote sampling system for use during remediation of contaminated process-waste storage tanks.

The Cesium Removal Demonstration project began in June 1995. The goal of the project was to remove cesium from process-waste storage tanks in the 7900 complex at ORNL to allow for future remediation of the tanks. The complex includes the experimental High Flux Isotope Reactor and the Radiochemical Engineering Development Center.

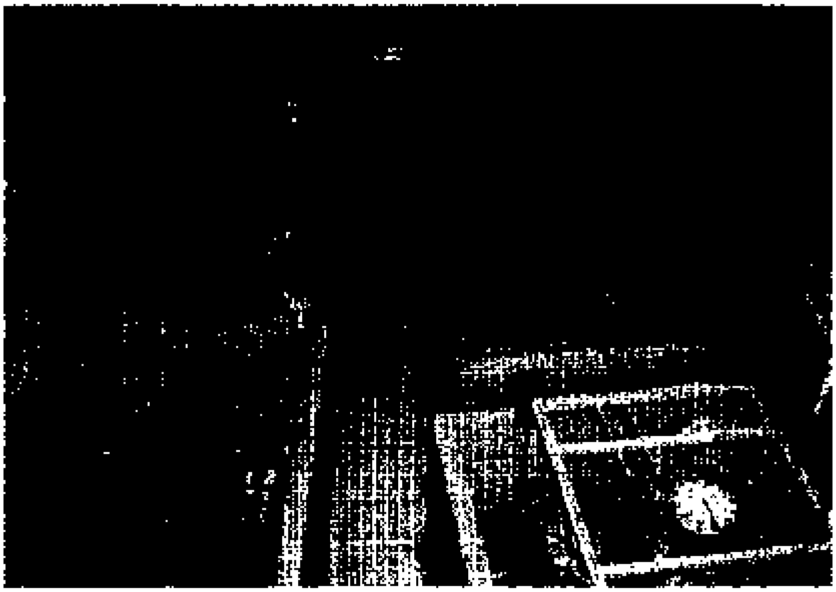
The initial request was to help with the conceptual design for the controls part of the system and to provide assistance writing a specification for outside procurement for instruments and fabrication of the mechanical systems. It was then requested that the data acquisition and control system be fabricated in-house. The system would be fabricated and tested in-house with input from customers and then be shipped to the fabricator's test site for overall system testing when completed.

The system we designed was a stand-alone data acquisition and control system capable of controlling more than 300 input/output points and of providing emergency logic should an off-normal condition occur. The system was designed with safety interlocks to help prevent errors in operation that could cause personnel exposure, equipment damage, or harm to the environment. We also designed the system to provide feedback historical data for regulatory proposes.

After the system was fabricated and installed in September 1996, a request was made for the I&C Division to design a method to allow remote sampling of radioactive liquid from different sample ports. We designed a system using a commercial programmable laboratory sampler. The sampler was modified so that it filled sample containers using a positive-displacement, time-based metering pump rather than taking samples from containers. With this system, several samples could be taken from as many locations as needed with no human exposure during the process. This allowed for remote monitoring of radiation levels from samples and limited the number of entries in and out of high-radiation areas.

Although originally designed to be operated through fiscal year 1997 as a demonstration only, the system is now scheduled to be installed for actual operation. A similar system is in the design stages for the Savannah River Nuclear Power Plant.

This project was a Secretary of Energy O'Leary and President Clinton milestone for fiscal year 1996. It also received a Tennessee Engineering Award.



Process-waste storage tanks in the 7900 complex at ORNL.

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Molten Salt Reactor Experiment Remediation

We have developed an I&C system and on-line data acquisition system to control and monitor the removal of gases from drain tanks and associated piping within decommissioned nuclear reactors.

