LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

129
1989
(4)
(JB)

DR# 0610-6

ornl

ORNL-6524

OAK RIDGE
NATIONAL
LABORATORY

MARTIN MARIETTA

Instrumentation and Controls Division
Progress Report for the Period
July 1, 1986 to June 30, 1988

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

MASTER

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A14; Microfiche A01

ORNL-6524
Distribution Category 506
Instruments, Engineering, and Equipment

INSTRUMENTATION AND CONTROLS DIVISION PROGRESS REPORT FOR THE PERIOD JULY 1, 1986 TO JUNE 30, 1988

ORNL--6524

DE89 007857

B. G. Eads, Director

LaWanda E. Klobe, Editor

1. Research Instruments . . . . *H. R. Brashear, Section Head*
2. Measurement and Controls Engineering . . . . *D. W. McDonald, Section Head*
3. Reactor Systems . . . . *D. N. Fry, Section Head*
4. Telerobotic Systems . . . . *W. R. Hamel, Section Head*
5. Maintenance Management . . . . *D. R. Miller, Department Head*

Date Published: December 1988

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

Reports previously issued in this series are as follows:

ORNL-714	Period Ending April 15, 1950
ORNL-796	Period Ending July 15, 1950
ORNL-924	Period Ending October 31, 1950
ORNL-1021	Period Ending January 20, 1951
ORNL-1056	Period Ending April 20, 1951
ORNL-1159	Period Ending July 20, 1951
ORNL-1160	Period Ending October 20, 1951
ORNL-1335	Period Ending January 20, 1952
ORNL-1336	Period Ending April 20, 1952
ORNL-1389	Period Ending July 20, 1952
ORNL-1436	Period Ending October 20, 1952
ORNL-1492	Period Ending January 20, 1953
ORNL-1694	Period Ending July 31, 1953
ORNL-1749	Period Ending January 31, 1954
ORNL-1768	Period Ending July 31, 1954
ORNL-1865	Period Ending January 31, 1955
ORNL-1997	Period Ending July 31, 1955
ORNL-2067	Period Ending January 31, 1956
ORNL-2234	Period Ending July 31, 1956
ORNL-2480	Period Ending July 1, 1957
ORNL-2647	Period Ending July 1, 1958
ORNL-2787	Period Ending July 1, 1959
ORNL-3001	Period Ending July 1, 1960
ORNL-3191	Period Ending July 1, 1961
ORNL-3378	Period Ending September 1, 1962
ORNL-3578	Period Ending September 1, 1963
ORNL-3782	Period Ending September 1, 1964
ORNL-3875	Period Ending September 1, 1965
ORNL-4091	Period Ending September 1, 1966
ORNL-4219	Period Ending September 1, 1967
ORNL-4335	Period Ending September 1, 1968
ORNL-4459	Period Ending September 1, 1969
ORNL-4620	Period Ending September 1, 1970
ORNL-4734	Period Ending September 1, 1971
ORNL-4822	Period Ending September 1, 1972
ORNL-4990	Period Ending September 1, 1973
ORNL-5170	Period Ending September 1, 1973
ORNL-5032	Period Ending September 1, 1974
ORNL-5195	Period Ending September 1, 1974
ORNL-5196	Period Ending September 1, 1976
ORNL-5197	Period Ending September 1, 1976
ORNL-5482	Period Ending September 1, 1978
ORNL-5483	Period Ending September 1, 1978
ORNL-5758	Period Ending September 1, 1980
ORNL-5759	Period Ending September 1, 1980
ORNL-5931/V1	Period Ending July 1, 1982
ORNL-5931/V2	Period Ending July 1, 1982
ORNL-6105/V1	Period Ending July 1, 1984
ORNL-6308	Period Ending July 1, 1986

NOTICE

Mention of brand names or of companies that supply products or services is made in this report for information purposes only and does not imply endorsement by the Oak Ridge National Laboratory, the U.S. Department of Energy, or any other organization.

CONTENTS

Section 3. REACTOR SYSTEMS

Section 4. TELEROBOTIC SYSTEMS

Section 5. MAINTENANCE MANAGEMENT DEPARTMENT

APPENDIX

DIVISION OVERVIEW

MISSION STATEMENT

The Instrumentation and Controls (I&C) Division of Oak Ridge National Laboratory (ORNL) performs basic and applied instrumentation and controls research, development and design engineering, specialized instrument design and fabrication, and maintenance services for instruments, electronics, and computers. The I&C Division is one of the largest R&D organizations of its type among government laboratories, and it exists as the result of an organizational strategy to integrate ORNL's instrumentation and controls-related disciplines into one dedicated functional organization to increase the Laboratory's expertise and capabilities in these rapidly expanding, innovative areas of technology.

The Division participates in the programs and projects of ORNL by applying its expertise and capabilities in concert with other divisions to perform basic research and mission-oriented technology development. Many of the Division's R&D tasks that are a part of a larger ORNL program are of sufficient scope that the I&C effort constitutes a separate program element with direct funding and management responsibility within the Division. The activities of I&C include performance of an R&D task in I&C facilities, the participation of from one to many I&C engineers and scientists in a multidisciplinary team working in a specific research area or development project, design and fabrication of a special instrument or instrumentation system, or a few hours of maintenance service. In its support and maintenance work, the role of the I&C Division is to provide a level of expertise appropriate to complete a job successfully at minimum overall cost and time schedule–a role which involves I&C in almost all ORNL activities.

The principal funding agencies for I&C programs currently are the U.S. Department of Energy, the Department of Defense, the National Aeronautics and Space Administration (NASA), the U.S. Nuclear Regulatory Commission, and the Federal Emergency Management Agency.

PROGRAMMATIC TRENDS

The past two years are best characterized as stable in terms of programmatic trends. Modest growth has occurred in some programs with offsetting decline in others.

The DOE Advanced Controls Program has experienced some growth. The establishment of the new advanced controls (ACTO) center for modeling and simulation is a key milestone for this program and a major new capability for the Division. The Division's role in the U.S. Navy Acoustic Instrumentation Research and Development Program has grown, particularly in the area of digital signal processing. Involvement in the Bureau of Engraving and Printing program for currency and stamp inspection has grown in the areas of image processing and machine vision R&D. Further growth in robotics funding and the existence of several new opportunities led to formation of the Telerobotics Systems Section. Major new programs for NASA and the U.S. Army are part of this new section's activities.

Successful completion of the U.S. Immigration and Naturalization Service remote sensing program has resulted in decreased funding as no appropriate role for ORNL exists in the continuing INS program. The Division's participation in the Oak Ridge Y-12 plant factory automation program grew to about 20 staff members and has remained at that level.

U.S. Nuclear Regulatory Commission programs have continued the decline of the previous biennial period and are now at about the $0.5M level. New programmatic sponsors include NASA (robotics, electromagnetic levitation, and high-temperature thermometry) and several DOE sponsors of subcriticality measurement R&D.

TECHNOLOGY TRENDS

The technological base of the Division has remained strong in the traditional areas, while progress has occurred in some areas and some new areas are opening up.

Traditional Division capability in electronics has strengthened and is now at the state of the art with a fully established capability in semi-custom and custom very large scale integrated (VLSI) chips. The staff has demonstrated the ability to apply VLSI technology to execute cost-effective and timely solutions to a variety of problems. They are collaborating with leaders in this field at several universities as well as at the Defense Advanced Research Projects Agency, the National Science Foundation, and other federal agencies. The remaining significant need in this area is to acquire a VLSI tester.

Progress in computing has seen the real-time computing base of I&C expand into the area of very high-speed digital signal processing. Engineering workstations that utilize the UNIX operating system have come into wide use and are an important tool, not only in VLSI chip development but also in advanced reactor controls, robotics, signal and image processing, and other miscellaneous applications. Recent significant computing achievements are the embedded processing of the NASA telerobotic arms and the receipt of an R&D-100 Award for development of the OPSNET parallel computer. The Encore parallel computer of the ACTO Center represents a powerful new resource for the Division.

New areas of R&D include the fields of image processing and machine vision as applied to solve problems for the Bureau of Engraving and Printing. Work in neural networks is in progress, although it is still at an embryonic stage of development at this time. Electromagnetic technology activities have progressed from a strictly support activity to a healthy mixture of R&D and support efforts. Although not major in terms of size, notable contributions were made in microwave technology and radiation-hardened electronics in support of the fuel reprocessing program at the Laboratory.

The whole area of reactor controls is being revitalized by the challenges of the Advanced Controls Program. Although the early work is entirely in software, there is strong indication that there will soon be opportunities to apply the new concepts in an actual nuclear power plant. The R&D activities for the Advanced Neutron Source–the planned replacement for the High Flux Isotope Reactor–are also providing new challenges and opportunities in reactor controls.

MAINTENANCE

During this reporting period the I&C Maintenance Management Department has been driven by a series of compliance issues that are a part of the DOE objective to be self-regulating. Some of these issues are (1) more emphasis on formalized procedures for maintenance of nuclear facilities, (2) increased emphasis and regulations governing the environment and waste management, (3) greater demands for documentation and auditability of maintenance, and (4) more stringent rules for configuration control of facilities and their maintenance. Upgrades to the MAJIC management information system have been made to allow cost-effective response to some of the new compliance issues. The Department staff has done an excellent job of responding to its many customers and to the new demands being placed on it; however, these have all combined to initiate major cultural changes which are still in progress.

STAFFING AND FACILITIES

In the past two years the previously anticipated staff growth of about 10% has not occurred, but subcontracting has been employed to absorb the peak staffing needs. Subcontracting itself peaked in FY 1988 and is expected to be down sharply in the coming fiscal year.

Space constraints continue to plague the I&C Division, and little opportunity exists to take on new initiatives that would require floor space. Current needs in this realm are for a Class 4 laser facility, a clean room of Class 10,000, a robotics development and staging area, more staging space for new computer systems, and a central space in which to consolidate some widely dispersed maintenance functions. Plans are still going forward to construct a new building to house a portion of the Division, and funding in FY 1990 now appears to be a real prospect. General Plant Project requests have been submitted for the laser laboratory and for a maintenance facility.

