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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Instrumentation and Controls Division Progress Report for the Period July 1, 1992, to June 30, 1994

INSTRUMENTATION & CONTROLS DIVISION

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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INSTRUMENTATION AND CONTROLS DIVISION
Progress Report
for the Period July 1, 1992, to June 30, 1994

D. W. McDonald, Director

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DIVISION OVERVIEW

D. W. McDonald

The Instrumentation and Controls (I&C) Division serves a national laboratory, and, as such, our domain is expansive: science, industry, and national defense. We advance national policy through our projects and are subject to its whims. A brief overview is presented here, with a more detailed summary appearing in the following sections.

Science

We have expanded our collaboration in major physics experiments. We developed a national and international reputation from our Superconducting Super Collider (SSC) activities. Building on this reputation, we have developed and tested electronic systems for several experiments at CERN and for the PHENIX and PHOBOS detectors at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. These systems have substantially reduced the cost and size of important measurement subsystems at these facilities. We expanded our involvement with the Advanced Neutron Source and increased our instrument development for experiments at the High Flux Isotope Reactor.

Industry

This reporting period was dominated by the swift and significant growth of work with U.S. industry. The I&C Division led the Laboratory in the dollar volume of cooperative research and development agreements (CRADAs) with private industry. Division staff members have been visiting and working in production facilities all over the United States. Under the Bush Administration, emphasis was on "critical technology," and we began our work with the semiconductor and high-performance ceramics industries. Under the Clinton Administration, an "economic competitiveness and job formation" theme emerged, and our work expanded into the textile, steel, and automotive industries as well. We continued our support of the electrical power utilities through our work with the Nuclear Regulatory Commission and the Electric Power Research Institute.

National Defense

We significantly increased our activities with the Department of Energy in the area of nuclear nonproliferation and weapons dismantlement. One of the instruments developed in the Division is being considered for use in validating nuclear warhead dismantlement under agreements between Russia and the United States. We continued our significant efforts in support of the U.S. Navy. We completed assembly and testing of the Acoustic Measurement Facility Improvement Program's telemetry and beamforming system. The event was honored as an ORNL Outstanding Engineering Achievement by ORNL Director, Al Trivelpiece. Testing and certification at sea will occur throughout fiscal year 1995. We significantly increased our interactions with the U.S. Army. We are assisting the Army with the development of new, miniaturized calibration standards for use in the field which we anticipate will decrease the required equipment volume by a factor of 3. We are also developing new machine vision systems for use in artillery shell classification and automated armored vehicle rearming systems.

New and Emerging Technologies

We continue to advance the state of the art in our core capability areas: electronics, controls, measurements, signal processing, and systems integration. In addition, we have introduced new technologies that we believe will increase in significance in our future work. Technologies first discussed in previous biennial reports as emerging technologies—wavelets, application-specific integrated circuits, computer-generated holograms, and neural networks—are now tools integrated by our staff and used in our development projects. In this report we report for the first time on hybrid optics (refractive/diffractive), anticipatory systems, and nano-dimensional standards. Each of these technologies has potential in addressing new applications in ways not possible with our previous technology.

Technical Support to ORNL

Our core mission is to support the scientific apparatus of the Laboratory and all systems that protect the safety and health of people and the environment. The Laboratory has formalized a process for identifying key facilities, systems, and instruments that pose unusual risk. The Division is a central component of the Laboratory process, responsible for assuring the proper operation of thousands of instruments via calibration and maintenance activities. We have made significant changes and commitment to assure the overall success of this process.

A new 20,000-ft^2 building has been constructed and is scheduled for occupancy in mid-FY 1995. This building, the Measurement and Controls Support Facility, will allow us to consolidate several shops and teams who are now distributed throughout the Laboratory in substandard space into a modern facility optimized for multidisciplinary interactions. Exciting new possibilities in cross training and improved organizational effectiveness will be realized through this consolidation.

Organization

Toward the end of this reporting period, Martin Marietta Energy Systems offered a Special Retirement Incentive Program. Forty-four people retired from our division under this program. A significant percentage were members of the management staff (section heads, group leaders, and first-line supervisors). The Division was reorganized around our core capabilities. We reduced the number of "managers" by 18% and increased the number but decreased the size of the sections. The technical missions of the sections and the groups were better defined to reduce redundancy.

The Division formed the National Program Office (NPO) to coordinate the Division's response to important new national initiatives. The NPO maintains a national network of contacts with policymakers throughout the federal infrastructure. This has provided the Division with a focus for program development activities.

1. PHOTONICS AND MEASUREMENT SYSTEMS

1.1 OVERVIEW

Sensors and measurement technology are an integral part of virtually every development activity being conducted by the I&C Division. The Division was a pioneer in the development of specialized detectors and instruments for nuclear physics research and for reactor operations. This work continues to be active and vital, but our technical focus and expertise have broadened greatly as the Laboratory's research programs have become more diverse over the years. Our experience base includes the application of a wide variety of commercially available sensor and measurement technologies ranging from conventional process measurements to large systems of optical or acoustic sensor arrays. We also have developed several specialized sensors and measurement techniques and have established capabilities in key areas such as photonics, optical diagnostics, and in-process metrology. Our experience and expertise in sensors and measurement technology, combined with other I&C and Laboratory capabilities in the areas of electronics, signal processing, systems integration, and materials, provide a valuable resource for solving difficult measurement and control problems for both government and industry. The following examples illustrate some of our work in this area.

1.2 NUCLEAR WEAPONS IDENTIFICATION SYSTEM

The Oak Ridge Y-12 Plant and the DOE Office of Arms Control and National Security (NN-20) have supported the development of a nuclear weapons identification system (NWIS) as a verification technology for arms control treaties and for special nuclear material management. This system can be used for shipper/receiver confirmatory measurements. Work on such a system in various stages of development has been in progress at Oak Ridge since 1984. In this method, time- and frequency-analysis techniques are used to process the fluctuations of signals from a self-counting ^{252}Cf neutron source and two detectors. The method obtains time- or frequency-dependent correlations between the source particles and those transmitted through the target assembly (Fig. 1.1), scattered by it, or emitted as a result of fission chains induced in the assembly by source neutrons. The frequency content of the signal arises from the statistical nature of these processes and varies significantly with the quantities and configuration of materials in the target assembly, which could be a nuclear weapon or component or other container of nuclear material. Thus the frequency spectra are used in much the same way as an acoustic signature for voice or naval vessel identification. The signature is quite sensitive, robust, and multidimensional and therefore difficult to defeat. Comparison of this signature with reference signatures or standards allows its use to identify or quantify fissile material configurations for quality control testing in production, accountability, identification, security, and nuclear criticality safety. Thus, it can be used to identify nuclear weapons/components and fissile materials nonintrusively for arms control and nonproliferation purposes. This developing NWIS technology also has use for nuclear warhead dismantlement. Extensions to process plant monitoring and control and nuclear criticality safety applications are also practical.

The NWIS employs unique methods of exciting a fissile assembly with neutrons, which initiate fission chain multiplication, processing and averaging the resultant signals in a pair of detectors due to neutrons and/or gamma rays emitted from the system, and obtaining a set of values that constitute a signature of a particular assembly configuration.

The components of the system are a pulse-mode ionization chamber containing about a microgram or less of the spontaneously fissioning isotope ^{252}Cf (614,000 spontaneous fissions per second per microgram of Cf) and two detectors sensitive to neutrons and gamma rays. Using pulse shape discrimination, each detector can provide separate signals for gammas and neutrons. Each fission of ^{252}Cf produces an electrical pulse in the source ionization chamber that signals the emission time of fission neutrons that can enter the assembly and initiate the fission chain multiplication process. Development and testing have demonstrated the high sensitivity of noise analysis measurements to small changes in the system under interrogation. Nearby material is not a problem since the correlated information comes only from the region between the source and detectors. This characteristic simplifies the use of NWIS in warehouse or storage configurations. In verifications already performed, hundreds of units were stacked in and close to the verification area.

For time-domain measurements, the time distribution of neutrons and gamma rays directly transmitted, scattered, and fission multiplied is measured with respect to the time of emission of ^{252}Cf neutrons or with respect to previous events in the same or the other particle detector. Frequency-domain measurements have an advantage because, in the cross power spectral densities between detectors, the background or uncorrelated information averages to zero after many samples of data. As a result, meaningful measurements can be made when the ratio of the correlated to the uncorrelated parts of the signal is as low as 10^{-3}.

NWIS signatures are currently being used in the Weapons Returns Program at the Oak Ridge Y-12 Plant.The existing NWIS hardware has been used successfully at the Oak Ridge Y-12 Plant to confirm that B33 trainer parts for an artillery weapon shipped from military bases to the Oak Ridge Y-12 Plant were as declared by the shipper. These verifications were conducted in a timely, reliable manner with no false positives for 512 verifications with as many as 32 verifications performed in one shift. These verifications revealed that weights of eight components were not as declared by the shipper and that ten other components had as little as ~4% of the mass removed, thus illustrating the sensitivity of the method.

Future uses of NWIS at the Oak Ridge Y-12 Plant will include shipper/receiver confirmatory measurements for weapons returns and dismantlement and criticality safety.

1.3 HIGH FLUX ISOTOPE REACTOR CONTROL AND SAFETY CHAMBER

The need for replacement ion chambers at the High Flux Isotope Reactor (HFIR) initiated a search for the most cost-effective and advantageous criterion for selecting the new chambers. Redesign and fabrication of the old PCP-II and PCP-III designs, by a vendor or Oak Ridge National Laboratory (ORNL), would be extremely costly and have no significant advantages. Therefore, a new design has been made using two industry standard ionization

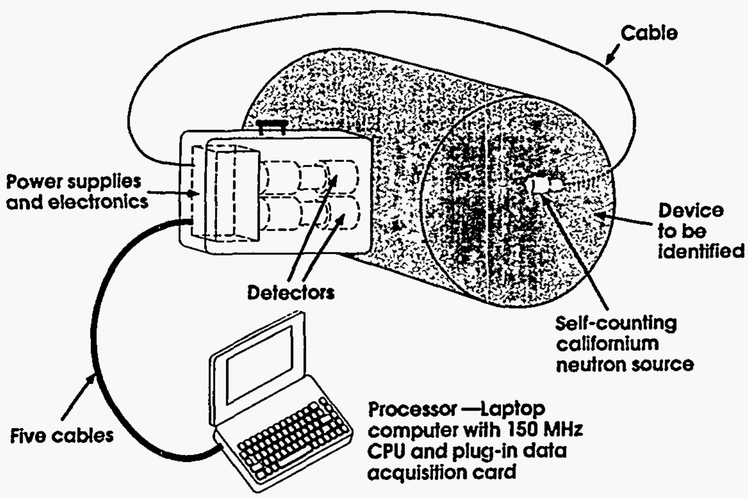

Fig. 1.1. Conceptual sketch of the field-portable nuclear weapons identification system.

chambers that will be placed side-by-side inside a new chamber housing assembly. The new housing assembly will be fabricated to directly replace the original PCP-II and PCP-III ionization chamber, fitting in the same volume and interfacing to the existing reactor protection and control system. Working with the Research Reactor Division (RRD), a conceptual design (see Fig. 1.2) was developed, two commercial chambers were identified, and the system was modeled to determine ion chamber response time and sensitivity.

The initial design phase consisted of detailed design calculations, development of conceptual drawings, and interfacing with prospective vendors. Additionally, the I&C Division was responsible for the neutron flux modeling and calculation, while Computing Applications Division (CAD) supplied thermal modeling. Following DOE approval of the design and modeling results, a specification for construction (RRD-ES-119) was developed, approved by I&C and RRD, and sent out for bids.

Because of potential failure of the existing old chambers and the long procurement lead time, I&C was requested to consider in-house fabrication of this assembly. As a result of that request, I&C is now in a second phase consisting of generating detailed engineering drawings, fabricating the assembly, and ultimately final testing and installation at the HFIR. The technology used to develop these new ionization chambers for the HFIR may prove to be beneficial to the Advanced Neutron Source (ANS) reactor and will qualify commercial vendors to supply what are presently in-house designs.

1.4 CONTINUOUS AUTOMATED VAULT INVENTORY SYSTEM

1.4.1 Y-12 Monitoring System Development

The Continuous Automated Vault Inventory System (CAVIS) has been under development in the I&C Division in collaboration with several Y-12 Plant organizations. Continuous monitoring of special nuclear materials (SNM) attributes in long-term storage is a high-priority mission at the Oak Ridge Y-12 Plant. New monitoring technologies that will reduce cost, employee exposures, and effort required to do nuclear material inventories are being evaluated. Three different technologies are being explored to fulfill this mission. These techniques include a

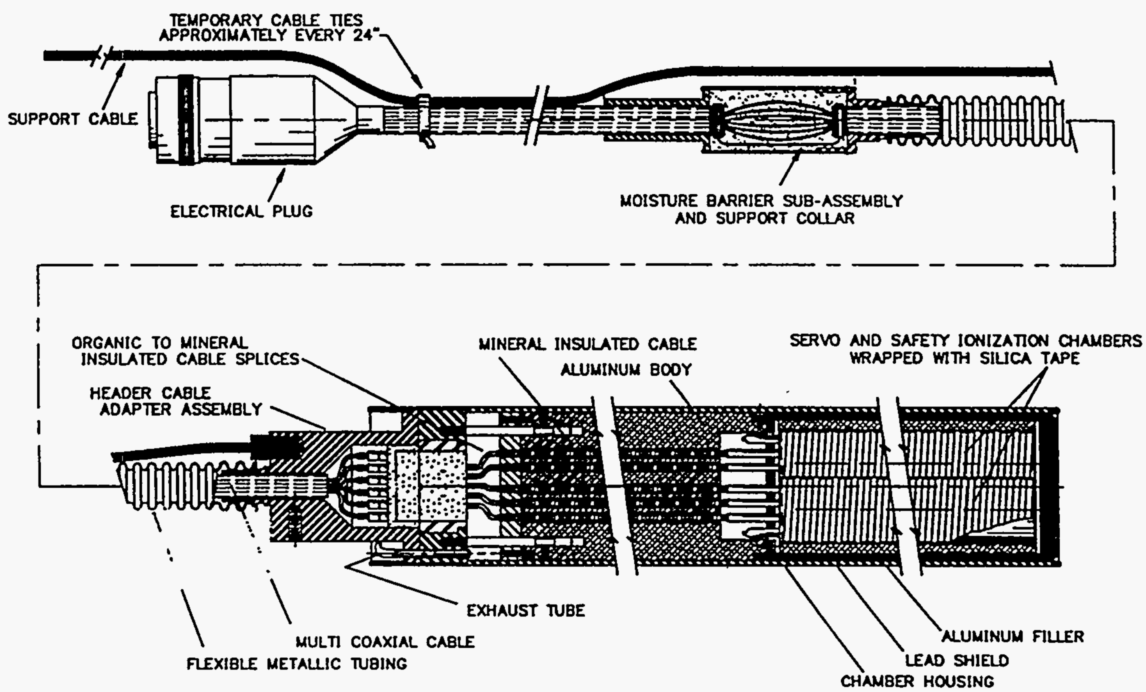

Fig. 1.2. Concept design for the new HFIR control chamber.

distributed scintillator and fiber-optic light pipe system, a very low cost scintillator and photodiode system, and a slightly more expensive system based on a positive-intrinsic-negative (PIN) photodiode that offers the possibility of spectral identification.

A very inexpensive system has been designed and tested that consists of an array of small (3-mm-diam by 3-mm-tall) CsI scintillation crystals, each attached to an inexpensive photodiode. The photodiode is operated in the zero-bias, short-circuit current mode. The total photocurrent is monitored as an indicator of total radiation dose. There is no spectral information, and individual pulses are not counted. In a sense, this device operates as a "thermocouple" for radiation fields. It is simple, small, totally passive, and low cost ($3). Each sensor requires only a simple pair of wires to a data system, which can be located remotely, away from vault security and radiation dose considerations.

Where more detailed information is of interest, a system providing pulse and spectral data may be necessary. A small, solid-state gamma ray detection device whose components are estimated to cost less than $15 per unit was implemented in several configurations and can be adapted to enhance existing monitoring systems. The silicon diode radiation monitor is composed of low-cost, off-the-shelf microcircuits that combine a low-voltage, reversed-bias X-ray and gamma ray photon detector with a simple preamplifier, a pulse-shaping amplifier, and a discriminator circuit. The discriminator circuit eliminates spurious noise pulses and low-energy gamma ray pulses. The system can provide useful count rates from background to 4-Gy/h radiation levels. Output signals can be cabled to a central data station and analyzed. In addition, each unit could contain a count rate display to facilitate on-site checks and maintenance. The system is small (i.e., 1 × 2 × 4 cm), rugged, highly sensitive, and low cost. The detector chip costs less than $2, and the system, including supporting electronics, costs less than $15. The fiber-optic and scintillator technology (FAST) is described in more detail in the following section.

1.4.2 Fiber-Optic and Scintillator Detector Technology

The basic concept of the FAST detector system is to provide a scintillator material [plastic scintillator for gamma radiation and ^{6}LiF and ZnS(Ag) powders in an epoxy binder for neutrons] for each item to be monitored that converts ionizing particles to photons (light energy). The photons are then coupled into a fiber-optic cable using wavelength shifting (WLS) fiber and transmitted to a location outside the vault area. In this configuration, there are no active components inside the SNM storage vault that require periodic maintenance, and therefore the need for human intervention is minimized. A system block diagram of a FAST detector system is shown in Fig. 1.3. A variety of FAST detectors has been designed and tested for gamma and thermal neutron detection, monitoring enriched uranium and plutonium (with moderation). The gamma-sensitive detector system was successfully demonstrated as a remote monitor of five depleted uranium sources in a modular storage vault (MSV) at a distance of 5 m. The thermal-neutron-

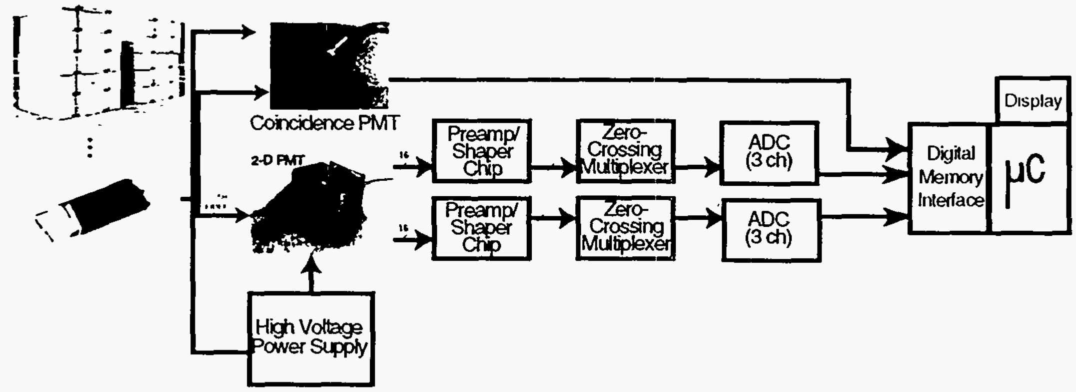

Fig. 1.3 FAST detector system for SNM storage.

sensitive detector system was tested using a 56.91-meV beam line at the HFIR.

1.5 HYBRID OPTICS

The term hybrid optics describes optical systems that combine refractive optics with diffractive optical elements. The resulting designs demonstrate excellent optical performance with regard to chromatic and other aberrations using fewer elements, which reduces their cost, weight, reflective losses, and alignment complexity (Fig. 1.4). Forming the diffractive surface on a curved base surface provides an extra degree of freedom not currently available in conventional optics for correction of aberrations, making high-performance optical systems better, smaller, and cheaper. Hybrid optic system designs are prevalent in the literature. The issue, however, is providing a cost-effective, viable technology for manufacturing and mass producing these designs on curved or flat surfaces. The I&C Division along with the Y-12 Centers for Manufacturing Technology and an industrial partner, Geltech, are involved with an Army Small Business Technology Transfer program and a DOE Energy Research CRADA program to explore using diamond-turned molds coupled with sol-gel technology for mass producing hybrid and diffractive optics.

Diamond turning is an ideal method for producing the necessary phase profiles for the diffractive elements on a curved base surface. Oak Ridge has made significant contributions to the manufacturing of optics using single-point diamond turning over the last 30 years, primarily for metal mirrors used in high-energy laser applications in the infrared portion of the electromagnetic spectrum. This unique capability can be used to produce hybrid optics for the visible or infrared (0.4- to 3.2-µm) portions of the spectrum using single-point diamond turning. Using all of the advantages offered by diamond turning, such as complex aspheric surfaces made possible with the Fast Tool Servo and diffractive optical elements formed on curved surfaces, a new

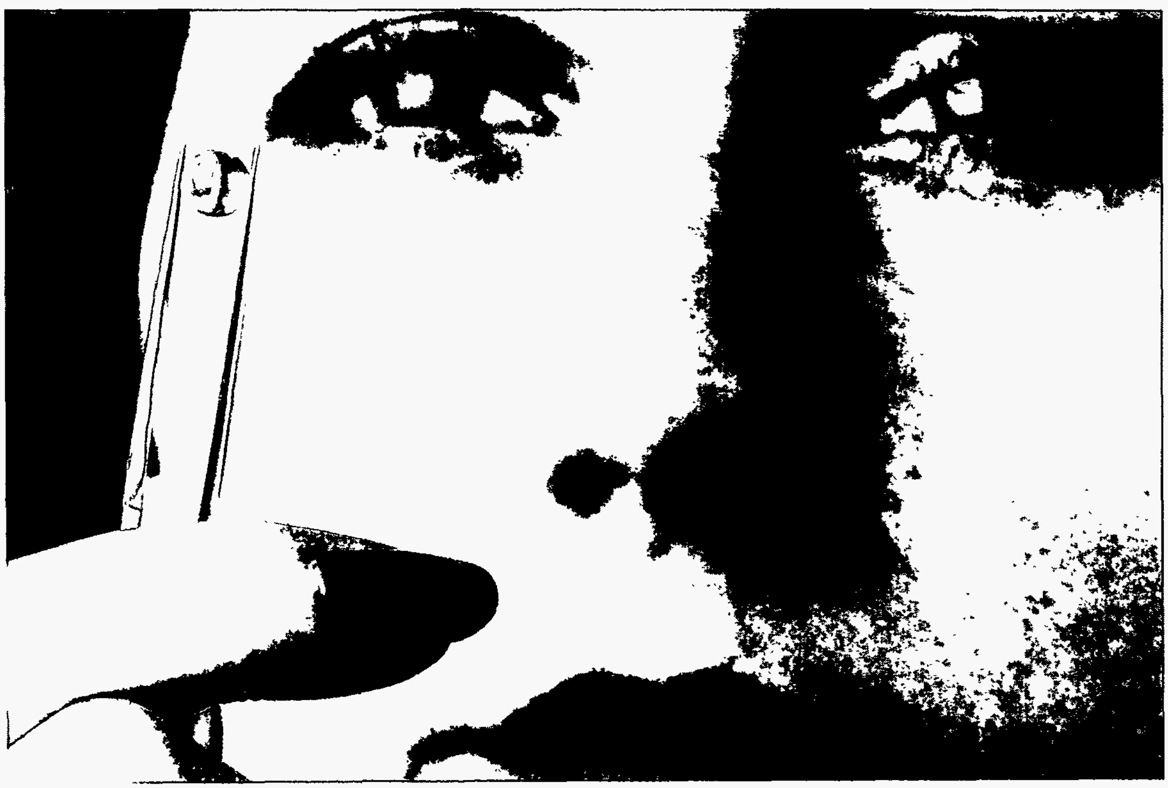

Fig. 1.4. Hybrid optic system.

class of optics will become available for solving even the most demanding imaging applications. When combined with the controlled shrinkage inherent in the sol-gel replication process, the residual tool marks from the diamond machining will be reduced to a size smaller than the wavelength of light. While diamond turning is not cost-effective for producing large quantities of a lens, the required lens shape can be produced in a suitable tooling material (e.g., electroless nickel), and this tooling can be used to produce a large quantity of molds that are then used in the sol-gel replication process to realize a great economy-of-scale when large numbers of optic elements are needed.

1.6 OPTICAL DIAGNOSTICS

In the early 1980s, researchers from Oak Ridge developed noncontact temperature measurement techniques based on thermographic phosphors. The first application of the technology at Oak Ridge was the measurement of the rotor wall temperature of advanced gas centrifuges used for uranium enrichment. This application required measurement of the temperature of a moving surface and provided an important parameter in the optimization of the centrifuge design. Since that time, researchers at Oak Ridge have used thermographic phosphor technology in noncontact applications from cryogenic temperatures to 1600°C. These applications include noncontact temperature measurements in permanent magnet motors, first-stage vanes of a commercial jet engine, blades of a burner test rig for testing high-temperature materials, and the vanes of an advanced turbine engine gas generator.