The Molten Salt Reactor Experiment at ORNL has been shut down since December 1969, at which time the molten salt mixture of $LiF\text{-}BeF_2\text{-}ZrF_4\text{-}^{233}UF_4$ was transferred to fuel salt drain tanks for storage. In the late 1980s, increased radiation in one of the gas lines from the drain tank was attributed to $^{233}UF_6$. In 1994 two gas samples were withdrawn and analyzed. Surprisingly, 350 mm Hg of F_2, 70 mm Hg of UF_6, and smaller amounts of other gases were found in both of the samples. To remove this gas from above the drain tanks and all of the associated piping, a reactive gas removal system (RGRS) was designed.

To support the RGRS, we have developed an I&C system and on-line data acquisition system to control and monitor the removal process. The control system controlled the flow of the extremely reactive and corrosive gases to the reactive gas traps, which were filled with NaF for the collection of UF_6 and with alumina for the collection of fluorine. The data from the instrumentation, including pressure transducers, flow controllers, Fourier transform interferometer cells, thermocouple assemblies, and the nondestructive analysis system, were monitored and recorded with an on-line data acquisition system and Labview software.

The RGRS instrumentation monitors the gas flow and temperatures in the uranium and fluorine traps to ensure that the trap temperatures are maintained within specifications. Separate counting channels that include gamma sources and detectors determine the level of uranium in the NaF trap and are used to stop gas flow when the NaF trap is full. Thermocouples provide redundant indication of trap fill level by showing where the reaction front is as the uranium and fluorine are trapped. A data acquisition system displays the current system conditions, provides alert and alarm indications on measured and calculated parameters, and communicates over a network with a Fortran model that continuously estimates the amount of uranium accumulating on the NaF trap. Data recorded by the data acquisition system are used for detailed analysis of each run. The instruments integrated with logic circuits provide interlocks and shutdown for safe operation of the system.

Molten Salt Reactor Experiment reactor gas removal control room.

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Instrumentation and Controls Division

Off-Gas Ventilation System and NESHAP Sampler

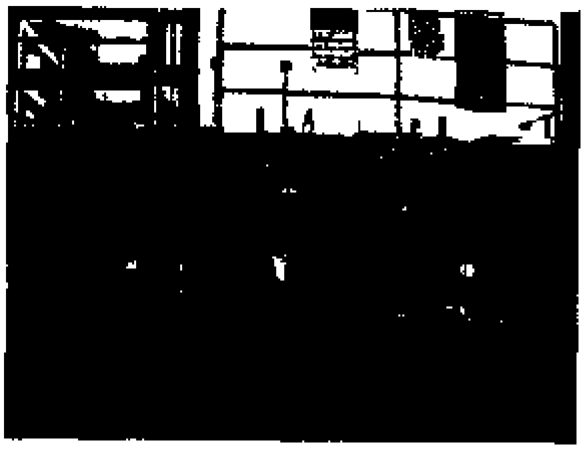
We have developed a tank off-gas ventilation and compliance sampler system.

This system is being used in the North Tank Farm at ORNL to provide negative off-gas and National Emission Standards for Hazardous Air Pollutants (NESHAP) compliance sampling of gaseous effluent from in-ground tanks. The ventilation and sampler system is a portable, cost-effective way to meet the requirements of both off-gas ventilation during in-tank operations and NESHAP compliance sampling. In contrast to the original design concept and cost estimate of $300,000 from a commercial firm, our development was constructed at a total cost of approximately $30,000.

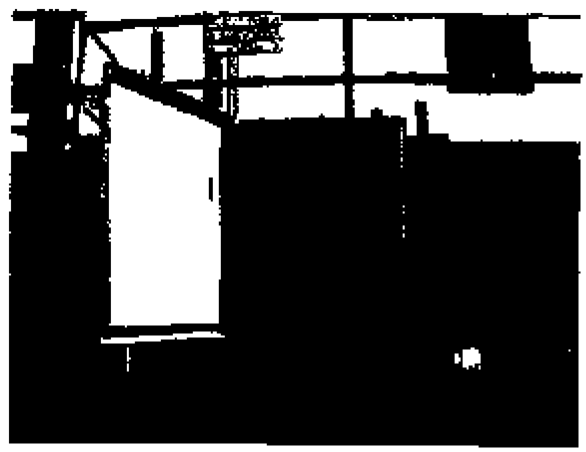
To design the system, we used an off-the-shelf high-efficiency particulate air (HEPA) ventilation system and modified it to provide constant off-gas pressure. The system also incorporates an alarm and control panel designed to control the system and provide system alarms in the event of a loss of tank pressure. A loss-of-system-power alarm alerts operators in the event of a total power loss. The loss-of-power alarm uses a battery backup and an off-the-shelf battery maintainer to activate an alarm beacon for up to 20 minutes in the event of a power failure.