1. RESEARCH INSTRUMENTS

OVERVIEW

H. R. Brashear

The Research Instruments Section (RIS) researches, develops, designs, fabricates, tests, and implements instrument systems for measurement, nuclear research and applied health physics. Its activities support the projects of ORNL, U.S. Department of Energy (DOE) fusion and fission energy programs, and national defense programs. Section activities range from generic research on sensors and measurement techniques and development of state-of-the-art instruments not commercially available to application of complete one-of-a-kind data collection systems, custom data reduction software, and computer control of research and engineering experiments.

ACCOMPLISHMENT HIGHLIGHTS

- Completed research assessment of high-temperature superconductor (HTSC) devices (Sect. 1.2.1).

- Demonstrated precise measurement of neutron fluxes in weapons tests using a newly developed detector system that minimizes the effects of gamma rays (Sect. 1.2.2).

- Developed a networked real-time, pseudomultitasking personal computer monitoring system (Sects. 1.1.3 and 1.2.5).

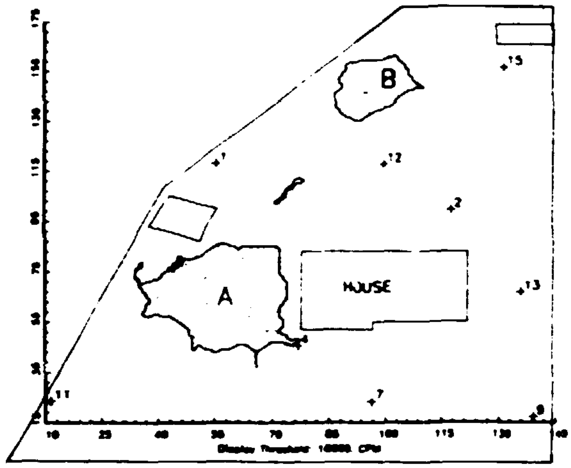
- Successfully transferred the technology of the ultrasonic ranging and data system (USRADS) shown in Fig. 1-1, thereby bringing a new commercial company to Oak Ridge (Sect. 1.2.5).

- Achieved unique and innovative developments in microwave communication of simultaneous video and high-speed bidirectional digital data in a highly reflective and harsh environment (see Fig. 1-2). Completed theoretical and hardware demonstration phases of the work (Sect. 1.2.5).

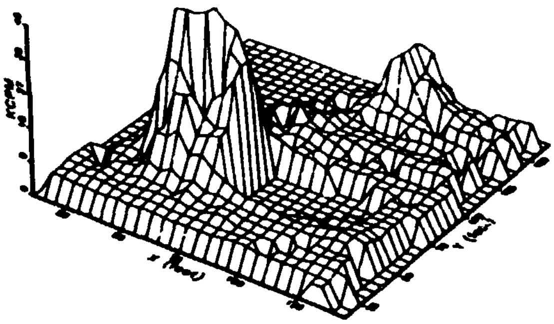
- Demonstrated for the U.S. Navy a portable automatic, autoranging, multifunction radiation survey instrument with internal gamma detector and multiple plug-in external probes (Sects. 1.2.2 and 1.2.3).

- Developed an automated calibrator (now in the fabrication phase) for the U.S. Navy's new multifunction radiation survey instrument (Sect. 1.2.5).

- Established Unix-based computer-assisted engineering (CAE) capability using engineering workstations (see Fig. 1-3) in all I&C Division engineering sections (Sect. 1.2.7).



(a) Threshold map



(b) histogram of contamination by location

Fig. 1-1. Example of USRADS survey.

ORNL Photo 6543-88

Fig. 1-2. 94-GHz data transmission system.

ORNL Photo 2889-87

Fig. 1-3. Computer-aided engineering and design capabilities.

- Established a Monolithic Systems Development Group, which is providing cost-effective electronic solutions by developing application-specific integrated circuits (ASIC) using very large scale integration (VLSI) technology (see organization section).

- Developed and fabricated seven working VLSI circuit chips during FY 1988 (see Fig. 1-4). Most chips worked the first time through fabrication (Sect. 1.2.3).

- Now building a complementary metal-oxide semiconductor (CMOS) analog function cell library by custom crafting functions as cells and placing them in a data base (Sect. 1.2.3).

- Now developing a conceptual microgravity materials research device with target specifications of temperatures to 2500°C and cooling rates of 1 M deg/s (Sects. 1.1.4 and 1.2.5).

- Initiated establishment of an ongoing electro-optics R&D capability (Sect. 1.2.4).

- Now developing techniques for simultaneous, noncontact strain and temperature measurements up to 2000°C (Sect. 1.2.4).

ORNL Photo 9297-87

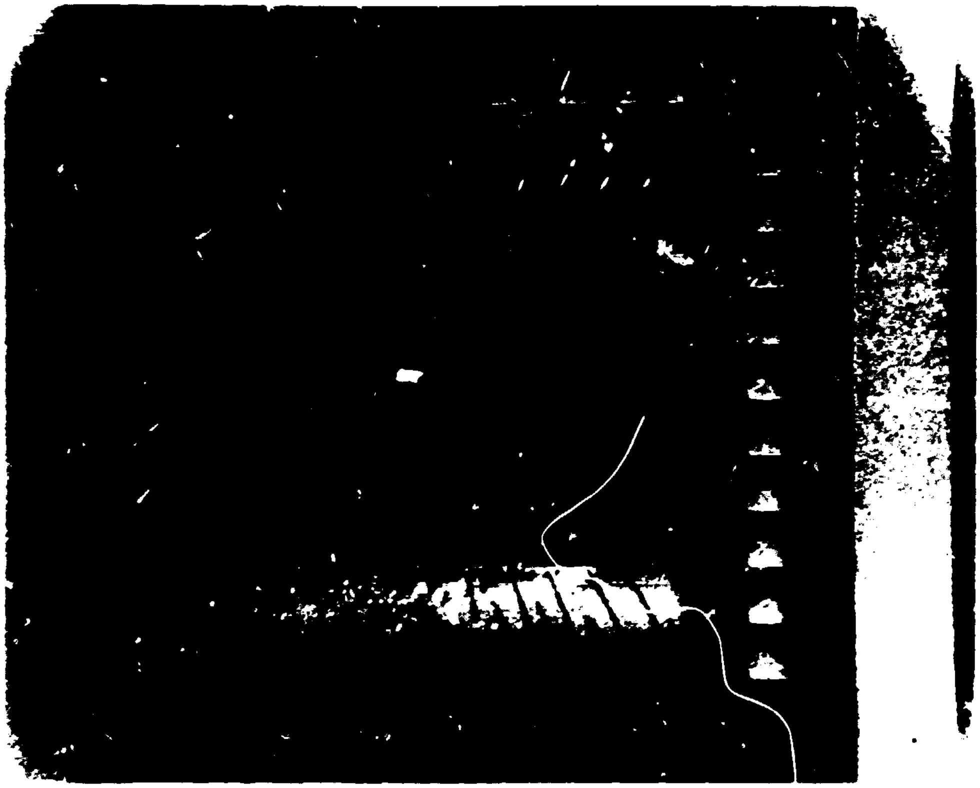


Fig. 1-4. Universal RADIAC chip (URC) designed by I&C and implemented using MOSIS.

FUTURE TRENDS

The trend toward de-emphasizing nuclear-based technology has begun to level off. The Advanced Controls Program and the proposed Advanced Neutron Source (ANS) research reactor continue to receive funding for detailed planning, and construction funds are expected in the near future. With the advent of the ANS, measurement requirements will be beyond the capabilities of present instrumentation. Because of this lack and because of new machines being planned by the particle physics community, RIS expects to increase ionizing detector research and development in the next 2 years. Generic detector systems research has already begun for the proposed Superconducting Supercollider (SSC).

Application-specific integrated circuits will continue to be in demand as new process technologies such as gallium arsenide (GaAs), bipolar, and radiation hardening become available through the metal oxide semiconductor implementation system (MOSIS). These developments are vital to the success of detector systems R&D as well as to fulfillment of the continuing demand for more computing power in instrumentation. The quest for information (rather than data) and "smart" sensors, "smart" power electronics, and "smart" control systems dictates the move to monolithic systems for economics and reliability. Sophisticated smart devices are complex, and their development requires the use of leading-edge computer-aided engineering (CAE) tools.

Pursuit of CAE software will continue, particularly in the very large scale integration (VLSI) and analog electronics areas, and will begin to embrace computer-aided software engineering (CASE). Mechanical engineering CAE tools will become as commonplace as design tools. Engineering workstation platforms that are appropriately networked will be moving from a central location into the engineers' offices, and many may be diskless and tied to a central server.

Funding from federal agencies other than DOE, principally the U.S. Department of Defense (DOD), has risen over the past 2 years and is expected to be constant for the next 2 years. Technology transfer within the section has received considerable attention, and that thrust is expected to continue. The trend toward establishing more of a research posture while maintaining a strong development character will continue.

ORGANIZATION

The RIS technical staff includes electrical and electronics engineers, physicists mechanical engineers, engineering technologists, drafting technologists, and designers. Functional teams are organized from line management groups, other I&C sections, and ORNL divisions to obtain the proper mix of expertise required for a particular project. Administratively, the section is organized into seven groups. A brief description of their assignments follows.

ACCELERATOR PHYSICS

G. K. Schulze

J. L. Blankenship	T. A. Lewis
N. W. Hill	M. J. Meigs
R. W. Ingle	J. H. Todd
R. C. Juras	

The Accelerator Physics Group functions as an integral part of the ORNL Physics and Engineering Physics and Mathematics (EP&M) divisions as well as collaborates with researchers at other national laboratories. The members participate in joint teams for research, engineering design, development, and implementation of systems and electronics for research experiments, particle detector development, and accelerator development and operation. These accelerators are the Oak Ridge Electron Linear Accelerator (ORELA), the Holifield Heavy Ion Research Facility (HHIRF), and the Oak Ridge Isochronous Cyclotron (ORIC).

One RIS staff member has developed a beam sweeper which has eliminated much of the afterpulse output from ORELA, and his Low-Energy Positron Facility (now in its installation phase) is opening up new avenues of research in positron microscopy. The electron gun development laboratory, which he established, has produced a new gun that significantly increases the joules-per-nanosecond output of the linear accelerator and has more than doubled gun life (>10,000 h operational).