The most recent application of the thermographic phosphor technology at Oak Ridge is to surface measurements of galvanneal steel for the American Iron and Steel Institute (AISI). This program is a joint effort between ORNL's Engineering Technology Division and I&C. Galvanized steel is used for a variety of commercial applications such as automobile panels. The galvanizing process is particularly difficult to control because of the absence of surface temperature information as the steel goes from a molten zinc bath and into an oven (induction or convection). Conventional techniques such as multiwavelength pyrometry are inadequate since the surface emissivity varies extensively in this region of the process. The system being developed for AISI by Oak Ridge will consist of a device to deposit a thin spot of phosphor on the galvanneal surface and a measurement system to excite the phosphor with a laser and quantify the decay rate of the resulting fluorescence as the phosphor spot passes through an oven. The fluorescent decay rate is then directly proportional to the temperature of the surface.

1.7 ADVANCED IMAGING SYSTEMS

The color subtask within the American Textile (AMTEX) Computer and Fabric Evaluation (CAFE) program is a joint effort between I&C Division and Sandia and Lawrence Livermore laboratories. The purpose of the color subtask is to develop an on-process inspection system for printed color goods such as bedsheets, curtains, fabric, etc. The specific task which I&C has undertaken is the development of an imaging colorimeter system that has the capability of making spatially detailed colorimetric measurements in printed patterns, on-line. These measurements are initially targeted toward quality assurance, providing the means for evaluating the color quality of printed goods on-process from a human perspective. The long-term goal is the development of on-process quality control. No imaging colorimeter system is presently available in industry, and the development will represent a significant step forward in color science applied to industrial processes.

The system being developed at Oak Ridge combines advanced optical system design and inversion theory. Major technical hurdles being addressed by the program are

- the optimization of camera filters to facilitate transformation of the output to standard tristimulus values;
- the design of the illumination staging to provide uniform, well-characterized illumination over the measurement area;
- optimization of light throughput in high-speed imaging systems;
- optics/camera interface for best image registration; and
- color segmentation and defect characterization.

1.8 CALSETS 2000

The U.S. ARMY Test Measurement and Diagnostics Activity (TMDE) supports the field calibration of the Army's equipment and weapons systems throughout the world. Field calibrations are performed by military personnel using Reference Standard Sets, which are referred to as CALSETS. The CALSETS support a wide variety of calibration capabilities, including dc and low-frequency electrical, rf, microwave, physical and mechanical, and electro-optics. A fully equipped field-deployable CALSET is housed in two 5-ton expansible vans. The present CALSETS were deployed in the late 1970s and are nearing obsolescence. The I&C Division, in cooperation with the Oak Ridge Y-12 Plant and TMDE, teamed in the development of the next generation of CALSETS. The emphasis is on the application of new and emerging sensor and electronics technology to achieve significant size and weight reductions without sacrificing the performance required of the reference calibration systems.

The first phase of the project was to perform an assessment study of emerging technologies and develop a concept for the CALSET of the future. The assessment report then led to the selection of a few key technologies and concepts that could be used to build a prototype (demonstration) system. It was decided that the prototype system would demonstrate the concept of a "virtual instrument" computer workstation that would provide a universal operator interface for use with any type of calibration equipment. This "universal" workstation would replace the present individual stations for different CALSET systems (microwave, electrical, pressure, torque, optics, etc.). To demonstrate the possibility of using new sensor technology to miniaturize calibration equipment, a pressure calibrator and torque calibrator were also built to interface to the virtual instrument workstation.

The torque calibrator was a specially designed multirange aluminum flexure system (fabricated at Y-12) with an optical encoder that uses internal diffraction gratings to achieve microdegree resolution. This calibrator will replace the current set of six strain-gage torque transducers and their associated electronics and digital display unit. (The virtual instrument station replaces the display unit.) The pressure calibrator provides multiple solid state transducers in a single box with an internal liquid CO_2 pressure source that can perform a variety of automated pressure calibrations up to pressures of 10,000 psig. This calibrator will replace the current pressure system, which consists of two pneumatic boxes and a hydraulic box with their individual electronics and digital displays. The current system also requires external gas cylinders and a hydraulic pump, neither of which is required with the new system. The pressure calibrator interfaces to the same virtual instrument workstation as the torque calibrator. Figure 1.5 shows the pressure and torque calibrators along with the virtual instrument workstation, which is implemented on a notebook computer.

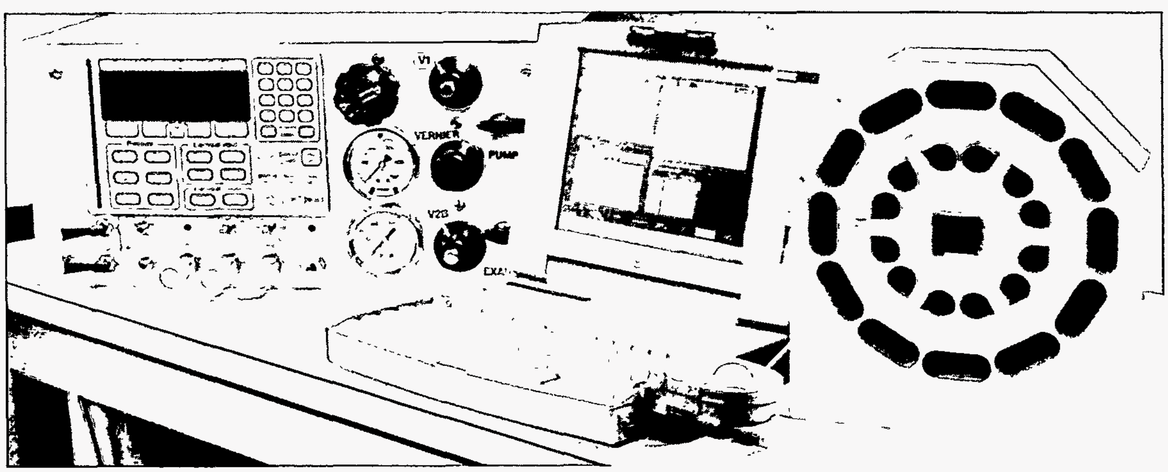

Fig. 1.5. Pressure and torque calibrators with virtual instrument workstation.

1.9 JOHNSON NOISE TEMPERATURE CALIBRATION OF RESISTANCE THERMOMETERS INSTALLED IN FOSSIL POWER PLANTS

Steam temperatures of 450 to 800 K (500 to 1000°F) are measured with industrial resistance temperature detectors (RTDs) in fossil power plants to optimize the efficiency of energy production. A 1% error in steam temperatures results in about a 1% reduction in power production, which could cost utilities $500 million per year. In addition to the costs of heat rate reduction, a further penalty in maintenance costs is incurred by excessive temperatures in steam generators and turbines. Calibrations of typical resistance thermometers can be expected to drift as much as 0.2% per year at 800 K (1000°F). However, many power plant RTDs need to provide accurate temperature information for longer periods of time.

ORNL is developing a technique for in situ measurement of RTDs that uses concurrent Johnson noise and dc resistance for validating or correcting RTD calibrations. The goal is to be able to restore their accuracy to better than 0.5% under actual operating conditions. The project is supported by the Electric Power Institute (EPRI) and the Tennessee Valley Authority (TVA). Demonstration tests were made by ORNL at TVA's Kingston Steam Plant in January and June 1994. These tests produced agreement between temperatures obtained from standard laboratory dc resistance vs temperature calibrations and on-line Johnson noise measurements of better than 0.4% for five out of eight trials. Of the three remaining trials, one sensor was found to have a bad connector, and the other two exhibited discrepancies of about 2% at 800 K. No reasonable explanation for these discrepancies could be found in these trials. The severe plant environment—high ambient temperatures, large amounts of mechanical vibration in plant structures, and significant differences in ground potentials—required extra precautions to be taken against intrusions of nonthermal noise signals and failure of the measuring equipment.

This demonstration of the potential for accurate noise temperature measurements to be made under fossil plant conditions will allow the development of RTDs for use at temperatures up to about 1300 K (1800°F). No industrial RTDs are now available for temperatures greater than 900 K (1200°F). At these temperatures (1300 K), RTDs can be expected to drift about ten times faster than when used at 800 K, (i.e., several percent per year). Development of such thermometers and the Johnson noise technology for maintaining their calibration indefinitely is the goal of the EPRI project at ORNL for the coming year.

Figure 1.6 shows ORNL staff members checking out equipment in the lab prior to making measurements in the Kingston Steam Plant in June 1994.

1.10 HIGH-ACCURACY DIMENSIONAL MEASUREMENT TECHNOLOGY

An R&D initiative has been undertaken in the I&C Division to address the need for more accurate dimensional measurement technology to support precision tolerance manufacturing in the United States. More precise manufacturing capability is being developed in semiconductors, optics, automobiles, and the communications industry to enhance industrial competitiveness. The next generation of diagnostic and inspection equipment needed to support these manufacturing technologies will require positioning, indexing, and sensing accuracies at the nanometer level. The I&C initiative is currently focusing on the development of positioning and measuring instrumentation that will enable manufacturing tolerances to improve. Specifically, ultraprecision dimensional metrology instrumentation will be developed to support enabling fabrication technologies. Continuing research toward the development of dimensional standard artifacts at the nanometer level is the long-term focus.

The measurement technique being developed relies on frequency tracking Fabry-Perot etalon interferometry to realize a metric in the measurement space. Figure 1.7 shows schematically the system being utilized.

Light from a tunable laser is transmitted through the etalon when its length equals an integral number of half wavelengths of the tunable laser. This condition defines the locked condition in which length or displacement is now defined in terms of laser frequency. Under this locked condition, part of the tunable laser is split off and

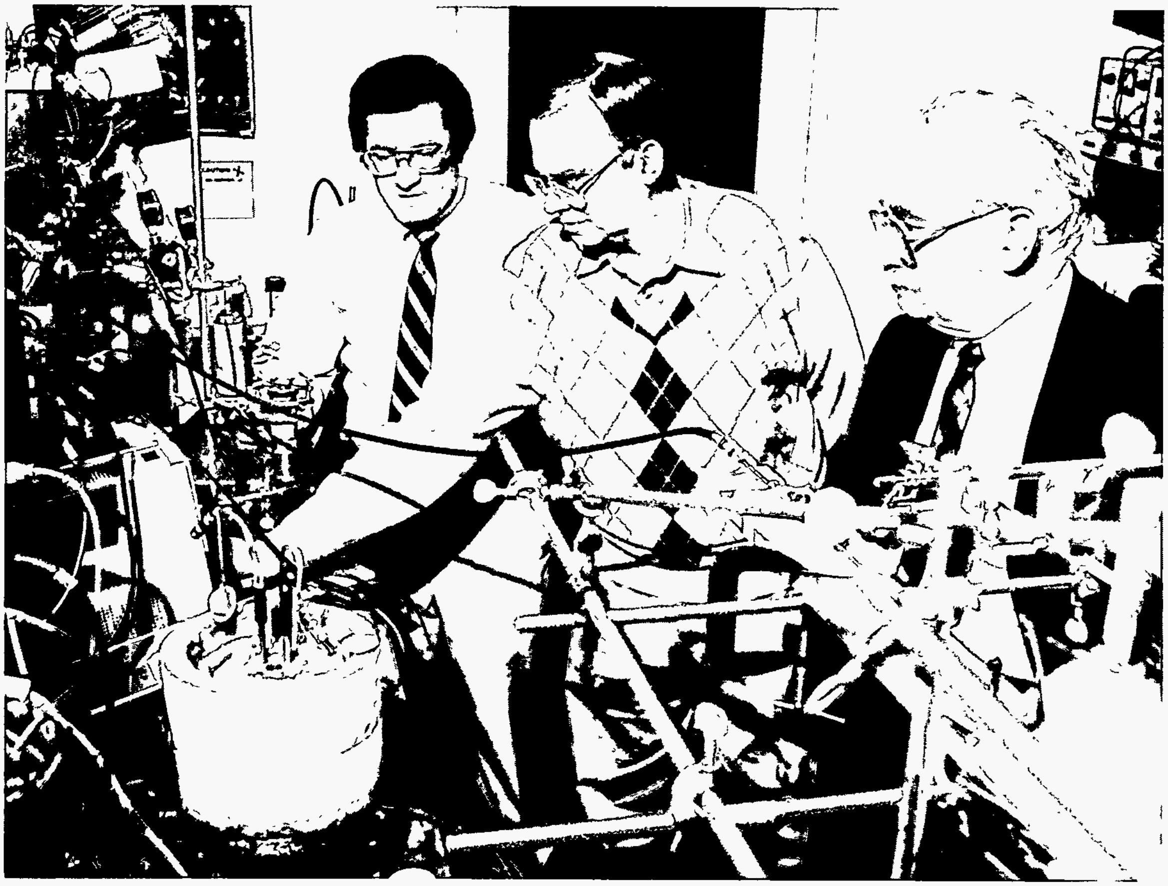

Fig. 1.6. ORNL staff members preparing a resistance thermometer for installation in the Kingston Steam Plant.

mixed with a frequency standard iodine stabilized helium-neon laser that relates the generated displacement or dimensional metric to the frequency metric via a beat frequency. The beat frequency can be measured to part-per-billion accuracies defining incremental length changes on the order of a fraction of an atomic dimension.

Generating repeatable motions of a probe relative to a test object will be essential for dimensional metrology. The distance between two points on an object must ultimately be measured by sensing one point with a probe and then moving the probe or the object such that the probe is positioned over the second point while simultaneously determining the displacement of the moving member. In attempting to generate straight-line motion, a lack of repeatability can give rise to two sources of uncertainty—those associated with cosine errors and those with Abbé offset errors. To minimize these uncertainties, the X and Y motion axes of this system are constrained in five degrees of freedom entirely by flexure hinges. In addition, the metric axes of the X and Y Fabry-Perot etalon actuators are imbedded within this monolithic flexure guide system, thereby making the metric axes coincident with coordinate axes in the X-Y plane.

To date, we have demonstrated the capability of locking a tunable laser to a Fabry-Perot etalon actuator with a finesse greater than 100,000 and sweeping the etalon to generate displacements on the order of 1 μ with an uncertainty of 1 ppm. Continued efforts will focus on establishing a two- and three-dimensional metrology coordinate frame within which research will be conducted on the development of nanometer-scale dimensional standard artifacts.

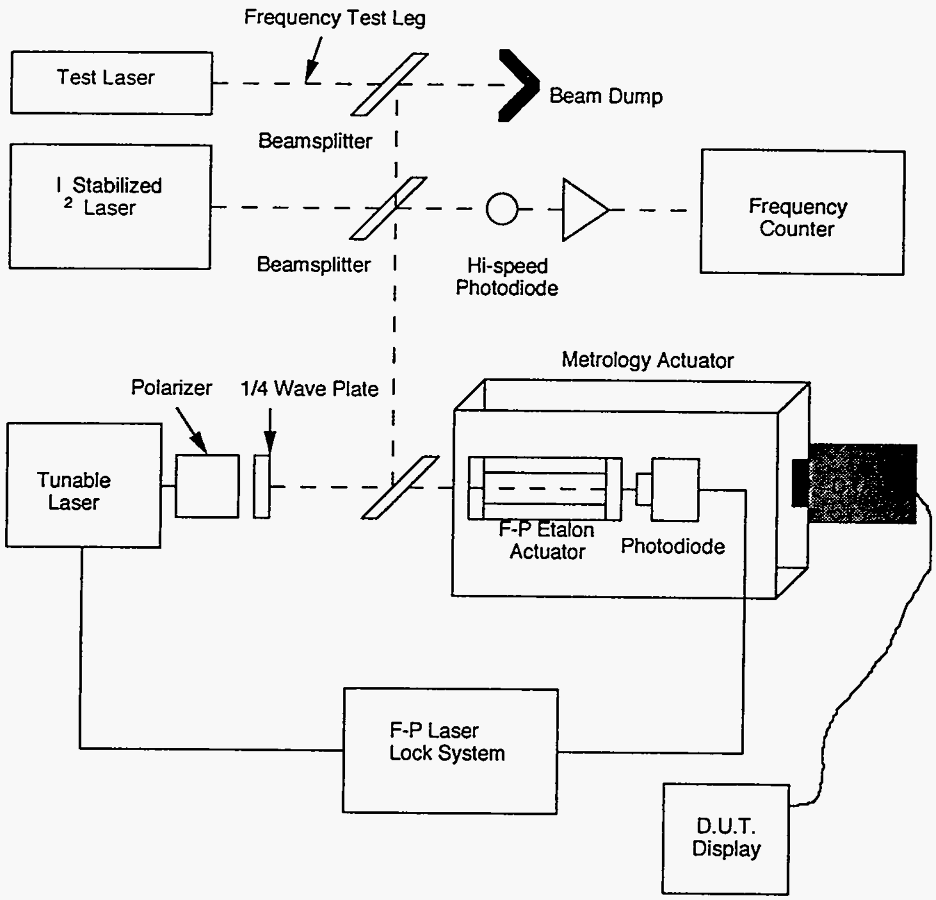

Fig. 1.7. Schematic of apparatus for measuring displacement by tracking the frequency of a transmission peak of a Fabry-Perot etalon.

2. ELECTRONIC SYSTEMS

2.1 ELECTRONICS AS A CORE CAPABILITY

Electronics is one of the designated core capabilities forming the technical foundation of the I&C Division. Electronics, in some form, plays an integral part in virtually every development activity being conducted within the Division. We have a varied electronics capability portfolio comprised of a wide array of talents and expertise ranging from theoretical analysis and modeling of semiconductor devices to design and development of electronic circuits, to prototype fabrication and packaging, and all the way to the testing of finished prototypes in real-world environments and conditions. This combined expertise has proven essential to the success of DOE programs and programs for other federal agencies not only within the I&C Division, but also within other divisions in the Laboratory. Industrial collaborators, through cooperative research and development agreements (CRADAs), have also discovered the value and technical excellence represented by this core capability. The trend of increased interactions with private industry during the past 2 or 3 years is indicative of this fact. This capability is crosscutting and covers a wide range of technical areas, including radio-frequency and microwave systems, embedded microcontroller systems, printed circuit board-level analog and digital systems development, and application-specific integrated circuits (ASICs).

Analog circuit and systems development, the innovative use and application of microwave technologies, and the development of embedded and digital systems are primary strengths and serve as key differentiators for us. Another area of strength lies in our ability to quickly go from concept to working prototypic hardware. We are particularly adept at developing hardware for deployment in field environments, including harsh environments. We use "best-fit" technologies and, in some cases, "extend the envelope" in meeting the needs and requirements of our sponsors. In addition, we are well-positioned to quickly respond to changes in those needs and requirements. The following examples serve to illustrate the diversity, crosscutting nature, and the national impact of our electronics capability.

2.2 LOGARITHMIC ELECTROMETER FOR SOLAR RADIOMETERY EXPERIMENTS

In support of solar radiometry experiments, it was necessary to develop a current measuring technique that had wide dynamic range and operated over a wide temperature range. Continuous-time integrating electrometers and multirange switched feedback electrometers were rejected because of limited dynamic range, complexity problems, or wide temperature error problems. Although log electrometers can provide wide dynamic range measurements at room temperature with fairly simple circuits and no switching, elevated temperature exposure can produce significant errors. To provide a simple and highly reliable measurement, an innovative, seven-decade, temperature compensated, logarithmic electrometer was developed as the preamplifier for photodiode detectors in the Atmospheric Radiation Measurement (ARM) Program radiometer. The logarithmic electrometer is designed to operate with input currents from 1 pA to 10 µA. Temperature compensation of the electrometer is accurately achieved through the use of a monolithic array of four dielectrically isolated and very well matched pairs of bipolar transistors as feedback elements in two logarithmic amplifiers biased at different quiescent current levels and straightforward output signal postprocessing techniques. Use of this method results in <1% error over a temperature range of –18 to 71°C for the upper 5 decades of input currents and for 6.5 decades for temperatures below 21°C. In addition, errors resulting from variable forward current emission coefficients of the logarithmic elements are eliminated by using dual feedback transistors and excellent matching between opposite logarithmic amplifier transistor pairs. The design is suitable for totally integrated monolithic fabrication in an appropriate dielectric isolated fabrication process. The temperature compensation method has been patented.

2.3 VARIABLE-FREQUENCY MICROWAVE FURNACE

A new type of microwave processing furnace has been developed in which the operating frequency can be varied continuously from 4 to 8 GHz and the power level varied from zero up to 2.5 kW. The extraordinary bandwidth of this furnace is achieved by using a traveling wave tube (TWT) amplifier originally developed for electronic warfare applications. The TWT is a linear beam device characterized by a traveling electromagnetic wave that extracts energy longitudinally along the path of an electron beam. The desire for a variable-frequency microwave processing system was motivated by the reality that mechanical mode stirring does not adequately eliminate power nonuniformities in an untuned cavity and that the efficiency of coupling to a loaded cavity is highly frequency dependent. By using the variable-frequency microwave furnace, heating efficiency and uniformity improve dramatically as the frequency is varied over a wide range [this furnace is capable of sweeping over octave bandwidth frequencies at millisecond repetition rates] (see Fig. 2.1). Also, frequency and power can be controlled real time to minimize reflected power and/or maintain a preset temperature or heating rate. This technology has been licensed, and this significant new material processing capability is expected to generate a new international growth market.

2.4 GERMANIUM STRIP DETECTOR ELECTRONICS FOR THE NAVAL RESEARCH LABORATORY

Improvements in gamma ray astrophysics require development of new detector technologies to improve sensitivity and resolution

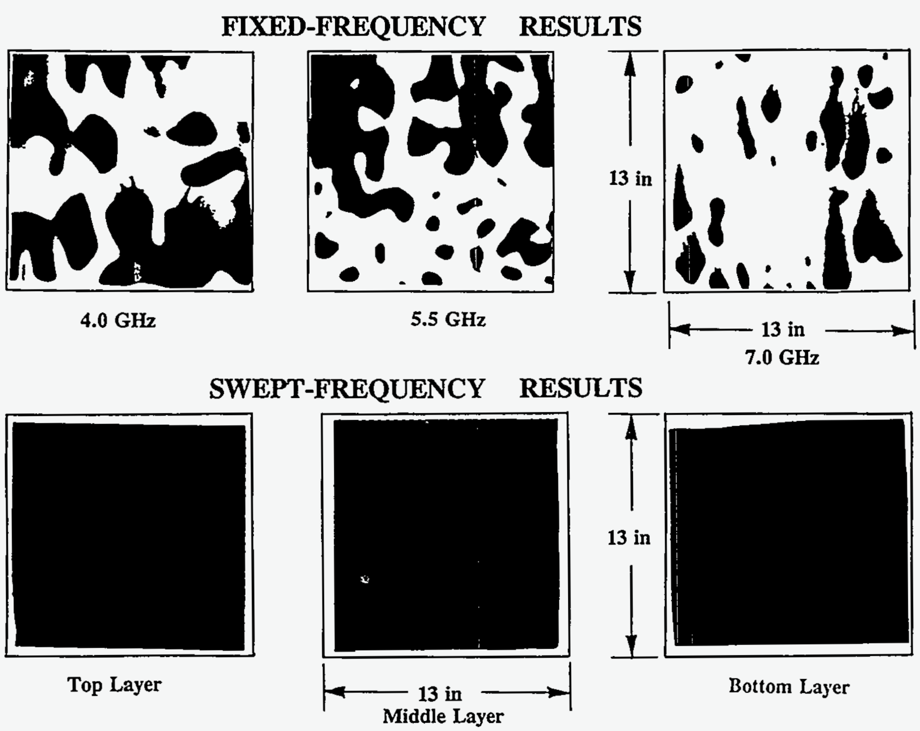

Fig. 2.1. Power maps showing the fixed-frequency and swept-frequency results. The darkened areas above represent heating of sample to a temperature of 100 to 125°C.

characteristics for imaging and spectroscopy applications. We have undertaken a collaboration with the Naval Research Laboratory to develop a prototype 50- to 100-channel, double-sided strip detector and electronics for space-based advanced gamma ray astronomy. In support of this advanced strip detector prototype, low-power, complementary metal-oxide semiconductor (CMOS), low-noise, charge-sensitive preamplifier, shaping amplifier, and peak detect and hold monolithic circuits have been designed, fabricated, and tested. The preamplifier and shaping amplifier achieved ~205 electrons rms noise (at 0 pF) with 3-mW/channel power consumption. Dynamic range was 0–3.3 MeV (Ge) with linearity of ±0.6%. Measured energy resolution was 3.7 keV full width at half maximum (FWHM) as compared to conventional discrete electronics with 2.3 keV FWHM using a room temperature junction field-effect transistor (JFET). The peak detect and hold circuit utilizes a unique rectifying current mirror design to achieve a low-power, high-performance track and hold amp without charge injection errors associated with the use of a rectifying diode normally found in hold amps. The use of complementary rectifying current source tracking circuits allows bidirectional signal processing for two-sided detectors. A 12-bit analog-to-digital converter (ADC) and system controller/computer interface have also been developed which allowed ORNL to deliver an entire low-power spectrometer system that is unique in the industry.

2.5 MOTOR CURRENT SIGNATURE ANALYSIS

Advances in signal processing and analysis techniques are continuing to strengthen motor current signature analysis (CSA) in the role of industrial equipment monitoring and problem diagnosis. Uses for CSA have expanded beyond the diagnosis of motor problems to include characterization of the load driven by a motor and even the detection and diagnosis of power system electrical problems.

The use of high-resolution ADCs has led to the development and implementation of synchronous sample triggering techniques, which not only improve frequency resolution and repeatability in a subsequent Fourier spectrum but also simplify analysis. In addition, this processing method actually provides a significantly wider frequency bandwidth for signal recovery than previous schemes while maintaining a comparable sensitivity to low-level signals.