The NESHAP compliance sampler uses off-the-shelf mass flow controllers to pass a representative gas sample through a particulate filter and a silica gel tritium trap. The filters and silica gel are then analyzed to provide release data.

The system efficiently provides tank off-gas and compliance sampling at a fraction of the cost of competitors' systems. The system is portable and can be moved to other tanks as needed. Its simple design includes few moving parts and is highly reliable. The simplicity of design also requires few replacement parts to ensure continuous operation.



Control cabinet for the off-gas system



NESHAP compliance sampling system.

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Instrumentation and Controls Division

Versatile Material Irradiation Control System

We have developed a data acquisition and control system for a high-capacity, multiple-user irradiation facility.

This system was designed for the Versatile Material Irradiation Facility at the University of Michigan's Ford Nuclear Reactor. The original request was to provide data acquisition for approximately 40 thermocouples and two channels of pressure. The final system was developed for a facility that could accept hundreds of specimens, with more than 50 electrical heaters, 25 heat zones, and independent temperature controls for each zone near the reactor core. The design also called for the capability for ORNL to remotely control operations such as loading and unloading specimens during reactor shutdowns and measuring gas flow, pressure, and moisture content.

The final system was completed and shipped to the Ford Nuclear Reactor. The final control system consisted of distributed control hardware using a human-machine interface for data acquisition and control for more than 300 points. Several operator screens were developed to allow the operators and experimenters to safely operate the system with ease.

The system can be operated and monitored peer-to-peer using a modem over a phone line, or be accessed over the Internet from anywhere in the world, provided the security measures are used properly. The system uses simple startup screens designed to prompt the operator to take certain steps at specific time intervals. It constantly monitors for off-normal conditions and notifies the operator when such conditions are detected. The system also logs all conditions, changes, and alarms to a password-protected file on site and at ORNL.

The Versatile Material Irradiation Facility is in operation with all systems performing as designed.

Core of the Ford Nuclear Reactor. The square housing immediately to the right of the control rods contains the control system designed by the I&C Division.

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Instrumentation and Controls Division