Two RIS staff members are developing barium fluoride crystal array detectors for the Physics Division, and another one of a different design is being constructed for EP&M. In addition, the group has continued to provide innovative state-of-the-art electronics for measurement of the cross sections and parameters of nuclides.

This group performs digital electronic design as well as detector and analog design. An IBM PS-2 Model 80 has been interfaced with the ORELA VAX-11/785 via an Ethernet link. Another PS-2 has been configured as an experiment controller via hardware access between the instruments of the experiment and the microbus of the computer. In addition, a parallel transfer memory controller has been implemented.

Two staff members have done much work on upgrading the Tandem Accelerator at the HHIRF. Their teamwork has resulted in more experimental hours this past year and operation at a world-record-breaking voltage of 23.4 MV.

The numerous publications of this group are evidence of their involvement in basic research.

COMPUTER SYSTEMS DEVELOPMENT

E. Madden

M. L. Corbett	J. W. Reynolds
B. S. Hoffheins	R. T. Roseberry
S. R. Maddox	D. E. Smith
J. M. Madison	G. W. Turner
D. E. McMillan	R. I. Vandermolen
C. R. Mitchell	

The Computer Systems Development Group provides a wide variety of custom circuit and hardware design and software development, primarily involving mini/microcomputer-based research instrumentation systems. Group members employ computers and custom circuit design in instrumentation applications such as distributed computer data acquisition and control, CAMAC-based nuclear data acquisition and experiment control interfaces, real-time embedded controllers, time-of-flight (TOF) data acquisition, remote environmental sensor monitoring, distributed security management, remote distribution of laser videodisk data and pictures, remote sensor monitoring of personnel and vehicles, and nuclear fuel plate inspection.

Recent group activities have involved networks and distributed systems utilizing IBM PS-2 computers, OS-2 operating systems (beta site), knowledge-based expert systems development, computer/operator interactive screen design, interactive videodisk instruction program development, security systems design, badge reader systems development, PC-based remote sensor monitoring, nuclear radiation-tolerant digital circuit design, CAE digital circuit design, data base design and report generation, CAMAC module design, optical laser disk document storage, CASE, and software quality assurance procedures.

Software programming languages and operating systems used are C, FORTH, PolyFORTH II, FORTRAN, Assembly, Basic, LISP, OPS5, DOS, Microsoft Windows, and RSX11M.

ELECTRONIC SYSTEMS DEVELOPMENT

C. H. Nowlin
D. W. Bible J. A. Moore
R. L. Crutcher J. M. Rochelle*
W. Holmes S. F. Smith
E. J. Kennedy C. W. Sohns

The Electronic Systems Development Group provides custom electronic circuit and instrument development for ORNL research divisions at the X-10 and Y-12 sites, for various divisions at ORGDP, and for other government organizations under interagency agreements. During this reporting period, some of the members of the Electronic Systems Development Group transferred to help form the nucleus of the new Monolithic Systems Development Group. Although there is still considerable overlapping of group interests, the Electronic Systems Development Group emphasizes analog systems more than digital, and printed circuit board systems (using custom integrated circuits if appropriate) more than integrated circuit development. Significant group capabilities include modulation and demodulation techniques for carrier frequencies ranging from 60 Hz to 94 GHz, and rf transmission and reception from standard broadcast to microwave frequencies.

Teams and individual group members work with customers to solve measurement or communication problems or to develop specialized instrumentation not yet commercially available. Three particularly stimulating projects this last year were the reverse engineering project for the U.S. Navy, the reflective environment communications system project, and the motor current demodulation project. In addition, the group continues to specialize in designing radiation-hardened electronic equipment.

MECHANICAL SYSTEMS DEVELOPMENT

G. W. Allin
C. A. Hahs

The Mechanical Systems Development Group specializes in mechanical development and design in support of other groups and divisions within ORNL as well as outside agencies through work-for-others agreements. These designs cover a broad range of disciplines including sensor components, pressure vessels, vacuum systems, piping systems, positioners, and special instrument packaging. This group becomes a part of the design team when special fabrication techniques, material compatibility, or tooling design are required to successfully produce intricate parts. The group also has the responsibility for managing the AutoCAD graphics system used to produce computer-aided drawings within the I&C Division.

*The University of Tennessee, Knoxville.

MONOLITHIC SYSTEMS DEVELOPMENT

G. T. Alley

M. S. Blair
D. W. Bouldin*
C. L. Britton
M. S. Emery
M. N. Ericson
L. C. Maxey
D. F. Newport*
R. A. Todd
R. A. Wilkens

The Monolithic Systems Development Group was formed during the latter half of this reporting period. This group performs electronic circuit and systems R&D for divisions within ORNL and for other Energy Systems installations as well as for government agencies through interagency agreements. The group provides mission-specific solutions in a variety of applications including analog and digital circuit design, software development for embedded systems, image processing systems, data acquisition systems, and hybrid microcircuit design.

A unique facet of the group's activities involves design of VLSI circuits, both full-custom analog and digital and standard cell digital. Seven chips of varying complexity and functionality have been fabricated since the group came into being. Design and simulation of these circuits are carried out primarily with tools developed by universities and sponsored by the Defense Advanced Research Projects Agency (DARPA). A typical chip project has two or three members of the group assigned to a design team along with the customer with a leader chosen to coordinate the project. Members of the group usually alternate as leaders. This approach involves the sponsor more intimately in the project and nurtures leadership skills in the group. A strong base is developing quickly in VLSI technologies, particularly in complementary metal-oxide semiconductors (CMOSs).

The group provides support for both the U.S. Navy RADIAC and the process and long-range technical support (PLRTS) programs in the areas of program planning, systems integration, circuit design, and software development.

*The University of Tennessee, Knoxville.

PRODUCT DEVELOPMENT AND DRAFTING

B. P. Adkinson

K. F. Chapman	R. W. Jones
R. E. Cooper	E. C. Keith
M. D. Cutshaw	R. A. Maples
M. E. Greene	S. A. Shugart
R. L. Hassard	C. E. Stevenson
D. T. Hensley	T. R. Subich
S. M. Inman	J. C. Turner

The Product Development and Drafting Group provides a wide variety of support for the R&D programs of the I&C Division, particularly the Research Instruments Section, as well as for other ORNL research divisions, the Oak Ridge Y-12 Plant, and ORGDP. Group capabilities include design drafting, printed circuit board design, instrument packaging, materials specialties, and electronic photographic processing. The recent implementation of extensive CAD systems has increased productivity and further improved the overall services of this group.

Several types of CAD systems used by this group ensure high productivity and quality in keeping with the present-day drafting industry, and care is taken to keep the PC-based electronic drafting files compatible with changing technology. Host-based systems used are (1) computer-augmented design and manufacturing (CADAM) on IBM mainframes, (2) ANVIL on DEC minicomputers, and (3) DOGS on the DEC VAX [used for the I&C computer network (ICENET)]. Though used for unclassified documentation, CADAM has provisions for handling classified work. The DOGS graphics program is used primarily as an engineering sketch pad during project development. IBM PCs with drafting software packages are used in all applications, AutoCAD being the one most widely used. Most of this group's work is in the development phase of projects requiring electrical, electronic, and mechanical design. Both drafting and engineering staff use PC-based CAD systems, which increases flexibility in processing drawings. Optical disk storage has been implemented on the PC-based systems to provide archival storage. Figure 1-5 is an example of a new drawing format compatible with either CADAM or the PC-based system.

At Y-12, CAD Applicon facilitates design of printed circuit boards using DEC-11 host computers. The Y-12 system includes a PC, two color workstations, and extensive use of autoroute and autoplace algorithms in almost purely digital designs. Circuit board design at X-10, accomplished through PC ATs that permit file transfer between systems, is a mix of analog and digital designs, including multilayer boards and surface mount technology. Upgrades planned for CAD/CAM software and PC-based systems will enable engineers to enter schematic diagrams directly into the design system. Instrument packaging and printed circuit design are supported by a photoplotter and numerical-control drill tape outputs. Figure 1-6 illustrates a device designed and fabricated using a packaging design.

The materials specialties shop provides primarily engineering support, particularly for unusual fabrications. Its tasks comprise chemical milling, etching, special platings, photolithography masks for photocell fabrication, optical polishing, and new technique development for printed circuit board fabrication.

The photography laboratory processes primarily photoplotted filmwork produced by the Product Development and Drafting Group, a service required before printed circuit

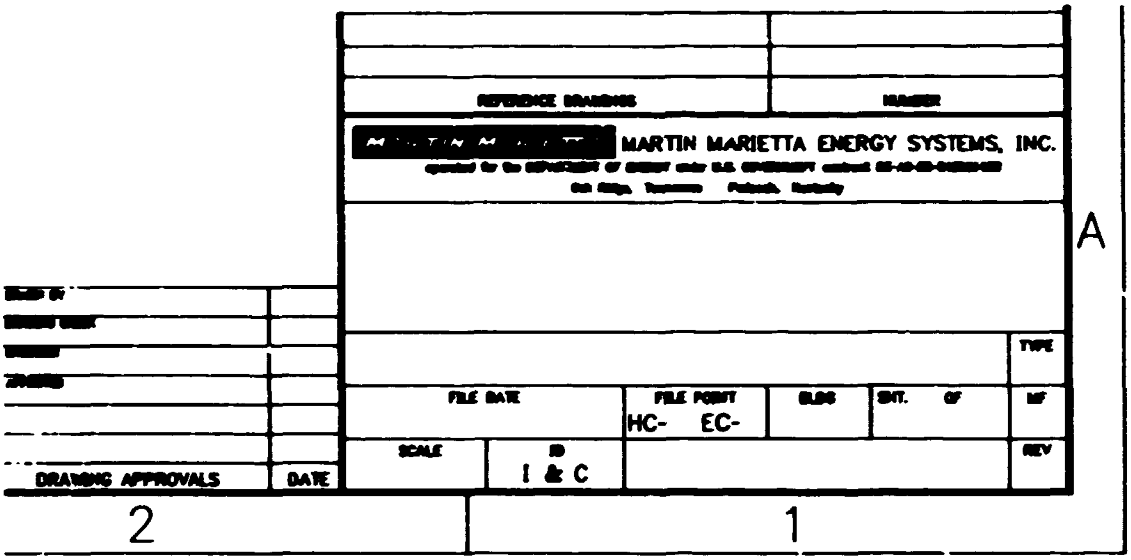


Fig. 1-5. Example of new I&C drawing identification format.