Much of the recent I&C Division effort in the R&D of CSA technology has been in support of the DOE uranium enrichment enterprise. In two plants, this enterprise involves literally thousands of compressor stages driven by motors of various sizes up to 3300 hp. In these plants, as in other industrial facilities, area control rooms have ammeters that display the load currents for most of the process motors. CSA systems developed by I&C typically use information contained in these ammeter currents to determine the status of the process stage equipment. One such system at the Portsmouth Gaseous Diffusion Plant in Piketon, Ohio, analyzes the ammeter currents from 50 1700-hp motors to detect a damaging condition, known as rotating stall, in the stage compressors. Another application currently being developed will use synchronous sampling and a network of nine personal computers (PCs) to monitor up to 800 compressor stages for high vibration, rotating speed, aerodynamic instabilities, and eventually motor and electrical system problems. Approximately $3.6 M/year is spent at the Portsmouth and Paducah, Kentucky, plants to replace failed compressors. Using CSA technniques, ~$1.5 M/year can be saved because problems can be identified before failure.

I&C personnel have had one patent issued in the technology area and have filed two more patents that are pending.

2.6 ELECTROMAGNETIC INTERFERENCE MEASUREMENT SYSTEMS

The I&C Division has designed and assembled electromagnetic measurement systems (both electric- and magnetic-field types) capable of unattended operation over a period of several months. Sponsored by the U.S. Nuclear Regulatory Commission, the measurement systems will collect long-term electromagnetic interference (EMI) data to profile the electromagnetic ambient in commercial nuclear power plants. The measurement systems are scheduled to be deployed at various locations throughout the United States. Data from the in-plant measurements will be used to establish the technical basis for regulatory guidance on EMI-related acceptance criteria for the U.S. nuclear industry. One measurement system assembled for deployment in nuclear power plants is configured to observe high-frequency electric fields from 5 MHz to 8 GHz. Two resistively tapered dipole antennas, covering distinct frequency ranges, act as broadband electric field probes and are connected to independent heterodyne-based processing circuits. The other measurement system is configured to observe low-frequency magnetic fields from 305 Hz to 5 MHz. This measurement system uses a passive loop antenna as a broadband magnetic field probe and wavelet-based digital signal processing to establish 14 octaves of frequency coverage. The output of each of the measurement systems is a two-dimensional histogram, providing both frequency and peak field strength data. The results of these measurements will be used to set standards for the EMI compatability and susceptibility of modern digital control and safety systems for nuclear power plants.

2.7 RADIATION-HARDENED ANALOG MEMORY FOR HIGH-ENERGY PHYSICS

Research into new measurement techniques supporting the GEM experiment for the Superconducting Super Collider (SSC) has led to the development of the first high-speed, high-linearity, radiation-hardened analog memory unit (AMU). Integrated electronics were determined to be the only feasible way to improve performance and reduce the size of high-energy physics detectors and electronics for the hundreds of thousands of channels of detectors needed for the SSC. The integration of analog memory as a delay element into monolithic electronics eliminates massive quantities of delay cable normally used in nuclear pulse processing to synchronize time and energy measurements with first-level triggers. The use of electronic delay with integrated monolithic electronics produces per-channel costs less than the cost of the eliminated delay cable. This radiation-hardened analog memory has been awarded the Martin Marietta Energy Systems Engineering Achievement Award for 1994. This technique has been employed successfully in other physics experiments such as WA98 at CERN. Our analog memory configuration is eight channels wide by 128 bins deep and operates at ~63 MHz. It has been tested to 5 Mrad total dose.

2.8 ELECTRONICS FOR INTERNATIONAL NUCLEAR PHYSICS EXPERIMENTS

Two mixed analog/digital very large scale integrated (VLSI) CMOS ASICs have been developed for readout of a 10,000-element lead glass calorimeter in the WA98 physics experiment being performed at the European Organization for Nuclear Research (CERN) (see Fig. 2.2). The first chip, called the PRE chip by designers, contains eight channels comprised of a charge integrating amplifier, two output amplifiers with gains of one and eight, a timing filter amplifier, and a constant fraction discriminator (CFD). This ASIC also contains a maskable, triggerable calibration pulser and circuits needed to form 2 by 2 and 4 by 4 energy sum signals used to provide trigger signals. The second chip, called the ATA chip by designers, is a companion to the first and contains an AMU section comprised of 16 analog memory channels with 16 cells each (AMU), eight time-to-amplitude converters (TAC), and a 24-channel ADC. The use of analog memories following the integration function eliminates the need for delay cables preceding it. Each analog memory saves the equivalent of 100 m of coaxial cable and nearly 1000 km of cable expense and volume for the entire WA98 experiment. The WA98 experiment consists of two walls of stacked lead glass scintillation light pipes and photomultiplier tubes (PMTs) arranged in 4 by 6 groups called "super modules" for ease of handling. A total of 416 super modules makes up the calorimeter walls. Initially, three PRE and ATA chips were arranged as a super-module support printed circuit card. To further reduce size and costs, six of the "super-module" cards were combined into one module called the SDM by designers. The SDM provides a full 144 electronic channels on a single printed circuit board. The SDM modules were attached directly to the rear of the detectors with PMT output signals cabled to the boards by miniature coaxial cable and the SDMs interconnected via ribbon cable to the data acquisition and data storage system. Measured

Fig. 2.2. Testing the lead glass calorimeter electronic readout system developed for experiment WA98 at CERN in Geneva, Switzerland.

results of this ASIC-based system indicate a timing resolution of ~280 ps at 2–3 GeV with less than ±250-ps walk over the entire 100:1 dynamic range in the CFD section. The AMU measurements indicate an integral nonlinearity of ±0.05% over 4.5-V signal range and cell-to-cell pedestal variations of 3.8 mV maximum, which represents less than one least-significant bit (LSB) for 10-bit conversion and 0- to 4-V operation. The TAC range was chosen to represent 200 ns as full scale. Noise measurements were run using a 10-bit digital-to-analog converter (DAC), which resulted in all 10,000 counts falling into a single timing channel, indicating a TAC rms noise level of 50 ps or less. Performance measurements of the multichannel, 80-MHz Wilkinson type, 10-bit ADC indicates integral nonlinearity over full scale of 0.2% and differential nonlinearity of 33% or 0.6 channels rms. Preliminary measurements indicate that the complete system will be capable of measuring the energy of particles from 50 MeV up to 50 GeV. This performance is comparable to discrete versions of these electronics. The real advantage lies in much lower costs and orders of magnitude improvements in density and functionality.

2.9 ELECTRONICS FOR ROBOTIC WHOLE-ARM OBSTACLE AVOIDANCE

An ASIC has been developed as a key element of the whole-arm obstacle avoidance (WAOA) system. The WAOA system (see Fig. 2.3) prevents a teleoperated robotic arm from colliding with nearby objects in unfamiliar and sight-limited environments. The WAOA system consists of multiple capacitive proximity sensors attached to all surfaces of a robotic arm and signal processing and communications electronics (1) to communicate impending obstacle contact to the teleoperations control computer that halts movement toward an obstruction and (2) to provide visual feedback to a human operator. The WAOA ASIC performs all analog signal processing associated with control and readout of

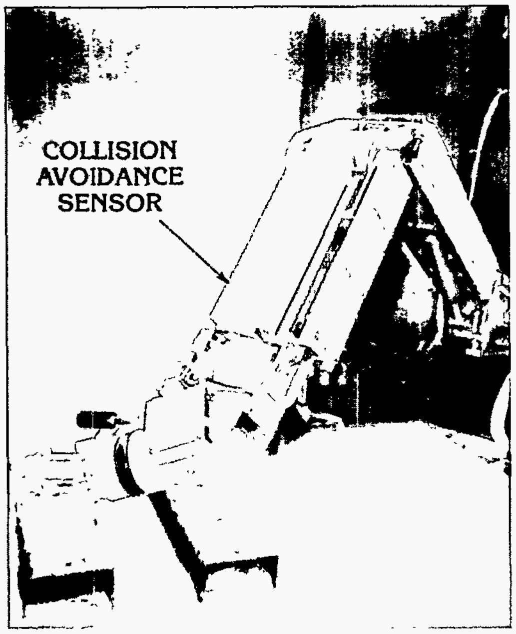

Fig. 2.3. Whole-arm obstacle avoidance system based on a custom integrated circuit developed in the I&C Division.

the capacitive proximity sensor, converts analog sensor signals to digital information, and transmits the digital sensor data to a microcontroller via a shared communications bus. The micro controller preprocesses digital sensor data from as many as 31 sensors and then communicates sensor data to the teleoperations control computer. The WAOA ASIC contains a sensor excitation oscillator, a charge-sensitive input amplifier, a digitally programmable gain amplifier, a synchronous demodulator, an output filter amplifier with digital offset control, a 10-bit ADC, control and status registers, and serial data shift registers. The sensor's digitized proximity measurement value and digital gain setting are loaded into an output serial shift register and transmitted to the microcontroller when selected. Conversely, control registers are loaded from the serial shift register with control data received from the data concentrator. The WAOA system operates in five modes: setup, acquisition, calibration, diagnostics, and data transmission. The use of an ASIC to control the capacitive sensor allows all signal processing and data communications support electronics to be packaged on a small printed circuit board attached directly behind the sensor. The WAOA sensor system has a response time of approximately 1 msec. It can reliably sense obstructions at a distance of 15 cm, with decreasing sensitivity as the distance increases.

2.10 ELECTRONICS FOR NUCLEAR PHYSICS EXPERIMENTS

The I&C Division is heavily involved in photon electron new heavy ion experiment (PHENIX) electronics development. The PHENIX detector is a general-purpose multisubsystem detector used to better understand nuclear physics. ORNL is responsible for electronics in the electromagnetic calorimeter, the multiplicity and vertex detector, the pad chambers, and the muon detectors. This project is just getting underway and is scheduled to run through 1998. It is a multimillion dollar development project that involves many I&C areas of expertise and several hundred thousand channels of electronics. Circuits developed for physics experiments such as WA80 and WA98 form the basis for extending these designs to satisfy PHENIX experimental detectors. Related to the work being done for PHENIX is the development of front-end preamplifiers for the PHOBOS Low-Transverse Momentum experiment at the Relativistic Heavy Ion Collider. We are working in collaboration with Massachusetts Institute of Technology on this small but interesting experiment. This experiment involves several thousand channels of electronics.

2.11 PORTABLE MICROWAVE DIAGNOSTIC PROBE

The field of nondestructive testing is always seeking new technologies that offer unique measurement capabilities. Unfortunately, microwave diagnostics have not been widely used in the past because of high costs, cumbersome equipment, and the need for specially trained operators. This situation may change, however, because of the recent development of a portable microwave-based diagnostic probe (see Fig. 2.4) capable of determining the internal structure of hollow clay tile walls. More importantly, this new technology may be applied to a wide variety of nondestructive testing tasks that do not lend themselves to other forms of investigation. The portable microwave diagnostic probe was developed for inspecting civil structures built from

Fig. 2.4. Portable microwave diagnostic probe aids in nondestructive inspections.

hollow clay tile blocks; however, the techniques used in this instrument could be adapted for other applications and materials. For example, the probe has enough sensitivity to respond to a single sheet of paper behind a 13-in.-thick block wall, suggesting the ability to detect nonmetallic or other small anomalies in a structure. Potential applications include inspecting bridges, monitoring composites for voids, locating buried polyvinyl chloride pipes, measuring the movements of fluids in nonmetallic pipes, locating nonmetallic land mines in dry sand, and detecting motion in adjacent rooms.

2.12 MUNITIONS CASE MOISTURE METER

A small, portable moisture meter (see Fig. 2.5) was developed jointly with TRAMEX, Ltd., to measure water content in combustible cartridge case munitions for the U.S. Army. TRAMEX, Ltd., manufactures commercial instruments capable of determining the moisture content in a wide range of materials used in the marine, construction, and lumber industries. The munitions case moisture meter is a handheld (6 × 3.2 × 1.6 in.), battery-powered measurement device capable of rapid and accurate determination of moisture content. The meter employs a capacitance measuring circuit operating at 12.5 kHz and is fitted with noninvasive electrodes on its rear side. The meter is held in contact with the exterior of the munitions case and measures the moisture content of the material of which the case is made, a nonwoven fiber matrix consisting of kraft paper, nitrocellulose fibers, and

Fig. 2.5. Munitions case moisture meter developed jointly with TRAMEX for the U.S. Army.

binding resins. The output of the munitions case moisture meter is then expressed as a percentage moisture content and displayed on an analog scale. This meter is capable of measuring moisture content from 5% up to 30% with an accuracy of 0.5%.

2.13 PORTSMOUTH PRODUCT CYLINDER ASSAY MONITOR

The product cylinder assay monitor provides control room operators with real-time information on withdrawal operations of uranium hexafluoride at the withdrawal stations at the Portsmouth Gaseous Diffusion Plant. The prototype is currently in operation in the control rooms of two of the withdrawal stations. The assay monitoring system uses a 386-type PC configured with six RS-232 communication ports and one parallel port to communicate with up to three mass spectrometers, four scales, and a printer. The system is designed to accommodate a worst-case withdrawal station field configuration of three mass spectrometers, four weight scale positions, and up to four different types of scales in any position. The operator can also input the values manually in case of a mass spectrometer or scale failure. The operator controls movement through the system by using function keys. The operator can assign via an interactive editing feature any withdrawal station field configuration in any combination. The assay monitoring system monitors and displays to the operator the on-line withdrawal processes with five different displays. The displays include strip-chart-type graphs, linear column graphs, plots, and actual numerical values. The position is placed on-line once the operator has inputted the target assay and target weight. When a mass spectrometer sends an assay value to the monitoring system, the system queries the assigned scale for the weight. The software then calculates the required data and displays the data to the operator. This new assay monitoring system offers several advantages, including improved on-line tracking, reduced amount of laboratory sampling while the cylinders are being filled, increased quality control, and overall increased efficiency and lower costs associated with the withdrawal operation. It is estimated that $50,000/year will be saved per withdrawal station as a result of using this system.

2.14 CRADAs

Our interactions with private industry through CRADAs have increased in the past 2 years. Through these interactions, various industrial partners have been able to tap into the broad base of electronics expertise resident in the I&C Division to help them develop new products and get those products to market as quickly as possible. We benefit from these interactions because of the technical challenges found in the work and the excitement of being able to significantly contribute to this nation's competitive posture in the marketplace. Although these types of activities are a relatively new experience for us, we expect interactions with industry through CRADAs or similar mechanisms to increase over the next several years.

Some CRADA activities have already been described in the discussions above. Additional summaries of CRADA highlights are presented below.

- General Motors

This CRADA was established for a period of 3 years and was targeted at developing new ignition system concepts for future automotive applications. Specifically, the I&C Division was tasked to (1) develop engine electronic systems suitable for under-the-hood high-temperature and high-voltage applications, (2) develop test hardware and procedures to reveal substandard components and materials before their installation into automobiles, and (3) identify common failure modes of ignition system components and develop cost-effective improvements. An important goal of this CRADA is to improve the reliability of U.S.-made ignition systems to compete with foreign manufacturers.

- A/C Rochester

This CRADA was established for a period of 3 years. Work has been focused on the development of advanced engine control techniques and methodologies. As with the General Motors CRADA, all the electronics have to be able to survive in the high-temperature environment of automobile engine compartments. As part of this involvement, an ASIC-based sensor/electronics module was developed. The ASICs were fabricated in a 1.2-µm CMOS process and operate over a wide temperature range (–40° to 150°C).

- Merritt Systems

This CRADA was established for a period of 1 year. Merritt is a small company specializing in robotic systems and, more recently, in collision avoidance systems for robot arms. Work on this CRADA has been focused on the development of collision avoidance control electronics for robotic arms and manipulators. The I&C Division's contribution has been in the area of advanced ASICs to implement sensor interface and control electronics. The main purpose of this CRADA is to create the first commercial source for these advanced systems.

3. SIGNAL PROCESSING

3.1 SIGNAL PROCESSING AS A CORE CAPABILITY

Signal processing has grown from a purely theoretical mathematical capability to a useful tool in the hands of engineering practitioners. Brought about by the development of high-speed computational capabilities and the practical deployment of parallel processing, signal processing R&D has grown from a few papers spread among many journals to several major journals covering both single and multi-dimensional processing of signals. From the exploitation of new methods such as nonlinear systems analysis and wavelets to the practical application of the fast Fourier transform, this technology is revolutionizing the ways we examine large quantities of data, both images and one-dimensional signals. Combinations of multiple sensors (i.e., sensor fusion) to enhance the ability to extract, detect, and quantify signals in high noise environments are benefitted by the new computational capabilities and new algorithmic methods. The summaries that follow cover the research, development, and deployment of this discipline that solves unique and challenging problems brought by our sponsors. From the development of beamformers for fusing thousands of sensor elements together for underwater acoustics applications to the inspection of semiconductor wafers, these techniques with integrated computational capabilities have made possible new ears and eyes for our customers to hear and see things previously undetectable.

3.2 APPLICATIONS OF ADVANCED ANALYTICAL METHODS

3.2.1 Wavelet Transforms

Unlike the more familiar Fourier transform that provides spectral coefficients from a stationary signal, the wavelet transform provides coefficients that depend on both time and frequency. Thus the wavelet transform is ideally suited for analysis of transient or nonstationary signals. Work in the area of wavelet transforms has resulted in a hardware device that uses the wavelet transform as the main signal processing technique and a general-purpose algorithm. The first is a magnetic spectral receiver used as a magnetic field analyzer. The heart of the device is a wavelet transform, hardware board designed, built, and programmed by members of the I&C Division. The wavelet transform is implemented with five AT&T 16-bit integer digital signal processing (DSP) modules. The device takes a broadband signal, produces a 14-level wavelet transform of the signal, and splits the signal into its 14 constituent, 1-octave-wide bands. The wavelet transform board is general purpose in nature and can be used in other applications.

A second application of wavelet transforms is in the area of signal identification. Using a personal computer platform, I&C Division staff members are working to demonstrate a speaker recognition system as well as a technique to recognize aircraft types from their acoustic emissions. The speaker recognition problem involves nonstationary signals having much lower bandwidth than the magnetic field analyzer. The goal of the demonstration is to train the system with phrases uttered by known speakers and later identify the speakers based on phrases that were not in the original training set.

3.2.2 Nonlinear Systems Analysis

"Chaos" is commonly defined as aperiodic, long-term behavior in a deterministic system that exhibits sensitive dependence on the initial conditions. The application of more traditional signal processing tools often provides little useful information for characterizing or controlling a chaotic signal. Analysis techniques based on chaos theory are needed to extract useful information from such signals. Members of the I&C research staff have been applying chaos-based analysis techniques in an effort to identify "descriptors" that can be used to characterize and classify the aperiodic, long-term characteristics of data associated with difficult signal analysis and control problems.

One example of the use of these techniques has been the application of specialized coatings to fuel pellets. The coatings are applied by injecting gases into a fluidized bed as the fuel pellets are transported through the system. Because of the nature of the process, in situ measurements of the coating quality are not practical. Chaotic time series analysis has been used to identify descriptors within the available process measurements which are an indicator of coating quality, thereby supplying information that can improve the quality of the manufacturing process.

3.2.3 Anticipatory Systems

Anticipatory systems take action based not only on past and present states, but on the expectations of future events. The primary difference between anticipatory systems and most common signal processing systems is that anticipatory systems are apparently noncausal in nature.

Two recent areas of research involving anticipatory systems are related to the current national emphasis on transportation. In the first research area, experimental and theoretical investigations into the feasibility of a noncontact airbag sensor for the National Highway Traffic Safety Administration are being performed. The study involves wavelet analysis and formal anticipatory systems theory to determine if a sensor can be developed that will reliably activate in response to an impending collision, yet not be susceptible to false alarms due to near-misses.

In addition to the airbag sensor study, a feasibility study has just been completed for the Federal Highway Administration on the problem of monitoring and controlling global traffic flow over a wide area. The major problem identified in implementing a wide-area surveillance system is deducing the future overall traffic flow status based on data from hundreds of distributed sensors. To be fully effective, an anticipatory system would be required to "recognize" impending traffic problems. The system could then provide real-time control of traffic signal timing, recommend alternate routes, etc., to help avoid major traffic problems. Follow-on work to the feasibility study is being pursued.

3.2.4 Mechanical Systems Monitoring

A new method for interpreting the vibration signatures of mechanical systems has been developed. The diagnostic method uses a mathematical model of the mechanical system to define relationships between system parameters, such as spring rates and damping rates, and measurable spectral features, such as the characteristics of resonance peaks. These model-determined relationships are then incorporated into a neural network, which is used to relate the measured spectral features to system parameters.

Sensor signals are conditioned and then transformed into frequency spectra by a fast Fourier transform (FFT) algorithm. The spectral data are decomposed, yielding frequency peaks and mode shape components. These spectral features are used as input to the neural network. The neural network output consists of estimates of the system parameters that would produce similar spectral features. Comparison of the latest estimated system parameters with previously estimated values shows whether degradation has occurred and indicates the location and severity of the degradation. In a laboratory test setup, the method was able to estimate the spring rates of a simple system to within 5 to 10% of the known values when given measures of the natural frequency and mode shapes.

The main advantage of the new method is that the signature interpretation is based on the mathematical model results rather than the intuition and judgment of an analyst. This approach removes much of the subjectiveness commonly associated with current signature interpretation methods. A second advantage over current methods is that it can provide an indication of the magnitude and location of the degradation, rather than merely detecting that degradation has occurred.

The modeling technique is independent of the monitoring method. For some applications, relatively coarse, lumped-parameter approximations may be suitable. For more demanding applications, detailed models employing sophisticated modeling techniques, such as finite element methods, may be used if needed.

3.3 APPLICATIONS OF IMAGE PROCESSING

3.3.1 Target Recognition and Guidance for Robotics Applications

The I&C Division has been assisting the U.S. Army in the development of the next generation battlefield artillery vehicle and its complementary resupply vehicle. Machine vision has been used by I&C research staff members as (1) part of one resupply strategy investigated by the Modular Artillery Ammunition Delivery System (MAADS) and (2) to perform automated ammunition and fuse identification.

The MAADS program investigates the feasibility of a design concept using a robotic resupply arm to transfer ammunition from the resupply vehicle to the artillery vehicle. A full-scale prototype robotic arm will be built and tested by a team consisting of I&C and Robotic and Process System Division research staff members. The main contribution by the I&C staff will be to develop a machine vision-based autonomous guidance system for the resupply arm which will measure the distance and direction to the receiving port on the artillery vehicle.

The autonomous guidance system began in June 1993 with a 3-month feasibility study to determine if autonomous guidance was possible using existing hardware. Based on the information gathered in this study, a configuration with a single video camera, mounted on the end of the resupply arm, along with a known, unique target, mounted on or near the docking port, was recommended for further development.

A prototype using the recommended configuration was built to demonstrate the basic measurement functionality required for autonomous docking. A miniature video camera and image processing computer are used to implement the measurement function. The target consists of either a set of easily identifiable points or simple geometric patterns such as circles. The camera is used to form an image of the area surrounding the docking port, including the unique target. An image processing system locates the target in the image and calculates the relative pose between the camera and the port. As the camera moves toward the port, the port occupies a larger percentage of the image, resulting in improved accuracy of the pose calculation for closer ranges. The measurement system has a graphical user interface to display the measurement parameters to an operator. Simulated gauges display the absolute values of position and orientation on a cathode ray tube screen. Relative positional information is presented via a "video game-like widget" that incorporates all six measurement parameters into a single graphical icon. The graphical interface has potential utility in monitoring the arm position for either manual or autonomous docking modes.

In 1995, the final version of the guidance system will be integrated with the MAADS arm to demonstrate fully autonomous docking. The measurement error is ~1%. The dominant sources of error have been identified, and the accuracy should be improved as refinements are implemented.

An integral component of an automated projectile handling and rearm system is an automatic ammunition and fuse identification system. This identification is required at several stages of the rearm procedure, including inventory and tracking in the resupply vehicle and final verification before firing in the advanced field artillery vehicle. The identification system will rely on a machine vision approach, which will acquire an electronic image of the projectile and fuse and then extract distinctive features for use in determining the type of projectile and fuse. A time delay integration (TDI) line scan camera will be used to image an axial strip of the projectile, which will be rotated through 360° around its major axis to build a two-dimensional image of the complete circumference of the projectile. The TDI sensor enables a fast acquisition using a single fluorescent tube for the light source. Image processing algorithms will be applied to the image to extract distinguishing features such as the number and location of spin rings, location of fuse components, principal color of the projectile, and text and symbol markings. Additionally, intelligent character recognition will be used to convert any relevant text, such as manufacturing lot number, printed on the projectile to machine format for inclusion in the identification process. Using these extracted features, a pattern classification algorithm can uniquely identify the type of projectile and fuse. The entire process of image acquisition and automatic identification will be completed in under 5 s.