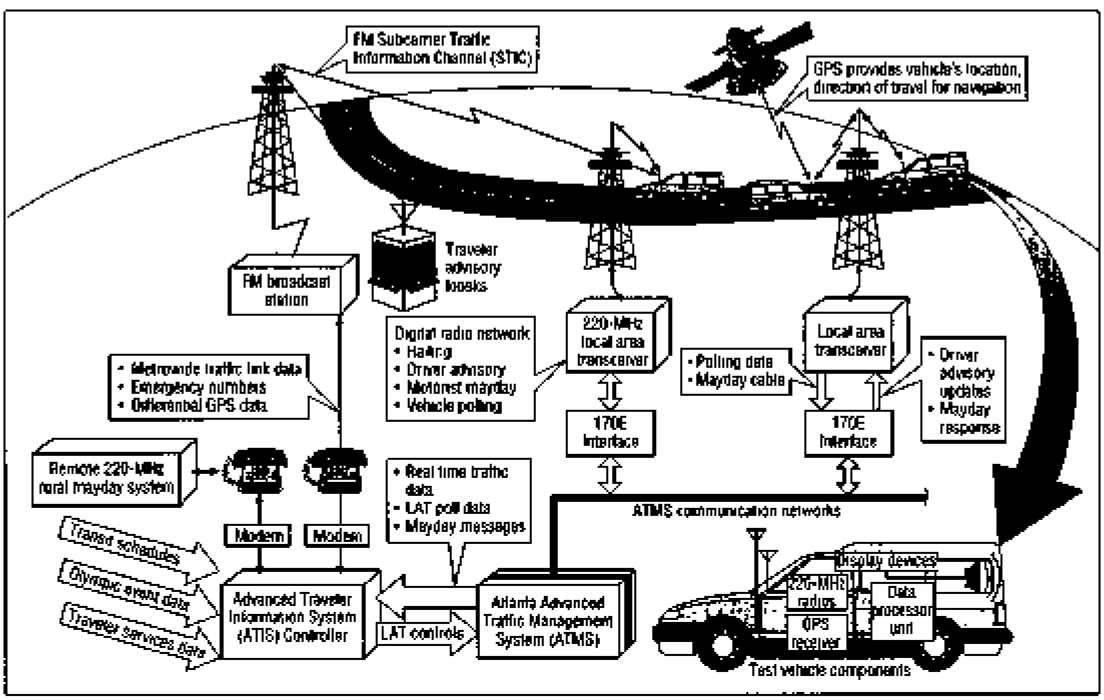
Advance Driver Advisory System

We developed a wireless driver advisory system that provides real-time navigational assistance.

In support of the Computer Science and Mathematics Division, the I&C Division worked with industrial, university, and other government groups to develop the Intelligent Transportation System for use during the 1996 Summer Olympic Games in Atlanta. The Advance Driver Advisory System (ADAS) was one of 17 operational tests that made up the National Intelligent Vehicle Highway System experiment. The goal of ADAS was to use test vehicles to evaluate the usefulness of on-board navigational systems and real-time traffic advisories.

Implementation of ADAS consisted of traveler information displays for 200 test vehicles and for booths at the Atlanta airport, bus and train stations, hotels, malls, and the Olympic Village and its parking lots. Adapting technology originally developed for defense-purpose helicopters, technicians equipped 200 vehicles with on-board navigation systems that display real-time traffic and routing information. The navigation systems and a traffic information control center communicated by radio signals as part of Atlanta's Advanced Traffic Management System. Signals from road sensors and satellites helped the control center pinpoint each driver's location with respect to known traffic bottlenecks so that it could suggest alternate routes.

The I&C Division helped design the displays and develop the computer software to transform digital data into words, icons, and maps that appeared on the display panels in cars and on kiosks. We designed the software to work with the hardware that was already available for use with kiosks and panel displays. The kiosks provided information about the events of the day and advice on how to get to various locations quickly and where to park. The in-vehicle displays offered five levels of real-time information, ranging from a few words (e.g., "Traffic Jam," or "Construction Ahead") to a full-blown navigational display showing the location of the vehicle with respect to congestion on local interstates. The display panel also highlighted alternate routes to avoid congestion.



Operation of the advance driver advisory system.

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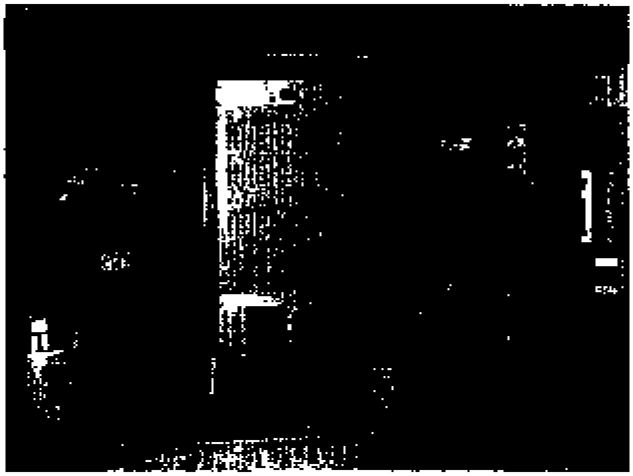
Control Panel Upgrades

We implemented a cost-effective, long-lasting remedy for indicator lamp burnout problems at two ORNL radioactive beam facilities.