ORNL Photo 11048-88

Fig. 1-6. Device designed and fabricated using an I&C drawing packaging design.

boards and instrument packages can be fabricated. The photo lab also processes filmwork for metalphoto products and custom design work.

SENSOR SYSTEMS DEVELOPMENT

M. L. Bauer

T. R. Barclay	V. C. Miller
A. A. Carey	A. C. Morris, Jr.
M. M. Chiles	J. A. Ramsey
C. E. Fowler, Jr.	M. L. Simpson
L. D. Hunt	J. R. Tarrant
S. A. McElhaney	

The Sensor Systems Development Group performs sensor research, development, and fabrication in the fields of nuclear radiation and electro-optics as well as design and fabrication of systems for use in the fields of health physics, environmental monitoring, and facility radiation contamination control and containment. Radiation detector designs include traditional gas, scintillation. and solid state types that require special attributes not commercially available. Sensor development spans the field, from position-sensitive neutron and ionizing radiation detectors with sensitive areas up to 1.2 × 1.2 m, through special fission chambers, to gross gamma and beta detectors for environmental monitoring and health physics survey instruments. A new area of emphasis is in electro-optic instrumentation and systems including fiber optic sensors, particle detection, and optical computing. Two specific areas identified as needing research are laser-based particle characterization and high-temperature (above 1000°C) strain measurements in rotating equipment and in advanced materials research. Group members consult with customers, both inside ORNL and out, who require expert assistance with radiation shielding calculations and knowledge of radiation effects on materials and electronics. A current, and slightly unusual, project is under way for the Bureau of Engraving and Printing to develop a test plan for ev luating currency inspection systems.

1.1 PROGRAM SUMMARIES

1.1.1 MONITORING INSTRUMENTATION PROJECTS MANAGER

R. T. Roseberry

In May 1987, the new position of ORNL Monitoring Instrumentation Projects Manager was established. The manager reports administratively to the Director of the Instrumentation and Controls Division and programmatically to the ORNL Executive Director. This manager will oversee ORNL environmental, radiation, and safety monitoring systems to ensure the compatibility, necessity, and adequacy of proposed monitoring functions, and will coordinate the efforts of all contributing organizations involved in requirement definition, development, design, installation, modification, and maintenance.

1.1.2 ENVIRONMENTAL MONITORING SYSTEM UPGRADE

A. C. Morris

In cooperation with the ORNL Environmental and Health Protection Division and the Energy Systems Engineering organization, engineering support was provided for the environmental monitoring system upgrade line item project. Performance specifications were generated and bid evaluation, vendor design review, construction progress review, preshipment testing, system installation, and acceptance testing were conducted. An effort is under way during the system warranty period to maintain good configuration control without limiting necessary expansion.

1.1.3 IMMIGRATION AND NATURALIZATION SERVICE COMPUTER-ASSISTED DETECTION AND REPORT ENHANCEMENT DEVELOPMENT PROGRAM

D. E. McMillan

The objectives of the Immigration and Naturalization Service (INS) Computer-Assisted Detection and Report Enhancement (CADRE) Development Program were to demonstrate the use of a network of low-cost personal computers in a U.S. border-crossing remote sensor/monitor system and to identify the functional requirements for such a system through prototype development and field testing. (See Sect. 1.2.5.2 for details.)

As the national immigration problem intensified, increased attention to and funding for immigration matters by the U.S. Congress resulted in a large increase in the number of sensors deployed and Border Patrol agents assigned, and additional funds were made available to INS for computer systems.

CADRE performed well at Border Patrol sites of the size originally envisioned for the system. However, Border Patrol personnel at larger sites felt that their increasing needs could best be met by the use of larger minicomputers rather than by personal computers. The INS therefore made the decision to direct future site expenditures toward minicomputer-based systems. Because such systems can be based on readily available commercial hardware and software, there will be no need for ORNL to remain involved in this project. It is anticipated that the existing CADRE prototype systems will be used for several years, and that the knowledge acquired will be the basis for the future commercial procurements.

1.1.4 NASA ELECTROMAGNETIC LEVITATOR PROGRAM

C. A. Hahs

The National Aeronautics and Space Administration modular electromagnetic levitator (MEL) Program is currently involved with formulating conceptual design proposals for levitating, heating, and then splat-cooling ultrapure metal-ceramic samples (e.g., niobium and its alloys and mixtures) in a microgravity environment. Objectives of this experimentation, predominantly metallurgical in nature, are centered on investigating the properties of supercooled materials that are rapidly cooled. Basic metallurgical theories will be on trial. Conceptual design phases will cover (1) levitation methods, (2) high-efficiency induction heating, (3) 2500°C remote thermometry, (4) high vacuum with very low oxygen contamination, (5) ultrahigh-speed video recording, (6) sample transport in microgravity, and (7) very rapid splat-cooling methods (>10^6 °C/s). Approval of this conceptual design could lead to a project to produce a working, test-flying prototype MEL within 5 years (See Sect. 1.2.5.1).

1.1.5 U.S. NAVY/ORNL RADIAC DEVELOPMENT PROGRAM

W. L. Bryan

The U.S. Navy/ORNL RADIAC Development Program is a continuing project to produce new and improved radiation monitoring instruments in support of fleet, shipyard, and shore-based functions of the U.S. Navy. The Navy Sea Systems Command has assigned the I&C Division its lead research and development activities in this area. Major development needs for the U.S. Navy are (1) improved detectors for use in multifunction RADIAC (MFR) instruments; (2) MFR support chips using VLSI technologies for sound annunciator, probe-interfacing, and display-interfacing monitoring instrument functions; (3) MFR/ARCADES (automatic RADIAC calibration and diagnostic equipment system) software for automatic calibration, hardware diagnostics, and display simulations; (4) transfer of the RADIAC beta-counting system standardization program to ORNL from the Naval Surface Weapons Center-White Oak; (5) a systems study for a conceptual, improved Explosive Ordinance Depot dosimeter; (6) engineering for the ARCADES gamma calibrator design; and (7) construction of an ARCADES gamma calibrator for RADIAC testing.

1.2 RESEARCH AND DEVELOPMENT ACCOMPLISHMENTS

1.2.1 MEASUREMENT RESEARCH

1.2.1.1 Smart Drill—An Autonomous Subsurface Explorer

In cooperation with the ORNL Engineering Physics and Mathematics (EP&M) Division, a project is under way to develop a prototype smart drill bit capable of sensing subsurface environments (such as radioactive or chemical contaminants and obstructions) while drilling. The system will provide comprehensive real-time information to drill operators so that drilling into hazardous zones, contaminated areas, or obstructions can be avoided. Success in this phase of work will reduce the time and cost of drilling programs while minimizing contamination of equipment and surrounding earth surface. Research will address the key technical issues of in situ sensing, real-time data communication and interpretation, and decision making in hostile environments to produce drill bit-mounted sensors and up-hole communication modules capable of withstanding mechanical shock, abrasion, high temperature, and high pressure.

1.2.1.2 Opportunities in Superconducting Power Electronics

Research to identify opportunities in superconducting power electronics was performed as part of the DOE/Electric Power Research Institute (EPRI) Program assessment of energy productivity applications of high-temperature superconductors. Because the refrigeration problem is eased by the increase in the critical temperature of recently discovered superconducting ceramics, deployment of superconductors has become possible for applications such as motors, magnetic energy storage, magnetic field-enhanced materials production, intense magnetic field material separation, and power electronics. The DOE/EPRI assessment determined what applications promise either energy conservation or energy productivity improvements and identified possible areas where research should be sponsored. The I&C Division performed the research in power electronics, determined that a superconducting high-current, high-voltage switch could be developed, and recommended that research begin immediately. The contributions resulting from this research will be included in a book to be published by EPRI.

1.2.1.3 Development of Novel Thick-Film Circuit Materials

Research to develop novel thick-film circuit materials was begun in April 1988 using ORNL Exploratory Fund. The project will determine whether certain ceramic materials can be used as thick-film conductors for hybrid circuits. Several ceramic compounds from the perovskite group exhibit attributes that motivate this exploration. These compounds exhibit reasonably high conductivity, are inexpensive and readily available, and are inherently compatible with thick-film substrates and materials. Applications of these improved ceramics may overcome several of the industry's current problems such as solder leaching, silver migration, and the high cost of the precious metals currently used as thick-film conductors.

1.2.1.4 ^{238}U Capture Cross-Section Measurements

A system for precision measurements of the neutron capture cross section vs neutron energy of ^{238}U has been engineered using the pulsed-neutron source generated by ORELA. Measurement uncertainty for neutron energies between 1 and 100 keV was reduced from 10% to 4% by using new techniques. The neutron capture was detected by a 3000-l liquid scintillator. Resulting time-of-flight (TOF) and pulse-height information was digitized for processing by a multiparameter program on the ORELA data acquisition computer.

1.2.2 SENSOR SYSTEMS DEVELOPMENT

Sensor R&D spans many fields of science and has found numerous applications in each field. Traditionally, sensors have been categorized not just by what is sensed but also by experimental application. Hence, research detectors are identified with the research programs for which they are developed, whereas radiation and chemical sensors are classified by the importance of their function to the user.

1.2.2.1 Sensors: Research Detectors

Research detectors have applications in numerous fields, two of which are as neutron detectors with widely different purposes. One detector has been designed for basic neutron research in the low-energy, low-noise range while the second was used as a flux monitor in a weapons test, where it delivered a great amount of significant data in a short time before being consumed by the test it monitored. In two other cases, large multicrystal arrays of BaF_2 scintillator material and associated electronic signal-processing instrumentation are being used as spectrometers, outwardly similar but with different applications. One spectrometer is for the study of nuclear particle interaction with specific nuclei, while the other is for study of the ratio of neutron capture to fission of fissile isotopes. Other research detectors are used in position sensing and timing and in material analysis.