3.3.2 Industrial Competitiveness Through Machine Vision Automation

3.3.2.1 American Textile Partnership computer-aided fabric evaluation

The American textile industry has lost an estimated 400,000 jobs to offshore competitors since 1980. It is predicted that by the year 2002, it will lose an additional 600,000 jobs. These losses and the resulting economic threat to the U.S. textile industry can be attributed to the offshore competitors' low operating costs resulting from extensive use of cheap labor. To stem these rising losses and gain back lost market shares, the American textile industry has entered into a collaborative research agreement with DOE. This agreement, the American Textile (AMTEX™) Cooperative Research and Development Agreement (CRADA), is a working relationship aimed at leveraging technologies that currently exist at the national laboratories for the benefit and development of a competitive market edge for the U.S. textile manufacturers. Because the minimum U.S. labor rate is well above that of its off-shore competitors, one of the competitive factors that the U.S. industry hopes to gain is a higher quality fabric. To facilitate the production of high-quality fabric, a Computer-Aided Fabric Evaluation (CAFE) system (automated fabric inspection process) will be developed by the CAFE National Laboratory Working Group to increase product quality, material throughput, and manufacturing efficiency. The CAFE working group will be composed of researchers and scientists from Argonne National Laboratory, Idaho National Engineering Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, Lawrence Berkeley Laboratory, Lawrence Livermore National Laboratory, Pacific Northwest Laboratory, and Sandia National Laboratories. This consortium forms the technology base for the CAFE Project.

The CAFE system will provide two collaborative paths for producing increased product quality. The first will be an on-line inspection system for both greige goods (unprinted fabric) and yarn. The second will be an on-line inspection system for printed color. Each method will provide an intrinsic increase in fabric quality by detecting and identifying defects in the formed fabric. Figure 3.1 shows the Oak Ridge Web Testbed facility, which is being used to support portions of the AMTEX™ initiative by providing a laboratory environment that can simulate certain high-speed manufacturing processes for continuous products like textiles.

The greige good program participants include an I&C team working in concert with teams from two other national laboratories. The ORNL team has proposed to accomplish their portion of the inspection task by integrating a vision-based sensor into the loom to inspect the fabric in real time. The information obtained from this sensor is to be analyzed by utilizing a variety of techniques within the fields of image processing and pattern recognition to achieve on-line defect detection, classification, and defect map generation. Our laboratory partners have undertaken a similar task but with emphasis on different sensor technologies. Ultimately, the overall fabric inspection system will incorporate all of the developed technologies in an integrated fashion.

The printed color inspection system represents a key area where national laboratory technology is helping to enhance the manufacturing and economy of textile products. Color and pattern quality on printed textile products represents a value-added process in the textile industry. Real-time on-line monitoring of textile color and surface quality is of paramount importance when extracting the value-added benefit from the process. The difficulty in characterizing product quality for colored materials arises because of the dynamic printing capabilities of modern production facilities. The use of human inspectors is generally employed for quality assessment of the finished textile material through off-line colorimetry and visual pattern matching and comparison. To exact the maximum benefit from this value-added process, a flexible, color-printed pattern measurement system is being developed and integrated into the finishing line. The color-printed pattern system will integrate several enabling technologies developed by the national laboratory working group associated with machine vision inspection and advanced computing concepts related to color measurement, pattern recognition, and image understanding. The system will be capable of color imaging for pattern recognition and pattern verification and will

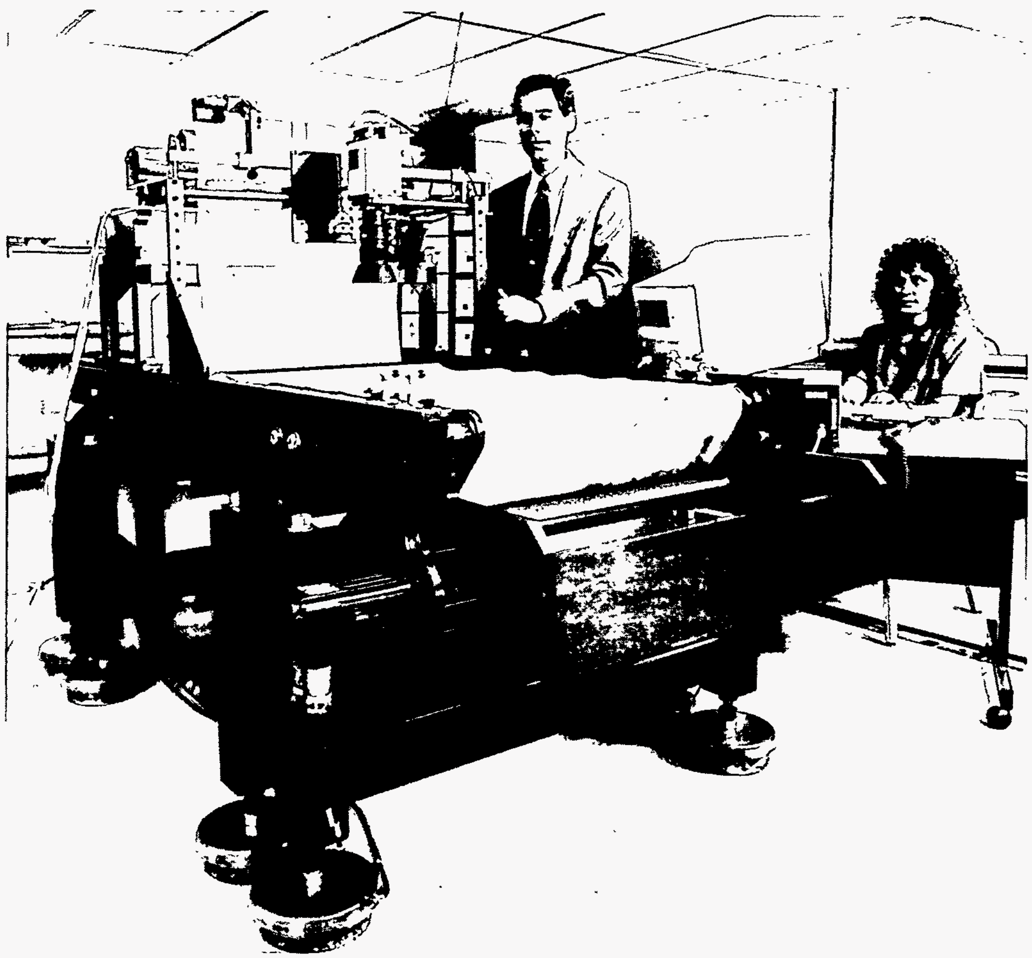

Fig. 3.1. The Oak Ridge Web Testbed is a unique facility for developing and testing machine vision systems on high-speed moving webs.

provide a tristimulus response for colorimetric evaluation.

3.3.2.2 Pattern recognition in the semiconductor manufacturing industry

Machine vision technology is currently being applied to semiconductor manufacturing technology in order to improve product yield. Automatic detection of defects during the fabrication of semiconductor wafers is largely automated, but the classification of those defects is still performed manually by technicians. Projections by semiconductor manufacturers predict that with the trend toward larger wafer sizes (up to 12 in. in diameter) and smaller line width technology (0.25 μ) the number of defects to be manually classified will increase exponentially. Through a joint venture between the I&C Division at ORNL and the KLA Instruments Corporation, concepts, algorithms, and systems are being developed to automate the classification of wafer defects to decrease inspection time, improve the reliability of defect classification, and hence increase process throughput and yield. Image analysis, feature extraction, pattern recognition, and classification schemes have been jointly developed that will be integrated into the KLA line of wafer inspection hardware. Figure 3.2 shows an example of a polyline defect.

Other defect examples are missing pattern, extra pattern, fall-on particles, embedded particles, resist flakes, scratches, and corrosion. Another venture in the area of semiconductor manufacturing is currently under way with SEMATECH, a federally funded consortium of the major U.S. semiconductor manufacturers.

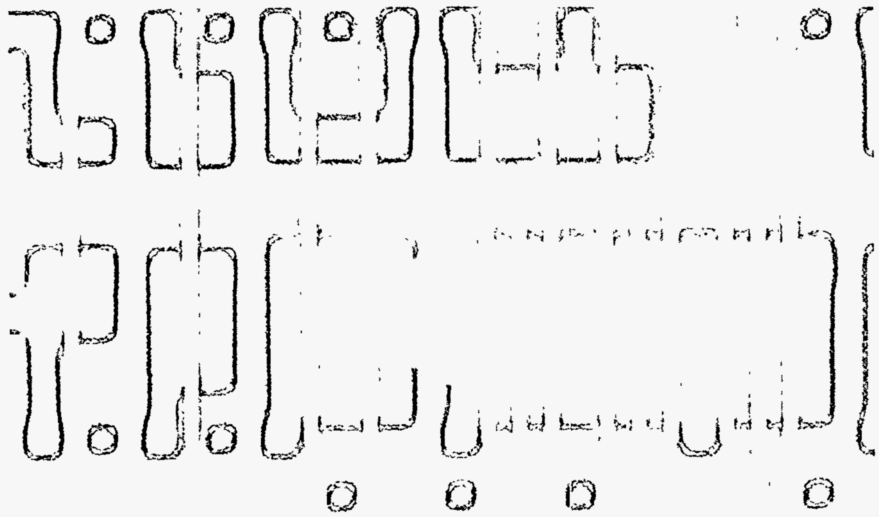

Fig. 3.2. Image of a semiconductor at 100X magnification. The defect in the center of the image is called "poly:extra pattern."

Members of the I&C Division are working hand-in-hand with SEMATECH staff in order to assess the state of the art in automatic defect classification (ADC) technology. I&C staff are providing technical assistance to SEMATECH to help accelerate the development of commercially viable ADC systems, which will improve U.S. competitiveness in the semiconductor manufacturing industry.

3.3.2.3 Vision-based quality monitoring of ceramic substrates

Previous web inspection and machine vision experience is being leveraged in an ongoing technology transfer program with the Coors Ceramics Company, Grand Junction, Colorado. Coors produces flat, durable, ceramic, thick-film substrates for printed circuit board use in the electronics and automotive industries. At least seven boards can be found in the electronic control systems of most new automobiles built in the United States. Substrates must be inspected for both dimensional tolerance (0.5% or better) and for the presence of a variety of surface and structural defects, including edge chips, surface blemishes, burrs (excess body), pits, dents, ridges, blisters, open cracks, and hairline cracks. Out-of-tolerance boards are unusable in many subsequent manufacturing steps and must be rejected. Undetected defects on parts can cause tearing of the silk screens used in the circuit printing or lead to eventual board structural failures in the finished product.

The first system is being developed jointly with Coors. Coors engineers have already been applying much of their newly acquired technology to other inspection tasks elsewhere in their plant. The current system, which uses specially designed structured illuminators, dual high-resolution digital cameras, and state-of-the-art parallel pipeline image processing hardware to acquire and process six 1.2-MB high-resolution digital images in 2 s is now under test and is expected to go on-line by the end of the year. Each surface is screened for defects using a battery of filters. Subpixel edge detection technology is employed to make precise dimensional measurements in less than half a second. New applications for these technologies are already being discussed which will permit Coors to introduce new ceramic products and effectively compete with their Japanese and German competitors.

3.4 APPLICATIONS OF ONE-DIMENSIONAL SIGNAL PROCESSING

3.4.1 Sonar Signal Analysis System—Postevent Beamforming Technology

The Sonar Signal Analysis System (SoSAS) has been enhanced to allow analysts to perform after-the-fact beamforming on acoustic emissions data gathered from passive arrays from submarines. After-the-fact beamforming/tracking provides analysts with the ability to locate and track multiple targets from the array data. Previously, analysts were limited to preformed beams focused in a predetermined direction whenever data from arrays were studied. Although different data sources have been added, the main mission of SoSAS has remained to provide the U.S. Navy with a tool to investigate new techniques for acquiring and analyzing information from sonar equipment.

While the benefits of performing after-the-fact beamforming/tracking are clear, many more sensors must be verified prior to performing beamforming/tracking operations. To assist in the validation of the recorded data for these sensors, ORNL developed and delivered software that allows the operator to visually examine these data quickly by visually displaying a gray-scaled representation of the root mean square for each element of the array. Once the operator locates areas of interest, more advanced tools, such as plotting the time series, computation of delay times, and a two-dimensional FFT of spatial/temporal data, are available within the software package.

3.4.2 Sonar Self-Noise Project—New High-Speed Digital Tape Technology

The Sonar Self-Noise Project was delivered to the Carderock Division of the Naval Surface Warfare Center (CDNSWC) in June 1994. For this project, ORNL fabricated and tested a tape interface unit (TIU), developed a user-interface for configuring and controlling the unit, and provided run-time libraries for use by CDNSWC in its own code development. In addition, diagnostic software was provided for the unit so that proper operation can be verified in the field.

The TIU was developed to enable the connection of MIL-STD-2179 and ID-1 high-density digital recorders (HDDRs) (capable of playback speeds of 50 MB/s) to processing equipment. The TIU provides up to eight channels of analog output. The digital-to-analog converter module consists of a phase-lock loop that derives conversion rates from the frame rate. Each channel has its own clock divisor, thus allowing multiple rate conversion up to 500,000 samples per second.

Using a process known as decommutation, the TIU selects, extracts, and assigns user-selected data to one or more output devices. Decommutation enables the user to select only the data pertinent to the specific application, thus effectively reducing the data rates and the cost associated with high-speed interfaces. The modular architecture of the TIU allows for several combinations of output devices. The TIU may be deployed on a variety of platforms, including SUN, VAX, and PCs.

Data from the HDDRs are organized in frames. A frame is defined as a sequence of 16-bit slots that is periodic at a base sampling rate (frame rate). The TIU maintains synchronization with the HDDR by continually checking six synchronization patterns with known locations within a frame. Synchronization is used both to verify communication with the HDDR and to organize data. If a user-specified number of consecutive frame errors occur, the TIU attempts to resynchronize to the HDDR. During resynchronization, the TIU maintains time and slot synchronization with the digital output device to ensure that the organization of data does not change.

The TIU core architecture allows it to be adapted for applications other than data acquisition from an HDDR. For instance, the HDDR interface and playback decommutator (IPD) has been adapted for a general purpose digital-to-analog converter subsystem. Other applications include interfaces to data sources which are subject to bit errors such as remote data acquisition equipment and communications equipment.

3.4.3 Acoustic Measurements Facilities Improvement Program, Phase II (AMFIP-II)—Acoustic Beamforming and Large-Scale Electronics

Two state-of-the-art prototype acoustic measurement systems were developed to support testing and operation of advanced submarine designs beginning in FY 1995. These systems operate in real time to produce accurate measurements and dynamic images of the acoustic emissions from test vessels that would otherwise be hidden within the ambient sea noise. The first of these systems was completed and installed in 1994. The development of these systems relies heavily upon division strengths in three main areas: electronics for the telemetry system, signal processing for the beamformer system, and systems integration.

3.4.3.1 Telemetry system

The telemetry system is a massive electronics gallery that conditions and converts the low-level sensor signals into digital form for optical transmission via fiber-optic cable to the host ship, the USNS Hayes, for subsequent processing and analysis. The 1300 sensors for each system are organized into a volumetric array in a manner that allows measurements over an acoustic frequency range spanning five octaves. Aggregate data rates for each array exceed 1.1 Gbit/s. High-speed, high-resolution signal digitization; high-voltage dc power distribution; and very high speed data multiplexing were incorporated into the design after rigorous evaluation and validation of commercial technology candidates.

The telemetry system consists of ~2400 custom printed circuit boards. Build-to-print documentation for these boards was completed in 1993 with fabrication performed by a subcontractor following a competitive bid process. Fabrication and testing of all boards were completed in 1994. Figure 3.3 shows 4 of the 16 underwater assemblies that were built as part of this effort.

3.4.3.2 Beamformer system

The beamforming and signal processing system receive data from the telemetry system and digitally beamform the underwater sensor data to produce calibrated sound pressure level measurements of the radiated energy of the test vessel. The beamformer system design is unique

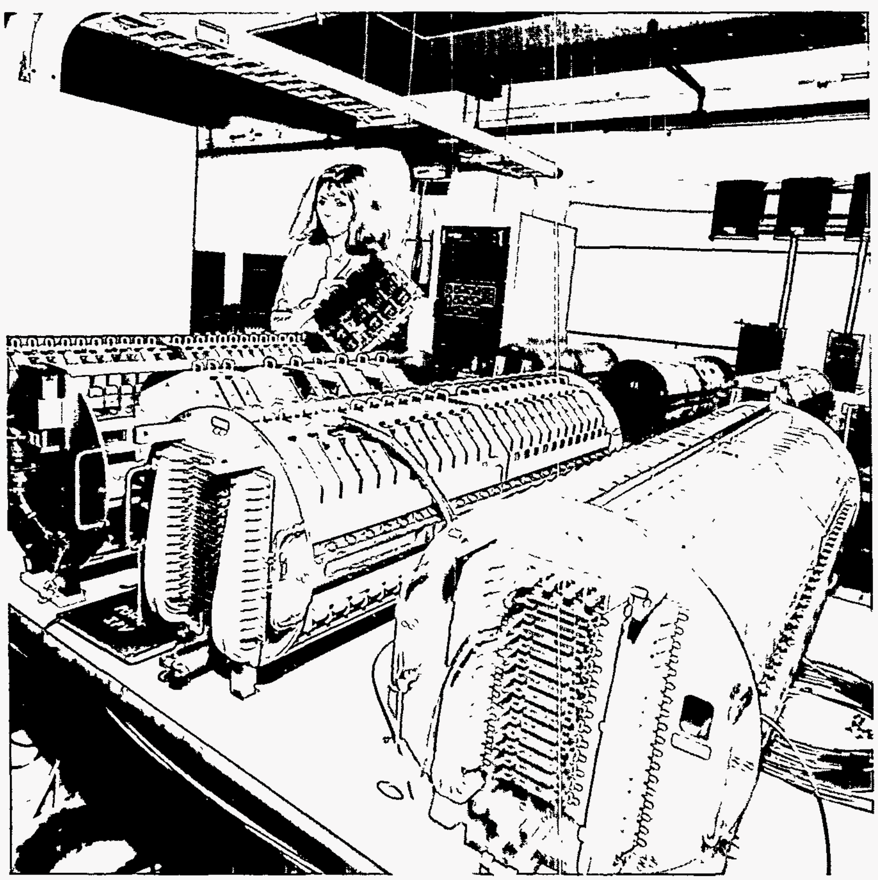

Fig. 3.3. Four of the sixteen underwater telemetry assemblies.

in that it provides consistent measurement performance over a broad range of frequencies. The system requirements were organized into a technical specification, which was then used in a competitive acquisition process. The beamforming systems were procured in 1993 from Cray Research, Inc., for $5M. ORNL engineers developed all of the operational beamformer and signal processing software. Figure 3.4 shows one of the beamforming systems. Each beamformer system provides over 20 Gflops of computational capacity.

Data products of this system include 60 precision measurement beams and 1740 high-resolution acoustic image beams that can be steered and used for continuous real-time spectral analysis. The system simultaneously processes signals from the 1300 sensors in the arrays to produce the required measurement in real time. The incoming data rate for each measurement system is 90 MB/s, sustained. Images are used to verify that proper beam-target tracking synchronization exists and to detect unwanted acoustic hot spots in the background area. Data are processed and stored for subsequent retrieval and analysis. In addition to digital outputs of the measurement and image beams, the beamformer also includes a high-resolution digital-to-analog converter designed by ORNL to produce high-quality analog outputs for selected beams.

3.4.3.3 Systems integration

The beamformer system was installed at ORNL in March 1993. Detailed software development efforts began at this time. The first production telemetry assemblies were also installed in March 1993, with additional telemetry

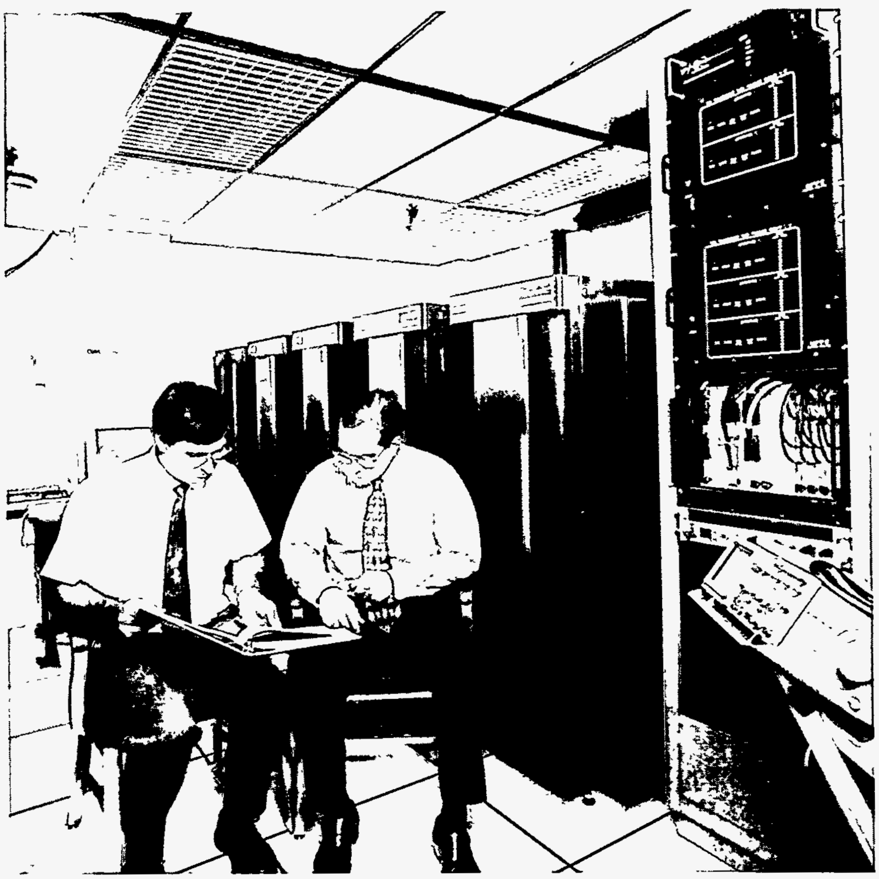

Fig. 3.4. A beamformer system: This system provides over 20 Gflops of computational capacity.

components added until June 1994. Detailed system integration, checkout, and testing began in the winter of 1994 using a combination of prototype and production assemblies. Final test and certification began in August 1994.

These systems will be delivered and installed aboard the USNS Hayes, a ship-based laboratory operated by CDNSWC. The first system was delivered in September 1994, and the second system will be delivered and installed in early FY 1996.

3.4.4 Postdelivery Support for the Large Cavitation Channel

The I&C Division has provided both on-site and telephone support for the Large Cavitation Channel (LCC) real-time measurement system since its delivery by ORNL to the CDNSWC in June 1991. The LCC is the world's largest water tunnel and is used for R&D in the support of new ship and submarine designs to ensure reduced noise emanations. On-site support activities include the integration of removable disks required for processing classified data, software enhancements to support beamformer calibration, and system level troubleshooting efforts. In addition, ORNL has provided technical assistance for the integration and testing of the hydrophone array.

3.4.5 Four-Plant Medical Computer System

The Four-Plant Medical Computer System (FPMCS) is a multiuser data management system that maintains medical records for each employee and special data of interest to Industrial Hygiene personnel. The FPMCS was upgraded from a 14-year-old computer system to a new dual CPU-based system to ensure increased system availability. Extensive testing of all the user application software was performed to assure functionality and security, and parallel operation of the old and new systems was utilized to eliminate any downtime for the Health Centers. To decrease the probability of data loss, journaling of all data to separate disk volumes was added.

The computer system is comprised of a VAX 4000-300 computer, 8-mm tape drive, two removable 1.7-GB disks, printer, and console terminals (Fig. 3.5). There is a duplicate system for backup and testing. A 9-track tape and two more disks are shared between the two systems. Two communication servers supporting up to 32 lines each are connected to modems for the terminal lines at ORNL and the Oak Ridge Y-12 Plant. Three terminal servers supporting eight lines each connect the dedicated lines and dialup lines for the Paducah Gaseous Diffusion Plant, the Oak Ridge K-25 Site, and auto data lines for ORNL and Y-12 and local I&C support terminals.

The system contains medical data for Oak Ridge DOE employees, Oak Ridge Associated Universities employees, and ORNL, Y-12, K-25, and Paducah employees. The system with its retrieval capabilities permits studies on a very large, diverse population to provide long-term studies of diagnostic findings and occurrences for

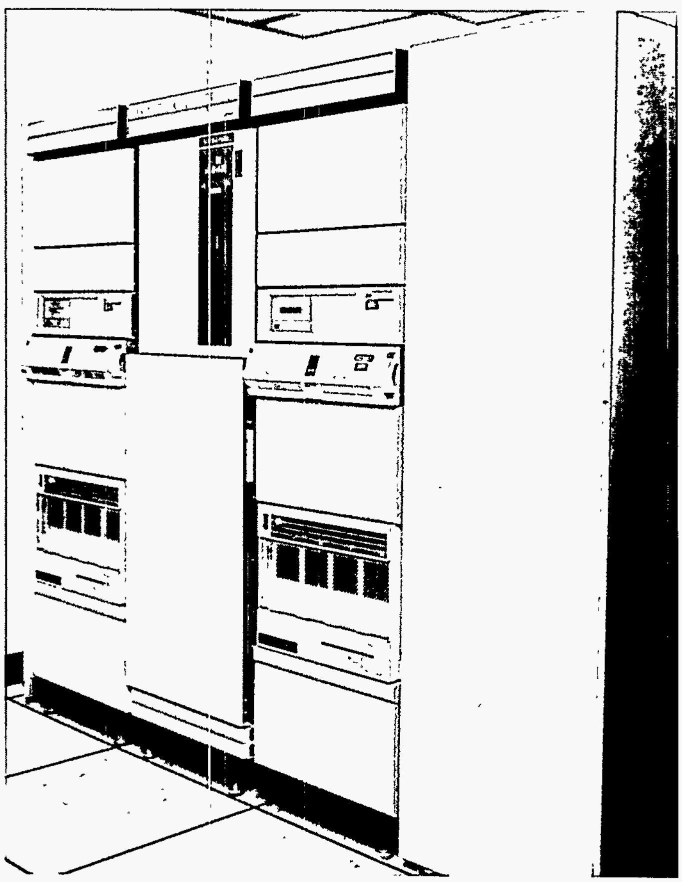

Fig. 3.5. A dual VAX 4000-300 computer, 8-mm tape drive, two removable 1.7-GB disks, printer, and a console terminal comprise the Four-Plant Medical Computer System.

employees who receive frequent physicals and laboratory screening tests.