Accelerator-based research requires effective monitoring to ensure reliable results as well as safety. The Oak Ridge Electron Linear Accelerator (ORELA) facility and the Holifield Radioactive Ion Beam Facility had long been plagued with the problem of crucial control panel indicator lamps continually burning out, frequently within 90 days of being installed. Maintenance technicians routinely replaced hundreds of incandescent lamps (there are more than 1000 indicators in the two facilities) almost every three months. Although the cost of the incandescent bulbs was low, technicians assigned to the facilities were required to spend an excessive amount of time replacing burned-out lamps. Moreover, because of the frequent burnouts, accelerator operators could not rely on the indicators to accurately display equipment status.

I&C technicians decided to replace the existing 24-volt incandescent indicators with plug-in, long-life light-emitting diodes (LEDs). Whereas replacing the incandescent bulbs with older LEDs required time-consuming soldering and equipment modification, these newer lamps can be used in place of the old bulbs with no circuit or hardware modifications. LEDs are also cooler and more efficient than incandescent bulbs, with a power consumption that is one-fourth that of incandescent lamps. These solid-state devices require far less maintenance than incandescent lamps, resulting in long-term cost savings in labor and parts. The old lamps were replaced more than a year ago, and no new LED indicators have failed.

In addition to the significant cost savings, this upgrade gives researchers and equipment operators more confidence in the indicators, which are crucial to everyday equipment operation and to the safety of facility staff.



I&C Division staff member Bud Ketner checks the LED indicator status on the ORELA control room console.

This photo indicates the size of the LED lamps.

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Instrumentation and Controls Division

Radiation Monitor Upgrades

We have implemented radiation monitor upgrades for ORNL radiological facilities to provide more reliable, efficient, and cost-effective radiation monitoring equipment for the protection of ORNL personnel.

The upgraded monitors are used to detect any alpha or beta-gamma contamination on personnel exiting a radiological area at ORNL facilities. During 1997, 188 new monitors were put into service, replacing the old monitors. These new monitors are compatible with existing alpha and beta-gamma probes being used. They are also more user friendly and have less downtime because of failure.

The new monitors are calibrated using a computerized calibration system developed by the I&C Division. The computerized calibration system was developed in the early 1990s to fill the need for an automated, high-capacity calibration system with computer-generated calibration reports. There are two options for calibration: monitors can be transported to the radiation instrument shop for calibration or be calibrated in the field using a notebook computer. The shop option is used for facilities where the number of monitors requiring calibration is small or space is not available for setup of the calibration station. The field option is used when a large number of monitors are to be calibrated. The field calibration method reduces the need for health physics support, eliminates problems created by monitor downtime, and reduces the effect of calibrations on facility operations. The net results of the computerized calibration system are a significant reduction of calibration time, increased calibration consistency, and printed calibration reports.

These Bicron alpha and beta-gamma monitor upgrades will ultimately provide greater reliability, reduced maintenance costs, and a reduced spare parts inventory. The calibration time has been reduced from approximately 3 hours to approximately 1 hour. Annually, this equates to a savings of approximately 376 work-hours, resulting in a savings of about $18,500 in calibration costs alone. Additionally, spare parts for these new monitors are more readily available through the manufacturer and third-party vendors than are parts for the monitors built in-house. The monitor upgrades have also increased the availability of spare monitors.

Bicron monitor modified for use as a stationary alpha and beta-gamma monitor.