Low-Energy Neutron Research. Organic proton-recoil scintillation detectors have been used for decades for MeV neutrons, but their utility for keV neutrons has been limited by PMT noise.

In cooperation with the EP&M Division, an efficient NE-110 proton-recoil scintillation detector with reproducible, stable efficiency (see Fig. 1.2-1) has been designed for neutron research in the energy range from 2 to 50 keV. The detector consists of a 9 × 9-cm scintillator 1 cm thick, viewed on two opposite edges by 12.5-cm-diam RCA 8854 PMTs. Each PMT is biased below the single photoelectron level, and a coincidence is required between the outputs of the two PMTs to eliminate counts due to PMT noise. This new keV energy range neutron detector should find a broad range of applications in keV neutron research because it has greater efficiency for keV neutrons than other detectors now in use and, in contrast to other detectors, it has essentially zero background from eV neutrons. Hence, for time-of-flight neutron measurements, this new keV neutron detector permits the use of a higher repetition rate than can be tolerated by other detectors. This detector will be used to measure the neutron total cross section of ^{238}U with very good energy resolution in order to extend the energy region for individual resonance parameter analyses from 4 to ~30 keV. Earlier definitive measurements on ^{238}U at ORELA using a ^{6}Li glass scintillator could not be analyzed above 10 keV because of poor statistics and inadequate energy resolution.

Weapons Research. A system was developed to measure neutron flux in a weapons test while excluding the effects from gamma rays (see Fig. 1.2-2). In collaboration with Los Alamos National Laboratory (LANL), a unique design was produced for the weapons test conducted by Los Alamos on the eve of the 1987 Washington summit. The detector was a multiple-deposit fission chamber, compensated to nullify the effects of gamma rays while producing amperes of signal current under the intense bombardment of fission-produced

ORNL-DWG 88-17238

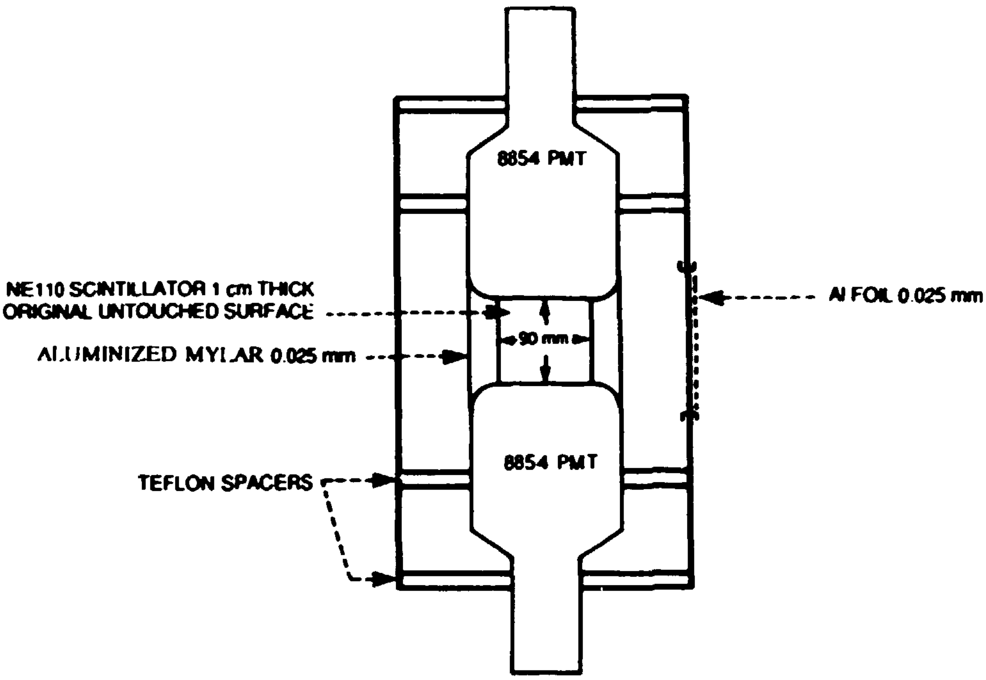


Fig. 1.2-1. NE-110 proton-recoil scintillation detector.

ORNL Photo 7577-88

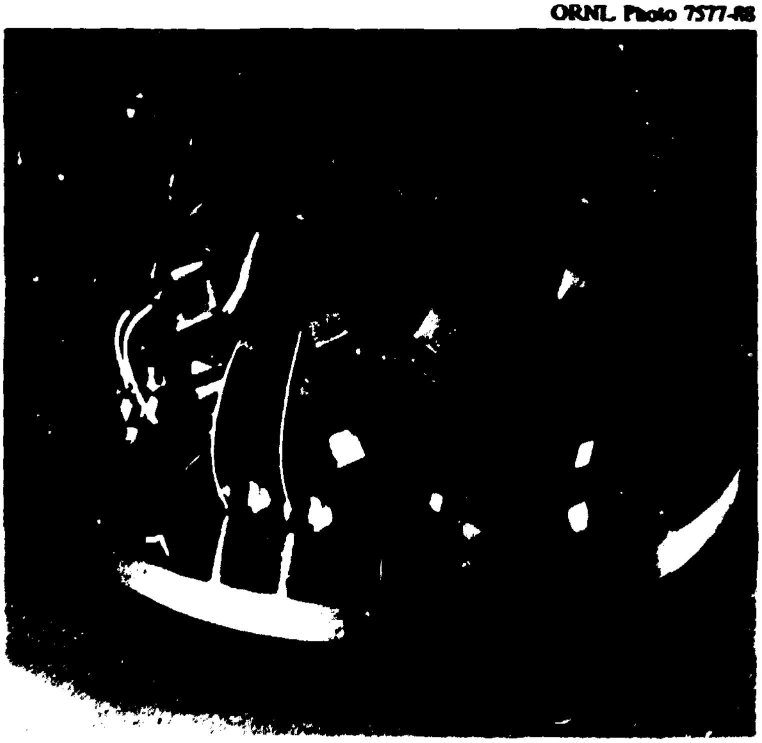


Fig. 1.2-2. Detector to measure neutron flux during weapons test.

neutrons. Successful test data hinged on this system. The large amount of data collected was analyzed in record time, with results that surpassed all expectations.

Physics Research Spectrometer. A large barium fluoride crystal array spectrometer is being constructed for the ORNL Physics Division. It will consist of four assemblies positioned around the beam line and pointed at the target. Each assembly will be an array of 19 large hexagonal crystals of barium fluoride and an associated fast quartz-window PMT and electronics. Barium fluoride has superior resolution and efficiency for gamma rays. The large, close-packed assemblies are necessary to contain the shower of secondary electrons and gamma rays that follow the pair production interaction of the gamma ray and an electron in the scintillator. These superior attributes will make this detector extremely useful for analysis of gamma ray emissions in basic nuclear physics studies involving elastic, inelastic, and deep inelastic interactions of particles with nuclei.

The crystals are in the form of a right equilateral hexagon having a width across the flats of 6.5 cm and a length of 20 cm (see Fig. 1.2-3a). The PMT chosen has a 5-cm (2-in.) diam photocathode, a rise time of 2 ns or less, and good gain stability. Only Hamamatsu could supply tubes to meet the gain stability specifications. A housing was designed and built to hold 19 BaF_2 crystals in a tightly packed array. The gross weight of the crystals is 82 kg, and eventually four of these assemblies will be used to position the crystals around a target chamber so that the axis of each 19-crystal pack will point to the target and be arrayed symmetrically around the exit beam line. A test set was developed to evaluate the timing performance of crystals and PMTs.

Fissile Isotope Research Spectrometer. A similar spectrometer is being constructed for the EP&M research staff at ORELA to precisely measure the ratio of neutron capture to fission of the fissile isotopes. The system consists of hexagonal cylinders of barium fluoride, each crystal 14 cm long × 8.67 cm face to face (see Fig. 1.2-3b). The first phase of this program will use 12 such crystals (see Fig. 1.2-4), and future plans call for 36 crystals.

ORNL Photo 0438-88 ORNL Photo 5754-87

(a) as used in the Physics Division spectrometer (b) as used in the EP&M Division spectrometer

Fig. 1.2-3. Barium fluoride crystals.

ORNL-DWG 86-7681

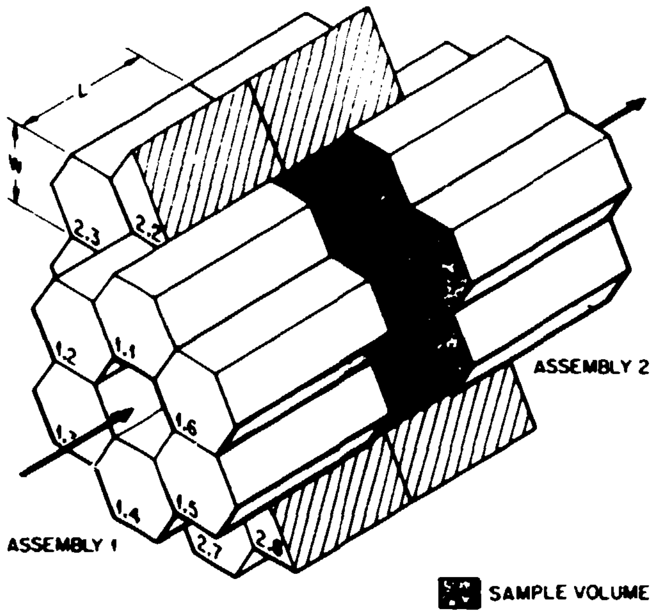


Fig. 1.2-4. Barium fluoride spectrometer for ORELA.

This project has involved evaluating the crystals for uv light transmission, pulse height resolution, fast light components, and alpha particle count rate from natural radium contamination. Measuring the characteristics of the PMTs used is also necessary. The tube chosen, an EMI 7.5-cm (3-in.) diam quartz face Type 9821Q, is selected for uv quantum efficiency, pulse height resolution, and count rate stability. The data acquisition system is a Multibus system with a Motorola 68000 CPU and an ORNL-designed input/output processor interfaced to a CAMAC crate.