The new system includes the ability to expand the automated data acquisition capabilities at ORNL and Y-12 while adding the capability at K-25. This system provides automatic data collection in the Health Divisions for audiometers, spirometers, blood chemistry analyzers, hematology systems, and vision systems.

Reports on types and purposes of visits, physicians' findings, and results of analyses are provided for the purpose of monitoring and maintaining employee health. Screening of the data, health risk assessment, and historical trending of individual employee data provide the physician with necessary information for the purpose of diagnosis and treatment. Doctors have the ability to display laboratory results, clinical diagnosis, electrocardiogram diagnosis, X-ray diagnosis, and workplace exposure data during routine physical examinations. ORNL and Y-12 Health Centers use this system to schedule examinations and to track employees in mandatory programs.

4. CONTROLS AND SYSTEMS INTEGRATION

4.1 OVERVIEW

In previous chapters of this report, we described important work in the core competencies of advanced measurement systems, signal processing and analysis, and electronics systems. In this chapter, we describe important work related to the Division's competency in controls and systems integration. These two technologies, "controls" and "systems integration," frequently are linked together in the real world because one is rarely satisfactory without the other. Historically, the Division has provided state-of-the-art control (and safety) systems for many of Oak Ridge's research reactors, as well as other premier experimental and operational facilities. The skills we developed in this work have allowed us to provide many other customers with improved control of experimental systems, process systems, manufacturing enterprises, and entire power plants.

The specific technical aspects of controls and systems integration which we have that are at the forefront of the state of the art are: modeling, simulation, and analysis of very complex systems, including the instrumentation and control (I&C) systems interacting with them (also human–machine interface); integration of hardware and software into automated systems; control strategies and theories for extremely robust and reliable systems; design of protection systems, including application-specific integrated circuits (ASICs); and qualification of I&C equipment for hostile environments. Specific technical aspects where we are not preeminent but are at the state-of-the practice are: software verification and validation; communication technologies for system architectures; and PC-based data acquisition and control.

The systems integration aspect of our work requires us to be expert in the understanding of our customer's world. We have become very knowledgeable about experimental and operational facilities in Oak Ridge. We also have become recognized experts in the understanding of power plants (nuclear and fossil) and certain manufacturing processes. We are moving into operations research in manufacturing, particularly in collaboration with the Centers for Manufacturing Technology. Through cooperative research and development agreements, we also are becoming familiar with automotive engineering, semiconductor manufacturing, and textiles production.

In the sections below, we describe recent work in these areas.

4.2 COMPUTING ARCHITECTURE REQUIREMENTS FOR STEP-WISE, PIECEMEAL UPGRADES TO POWER PLANT I&C

The increasing use of computer technology in the U.S. nuclear power industry has greatly expanded the capability to obtain, analyze, and present data about the plant to station personnel. However, it is necessary to transform the vast quantity of available data into clear, concise, and coherent information that can be readily accessed and used throughout the plant. This need can be met by an integrated computer workstation environment. As part of a cooperative research and development agreement (CRADA) with the Electric Power Research Institute (EPRI), ORNL developed functional.requirements for a Plant-Wide Integrated Environment Distributed On Workstations (Plant-Window) System.

The Plant-Window System (PWS) project was established to define the necessary characteristics and attributes of a functionally integrated computing environment, supported on a distributed architecture of interconnected workstations and I&C equipment, that provides personnel with plant systems access and software applications. The PWS targets the difficulties presented by step-wise, piecemeal I&C system upgrades at power plants. As digital systems are introduced to a plant, PWS workstations can serve as common computing interfaces for a variety of systems rather than relying on unique, special-purpose computer consoles for each system. In addition, incorporation of upgraded I&C systems and data sources into the PWS distributed network architecture provides access to information throughout the plant and reduces the number of stand-alone systems. Common access to plant systems and information allows the integration functions to support enhanced performance of activities by plant personnel.

The PWS functional requirements establish a computing environment framework based on a layered approach with the capabilities of lower levels supporting the functionality of higher levels. The basic layers of the Plant-Window environment are applications, the PWS application environment, standard system services, the workstation hardware, and networking. Each PWS workstation provides a base hardware platform connected as a node to a plant network. This platform supplies general-purpose computing system services through its resident operating system, its user console, and its network communications services.

The PWS application environment is common to all PWS workstations connected to the networks within the plant. This application environment supplies standardized functional modules and establishes consistent application programming interfaces to support integrated software applications. Thus the PWS application environment forms the basis of a "plug-and-play" computing environment through common services and interface conventions (Fig. 4.1).

The use of computers and digital I&C systems in nuclear power plants can provide a significant increase in the amount of information available to plant personnel. The integration and use of operator advisors, diagnostic aids, maintenance advisory and scheduling applications, and engineering analysis and planning applications can lead to improved plant performance and availability, enhanced reliability, increased safety, and, potentially, reduced operations and maintenance costs.

4.3 SPECTRAL RECEIVERS FOR MEASUREMENT OF ELECTROMAGNETIC INTERFERENCE IN NUCLEAR POWER PLANTS

Electromagnetic and radio-frequency interference (EMI/RFI) are known to cause malfunctions in safety-related I&C systems. As a result, the Nuclear Regulatory Commission (NRC) is in the process of issuing regulatory guidance on how to deal with EMI/RFI in nuclear power plants (NPPs) and has contracted with ORNL to execute a research program having as its objective the development of a technical basis for evaluating the potential threat posed by EMI/RFI events in NPPs and assisting the nuclear industry to ultimately achieve electromagnetic compatibility. A key technical issue is "What levels of electromagnetic interference should safety-related I&C systems be

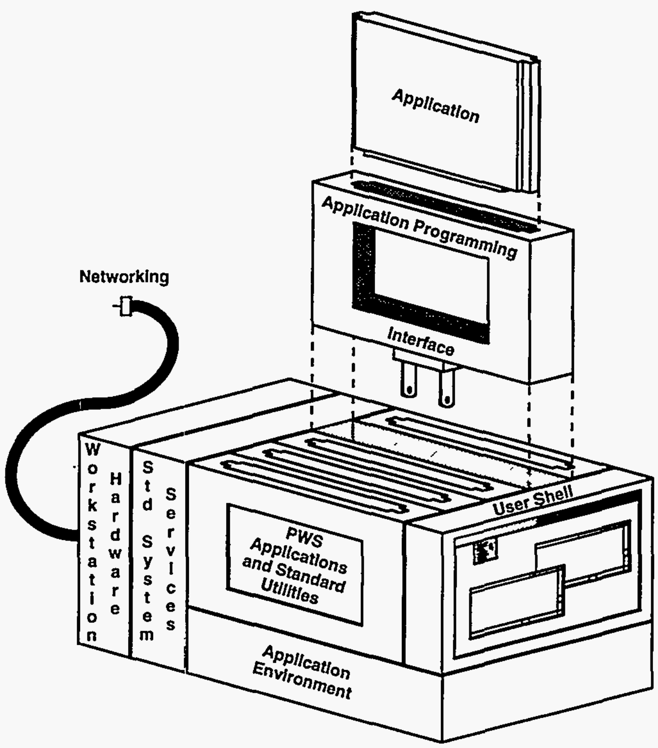

Fig. 4.1. Framework for PWS plug-and-play computing environment.

capable of withstanding without upset?" A closely related question for which answers are sought is "What ambient field levels can be expected in today's typical NPP?"

Since no commercial measurement equipment could be found that was entirely suitable for answering the latter question, ORNL I&C engineers designed their own. The result was two spectral receivers: one surveys electric fields in the frequency range 5 MHz to 8 GHz, while the other surveys magnetic fields in the frequency range 305 Hz to 5 MHz. Both are designed to operate unattended for periods of a month or more and provide time stamping of events of interest and automatic storage of results every 6 h. Both are heavily EMI-shielded and protected against power line disruptions with self-contained uninterruptible power supplies. The electric receiver is of a relatively conventional heterodyne (stepped local oscillator) design, whereas the magnetic receiver is based on cascaded wavelet filters implemented on digital signal processing (DSP) chips.

Figure 4.2 shows magnetic flux levels measured in a typical power plant control room environment using the magnetic spectral receiver. The EPRI-recommended withstand level is shown for reference. The upper extreme of the receiver's dynamic range is determined by saturation of the analog-to-digital (A/D) converter, whereas the lower extreme is set by A/D quantization noise. The receiver's overall gain is set so as to properly capture the magnetic activity expected in a power plant control room. The spectral receivers are scheduled for placement at the Oconee, Arkansas Nuclear One, Hope Creek, Salem, and Sequoyah nuclear power stations during fiscal year 1995.

4.4 CONCEPTUAL DESIGN OF A REACTOR PROTECTION SYSTEM USING APPLICATION-SPECIFIC INTEGRATED CIRCUITS

The Advanced Neutron Source (ANS) Project and EPRI are sponsoring the I&C Division to develop a demonstration reactor protection system using application-specific integrated circuits (ASICs). An ASIC-based design appears to have some advantages over analog- and software-based systems; accordingly, I&C Division has been tasked to design and fabricate two channels of a typical protection system so that design and operational features of ASICs in safety applications can be evaluated in detail. Features being studied include methods for verification and validation, design flexibility to tailor for function and form, methods for reducing the likelihood of obsolescence, and methods for simplifying

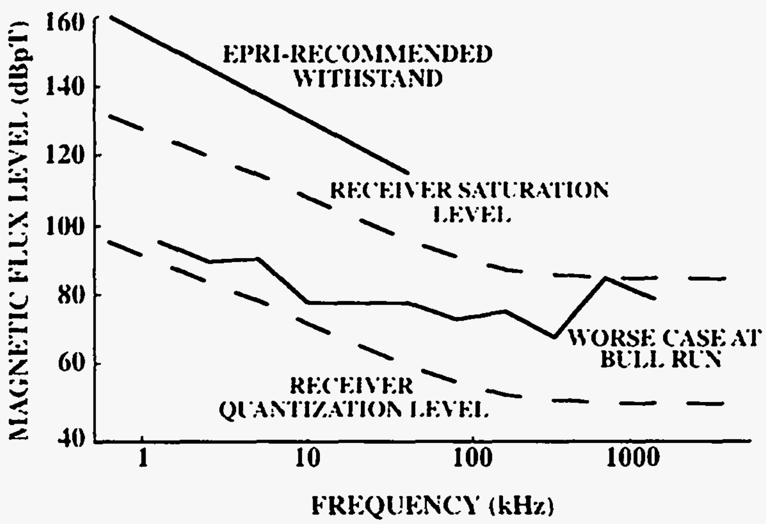

Fig. 4.2. Worst-case magnetic fluxes observed at the Bull Run Fossil Plant.

maintenance. Each of these features was considered in the conceptual design.

The fundamental design concept is to develop simple modules that can be combined to perform complex operations. The design consists of several ASICs, each of which is dedicated to a specific but basic operation. These ASICs can be combined as desired to implement any safety system function needed simply by modifying a controller ASIC. The basic operational modules include the following: comparator, square root, piecewise input/output function, multiplier, and adder/subtracter. Interface and support modules are input signal handling, computer interface, and controller. These modules are then combined to implement the safety functions of representative safety channels. The safety functions performed by combining these basic operations include lag, lead/lag, and rate filters; solving a quadratic equation (Callendar-Van Dusen equation for resistive temperature detectors); calculating flux tilt and modifying trip points with a piecewise function; comparing set points to measured or calculated parameters for low and high trips with hysteresis; and sums, differences, and multiplications for other computed values. Modular designs have the advantages that each module can be thoroughly tested, design and maintenance are simplified because only a few generic module designs need be supported, and many different functions can be performed by controlling the generic modules. Obsolescence likelihood is reduced because only a few designs must be supported and because the design is transferable to many different components. Operational testing can be automated through a computer or special test board interface.

A safety system demonstrator has been designed which uses eight field-programmable gate array (FPGA) ASICs rather than custom or semicustom ASICs (see Fig. 4.3). The signal input board has five analog inputs conditioned by antialias low-pass filters, five A/D converters, and one FPGA. A second printed circuit contains random access memory (RAM) and read-only memory (ROM) for storing intermediate results, set points, and other constants. There is an option to store constants and set points in ROM or load them from the computer into nonvolatile RAM. This board also includes an FPGA that interfaces

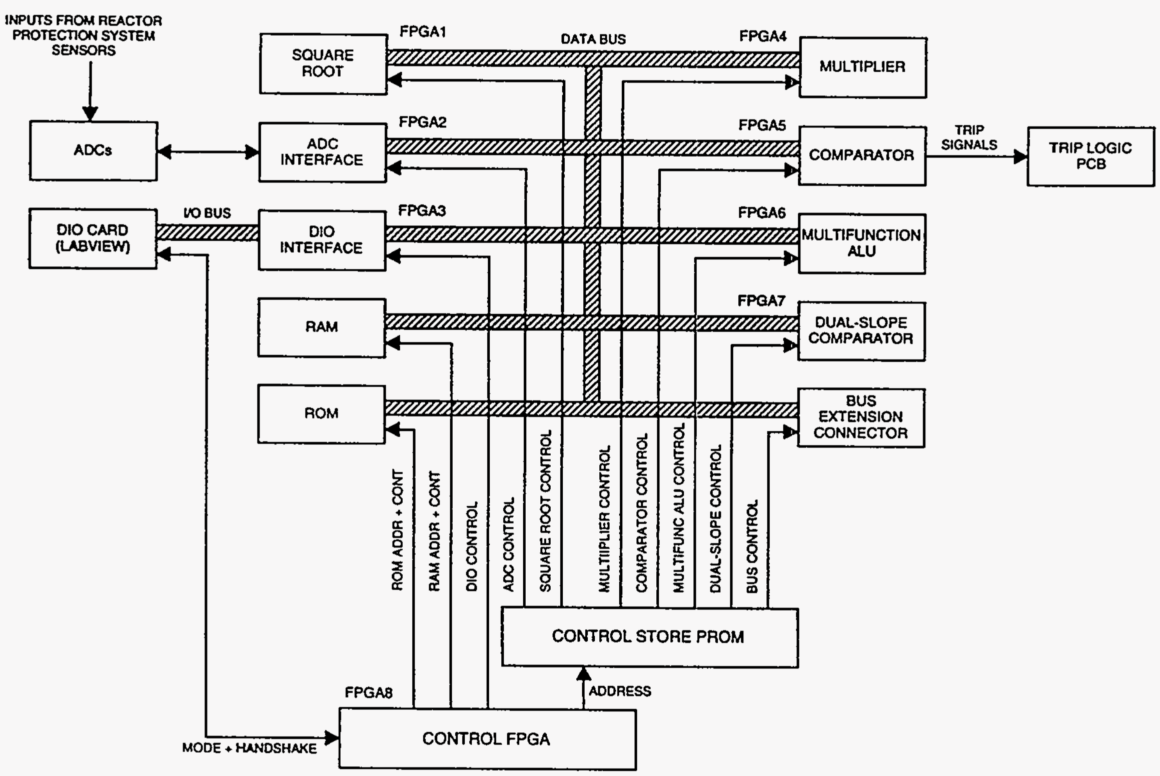

Fig. 4.3. Reactor protection system block diagram.

to a computer, on which is implemented the man–machine interface. Six FPGAs and programmable read-only memory (PROM) are on the third printed circuit. Five FPGAs perform the basic safety operations, and the sixth controls the PROM and other FPGAs. Computations use fixed-point arithmetic, and data are transferred over a 42-bit bus. The more complex safety functions are complete in ~2 ms for a system clock running at 1 MHz. The simpler safety channel completes its functions in ~0.2 ms. After the safety functions are completed, data transfer to the computer takes only a few milliseconds.

A goal of this project is to transfer ASIC technology to industry so as to allow ASIC-based designs to compete with and complement analog- and software-based safety systems currently available for nuclear power and research reactors. The safety system demonstrator will be shown to interested utilities and vendors to help accomplish this goal.

4.5 MODULAR, DISTRIBUTED HIERARCHICAL CONTROL SYSTEM FOR THE U.S. ARMY FUTURE ARMORED RESUPPLY VEHICLE PROOF-OF-PRINCIPLE DEMONSTRATOR

I&C Division staff members are working with ORNL's Robotics and Process Systems Division (RPSD) personnel to develop a modular, distributed hierarchical machine control system architecture for application to the U.S. Army's Future Armored Resupply Vehicle (FARV) proof-of-principle demonstrator program at RPSD. The control system allows commands issued on a graphical user interface (GUI) to be converted into machine motion in order to move and assemble/process artillery ammunition rounds. The overall demonstrator project involves the development of several stand-alone artillery round processing subsystems (lifting eye removal, fuzing, weighing, marking), which later will be integrated together with several additional artillery round handling and storage subsystems (upload boom, ammunition transfer device, fuze conveyor, storage racks) to form an integrated ammunition processing/handling demonstration system. Changing requirements/goals and limited workspace constraints require that the control system be sufficiently modular to quickly accommodate relocation, addition, deletion, and modification of hardware and/or software components. Development phasing and frequent demonstrations require that the subsystems be operable as an integrated system as well as individually.

Our solution to this challenge is a scaleable, modular, distributed hierarchical machine control architecture developed specifically for the FARV program. The architecture breaks the system down into a hierarchy of control layers: high-level commands are interpreted into lower level commands as they filter down through the control layers (Fig. 4.4). The highest level layer manages the system mode (upload ammo, download ammo, process ammo, transfer ammo, break-away, etc.), while the lowest level layer directly talks to the hardware. The architecture can be broken into two major layers: the job controller layer and the subsystem controller layer. A GUI intefaces to a job selector, which uses a separate job controller for each system mode. The mission of the job controller layer tasks is to break a high-level activity for a given mode such as "process ammo" into mid-level commands specific to the subsystem controllers such as "fuze round" to the fuzing subsystem controller," "weigh round" to the weighing subsystem controller, "mark round" to the marking subsystem controller, etc. The job controller layer tasks must manage the sequence and monitor the successes of each of the mid-level commands it issues, but it does not directly control any hardware and therefore is an asynchronous (soft real-time) layer. The subsystem controller layer modules are composed of two major tasks: an asynchronous task and a synchronous task (Fig. 4.5). The asynchronous task interprets mid-level commands into actuator-level commands, which are placed into a mailbox. The synchronous task executes a control loop on a clock, typically at 100 Hz. Each time the synchronous loop runs, the mailbox is checked for new commands, and the hardware is affected. The synchronous tasks on the subsystem controllers are the only ones that directly manipulate the hardware.

Homogeneous hardware and software platforms are used throughout the control system. This permits reuse of specially developed software modules. The software design has been implemented in C++, an object-oriented computer language, as a group of nested classes. Where

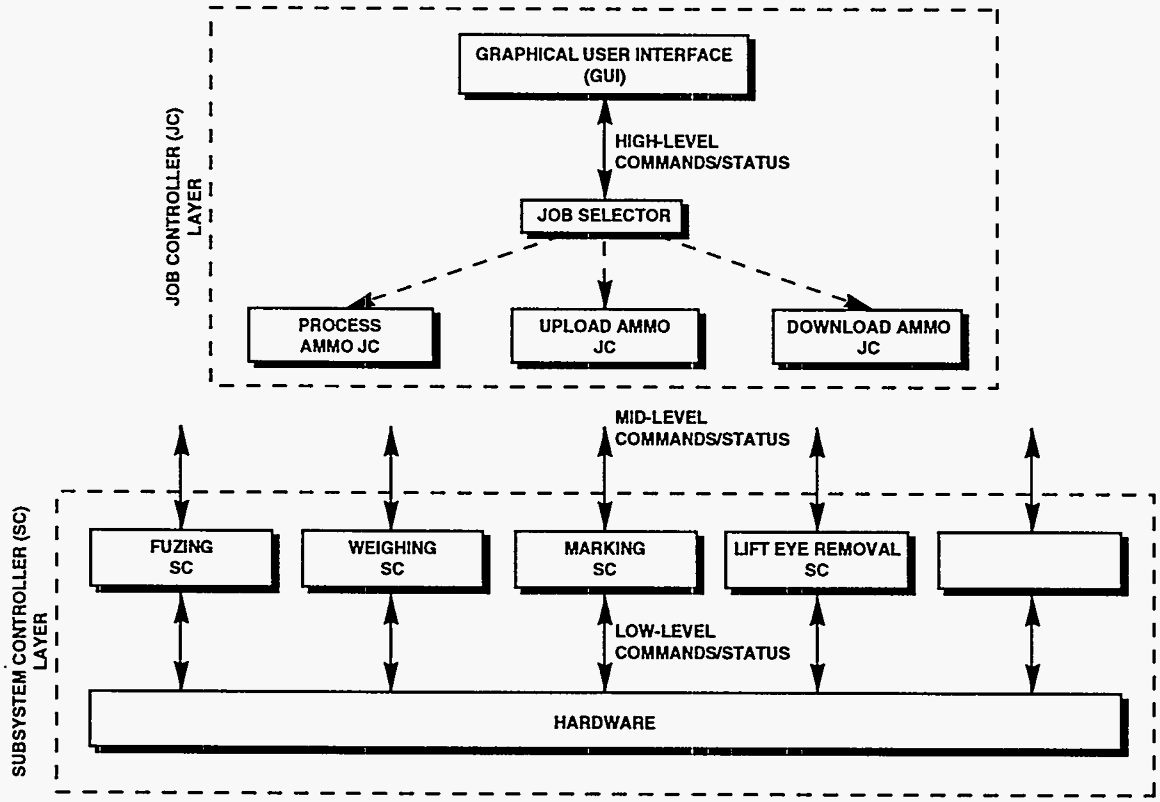

Fig. 4.4 The FARV control system uses a hierachy of control levels.

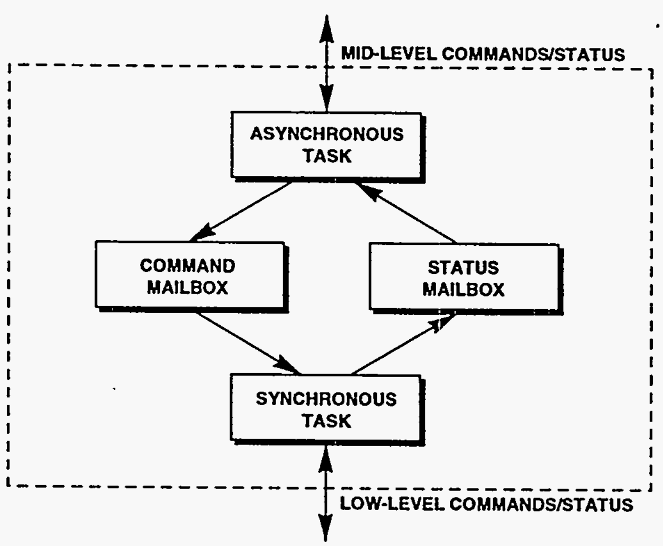

Fig. 4.5 Subsystem controllers use a mailbox interface between their synchronous and asynchronous tasks.

practical, object-oriented concepts have been used. The various control layers and their tasks are connected together using an Ethernet-message-based, network-transparent intertask communication system called the message manager. The message manager is key to system modularity because it allows software tasks to be moved from central processing unit (CPU) to CPU with ease. Tasks simply register themselves with the message manager and begin receiving messages. The message manager is built in part on the post office protocol (POP) but adds automatic registration mechanisms that allow any CPU to be attached to the Ethernet network and immediately be able to connect itself to the message manager "communication network" without any recompilation or reconfiguration. Prior to run time, it is not necessary to know which system tasks will run on which CPU. This is all worked out at run time as CPUs and tasks register. Because the registration is dynamic, it is even possible to add and subtract CPUs and move tasks from one CPU to the next "on-the-fly" without any modification to the system software.