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Instrumentation and Controls Division

Radio Console Upgrades

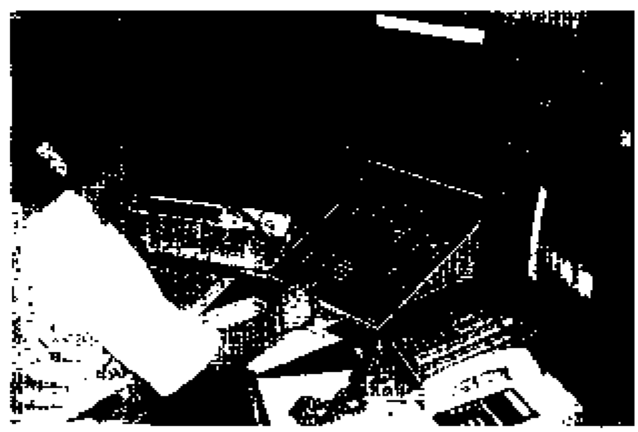
We implemented a major radio console upgrade for ORNL that has improved communications while reusing old equipment and saving funds.

Radio systems used at ORNL are crucial for effective and timely communications. I&C Division staff in the Communications and Security Maintenance Shop have been responsible for maintenance of the radio communications consoles at the Protective Services Central Alarm Station and the Laboratory Shift Superintendent's Office for many years. Our staff were aware that the consoles had been purchased and installed during the late 1970s and were approaching the end of their useful life. In addition, spare parts were no longer available from the manufacturer because of the age of the equipment. The ORNL radio systems manager and Maintenance Shop staff recommended that the consoles be replaced, but no funds were available to cover the cost of replacement by an outside vendor, which totaled more than $30,000.

Shop personnel contacted their counterparts in the Maintenance Department at the Y-12 Plant and discovered that several consoles were being removed as part of the trunking upgrade at the plant. These consoles were of much later manufacture than the current ORNL consoles and had very little usage on them, making them ideal replacements for the equipment at ORNL. After approval was granted for transfer of the equipment, our technicians installed the consoles at ORNL. Y-12 Radio Shop personnel provided technical assistance with reprogramming of the consoles.

Because of its success, replacement of the consoles at the Protective Services Central Alarm Station and the Laboratory Shift Superintendent's Office became the first step for complete replacement of the radio systems at ORNL. During the next 18 months, the consoles for the Fire Department, Protective Services (Security), and Emergency Preparedness were replaced and a new ORNL UHF Emergency Management Repeater Network was established. In addition to improved radio communications at a fraction of the estimated cost, modifying the equipment from Y-12 enabled use of approximately $140,000 of on-hand equipment that could not be used with the old consoles.

Upgraded radio consoles at the Protective Services Central Alarm Station.



Upgraded radio console at the Laboratory Shift Superintendent's Office.

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Instrumentation and Controls Division

Radiological Metrology

We provide radiological metrology in support of the Radiation Protection Program at ORNL and assist other organizations in the evaluation and design of radiation monitoring instrumentation.

For ORNL to have a quality Radiation Protection Program, expertise must be available to analyze various problems or questions that arise with radiation protection instrumentation. Unlike operations that depend solely on the instrument manufacturer for their technical basis, ORNL relies on the expertise available within the I&C Division to analyze what an instrument does and what it is intended to do.

Our radiation metrology staff are recognized experts in radiation protection instrumentation and are members of the ORNL Health Physics Instrument Committee (HPIC), the policy-setting organization for radiation instrumentation at the Laboratory. One person is also a member of the government-owned, company-operated HPIC and is a U.S. delegate to the International Electrotechnical Commission, Technical Committee 45, "Radiation Instrumentation."

Our responsibilities include evaluating instruments for purchase and for environmental and operational limitations. We also validate calibration and measurement techniques to ensure that instruments operate as expected. Evaluations include monitors used at ORNL for the automated performance of contamination frisking, air monitoring equipment, radiation surveying instruments, and many other instruments.

In addition to supporting the ORNL radiation protection program, radiation metrology staff members have been and continue to be involved with the upgrade or integration of radiation monitoring capabilities on other types of equipment. We are able to analyze a design both electronically and radiologically, determine possible weaknesses, recommend and make improvements, and then reevaluate the changes or design to ensure that design and operational specifications are met. By having these capabilities available in a single organization, high-quality, cost-effective evaluations are performed for various customers from both government and private organizations.