Materials Research. Boron-10 is one of the most widely used materials for neutron detection because of its simple reactions with neutrons. A unique means of measuring the ratio on (n,γ) and $(n,\alpha\gamma)$ reactions in ^{10}B has been engineered. Regardless of the neutron absorption reaction, two particles with different energies are generated, one alpha and one ^{7}Li fragment. In addition, a 465-keV gamma ray is generated in the $(n,\alpha\gamma)$ reaction. The two particles from either reaction emerge 180° from each other. modified by the direction and energy of the neutron. For the measurement, two surface barrier detectors were mounted face to face in a vacuum. The surface of one was plated with a thin (~14 mg/cm^2) layer of ^{10}B (see Fig. 1.2-5). This configuration allowed summation of the energy of both particles. Time-of-flight techniques on the neutron beam from ORELA were used for neutron energy measurements. Measurement of the ratio of these two reactions from 1 meV to 10 keV is presently under way.

Heavy Ion/Light Ion Research. A gas-filled parallel plate avalanche counter (PPAC), designed for timing and horizontal position sensing, has been developed for use by the ORNL Physics Division in the Heavy Ion/Light Ion (HiLi) detector system. The counter consists of four independent quadrants of PPACs to enable four particles from one event to be sensed and measured simultaneously. Similar to the rest of the HiLi system, this

ORNL Photo 5770-87

Fig. 1.2-5. Surface barrier detectors used to measure the ratio on the (n,γ) and $(n,\alpha\gamma)$ reactions in ^{10}B.

detector design has a hole in the center of the four detectors to permit beam particles to pass without interacting with detector construction materials, which would create undesirable particles and gamma ray background. The anode signal is used as the event-definition signal, and ion chamber anode drift times provide vertical position information of the detected particle track.

1.2.2.2 Sensors: Radiation Detectors

Radiation detectors, like research detectors, are used in varied environments to sense equally varied species of nuclear radiation. Several of the sensors discussed below are neutron detectors for monitoring within the confines of nuclear reactor facilities. Still others have found application as health physics detectors for monitoring neutron, gamma, and alpha radiation and for assaying during isotope production.

Because of the importance of accurately measuring nuclear radiation in health physics applications, the quality of detectors used at ORNL is closely monitored. This process is discussed in a later section.

Reactor Applications. A RIS design team furnished 10 fission detectors of a snake-type (Q-2641B) design for the High Flux Isotope Reactor (HFIR) facility. Difficulties in inserting and removing the detectors had been traced to an interference problem between the outer diameter of the flexible bellows and the curvature of the guide tube within the reactor. The bellows was reduced in size by 3 mm (1/8 in.), and changes in detector fabrication were approved and incorporated.

An ultrahigh-sensitivity, high-temperature neutron detector was developed for in-vessel flux monitoring in a liquid metal reactor. The detector, which must operate at 550°C, was designed in cooperation with members of the I&C Reactor Systems Section (RSS). This design incorporates concentric tubes as a simplified means of achieving the required electrode spacing. The detector was fabricated using Inconel tubing plated with uranium oxide, Inconel bar stock, Inconel, and Inconel wire (see Fig. 1.2-6). During preliminary testing in an oven at 500°C, oxide coating from two tube assemblies failed. These tubes were electrically isolated from the system, and tests will be resumed when the final closure welds are made.

In cooperation with RSS staff members, a RIS team developed a means to increase efficiency and reduce data collection time during subcriticality measurements. Subcriticality experiments require high-efficiency radiation detectors sensitive to gamma radiation and neutrons (thermal and fast) over a wide energy range. The need for such detectors arises from various requirements including physical limitations, cost effectiveness, and simplicity. The objective of this project was to develop a single detector capable of replacing the separate detectors previously needed to detect different radiation emissions. The new design consists of two scintillators assembled on a single PMT. One scintillator is glass loaded with lithium enriched in ^{6}Li and has high efficiency for low-energy neutrons, while the second scintillator is a thick plastic having very good efficiency for higher energy neutrons. Scintillations occurring in either scintillator are detected by the PMT, which generates an electronic pulse for counting each event.

A smaller, more compact neutron detector with better temperature control and better stability developed for the Tower Shielding Facility consisted of a small Hornyak-type scintillation detector and preamplifier. The ZnS(Ag) phosphor/methylmethacrylate Hornyak button 6 mm diam (0.25 in.) × 1.5 mm thick (0.06 in.) was mounted on a (0.75-in.) 20-mm-diam, high-gain PMT. The scintillator, PMT, voltage divider, and new amplifier assembly were integrally packaged. To maintain constant temperature, a heater tape connected to a temperature controller was wrapped around the scintillator and the PMT. Six layers of "superinsulation" were placed around the heater tape to reduce loss of heat to the outside environment. The assembly was then installed inside a 32-mm (1.25-in.)-diam aluminum

ORNL Photo 4011-87

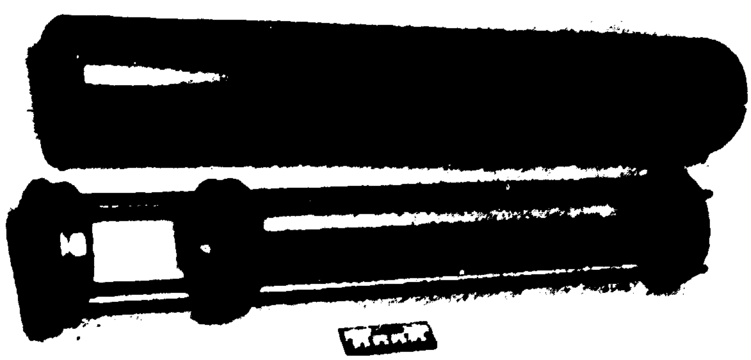


Fig. 1.2-6. Self-contained electrode assembly of the high-temperature, high-sensitivity fission counter.

housing. Laboratory tests indicate that the temperature of the unit is controlled within 1°C. The gain stability was very good when operated at a controlled temperature.

Health Physics Applications: Neutron Detectors. Several RIS staff members participated in a project to develop and design neutron-sensitive detectors for health physics survey applications. Several neutron-sensitive scintillators and combinations were investigated to help determine how best to develop a smaller, more compact wide-energy range neutron detector. One such detector comprises two scintillators optically coupled and mounted on a single PMT. The first scintillator is a ^{6}Li loaded glass, and the second is plastic (BC 400). The ^{6}Li glass scintillator emits light with a time constant of ~60 ns, whereas the plastic scintillator emits light with a time constant of ~3 ns. This difference in characteristic time constants between the two scintillators is conducive to electronic separation of the pulses occurring in each scintillator. Pulse shaping and timing electronics have been combined to count the thermal neutron activity as well as the activity of the higher energy neutrons present.

A boron-loaded plastic scintillator (BC 454) was investigated for possible use in developing an improved instrument for measuring neutron dose. This scintillator is sensitive to both thermal and fast neutrons and, therefore, was evaluated for use as an EOD neutron detector for the U.S. Navy RADIAC Development Program. Monte Carlo calculations were run for a 25-mm-diam x 25-mm-long scintillator and a 50-mm-diam x 50-mm-long scintillator, and the response curve showed reduced efficiency in the epithermal region. Additional calculations to determine the response of the scintillator when encased in a 50-mm layer of polyethylene indicated an increase in efficiency for the epithermal region when polyethylene was added, which more closely resembles the response curve published by the International Commission on Radiological Protection (ICRP). Both scintillator sizes were coupled to a PMT and subjected to radiation from a ^{252}Cf source. The results were compared to the Monte Carlo data. Additional work is planned at ORELA to quantify the response to neutrons.

Health Physics Applications: Gamma Detectors. A project to monitor radiation from uranium mill tailings at incremental depths in punched holes was carried out for the DOE Uranium Mill Tailings Remedial Action Program (UMTRAP). A small-diameter scintillation detector was required to be lowered into 3-cm-diam holes punched in soil at locations where the presence of uranium mill tailings was suspected. Bismuth germinate (BGO) scintillation crystal was chosen instead of NaI(Tl) to increase efficiency, even though BGO has a high-temperature coefficient of amplitude response that presents a gain stability problem when operated in a gamma spectrometer mode. A 2-cm-diam x 7.5-cm-long crystal mounted on a 2-cm (0.75-in.)-diam PMT plus voltage divider network was integrally packaged inside a 2.5-cm-diam metal housing. A coiled, flexible coaxial cable was used to connect the detector to the mounted preamplifier in order to take up the slack as the detector was lifted from the bottom of a hole.

Health Physics Applications: Alpha Detectors. The search for a ruggedized, inexpensive alpha radiation probe for field use led to investigation and synthesis of several plastic semiconductors for use as alpha detectors in the solid state ion chamber mode.

Several organic semiconductor materials were synthesized and characterized for their radioconductive response by applying electrodes to pressed pellets. Materials examined include polypyrrole, copper TCNQ, polydiacetylene DCH, and polyphenylene sulfide (PPS). Some detectors were fabricated by melting, and doping PPS with TCNQ was attempted. None of the materials tested resulted in suitable radiation detectors, although the PPS materials appeared most promising. Most of the responses noted were due to parasitic air ionization chamber effects.

Another approach to alpha detectors was undertaken in cooperation with the ORNL Isotope Research Materials Laboratory to develop an alpha radiation detector with high efficiency and more rugged than current ones. The aluminized Mylar entrance windows currently used in alpha detectors are sometimes damaged by the hostile environments encountered in field surveys. A more durable, light-tight entrance window would reduce maintenance costs. The current developmental model consists of a thin sandwich composed of scintillator, opaque material, and scuff-resistant coating deposited on a glass substrate. Several scintillators have been evaluated for high light output and high alpha-to-gamma ratio. After optimizing the thickness of the scintillator, the layer is made opaque to ambient light by coating the front side with a light-tight material such as aluminum. The opaque entrance window is protected with a scuff-resistant layer of silicon dioxide, and the finished wafer is attached to a PMT to complete the detector assembly.