This architecture has simplified R&D efforts by providing seamless flexibility in a very dynamic environment. During subsystem controller development, we were able to use separate stand-alone computers for development of each subsystem controller, making development and testing cycles simpler and minimizing resource conflicts. During system integration, we were able to quickly map several stand-alone controllers onto a single CPU with little more than startup-script and field wiring changes. This architecture will likely be applied to future machine control projects

4.6 SEMICONDUCTOR MANUFACTURING

4.6.1 Mass Flow Controller Development Laboratory

In support of the U.S. semiconductor industry and SEMATECH (a consortium of semiconductor manufacturers which address semiconductor manufacturing technologies), calibration and performance characterization technologies have been developed for mass flow controllers (MFCs). These technologies have been implemented through a unique, innovative test facility that has the capability to accurately describe performance metrics for MFCs (Fig. 4.6). MFCs are installed on 75% of all semiconductor process tools and are presently one of the most unreliable subcomponents. Performance improvement (especially accuracy) must occur if the United States is to remain competitive in the worldwide semiconductor marketplace.

A significant R&D effort was initiated to develop a method for accurately calibrating MFCs used with hazardous gases. A metrology instrument was invented (and patented) which allows mass flows of gases to be measured very accurately (Fig. 4.7). This instrument is a gravimetric gas flow calibrator which uses a patented liquid suspension system to weigh small quantities of gas collected in a pressure vessel. It is unique in that it can accurately calibrate and characterize MFCs controlling hazardous semiconductor gases. The device advances the state of the art in calibration technology for hazardous gases by two orders of magnitude, to 0.1%. The project also presented several other technical and administrative challenges. The facility was designed to handle semiconductor process gases safely, many of which are toxic and highly flammable. A technique was developed to test and compare the reliability of MFCs from a number of suppliers (seven manufacturers, 28 MFCs in all). Feeding the performance data back to the manufacturers in a timely manner required an extremely tight schedule: The facility was designed, fabricated, and ready for operation in 9 months. The culmination of the facility development was an open house held on October 29, 1993, for industrial participants. The facility is now open to industry for testing and product development, and two contracts have been let to members of the semiconductor community. Application for the facility to become a national users center has been submitted to DOE.

4.6.2 Process Measurement and Control/Materials Development

A joint CRADA was signed with SEMATECH and Sandia Corporation to improve semiconductor manufacturing technologies for SEMATECH's ten member companies and SEMI/SEMATECH's 150 supplier companies. This CRADA has allowed the Oak Ridge complex to effectively apply its capabilities in assisting U.S. industry to

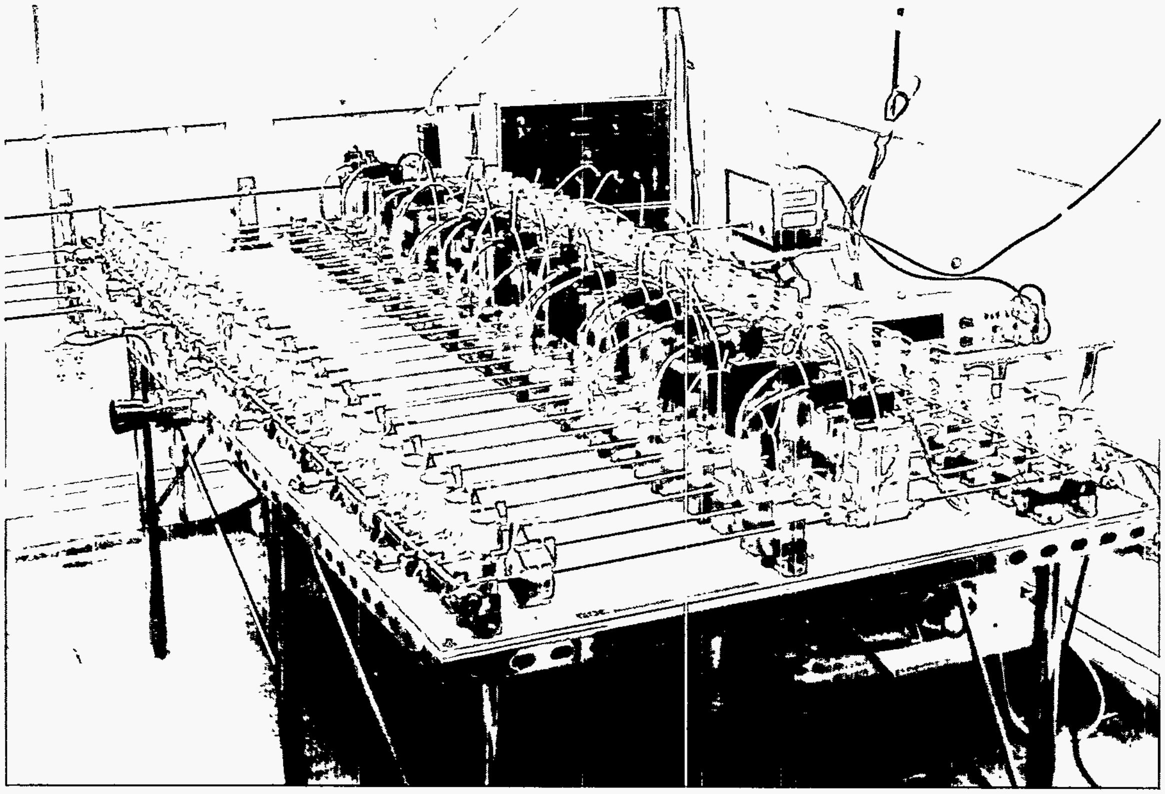

Fig. 4.6. Mass Flow Controller Development Laboratory—reliability test stand.

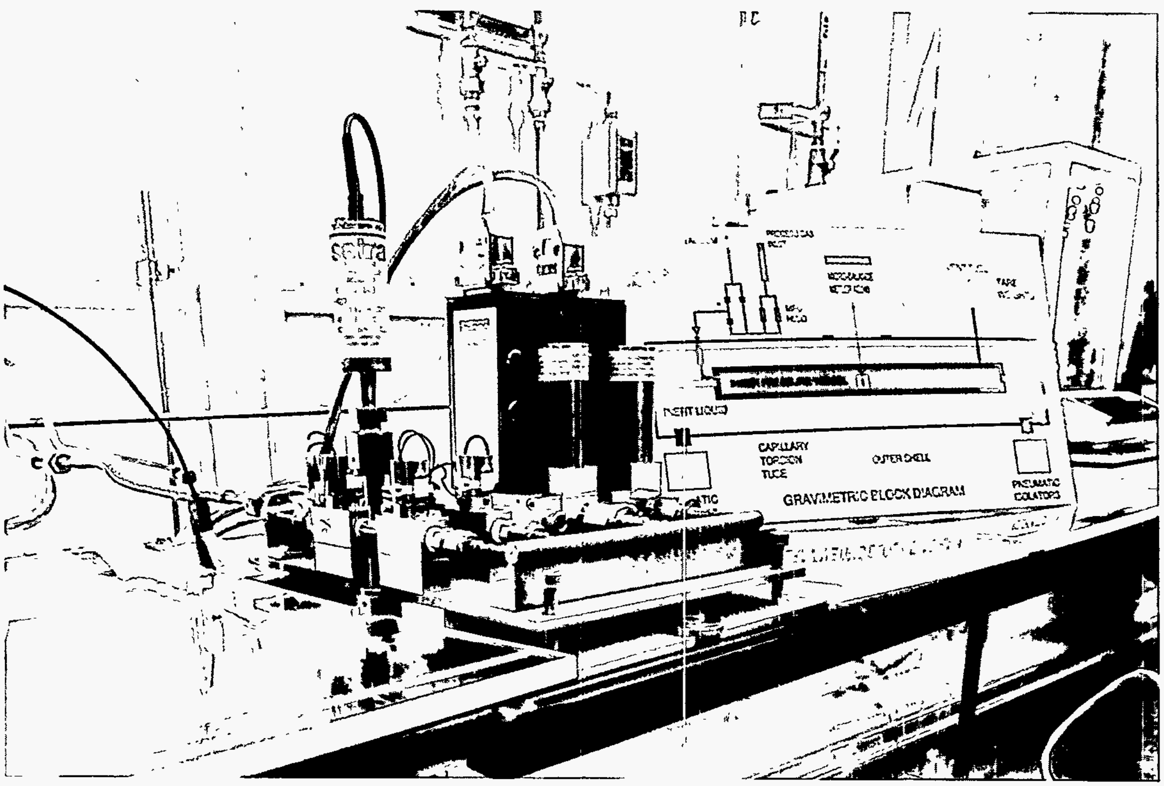

Fig. 4.7. Gravimetric calibrator for accurately calibrating process gas flows.

increase its international competitiveness. The general areas that are being addressed include

- equipment benchmarking,
- contamination-free manufacturing,
- process measurement and control,
- equipment and process modeling, and
- material development.

Results in these areas are CRADA-protected and cannot be discussed at this time.

Staff members from two divisions of ORNL (I&C and Fusion Energy) and personnel from the Centers of Manufacturing at the Oak Ridge Y-12 Plant are involved in these efforts. In addition, four staff members from the I&C Division are on off-site assignment at SEMATECH, where they are providing technical expertise and project leadership to the semiconductor industry in the areas of process measurement and control.

4.7 SEWING MACHINE CRADA

The I&C Division and Y-12 Development Division have teamed up with a small company, Quick-Rotan, Inc., to develop a small, direct-drive sewing machine motor that can reach speeds up to 10,000 rpm. The brushless dc servomotor is designed to replace the current ac servomotors that are driven by belts and pulleys rather than being mounted directly to the drive shaft. The advantages of a direct-drive motor are numerous: swapping of sewing machine heads can be done much more rapidly; maintenance is easier with a top-side motor mount; operators will have more leg room under the table; the table top need not be provided with a hole for the belt; and power loss, heat, vibration, and noise are reduced. Furthermore, there is no sacrifice in speed, despite a much smaller motor (about the size of a soda can). The direct-drive feature means that 10,000 rpm translates into 10,000 stitches/min, which is competitive with the largest under-the-table servomotors.

The goal of the project was to produce a motor and controller that could reduce sewing machine downtime. An additional goal was to bring the sewing machine motor/controller business back to the United States. Currently, all of the manufacturers in this business are overseas, primarily in Japan and Germany. Based on feedback from foreign manufacturers at the 1994 Bobbin Show in Atlanta where the new sewing machine motor was demonstrated, this project represents a major breakthrough in sewing machine motors. The motor was the result of a small CRADA between Quick-Rotan and Martin Marietta Energy Systems which was performed in a very short time. The CRADA will continue to focus on characterization of the motor, which will be essential to designing a controller for it that is commercially viable. Although the prototype demonstrated at the Bobbin Show generated a great deal of enthusiasm, it is not yet ready for commercialization.

The motor itself is a permanent magnet brushless dc servomotor that generates 1.4 hp. This is actually larger in power output than most ac servomotors connected by belts and pulleys that are many times larger than this motor. The new motor is 3.5 in. long by 2.5 in. in diameter and uses a Hall Effect encoder for position reading (see Fig. 4.8). The motor will be targeted not only to new sewing machines but also for upgrading old machines. Indeed, retrofitting old machines may be the most beneficial aspect of the project because of the the large amount of heat and power loss from these machines and the downtime associated with their replacement.

The work done by Energy Systems included the design of the drive system, integration of the motor into this drive system, and the design of the speed controller. Additional work will focus on system identification (possibly using wavelet analysis) since the sewing machine environment is corrupted by electrical noise. There is also a need for more sophisticated needle positioning embedded in the control system, possible incorporation of a skipped-stitch monitor, and reduction of mechanical vibrations in the motor and drive system. This work has already involved I&C's expertise in system identification, modeling, control theory, simulation, system integration, and motor technologies. Further work in this project will continue to involve these same core competency areas. The project may also lead to more work in the sewing and apparel industries involving automation, incorporation of advanced features, and increasing reliability of machines.

4.8 KWAJALEIN BIOREMEDIATION PROJECT

During WWII and with continuing operations, Kwajalein Atoll in the Marshall Islands has been the site of U.S. military facilities at which large

Fig. 4.8. Paul Manos, president of Quick-Rotan, Inc., explains the operation of the direct-drive sewing machine to Gordon Fee, president of Martin Marietta Energy Systems, Inc., as part of a CRADA between Energy Systems and Quick-Rotan.

quantities of diesel fuel were stored in tanks. The associated piping for these tanks was underground. The deterioration of the integrity of the walls of these pipes over the ensuing years has resulted in serious contamination of the island's groundwater and lens wells.

The Hazardous Waste Remedial Actions Program (HAZWRAP) office in Oak Ridge was assigned the tasks of evaluating the type and extent of the Kwajalein groundwater contamination and of developing and demonstrating a means of restoration. The restoration method attempted was bioremediation, a method by which the microorganisms that already exist in the soil are induced to metabolize the unwanted hydrocarbons in the water, thereby rendering them harmless. Oxygen and nutrients are injected into the soil to stimulate this process.

In response to the need for a means to collect the data required to determine the nature and levels of the pollutants as well as results of the bioremediation efforts, an I&C Division engineer designed a specialized data acquisition and analysis system and traveled to Kwajalein to effect the installation and testing (see Fig. 4.9). The system consists of sensing equipment positioned over various wells drilled into the water table. Air is pumped into the wells, and gases that return are analyzed chemically (see Fig. 4.10). The results are used to determine the success of the bioremediation process.

This work is ongoing. Initial performance of the data acquisition and analysis system has been excellent.

4.9 "EXPERIMENT-BY-WIRE" TECHNIQUE ENABLES IMPORTANT RESEARCH IN MICHIGAN TO BE CONTROLLED FROM OAK RIDGE

The Heavy Steel Section Irradiation (HSSI) experiments, part of a long-standing NRC program to study the embrittlement of reactor vessel materials, were made possible by a new remote data acquisition and control system developed by an I&C Division team. To study the potential embrittlement experienced by various steel alloys when used as materials in reactor components, specimens inside an aluminum

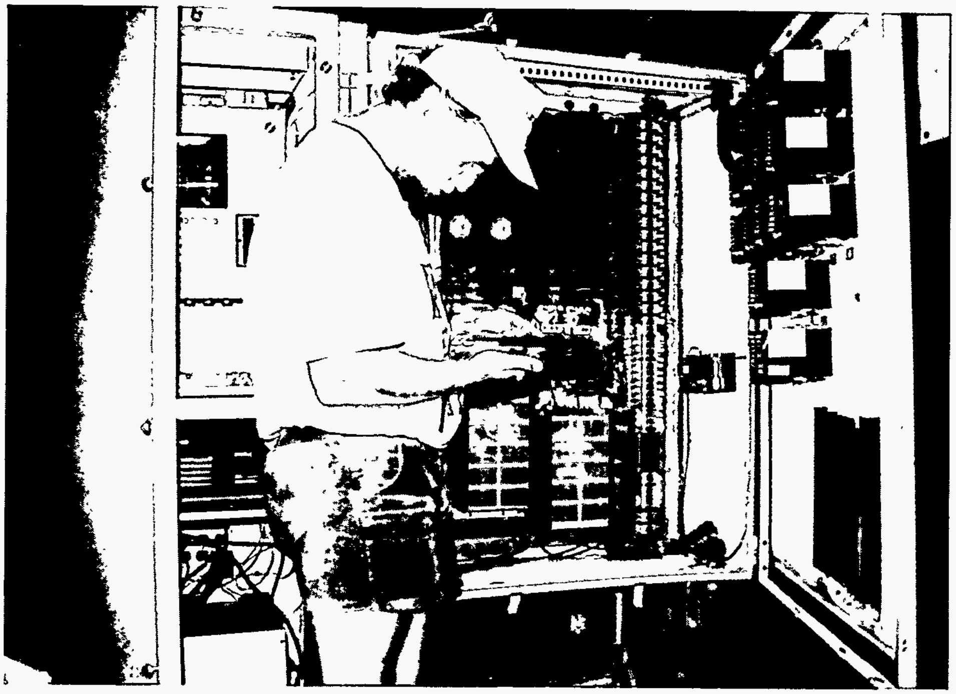

Fig. 4.9. At the Kwajalein data collection system, an I&C engineer checks the current load on the roots blower used to inject air into the wells.

Fig. 4.10. A view of the Kwajalein air injection and water distribution systems for many wells.

capsule are bombarded by fast neutrons. It is essential to ensure that the steel specimens are constantly maintained at a predetermined temperature during the bombardment. A means of controlling and monitoring this temperature as well as other experimental parameters is therefore crucial.

Because of scheduling problems at the High Flux Isotope Reactor at ORNL, it was necessary to find another reactor at which to conduct these experiments. The Phoenix Ford Reactor at the University of Michigan was ultimately chosen as the experimental facility. A great many difficulties were expected to ensue from this arrangement because of logistics problems resulting from the necessity for the experiments in Michigan to be conducted by a research team sited in Tennessee. The remote data acquisition and control system developed by the I&C team, however, allowed all of the experimental parameters to be manipulated and monitored and data to be acquired by a research team seated at a computer terminal at ORNL in Tennessee. This "experiment by wire" method tremendously reduced the costs incurred by traveling, the possibilities of confusion that can result from technical consultation by telephone, and the necessity of extensive training of an on-site technical support team.

After the system was designed and reviewed and its component modules were fabricated (Fig. 4.11), the I&C engineering team personally transported the equipment to Michigan to ensure its safe arrival. They provided oversight for the installation of the system and trained on-site craft personnel to perform minor maintenance procedures and to repair any equipment failures. Such failures, along with any other technical problems, can be diagnosed via the remote system, again saving funds and obviating excessive downtime.

4.9 INTEGRATED, AUTOMATED MONITORING AND TESTING OF ALARMS AT THE REDC FACILITY

The Radiochemical Engineering Development Center (REDC) facility houses hot cells and radiological areas where Californium sources and isotopes for industry are produced. This type of nuclear facility requires extensive monitoring of building ventilation controls, radiation levels, building temperatures, pressures, and sump levels to assure building containment and safe operating conditions. To improve accountability and maintenance of existing on-line facility instrumentration, a computerized data acquisition and monitoring system has been developed for the REDC at Building 7930. The system is also being expanded to include Building 7920. All relevant building instrument indicators and alarms can be monitored from one or more stations throughout the complex. Specific signals that are monitored include those mandated by the facility Operational Safety Requirement (OSR), such as building ventilation parameters, facility radiation monitors, and associated alarms.

Features of the system include real-time status of any instrument, simultaneous display of historical data and trends, automated archival of all operational safety signals, and operator control of alarm acknowledge and reset functions (Fig. 4.12). An operator may interrogate any sensor in the REDC complex by positioning a cursor on a computer screen to a pictorial representation of any facility control panel and then zoom in to view any instrument or annunciator of interest. Because the display on the computer is a graphic representation of existing control panels, familiarization with and learning of the new system are simple.

Another significant portion of this system is the Criticality Accident Alarm System (CAAS). The system monitors the status of up to five neutron monitors. Depending on the types or numbers of alarms generated, remote signals are also generated at Guard Headquarters, the Laboratory Emergency Response Center, and/or the Waste Operations Control Center. A particularly useful feature of the CAAS is the alarm test program. According to OSR specifications, all radiation monitor alarm permutations shall be tested monthly. A formerly 40-h manual operation was reduced to 25 min by an automated testing feature incorporated in the CAAS.

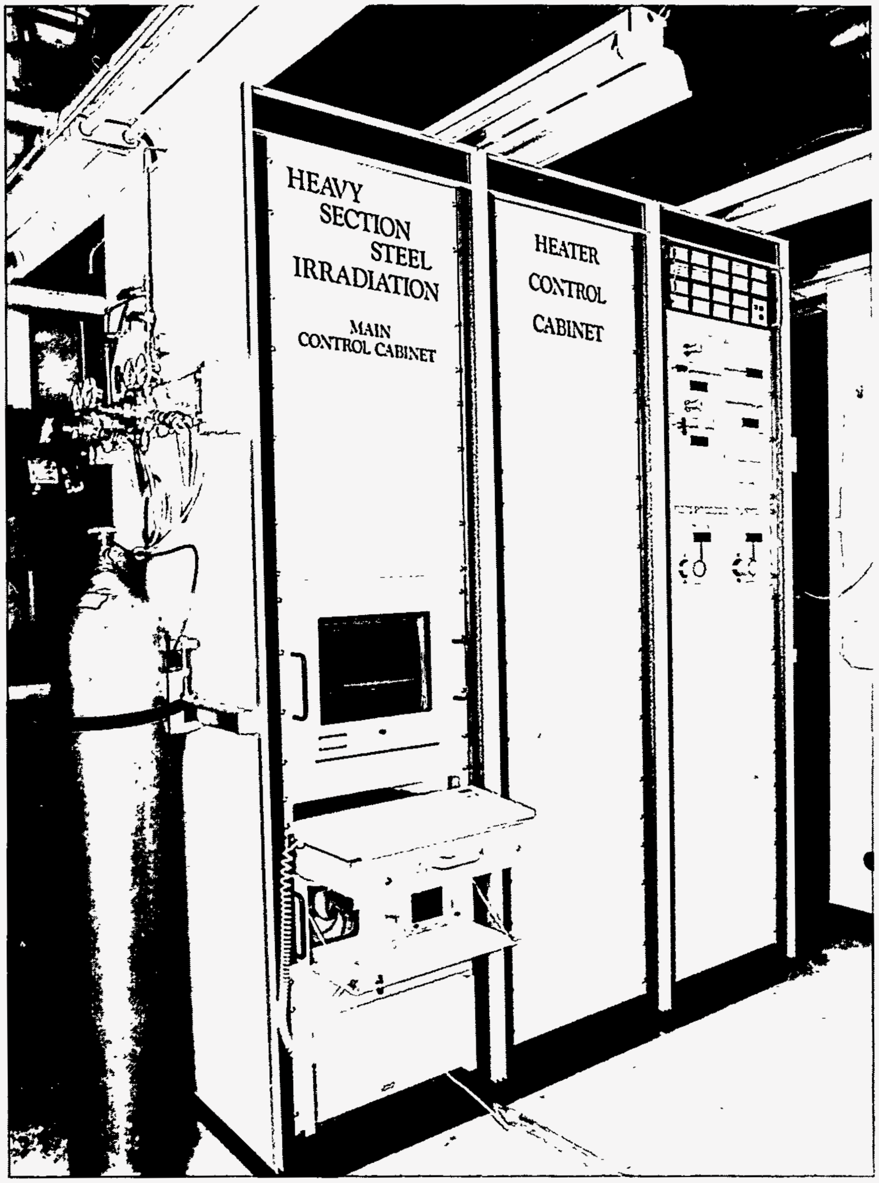

Fig. 4.11. The HSSI data acquisition and control system as installed at the Ford Reactor, University of Michigan.

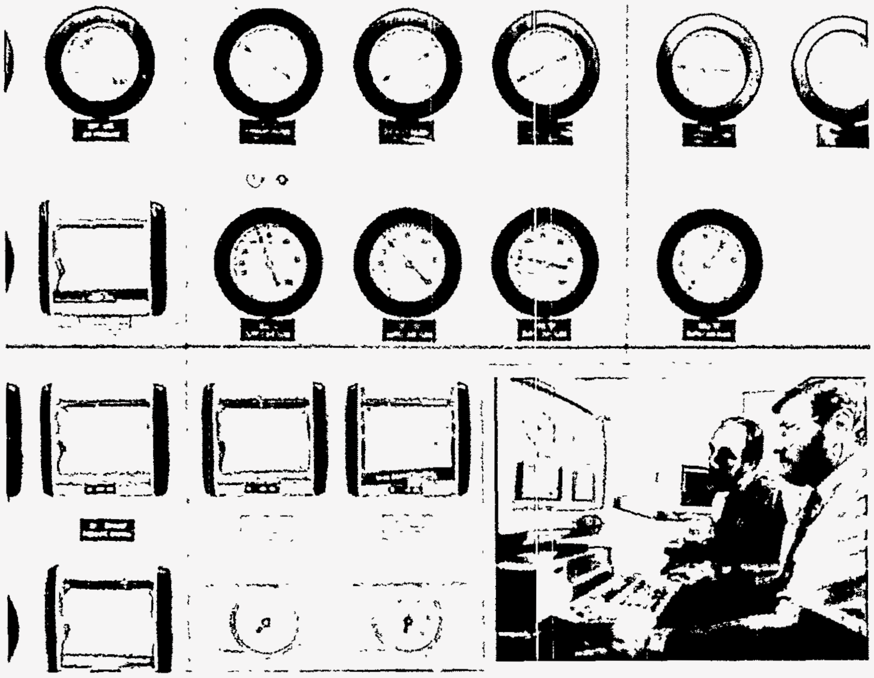

Fig. 4.12. From remote stations, the REDC data acquisition and monitoring system offers the operator a virtual view of the actual system.

5. TECHNICAL SUPPORT

5.1 OVERVIEW

The Technical Support Section (TSS), formerly the Technical Support Department (TSD), has the primary responsibility for the technical support and maintenance of instrumentation and controls (I&C) equipment at ORNL. During this reporting period, this obligation was fulfilled by a staff of ~100 instrument technicians organized into eight technical specialty groups. These groups were assisted by a staff of ~50 managers, clerical assistants, and technologists. The TSS staff possesses a breadth of expertise spanning a very large spectrum of disciplines such as electronics, pneumatics, computer science, analytical and process instrumentation, and metrology. This breadth of technical skill is augmented by the ready availability of the tremendous depth of professional specialization in the I&C Division's research and development (R&D) sections. Truly world-class R&D engineers and scientists are essentially always "on call" to assist TSS technical personnel. Because TSS resources are geographically located inside the Laboratory's periphery, TSS technicians can respond very rapidly to the needs of the ORNL research community.