With our support, design improvements and upgrades have increased the reliability and capability of many different instruments, the overall effect of which is increased user confidence and safety.

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Thermal Testing

We have developed an automated thermal fatigue cycling test system to evaluate the alternate heating and cooling of components for a variety of processes, such as casting, forging, heat treatment, and simulating thermal cycling in die casting.

An ORNL researcher from the Metals & Ceramics Division needed an economical, efficient way to test materials for thermal fatigue. Manually setting up and running such tests can consume a researcher's time and exhaust funds. Automatic cycling testing systems are available; however, the costs for these systems are often prohibitive. In this case, instrumentation requirements alone would have exceeded $40,000. By combining and modifying a Lepel high-frequency induction heater and a Research Incorporated Micristar programmable temperature controller, we developed a unique materials testing apparatus for a fraction of the cost of a new system (i.e., for less than $3,000).

This system is highly flexible, allowing for adaptation to changing materials and testing parameters. Data-recording equipment allows the system to be set up and run unmonitored for hours at a time. For the initial experiments, test specimens were heated quickly to a specific temperature, water-quenched, air-dried, and then recycled to complete a preset number of cycles.

Design and assembly of the system were joint efforts between staff from the I&C Division and several other divisions at ORNL. In addition to the initial cost savings, in-house development of this system had several advantages. The in-house staff who developed the system are readily available to provide service expertise and spare parts, and their familiarity with the research being conducted with the system will help with troubleshooting and with any modifications that may need to be made in the future.

I&C Division staff member Tom Parham adjusts the thermal testing system.

Inspecting the radio frequency induction heater within the testing system.

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Instrumentation and Controls Division

Instrumentation and Controls Division Fact Sheet

Division Director: D. W. McDonald (mcdonalddw@ornl.gov)

Sections:

Electronics Systems–G. T. Alley (alleygt@ornl.gov)
Measurement Science–J. D. White (whitejd2@ornl.gov)
Signal, Information, and Knowledge Processing–J. M. Jansen (jansenjmjr@ornl.gov)
Technical Support–R. A. Hess (hessra@ornl.gov)

Core Competencies:

Controls and Simulation–applications in process control, manufacturing, safety, and ultrareliable systems
Photonics–R&D in optical materials, environmental sensing, analytical instrumentation, electro-optics, lasers, and physical measurements
Custom Electronics–circuit development, design, fabrication, packaging, and testing. Unique capabilities in microelectronics and application-specific integrated circuits, radio frequency and microwave frequency devices, digital architecture development, and sensor-electronics integration
Sensors–technology and expertise to measure or observe virtually all physical, chemical, and biological phenomena
Signal Processing–real-time signal and image processing using traditional and advanced techniques
Systems Integration–demonstrated capability to design, assemble, and test large systems

Awards:

1996 ORNL Research Division of the Year
1998 Award of Excellence in Operations and Support in Technical Services
R&D 100 Awards–Since 1963, I&C has won 16 of ORNL's 85 R&D 100 Awards
Tennessee Quality Award–Commitment to Quality
Federal Laboratory Consortium for Technology Transfer–Award of Excellence (3 recipients)

Patents:

Since 1988, 156 disclosures have been filed, with 45 patents granted.

Technology Transfer Licenses
18 since July 1, 1994

Staff Assignees to Industry
6.5 FTEs since 1995

Budget

Total Budget about $30M

Breakdown by Market	%
Surveillance, Measurement, and Analysis Systems for National Security	37
Lockheed Martin Energy Systems/Lockheed Martin Energy Research (LMES/LMER) Internal Customers	27
Industrial Applications and Power Generation	12
Nuclear Detection, Measurement, and Analysis	5
External Operational Facilities	5
Semiconductor Process-and-Yield Improvement	6
Biological Sciences	6
Other	2