RIS staff members working with members of the ORNL Solid State and Metals and Ceramics divisions formed a multidivisional task force to explore new concepts for a more rugged, light-tight sensor entrance window for use in new-generation alpha detectors. The objective of this project was to develop an entrance window more rugged than conventional types currently in use at ORNL. A new technique for micromachining a thin silicon window was implemented. The scintillator materials used are silver-activated zinc sulfide [ZnS(Ag)] and europium-doped calcium fluoride [CaF(Eu)]. Optically clear epoxy was used to couple the scintillator material to a glass light pipe and to give support to the thin portions of the silicon window (see Fig. 1.2-7). Tests indicate that overall efficiency is comparable to detectors with conventional Mylar windows.

Detectors for Assay Applications. A system was developed to assay gadolinium pellets for isotope production application in the ORNL Operations Division. Intended to interface with production glove boxes, the system was designed around a high-purity germanium detector (HPGe) and an IBM PC-based multichannel analyzer. Lack of funding has kept the system from being installed. Multichannel analyzer boards from two manufacturers were evaluated for this application.

A detection and electronic assembly was provided for assaying low-activity ^{252}Cf samples at the Thorium-Uranium Recycle Facility (TURF). A previous neutron detector assembly had been designed, fabricated, and installed in Cell C at TURF to assay ^{252}Cf samples ranging from 10 to 50 mg. Conceptual design is almost complete for a new system being designed with greater neutron sensitivity to assay smaller ^{252}Cf samples (in the range from 0.1 to 10 mg). Proportional chambers will replace the lower neutron-sensitive fission chambers used in previous designs.

Also, a new design for a ^{252}Cf source having improved reliability was produced for LANL. A previous ORNL-designed parallel-plate fission chamber to double-contain ^{252}Cf was redesigned to utilize a newer coaxial connector and to provide protection for the connector to prevent physical damage. Its construction is all-welded stainless steel with a ceramic-to-metal insulated connector. The second housing (outer can) was extended to

Photo No. YP-5109

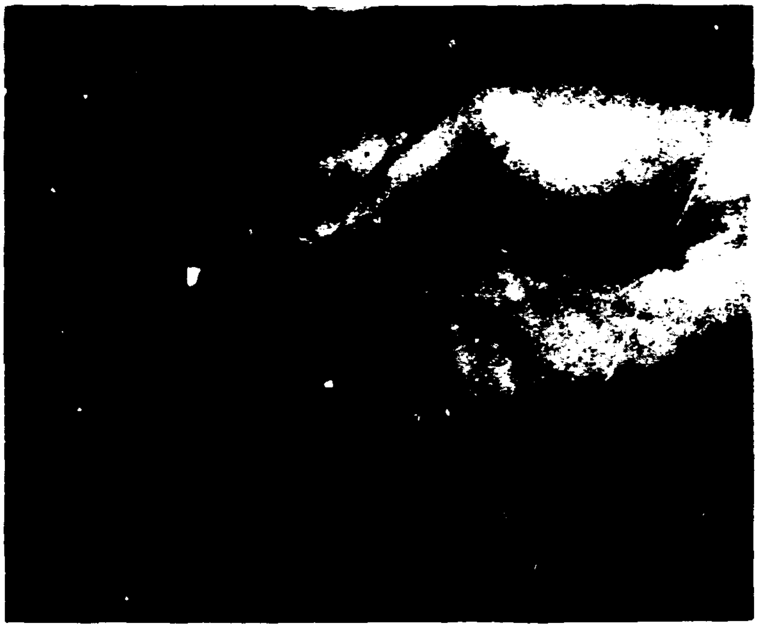


Fig. 1.2-7. Rugged light-tight sensor entrance window for use in new-generation alpha detectors.

protect the integrity of the coaxial connector in case it is dropped or smashed in an accident. Two chambers were fabricated and delivered to LANL, one containing ~1.26 ng of ^{252}Cf and the other containing ~5.12 ng.

Radiation Detector Quality Control. To ensure quality control on detectors purchased from commercial vendors, one RIS engineer is responsible for inspection of all commercially supplied radiation detectors received for ORNL stores stock. This includes inspection of incoming assemblies (or technical supervision of these inspections) and review and update of specifications for purchase of some detector items for stores stock. Recently a performance problem with a GM-type tube was discovered and reported to the commercial vendor, who was not aware of the problem. Test data were supplied for evaluation, and as a result the company corrected its manufacturing procedure and thereby improved its product.

1.2.2.3 Chemical Detector Development

While the chemical sensor field is extremely broad, RIS work has focused on two unique sensors for gas sensing and gas analysis.

At the request of the ORNL Chemical Technology Division, RIS engineers designed the mounting and electronics for a surface acoustic wave (SAW) crystal to be used for gas analysis at extremes of temperature and pressures. Two efforts were undertaken a year apart to design SAW crystal mounts and electronics assemblies for surface science work in CTD. These crystals resonate at about 120 MHz, with the exact frequency depending strongly on surface effects. Both assemblies were designed for high vacuums. The first was designed for cryogenic cooling, and the second was designed for high-temperature bake-out and ultrahigh vacuum. Several approaches have been tried for the oscillator electronics, with the latest unit using hybrid amplifiers manufactured by Micro Circuits.

RIS and ORNL Metals and Ceramics Division staff members developed a sensor capable of identifying gases. This work, which began in the fall of 1985, was funded by Cabot Corporation for ~18 months. The project team successfully developed a thick-film multisensor array on an alumina substrate for selective detection of various combustible gases. In 1986 and 1987 the chip's conductor design was optimized and the sensor ink improved for better performance.

1.2.3 ELECTRONICS DEVELOPMENT

Areas of electronics development during this reporting period include monolithic circuit design, control circuit design, power circuit design, radiation-hardened electronic design, and circuit designs of a more general nature.

1.2.3.1 Very Large Scale Integrated Circuits

Several custom and semi-custom VLSI circuits have been developed during this reporting period. These chips represent a wide range of design styles including full custom digital, full custom analog, and standard cell digital.

URC. In an effort to lower the overall life-cycle costs of the U.S. Navy RADIAC instrument and to conserve printed circuit board space, the universal RADIAC chip (URC) was developed to incorporate a number of functions and resources into a single chip. This chip includes three timer/counters optimized for use in pulse-counting instruments, an integral time base, and a MOTEL (MOTorola IntEL) bus interface that makes it usable with both Motorola and Intel microprocessor families. The chip also contains a small amount of RAM, which alleviates the need for an additional RAM chip in the system.

PARSAC. A programmable advanced RADIAC sound annuciator chip (PARSAC) was developed to provide audible indications of count rate and scalar information for the RADIAC system. The chip features a MOTEL interface; chirp, range, and alarm mode; volume control; and two output audio ports. A wire-wrapped prototype of this circuit was built during the design phase to evaluate the impact of the various sound effects. When the sound variations were satisfactory, the VLSI chip design was completed using 2-μm CMOS standard cells. Fabricated parts have been received and are fully functional. This chip replaces ~50 medium-scale integrated circuits.

SORTPIPE II. SORTPIPE II is a full custom VLSI chip that performs numeric array sorting in seemingly zero time. Implementing the so-called "sinking sort" algorithm, it performs "greatest-in, first-out" sorting in which current input values are compared with previous inputs and smaller inputs sink through the sorting array so that values are stored in descending order. This chip was fabricated using 3-μm CMOS technology. Chips have been received from the fabricator and are fully functional.

Analog Building Block Chip. A number of chips to be designed in the future will require a mixture of analog and digital circuitry. In preparation for these chips, an analog building block chip was designed and fabricated using the same CMOS process as that used for digital circuitry. Included on this chip was an operational amplifier, a voltage comparator, an analog switch, a differential transistor pair, and a substrate bipolar transistor.

Measurements of these building blocks show levels of performance that are quite acceptable, especially when one considers that they were fabricated using a process optimized for digital circuits, not analog. These building blocks form the core of a library of analog modules currently being developed.

PIC. The probe interface chip (PIC) is a CMOS standard cell chip containing the circuitry for power supply interface and pulse information storage for the RADIAC system. PIC generates timing waveforms needed for radiation detector control and data acquisition. It contains a frequency divider, a scaler, and associated control circuitry. A future version will have both analog and digital circuitry. The electronics being developed for the future version will provide high-voltage bias control for the detector and will process pulse information from the detector. To achieve a topology that can be integrated into a monolithic circuit, the power supply employs pulse frequency modulation (PFM). As with URC and PARSAC, (See Fig. 1.2-8), PIC was developed to lower overall RADIAC instrument costs, increase functionality, and reduce parts inventory.

1.2.3.2 Circuit Development

Circuit development in the Research Instruments Section has usually involved collaboration with federal agencies as well as with other ORNL divisions. It embraces a variety of applications including electrometer, data acquisition, and high-voltage circuits.

Multimode Beta-Ionization Cell. A RIS engineer, along with members of the Analytical Chemistry Division, has devised circuitry to operate a multimode beta-ionization cell in a time-multiplexed pulse mode for gas chromatographic applications. In conventional use, detector response can be changed by altering the pressure of a reagent gas inside. Work has been performed showing that various pulsing schemes (i.e., differing duty cycles and voltages) can replicate responses produced by pressure variations. By using a time-multiplexing scheme, multiple chromatograms can be run simultaneously, thus reducing overall analysis time and allowing separation of analysis peaks. Laboratory results indicate that pulsing can indeed simulate operation of the detector at various pressures because of similarities in detection mechanisms.

TORDAC. Considerable expertise is being developed in custom data acquisition systems. The torpedo data acquisition system (TORDAC), developed by members of RIS, MACES, and the ORNL Applied Technology Division (formerly the Enrichment Technology Applications Center), addressed some unique challenges in speed and package size. As part of the process of developing technology for torpedo applications, naval test vehicles are instrumented with sensors (and signal processors) whose outputs are recorded during in-water exercises. The high-speed, multichannel, onboard TORDAC will monitor and record transducer signals during routine and developmental in-water exercises. A block diagram of the wet system is shown in Fig. 1.2-9. A dedicated, cylindrical torpedo section 1.1 m (45 in.) long with an 0.47-m (18.5-in.) ID, supplied by the Naval Underwater Systems Center (NUSC), will house the TORDAC system. The design goal is a total cargo weight of <110 kg.

Data Acquisition Program. As part of the David Taylor Large-Scale Vehicle Project, RIS engineers completed design of a data acquisition system using commercial hardware.