Over the past 2 years, significant changes have occurred in the Section's organizational structure and cultural philosophy. These changes are embodied in a formal strategic plan, the composition of which was driven by the needs of the programs of ORNL in general and TSS's sponsors in particular. The new TSS "sponsor driven" structure and philosophy are being implemented in a Total Quality Management (TQM) environment with heavy emphasis on empowerment and teamwork. Working within this TQM-oriented environment has allowed TSS staff much greater flexibility and adaptability to rapid changes in technical and compliance requirements. As a result of this new management direction, TSS became the winner of a State of Tennessee Quality Interest Award for 1994.

As directed by the new strategic plan, TSS has, during this reporting period, pursued many new initiatives, including the following:

- To improve sponsor satisfaction, as measured by survey, such that the Section is rated as excellent by all users of our services. The development of an effective means of acquiring and analyzing sponsor satisfaction data was initiated and is still in progress.
- To identify important emerging technologies and to support those key technologies when they are implemented. An example of this effort is the new "one-stop-shop" Ethernet service. An ORNL staff member who needs Ethernet capability can now call one telephone number to have a PC connected to this state-of-the-art networking service. TSS then coordinates the activities of several ORNL divisions to accomplish all of the required tasks, making a great deal of laboratory organizational hierarchy transparent to the user.
- To assure, through synergistic teaming with facility managers, an excellent overall compliance record for ORNL. During this reporting period, TSS began the composition of a comprehensive implementation plan for compliance with DOE Order 4330.4B, "Conduct of Maintenance."
- To foster constant improvement in state-of-the-art maintenance techniques and the implementation of a program of uniform performance standards for all maintenance procedures in order to reduce instrument life cycle costs. A notable example of how a TQM environment encouraged this effort is the Remote Calibrator System, which was developed wholly by instrument technicians. This new maintenance technique is not only

much more efficient than the former, but also greatly reduces risks to personnel.

- To improve life on the job continuously through such measures as empowerment, safety training, and promotion of trust, ethics, and communication. In order to make all TSS personnel feel challenged and empowered to effect continuous improvement in the way work is performed, great emphasis has been placed on soliciting and responding to employee suggestions and comments through such programs as the Technical Improvement Notice, providing effective technical training to the staff through the Baseline Evaluation Testing and Training program, and providing updated tools, more space, and modern test equipment for each person to do the best possible job.

The Section has carried out its mission with the aid of a well-established infrastructure of facility resources. TSS maintains a complete instrument prototype and fabrication facility; systems for accomplishing National Institute of Standards and Technology (NIST) traceable calibrations on analytical, process, and maintenance and test equipment; and modern shops and equipment for the repair and upgrade of off-the-shelf and special one-of-a-kind instruments. To expand TSS capabilities even further, a new building (2033) for housing many existing and new TSS activities was planned and construction initiated during this reporting period. This state-of-the-art facility is slated for occupancy early in 1995.

5.2 REDC DATA ACQUISITION SYSTEM

A computerized data acquisition and control system was developed for the Radiochemical Engineering Development Center (REDC), Building 7930, and is being expanded to include Building 7920. An operator will be able to interrogate any sensor in the REDC complex by positioning a cursor on a computer screen to a pictorial representation of any facility control panel, like that shown in Fig. 5.1, and then "zooming" in on the instrument or annunciator of interest. He/she can see the instrument's status in real time, can ask for simultaneous display of historical data and trends, and can manipulate some of the controls associated with the instrument, all from the keyboard of a computer. Because the display on the computer is a graphic representation of existing control panels, familiarization with and learning of the new system is very simple.

5.3 REMOTE CALIBRATOR

With ALARA (as low as reasonably achievable) as a goal and empowerment as the creative process, TSS instrument technicians developed a means of remote calibration and testing of instruments used to monitor the level of highly contaminated liquids in buried storage tanks. Previously, calibrating and testing these tank level sensors involved some radiation exposure and imposed very uncomfortable working conditions on the technicians assigned to this onerous duty. As a result of supervisor encouragement, the technicians took upon themselves the task of devising alternative calibration and testing methods. Recent I&C emphasis on TQM was taken to heart by these technicians who, in a series of meetings among themselves, developed a method of remotely testing and calibrating these instruments by means of a lap-top computer, as seen in Fig 5.2. Implementation of this innovative maintenance technique eliminated the need to "dress out" and enter the areas in which the level sensors are installed.

Formerly, the simple task of calibrating one of these devices required roughly 24 work-hours because of the need for a health physicist and the complex logistics of "dress-out" and entry into the areas. The same task now requires less than 1 work-hour, resulting in tremendous cost savings as well. TSS management committed itself to the principles of TQM during this reporting period, and doing so has already borne notable fruit.

5.4 ELECTRONIC PC PARTS INVENTORY SYSTEM

An enormous inventory of parts and accessories is required for the support of ORNL's tremendous PC population. Since PCs are critical to many ORNL facilities and functions, procurement of spare parts must be rapid and accurate; the right part must be available at the right time. Because of the significant monetary

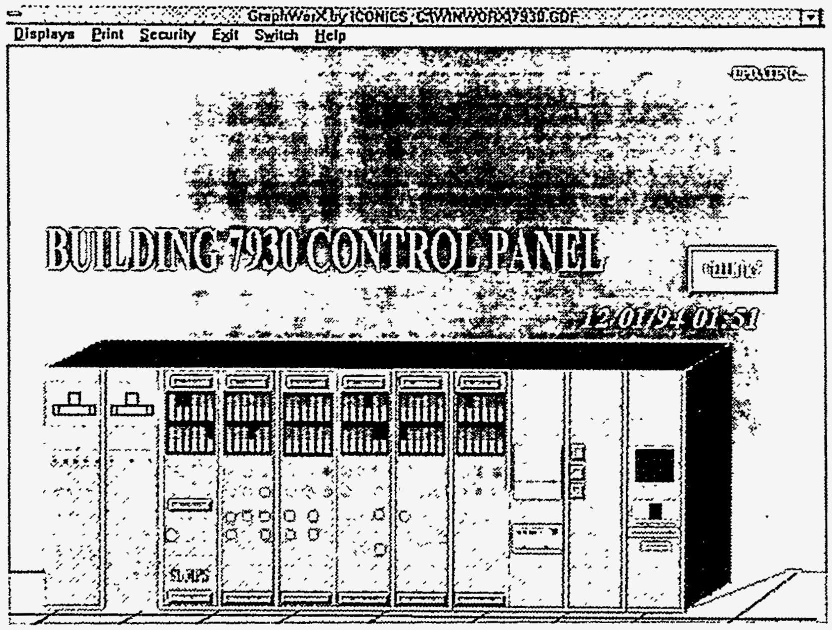

Fig. 5.1. Operators interrogate sensors in the REDC complex by positioning a cursor on a pictorial representation of any control panel.

value of this material, the ultimate disposition of all items must be positively tracked, as shown in Fig. 5.3. TSS has dedicated a full-time engineering technologist and has developed a tracking system for this critical effort.

5.5 "ONE-STOP" ETHERNET TEAM

Formerly, connection to an Ethernet network could require a prospective user to solicit the services and coordinate the activities of an electrician, a computer server technician, a PC maintenance technician, and perhaps a software specialist, all of whom are personnel from different ORNL divisions. This confusing and sometimes exasperating process is no longer necessary. A dedicated TSS team now handles all the coordination and ensures uniformity of Ethernet system connections throughout ORNL. As seen in Fig. 5.4, an ORNL staff member who needs Ethernet capability can now make one call to a single telephone number to have the proper cabling installed, the PC hardware and software upgraded and configured, and the host connection made to this state-of-the-art networking service.

5.6 AUTOMATIC DATA PROCESSING EQUIPMENT MAINTENANCE

TSS has 31 employees organized into two groups who provide in-house automatic data processing equipment (ADPE) maintenance.

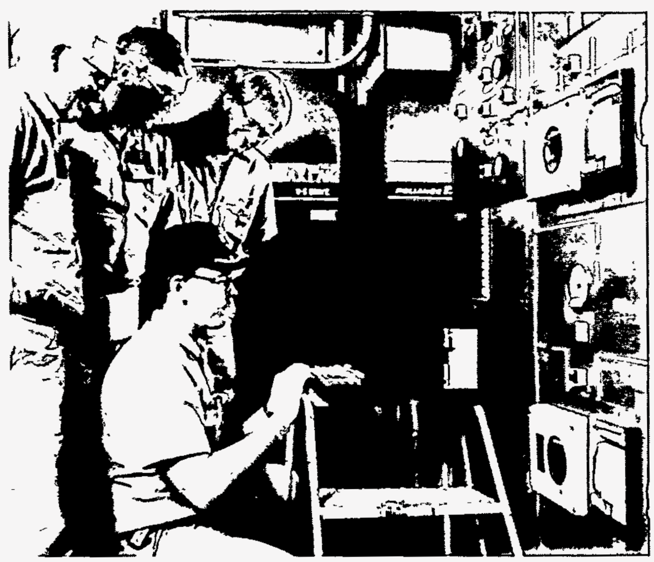

Fig. 5.2. Team interaction conceives an idea and nurtures it to maturity.

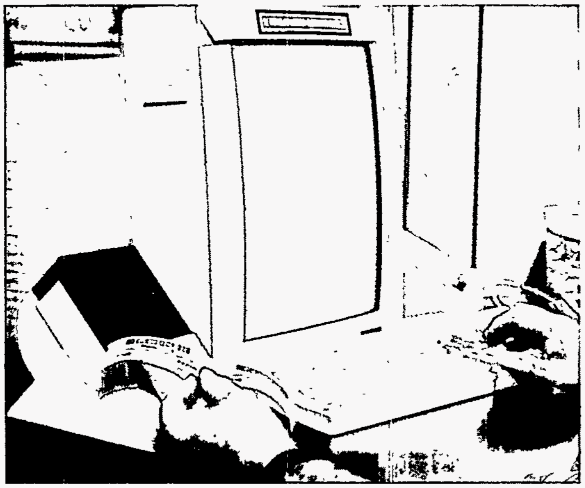

Fig. 5.3. An engineering technologist is devoted to managing the ORNL PC parts inventory.

Fig. 5.4. One call to TSS is now all that is required to begin using Ethernet at ORNL.

These groups operate in a matrix fashion with I&C R&D sections, from which they derive engineering support. These two groups provide ADPE support for 4448 computer systems (of 28 types), 5269 printers (from 77 manufacturers), 2128 terminal devices (from 90 manufacturers), and 9714 PCs (from 98 manufacturers). The total acquisition value of this equipment is approximately $50M.

The Network and Systems Support Group is responsible for the maintenance of minicomputers and peripheral devices, such as those seen in Fig. 5.5, as well as for maintenance of equipment interfaces, controlled devices, Ethernet networks, and workstations. The seven instrument technicians are assisted by two engineering technologists and a supervisor.

The Personal Computer Maintenance Group is responsible for maintenance of data communications devices such as modems, multiplexors, data concentrators, and remote job entry stations, as well as for terminals, PCs, and their peripheral devices. Most data communications equipment for the Computing and Telecommunications Services managed computer facilities is supported and maintained by this group. The 15 instrument technicians, five engineering technologists, and supervisor of this group accomplish acceptance testing, installation, repair, and modifications.

5.7 MOBILE ENVIRONMENTAL AIR MONITOR SUPPORT LAB

Because of the great distances separating ambient air monitoring stations at ORNL (one is as far away as Norris Dam), the calibration and maintenance required a significant amount of travel because the instruments at these stations had to be transported to a central maintenance shop. To increase the efficiency of this activity, an empowered TSS team configured a truck as the mobile laboratory, seen in Fig. 5.6. This mobile support facility is equipped with a generator, work benches, and climate control system. An air monitor maintenance team can now travel to the remote sites, saving an estimated $27,000 per year in travel costs.

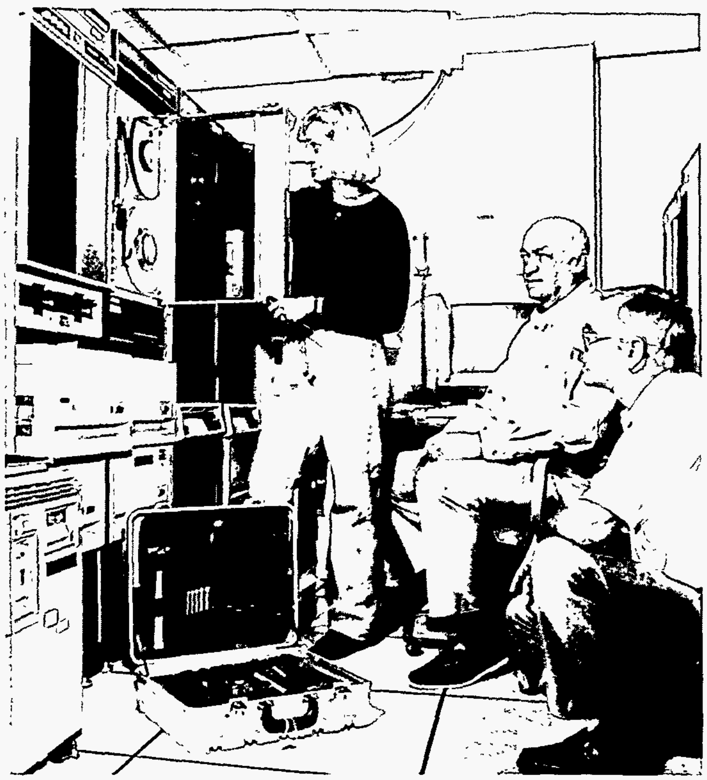

Fig. 5.5. Computers and peripheral devices are supported by TSS technical teams.

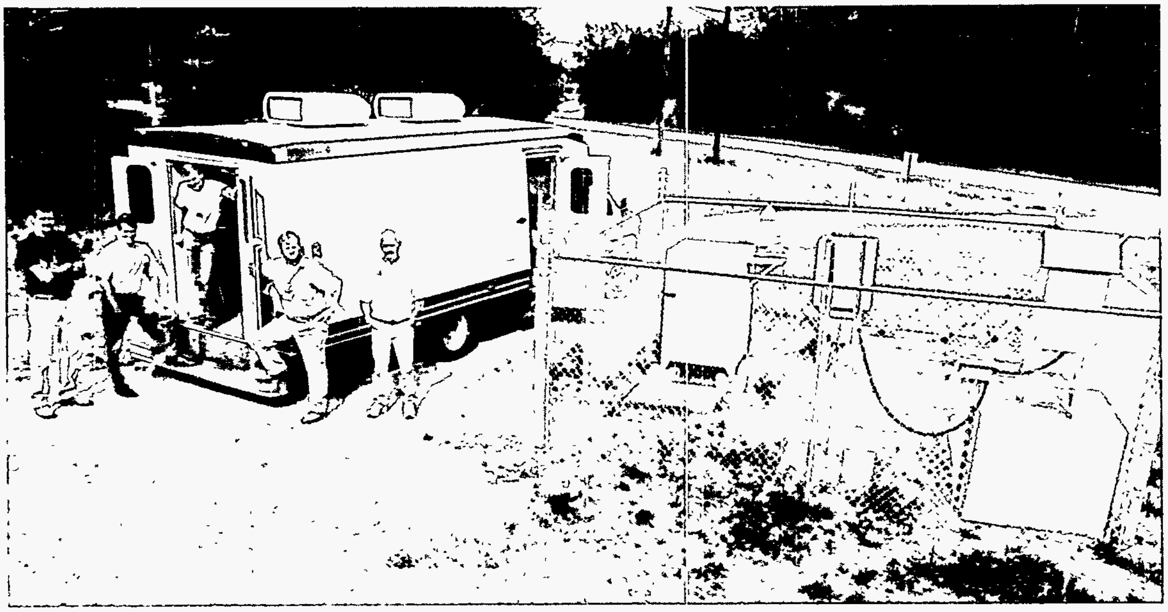

Fig. 5.6. The TSS Mobile Environmental Air Monitor Laboratory takes the maintenance shop right to the air monitor in the field.

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Valentine, T. E., and J. T. Mihalczo, "High Sensitivity of the Neutron Noise Analysis Method to Presence of Cadmium in HFIR Fuel Storage Racks," *Trans. Am. Nucl. Soc.* **65**, 252–53 (1992).

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Valentine, T. E., and J. T. Mihalczo, "Sensitivity of Calculations of ^{252}Cf-Source-Driven Noise Analysis Measurements to Cross Sections for Aqueous Fissile Solutions," in *Proceedings of the Topical Meeting of the American Nuclear Society, Nashville, Tennessee, Sept. 19–23, 1993,* CONF-930907-12, 1993.

Valentine, T. E., and J. T. Mihalczo, "Subcriticality of Advanced Neutron Source Reactor Fuel Elements During Fueling," presented at the Winter Meeting of the American Nuclear Society, Chicago, Nov. 15–20, 1992, *Trans. Am. Nucl. Soc.* **66**, 289–91 (1992).

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Wetherington, G. R., Jr., *User Interface Conceptual Design—Operator,* ORNL/Sub/85-SH517C&92/3/03, Oak Ridge Natl. Lab., May 24, 1993.

Wetherington, G. R., Jr., *AMFIP HGA Octave 3-5 Telemetry Prototype System, Factory Acceptance Test Results, Vol. I & II,* ORNL/Sub/85-SH517C&92/1/01, Oak Ridge Natl. Lab., Apr. 30, 1993.

Wetherington, G. R., Jr., *AMFIP HGA Octave 3-5 Telemetry Prototype System, Factory Acceptance Test Results, Vol. III,* ORNL/Sub/85-SH517C&92/1/01/V3, Oak Ridge Natl. Lab., Apr. 30, 1993.

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Wintenberg, A. L., T. C. Awes, C. L. Britton, Jr., L. G. Clonts, M. S. Emergy, M. N. Ericson, F. Plasil, M. L. Simpson, J. W. Walker, and G. R. Young, "Monolithic Circuits for Lead-Glass Calorimetry," presented at the Electronics for Future Colliders Conference, Montvale, New Jersey, May 11–13, 1994.

Wood, R. T., H. E. Knee, J. A. Mullens, J. K. Munro, Jr., B. K. Swail, and P. A. Tapp, "The Integrated Workstation System: A Common, Consistent Link Between Nuclear Plant Personnel and Plant Information and Computerized Resources," pp. 201–6 in *Proceedings of the Topical Meeting on Nuclear Plant Instrumentation, Control and Man-Machine Interface Technologies, Oak Ridge, Tennessee, Apr. 18–21, 1993,* American Nuclear Society, 1993.

Wood, R. T., J. A. Mullens, H. E. Knee, J. K. Munro, Jr., B. K. Swail, and P. A. Tapp, *Plant-Wide Integrated Environment Distributed on Workstations (Plant-Window) System Functional Requirements (Draft),* ORNL/M-3315, Oak Ridge Natl. Lab., February 1994.

Wysor, R. W., C. L. Carnal, and R. E. Igou, "Open Architecture in Control System Integration," pp. 17–21 in *Proceedings of the 22nd International Intelligent Motion Conference, Irvine, California, Oct. 24–29, 1993,* Intertec International, Inc., Ventura, Calif., 1993.

Young, K. G., M. L. Bauer, H. Cohn, Y. Efremenko, A. Gordeev, Y. Kamyshkov, D. Onopienko, S. Savin, K. Shmakov, E. Tarkovsky, R. Carey, M. Rothman, L. Sulak, W. Worstell, and H. Parr, "Effects of Radiation on Scintillating Fiber Performance," presented at the Institute of Electrical and Electronics Engineering Nuclear Science Symposium, Orlando, Florida, Oct. 27–31, 1992, *IEEE Trans. Nucl. Sci.* **40**, 461–65 (1993).

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7. PATENTS

Instrumentation and Controls Division Patent Applications Filed and Patents Issued July 1, 1992, to June 30, 1994

ESID number	Name	Description	Patent number and date
		Patents Issued	
522-X	R. L. Shepard T. V. Blalock M. J. Roberts L. C. Maxey	Optical Johnson Noise Thermometry	5,098,197 March 24, 1992
514-X	S. A. McElhaney M. L. Bauer M. M. Chiles	Scintillator Assembly for Alpha Radiation Detection and Method of Making the Assembly	5,149,971 September 22, 1992
770-X	C. L. Britton, Jr. A. L. Wintenberg	Method and Apparatus for Providing Pulse Pile-Up Correction in Charge Quantizing Radiation Detection	5,225,682 July 6, 1993
1205-X	R. L. Shepard T. V. Blalock M. J. Roberts	Dual-Mode Self-Validating Resistance/Johnson Noise Thermometer System	5,228,780 July 20, 1993
513-X	I. L. Larson M. M. Chiles V. C. Miller	Self-Filling and Self-Purging Apparatus for Detecting Spontaneous Radiation from Substances in Fluids	5,229,604 July 20, 1993
953-X	L. C. Maxey	Automated Interferometric Alignment System for Paraboloidal Mirrors	5,249,033 September 28, 1993
867-X	T. G. Kollie L. H. Thacker H. A. Fine	Instrument for Measurement of Vacuum in Sealed Thin Wall Packets	5,249,454 October 5, 1993
843-K	J. D. Muhs J. K. Jordan K. W. Tobin, Jr. J. V. LaForge	Apparatus for Weighing and Identifying Characteristics of a Moving Vehicle	5,260,520 November 9, 1993
924-X	J. T. Mihalczo	On-Line Tritium Production Monitor	5,264,702 November 23, 1993
945-X	J. T. Mihalczo	Two-Dimensional Position Sensitive Radiation Detectors	5,289,510 February 22, 1994
871-X	S. A. McElhaney M. M. Chiles	Unitary Scintillation Detector and System	5,317,158 May 31, 1994

Instrumentation and Controls Division Patent Applications Filed and Patents Issued July 1, 1992, to June 30, 1994 *(continued)*

ESID number	Name	Description	Patent number and date
		Patents Issued (continued)	
722-X	R. J. Fox	Velocity Damper for Electromagnetically Levitated Materials	5,319,670 June 7, 1994
870-X	T. J. McIntyre	Uniaxial Constant Velocity Microactuator	5,319,257 June 7, 1994
779-X	D. W. Bible R. J. Lauf	Variable Frequency Microwave Furnace System	5,321,222 June 14, 1994
948-X	T. A. Lewis D. C. Duckworth R. K. Marcus D. L. Donohue	Radio-Frequency Powered Glow Discharge Device and Method with High Voltage Interface	5,325,021 June 28, 1994
		Patent Applications Filed	
725-X	S. F. Smith K. N. Castleberry	Detector for Operational Conditions in an Axial Flow	
923-X	S. A. McElhaney M. L. Simpson	Thin-Film Fiber-Optic Refractometer (TFFOR)	
932-X	S. R. Maddox G. W. Turner R. I. Vandermolen W. L. Bryan	Automated Electronic Instrument Diagnostic, Testing and Alignment System with Records Generation	
938-X1	J. T. Mihalczo M. L. Simpson S. A. McElhaney	Dual Neutron Flux/Temperature Measurement Sensor	
985-X1	C. S. Daw J. A. Hawk	Fluidization Quality Analyzer and Automatic Control Loop for Fluidized Beds	
1015-X	D. W. Bible R. I. Crutcher C. W. Sohns S. R. Maddox	Handheld Microwave Instrument for Nondestructive Evaluation of Structural Characteristics	
1052-X	M. N. Ericson J. M. Rochelle	Logarithmetic Current Measurement Circuit with Improved Accuracy and Temperature Stability and Associated Method	
1064-X	L. H. Thacker	Gamma Radiation Field Intensity Meter	
1151-X	W. H. Andrews	High-Density Printed Circuit Board Connector Combining Through-Hole and Surface-Mount Contacts	
1154-X	J. O. Hylton C. J. Remenyik	Device for Accurately Measuring Mass Flow of Gases	

Instrumentation and Controls Division Patent Applications Filed and Patents Issued July 1, 1992, to June 30, 1994 *(continued)*

ESID number	Name	Description	Patent number and date
		Patent Applications Filed (continued)	
1159-X	T. J. McIntyre	System and Method for Generating a Displacement with Ultrahigh Accuracy Using a Fabry-Perot Inferiometer	
1224-X	J. T. Mihalczo M. J. Roberts	Position Sensitive Gamma-Ray Detection with Submillimeter Resolution in Two Dimensions	
1235-X	J. T. Mihalczo	Accelerator-Driven System and Method for the Transmutation of Radioactive Waste	
1260-X	B. S. Hoffheins R. J. Lauf	Thin Film Hydrogen Sensor	
1263-X	B. Damiano R. T. Wood T. Richard	Automated Method for the Systematic Interpretation of Resonance Peaks in spectral Data	
1307-X	S. F. Smith K. N. Castleberry	Method and Apparatus for Monitoring Machine Performance	
1369-X	D. N. Sitter, Jr.	Optical Wavelet Filter	
1378-X	D. W. Bible R. J. Lauf F. L. Paulauskas	Method for Curing Polymers	

8. SCIENTIFIC AND PROFESSIONAL ACTIVITIES, ACHIEVEMENTS, AND AWARDS

July 1, 1992—June 30, 1994

R. A. Abston
- Member, Kappa Mu Epsilon
- Member, Pi Tau Sigma
- Member, Tau Beta Pi

D. C. Agouridis
- Member, Institute of Electrical and Electronics Engineers
- Member, Eta Kappa Nu
- Member, Gamma Alpha
- Listing in *Who's Who in Technology*

D. B. Allen
- Member, Phi Kappa Phi
- Member, Institute of Electrical and Electronics Engineers
- Member, Eta Kappa Nu
- Member, Tau Beta Pi
- Engineer in Training License

G. T. Alley
- Member, Institute of Electrical and Electronics Engineers
- Member, Eta Kappa Nu
- Member, Tau Beta Pi
- Registered Professional Engineer
- Coorganizer, Short Course, "Introduction to Designing ASICs," presented at the 1993 Nuclear Science Symposium, San Francisco, November 1993
- Chairman, Continuing Education Committee, IEEE Nuclear and Plasma Sciences Society
- Chairman, Short Course Program, IEEE Nuclear Science Symposium

G. O. Allgood
- Senior Member, Institute of Electrical and Electronics Engineers
- Senior Member, Instrument Society of America
- Member, IEEE Control Systems Society
- Member, Operations Research Society of America
- Member, Eta Kappa Nu
- Member, Tau Beta Pi
- Listing in *The International Who's Who in Engineering*
- Registered Professional Engineer

W. H. Andrews, Jr.
- Member, American Defense Preparedness Association
- Member, Eta Kappa Nu

S. J. Ball
- Member, Society for Computer Simulation
- U. S. Representative/Chief Scientific Investigator for International Atomic Energy Agency Coordinated Research Program on Gas-Cooled Reactors

R. E. Battle
- Member, Institute of Electrical and Electronics Engineers
- Member, Tau Beta Pi
- Member, IEEE Nuclear Power Engineering Subcommittee
- Registered Professional Engineer

A. J. Beal
- Member, Instrument Society of America

R. R. Bentz
- MMES Significant Event Awards for Sonar Signal Analysis System, Large Cavitation Channel (June 1992), and Four-Plant Medical Computer System projects

J. E. Breeding
- Member, Institute of Electrical and Electronics Engineers
- MMES Significant Event Award for Development and Installation of the Large

Cavitation Channel Data Acquisition and Analysis System, Corecipient (June 1992)

M. E. Buchanan
Member, Eta Kappa Nu
Member, Phi Kappa Phi

M. A. Buckner
Member, Health Physics Society
Member, East Tennessee Chapter of the Health Physics Society
Lead Assessor, Department of Energy Laboratory Accreditation Program
Reviewer, *Health Physics Journal*
Member, Bubble Dosimeter Working Group (1992–1994)

C. L. Carnal
Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member, Phi Kappa Phi

K. N. Castleberry
Member, IEEE Nuclear and Plasma Sciences Society
Member, Health Physics Society
Member, MMES Inventors Forum
Member, K-25 Site Radiation Alarm System Configuration Control Board
Member, Microsoft Program Developers Group
Invited paper: "A Dedicated Compressor Monitoring System Employing Current Signature Analysis," K. N. Castleberry and S. F. Smith, *Proceedings of the 47th Meeting of the Mechanical Failures Prevention Group, Virginia Beach, Virginia, April 6–8, 1992*
Invited paper: "Machine Monitoring Via Current Signature Analysis Techniques," S. F. Smith, K. N. Castleberry, and C. H. Nowlin, WATTec '92, Knoxville, Tennessee, February 19–21, 1992
Invited paper: "GDP Compressor Failure Prevention with MCSA," K. N. Castleberry, MMES 2nd Annual Predictive Maintenance Forum, Knoxville, Tennessee, March 25, 1993

D. A. Clayton
Member, Digital Equipment Corporation Users' Society
Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society
Member, Eta Kappa Nu
MACES Technology Forum Coordinator, June 1992 to April 1993
I&C Division Technology Forum Coordinator, May 1993 to January 1994
President's Award for Continuous Improvements, May 1993

R. I. Crutcher
Registered Professional Engineer

B. Damiano
Member, American Nuclear Society
Member, American Society of Mechanical Engineers
Member, Tau Beta Pi
Member, Pi Tau Sigma
Registered Professional Engineer
Reviewer, *Nuclear Science and Engineering*
Patent Application: "Automated Method for the Systematic Interpretation of Resonance Peaks in Spectral Data" B. Damiano and R. T. Wood
Ph.D., The University of Tennessee, December 1992

W. B. Dress
Member, American Association for the Advancement of Science
Member, American Association for Artificial Intelligence
Member, American Physical Society
Member, Association for Computing Machinery
Member, FORTH Interest Group
Member, International Neural Network Society
Member, Institute of Electrical and Electronics Engineers
Member, Classification Society of North America
Adjunct Professor, The University of Tennessee, Knoxville
Reviewer, *Journal of Artificial Intelligence*
Reviewer, *Journal of FORTH Application and Research*
Member, ORNL Publication Award Review Committee
Proposal Reviewer for the National Science Foundation
Proposal Reviewer for U.S. Department of Energy Small Business Innovation Research

R. P. Effler

Member, ORNL X-ray Safety Standards Review Committee
Member, Instrument Society of America
Member, Advisory Committee for Pellissippi State Technical Community College (PSTCC)
Served on Panel for PSTCC "Forum for Teachers and Counselors" (February 1993)

K. R. Everman

Member, IEEE Control Systems Society
Member, IEEE Signal Processing Society
Member, IEEE Robotics and Automation Society
Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member, Tau Beta Pi

P. D. Ewing

Senior Member, Institute of Electrical and Electronics Engineers
Member, IEEE EMC TC-4 Committee
Member, Eta Kappa Nu
Member, Kappa Mu Epsilon
Member, Order of The Engineer
Registered Professional Engineer—Tennessee and Mississippi
NARTE-Certified EMC Engineer
Member, Tennessee State University College of Engineering Industrial Cluster
Member, ANSI C63 Committee

K. G. Falter

Member, Institute of Electrical and Electronics Engineers
Member, Sigma Pi Sigma

R. K. Ferrell

Member, Institute of Electrical and Electronics Engineers
Member, Society of Photo-Optical Instrumentation Engineers

E. B. Freer

Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society
Member, Phi Kappa Phi
Member, Tau Beta Pi
MMES Significant Event Award for Acoustic Measurment Facilities Improvement Program Beamformer Acquisition (1993)

D. N. Fry

Member, American Nuclear Society
Member, Tau Beta Pi
Member, Instrument Society of America
Chair of ANS Topical Meeting: "Nuclear Plant Instrumentation, Control and Man-Machine Interface Technologies," Oak Ridge, Tennessee, April 18–21, 1993
Session Developer and Chairman at the 3rd Annual ISA/EPRI Joint Controls and Automation Conference, Phoenix, Arizona, June 7–9, 1993
Session Developer and Chairman at the 4th Annual ISA/EPRI Joint Controls and Automation Conference, Orlando, Florida, June 1994
Technical paper reviewer for *Nuclear Science and Engineering* and *Nuclear Technology*

T. M. Gayle

Member, Air Pollution Control Association
Member, American Chemical Society
Registered Professional Engineer
Invited paper: "Field Experience with a Multisorbent Arrayed Sampler for In-Situ Collection of Vadose Zone Volatile Organic Compounds," R. A. Jenkins, C. E. Higgins, T. M. Gayle, G. W. Allin, and R. R. Smith, *Proceedings of the 3rd International Symposium on Field Screening Methods for Hazardous Wastes and Toxic Chemicals, Las Vegas, Nevada, February 24–26, 1993*

T. F. Gee

Member, Institute of Electrical and Electronics Engineers

A. C. Gehl

Secretary, Oak Ridge Chapter, Institute of Electrical and Electronics Engineers

J. E. Hardy

Member, Instrument Society of America
Registered Professional Engineer

R. A. Hess

Senior Member, IEEE Electromagnetic Compatibility Society
Member, Society of Automotive Engineers
Certified Electromagnetic Compatibility Engineer

J. S. Hicks

Member, Phi Kappa Phi
Member, Sigma Pi Sigma

M. S. Hileman
Member, Instrument Society of America
Member, Eta Kappa Nu
Member, Tau Beta Pi

M. A. Hunt
Member, Institute of Electrical and Electronics Engineers
Member, Society of Photo-Optical Instrumentation Engineers
Registered Professional Engineer
Member, Eta Kappa Nu
Member, Tau Beta Pi

M. T. Hurst
Member, Instrument Society of America
Invited paper: "Materials Testing, Remote Monitoring and Control," presented to the Southeast Intelligent User's Group, March 1993

J. O. Hylton
Member, Instrument Society of America

K. W. Hylton
Member, Phi Kappa Phi
Member, Instrument Society of America
Member, Society of Photo-Optical Instrumentation Engineers

J. M. Jansen
Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society
Member, IEEE Subcommittee on Real-Time Systems
Member, Kappa Mu Epsilon
Member, Phi Kappa Phi
Member, Sigma Pi Sigma

W. B. Jatko
Member, Golden Key Society
Member, Society of Motion Picture and Television Engineers
Member, Eta Kappa Nu
Member, Phi Eta Sigma
Member, Phi Kappa Phi
Member, Tau Beta Pi

T. P. Karnowski
Member, Institute of Electrical and Electronics Engineers
Member, Tau Beta Pi

S. W. Kercel
Senior Member, Institute of Electrical and Electronics Engineers
Registered Professional Engineer
Able Toastmaster
Certified Computer Professional
Guest Lecturer at the University of Michigan
Member, Eta Kappa Nu

K. Korsah
Member, Institute of Electrical and Electronics Engineers
Member, American Nuclear Society
Member, ANS/IEEE working group for revising IEEE-7-4.3.2/IEEE WG 6.4, "Standard Criteria for Digital Computers in Safety Systems of Nuclear Power Generating Stations"
Reviewer, *Nuclear Engineering and Design*

Roberto Lenarduzzi
Member, Institute of Electrical and Electronics Engineers

T. A. Lewis
Member, Institute of Electrical and Electronics Engineers
Member, Accelerators and Radiation Sources Review Committee
Member, Eta Kappa Pi
Member, Tau Beta Pi
Member, Phi Kappa Phi

R. D. Lovelace
MMES Significant Event Award for the Four-Plant Medical Computer System (1993)

W. W. Manges
Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society; Awards Chairman, Oak Ridge Section
Registered Professional Engineer (inactive)
Member, Industrial Computing Society
Member, Instrument Society of America
Vice President, Southern Appalachian Science and Engineering Fair

J. March-Leuba
Member, American Nuclear Society; Member, ANS Thermohydraulics Division Program Committee
Reviewer, *Nuclear Science and Engineering*
Reviewer, *Nuclear Technology*

L. C. Maxey
Member, Institute of Electrical and Electronics Engineers

Member, Instrument Society of America
Member, Society of Photo-Optical Instrumentation Engineers
Member, Eta Kappa Nu
Member, Tau Beta Pi
Member, Phi Kappa Phi
Member, ANSI IT-11 Interferometric Standards Committee
Member, Center for Optics Manufacturing Technical Advisory Committee

D. W. McDonald
Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member, American Association for the Advancement of Science
Member, Laboratory Member of AMTEX Operating Committee
Member, ORNL Operations Committee

J. A. McEvers
Member, Institute of Electrical and Electronics Engineers
Member, IEEE Automatic Controls Society
Member, IEEE Computer Society
Member, Society of Manufacturing Engineers

D. E. McMillan
Member, IEEE Computer Society

J. T. Mihalczo
Fellow, American Nuclear Society
Professor, Nuclear Engineering Department, The University of Tennessee, Knoxville
Member, Radiation Detection Review Panel, Office of Arms Control, DOE

G. N. Miller
Member, Institute of Electrical and Electronics Engineers
Fellow, Instrument Society of America; Director, Test Measurement Division; Associate Director, Aerospace Industries Division; Vice President, Local Section
Member of Executive Board for Instrument Society of America
Member, Eta Kappa Nu
Member, Omicron Delta Kappa
Member, Pi Mu Epsilon
Member, Tau Beta Pi
Member, Engineer's Council
Registered Professional Engineer
General Chairman for the 41st International Instrument Symposium, Denver

M. R. Moore
Member, Institute of Electrical and Electronics Engineers

J. A. Mullens
Member, ORNL Scientific and Technical Computing Technical Advisory Committee

J. K. Munro, Jr.
Member, American Mathematical Society
Member, American Physical Society
Member, IEEE Computer Society
Member, Society for Industrial and Applied Mathematics

M. S. Musrock
Member, Eta Kappa Nu

C. J. Remenyik
Member, Sigma Xi; July 1993: Member of delegation of faculty to Japan representing The University of Tennessee

F. R. Ruppel
Senior Member, Instrument Society of America
Member, American Institute of Chemical Engineers, Computing and Systems Technology Division

D. A. Schoenwald
Member, Institute of Electrical and Electrical Engineers
Member, Eta Kappa Nu
Member, Tau Beta Pi
Associate Editor, IEEE Control Systems Society Conference Evaluation Board
Adjunct Assistant Professor, University of Tennessee Electrical Engineering Department

A. A. Shourbaji
Senior Member, Instrument Society of America
Member, Nuclear Facility Review Committee

M. L. Simpson
Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member of Program Committee for the 1994 IEEE Nuclear Science Symposium

M. C. Smith
Member, Institute of Electrical and Electronics Engineers
Member, Tau Beta Pi; Florida Eta Student Chapter President, 1993–1994
Member, Society of Women Engineers

B. K. Swail
Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member, Tau Beta Pi
Secretary/Treasurer, IEEE Oak Ridge Section, June 1992 to May 1993
Vice Chair, IEEE Oak Ridge Section, June 1993 to May 1994
Chair, IEEE Oak Ridge Section, June 1994 to present

P. A. Tapp
Member, Institute of Electrical and Electronics Engineers
Member, IEEE Control Systems Society
Senior Member, Instrument Society of America
Member, Eta Kappa Nu
Member, Tau Beta Pi

R. M. Tate
Member, Institute of Electrical and Electronics Engineers
Member, Instrument Society of America
Member, Eta Kappa Nu
Member, Tau Beta Pi
Member, Phi Kappa Phi
Registered Professional Engineer
MMES Significant Event Award for Development of Acoustic Measurements Facilities Improvement Program, Phase I, System

R. W. Tucker
Senior Member, Instrument Society of America

B. R. Upadhyaya
Senior Member, Institute of Electrical and Electronics Engineers
Liaison Representative, IEEE Control Systems Society Technical Activities Board on Energy
Senior Member, Instrument Society of America
Member, American Nuclear Society; Member, Book Publishing Committee
Member, American Society for Nondestructive Testing
Member, American Society for Engineering Education
Member, Sigma Xi
Registered Professional Engineer
Reviewer, *Automatica, Journal of the International Federation of Automatic Control*
Reviewer, *IEEE Transactions on Automatic Control*
Reviewer, *IEEE Transactions on Systems, Man, and Cybernetics*
Reviewer, *IEEE Transactions on Neural Networks*
Reviewer, *Nuclear Science and Engineering*
Reviewer, *Nuclear Technology*

G. R. Wetherington
MMES Significant Event Award for first Acoustic Measurements Facilities Improvement Program, Phase II, beamformer installed at ORNL, Corecipient (1993)

B. R. Whitus
Member, Institute of Electrical and Electronics Engineers
Member, Instrument Society of America
Member, Eta Kappa Nu

A. L. Wintenberg
Member, Institute of Electrical and Electronics Engineers
Member, Tau Beta Pi
Adjunct Faculty, University of Tennessee, Knoxville (ECE Department)
Instructor, Short Course, "Designing Application-Specific Integrated Circuits," presented at 1993 Nuclear Science Symposium, November 1993

R. T. Wood
Member, Phi Eta Sigma
Member, Phi Kappa Phi
Member, Tau Beta Pi
Member, ASME Standard-Preparation Subgroup on Internals (Heat Exchangers)
Member, Instrument Society of America

W. E. Wright
Adjunct Faculty, Pellissippi State Technical Community College

K. M. Wysor
MMES Significant Event Award for Four-Plant Medical Computer System

R. W. Wysor
Member, Gamma Beta Phi
Member, Phi Eta Sigma
Member, Phi Kappa Phi
Member, Pi Tau Sigma
Member, Tau Beta Pi
Engineering in Training License

W. D. Zuehsow

Member, Institute of Electrical and Electronics Engineers

9. SEMINARS

Seminars Presented or Sponsored by Instrumentation and Controls Division Staff

"MACES Technology Forum," *Measurement and Controls Engineering Section,* August 13, 1992.

"MACES Technology Forum," *Measurement and Controls Engineering Section,* November 19, 1992.

"Wavelet Analyses for Engineering Application," *John K. Mattingly and Rafael B. Perez,* December 21, 1992.

"MACES Technology Forum," *Measurement and Controls Engineering Section,* January 4, 1993.

"I&C Division Technical Forum," May 20, 1993.

"Optics MODIL Cryo-stability Workshop," *L. C. Maxey, Host and Program Chair, Atlanta, GA,* June 28–29, 1993.

"Nuclear Weapons Identification System," *John Mihalczo, Vic Paré, et al.,* July 29, 1993.

"I&C Division Technical Forum," August 30, 1993.

"A Systematic Method for Interpreting Vibration Signatures," *B. Damiano, Reactor Systems Section,* August 30, 1993.

"Recent Neutron Cross Section Measurements on Radioactive and Very Small Stable Samples for Basic and Applied Science," *Dr. Paul E. Koehler, Los Alamos National Laboratory,* November 12, 1993.

"I&C Division Technical Forum," November 19, 1993.

"I&C Division Technical Forum," February 18, 1994.

"I&C Division Technical Forum," May 20, 1994.

"Dynamic Safety Systems (DSS) Meeting," *Ian Smith, AEA, United Kingdom; Dan Wilkinson, EPRI; and Don Miller, Ohio State University,* June 14, 1994.

"Neutrons 101: Lecture for Health Physics Certification Preparation," *M. A. Buckner, Oak Ridge, TN,* June 21, 1994.

10. SUPPLEMENTARY ACTIVITIES

SUPPLEMENTARY DIVISION ACTIVITIES

The Instrumentation and Controls Division maintains liaison with industry and the academic community through its Advisory Committee and consultants and through student and faculty research and training programs carried on within the Division.

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Mr. Bindi Chexal, Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94303

Dr. Robert M. Taylor, Capital Controls Company, 3000 Advance Lane, Colmar, PA 18915

Dr. Veljko Radeka, Brookhaven National Laboratory, Instrumentation Division, 535-B, Upton, NY 11973

Dr. Maurice M. Sevik, Carderock Division, Naval Surface Warfare Center, Code 1900, Bethesda, MD 20084-5000

Dr. D. F. Craig, Metals and Ceramics Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6132

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D. B. Koch
C. A. Mossman
L. C. Oakes
L. M. Smith
R. E. Uhrig
C. W. Ricker

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Lloyd Clonts
Amanda Duncan
Steve Hudson
Seth Hutchinson
Hamed Sari-Sarraf
Randal Smith
Harry Su Tanto
Barry Tolmas
Mike Womac
Min Xu

Coop Students

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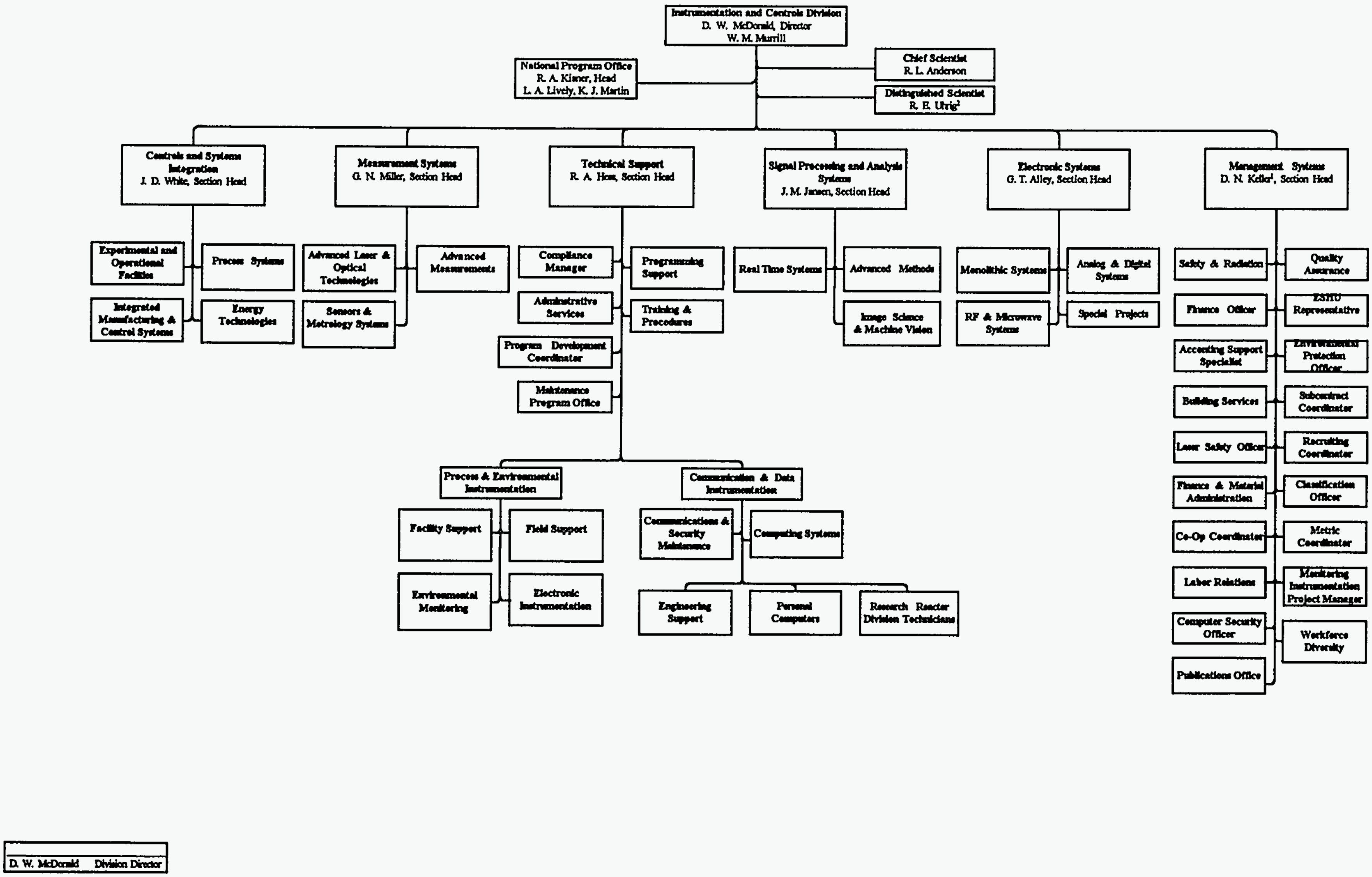
James M. Bembinster
Arturo Caines
Angela Christopher
James R. Jackson
B. S. Krongold
Timothy J. Lambert
Katrina L. Little
J. S. Powell
J. S. Price
Samual L. Rhodus
Donald N. Scruggs

11. TECHNOLOGY TRANSFER

A new type of materials processing furnace utilizing variable-frequency microwave technology has been licensed to Lambda Technologies in Raleigh, North Carolina. The furnace was developed by D. W. Bible of the I&C Division and R. J. Lauf of the Metals and Ceramics Division. In contrast to the limited energy efficiency and uniformity of conventional microwave furnaces, the variable-frequency microwave furnace offers high coupling efficiency and large-scale uniformity. These features make the variable-frequency microwave furnace ideal for advanced materials and plasma processing applications.

12. DIVISION ORGANIZATION CHARTS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R. L. Anderson
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Energy Technologies
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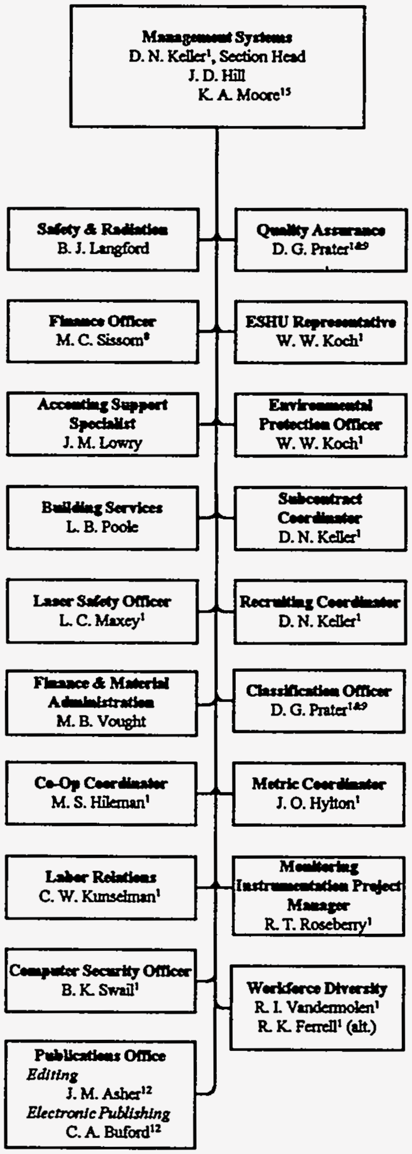

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