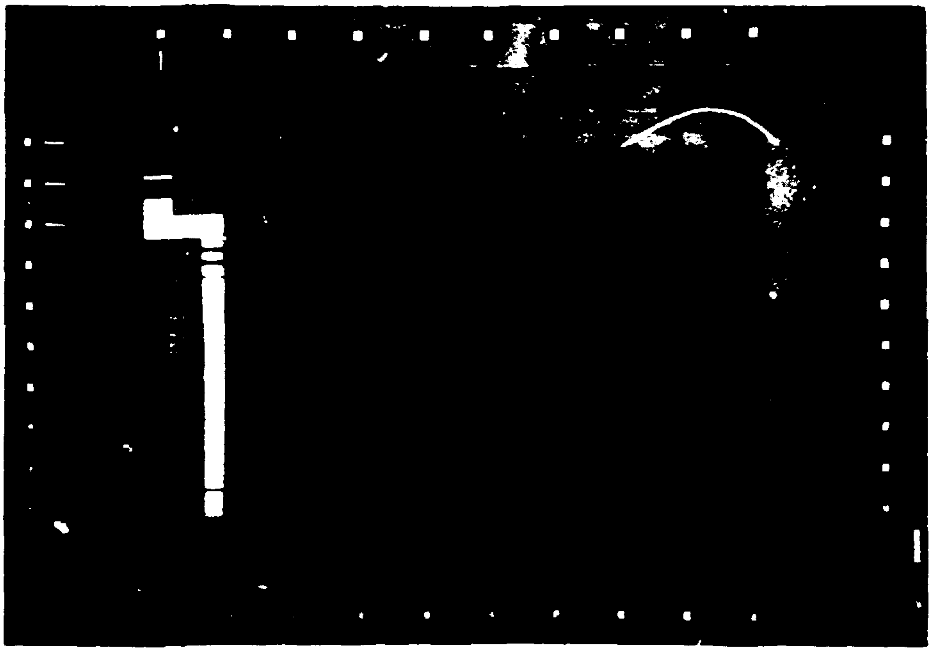


Fig. 1.2-8. Programmable advanced RADIAC sound annunciator chip (PARSAC)

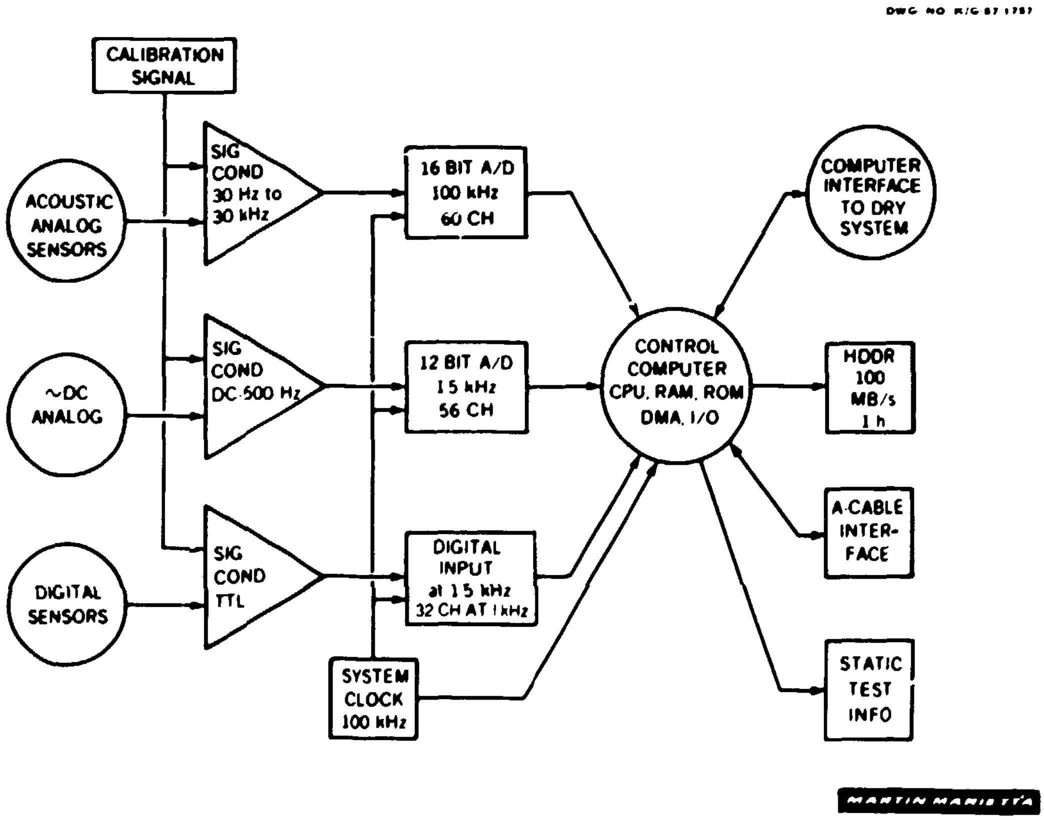


Fig. 1.2-9. Block diagram of TORDAC wet system.

This involved a VCR-based data logger, dc power modification to commercial instrumentation, modification to an HPIB bus expander, and a 24-channel isolation amplifier.

Vitrification Test Electrodes. Another interesting challenge was the pilot-scale in situ vitrification test at ORNL. Members of RIS and the ORNL Environmental Sciences Division successfully immobilized hazardous and radioactive wastes by placing electrical power in a volume of waste-contaminated soil via an array of molybdenum electrodes and raising the temperature above its melting point (~1500°C). The resulting glass was leach-resistant for contained radionuclides. Many contaminated soil locations at ORNL, particularly those with a high radionuclide inventory within a relatively small spatial volume (such as the old low-level radioactive liquid waste disposal pits and trenches), are considered prime candidates for stabilization and closure via in situ vitrification.

Fusion Energy Support. Designs completed for applications to fusion energy efforts include signal-conditioning circuits and a power supply for a Hall magnetic probe. Hall probes will be used to sense the magnetic fields in the X, Y, and Z coordinate systems. A control system and pellet diagnostic system for the Princeton Beta (fusion reactor) Experiment pellet injector have been implemented to automate the fill cycle and to increase system safety. The system included an eight-channel optical detector and camera synchronization. In another pellet-related activity, a tritium pellet injector was developed for diagnostic work at Los Alamos National Laboratory. Radiation-hardened, large-core, hard-clad silica fiber optics were designed in a helium-leaktight assembly as a light gate to detect the flight of tritium pellets traveling at speeds between 500 and 2000 m/s. A dual flash lamp trigger system was designed, and a digital system was fabricated to provide camera trigger delays.

Multifunction RADIAC. As part of the ongoing program for the U. S. Navy (see Sect. 1.1.5), an advanced version of the multifunction RADIAC (MFR) was developed. This system consists of a processor board and a display board. To keep the package small, surface mount technology was used. Three custom LCD displays and associated drive electronics, designed and implemented in prototype instruments, were assessed for use as user-instrument interfaces. Alternatives are being explored to arrive at the optimal design.

Speciality Circuits. Speciality circuits include one designed for the U.S. Air Force to detect the level of halon in fire extinguisher canisters. The circuit measures the halon level via an open parallel-plate capacitor built into the halon canister. As the halon level changes, the capacitor value changes (because it uses halon as its dielectric). The circuit triggers a warning signal when the level gets to a point at which an automatic fire extinguisher is inoperable.

1.2.3.3 Reverse Engineering

One ongoing program, reverse engineering, is a flexible, multidisciplinary effort to help military organizations buy spare parts at competitive prices. Many times the cost of a particular part can be reduced by a factor of 10 or more during the analysis/design process by experienced engineers with seasoned judgment. Overspecification and obfuscation have become such standard practice that Army Quartermaster Corps and procurement personnel are uncomfortable with technical data about their own hardware. Our efforts to use common equipment for common tasks and the resulting cost savings are being well received by Naval Parts Procurement and the Naval Sea Systems Command (NAVSEA).

Reverse engineering has grown to involve development of an inexpensive fluxgate sensor and advanced self-calibrating programmable electronics to allow construction of a compact, inexpensive precision magnetometer. After demonstration of this first reverse engineered product, we plan to pursue sponsorship to develop an application-specific integrated circuit (ASIC) for this instrument. It is conceivable that the entire instrument could be implemented by one or two ASICs that could have application in aircraft and spacecraft. Such a system would eliminate acceleration errors in high-performance aircraft magnetic heading systems, thus eliminating the need for compass stabilization with mechanical gyroscopes as well as allowing for dynamic elimination of compass deviation.

1.2.3.4 Control Circuit Development

From time to time, RIS groups develop and design stand-alone or PC-based control systems. Two recent applications for which the group provided control electronics are a scanning tunneling microscope and a control system for the Tore Supra fusion reactor pellet injection system. A three-part system controls the tip position of the microscope and acquires and reduces data. All hardware was developed at ORNL, and the software that was developed at AT&T Bell Laboratories was modified extensively at ORNL to run on an IBM PC AT using the ORNL-developed hardware.

A control system designed and developed for the ORNL Fusion Energy Division for the pellet injector of the Tore Supra reactor, operated by the Commissariat a l'Energie Atomique (CEA) of France, will be delivered to Cadarache in late 1988 or early 1989. The system is a mechanism to form deuterium fuel pellets and deliver them to a high-speed rotating Kevlar hoop, which captures and accelerates the pellets to ~1200 m/s. The system integrates a high-speed arbor drive system with stepping motor controllers, cryogenic systems, punch motor drivers, a vacuum system, pretrigger timing circuits, and numerous diagnostics. These items interface with mechanical devices developed by FED and the multibus control computer used by the French to coordinate the Tore Supra activities.

1.2.3.5 Power Circuit Development

I&C Division engineers have completed power control circuits for two programs for DOE enrichment installations. They developed a compressor monitor to continuously monitor a cell of enrichment cascade compressors and a recycle controller to control a cell if surge takes place. The monitoring function is unique in that the motor current flowing to the compressor is treated as a 60-Hz carrier, then demodulated. The demodulated spectrum contains information concerning the status of the compressor.

In cooperation with the ORNL Applied Technology Division, a control circuit for a 15,000-rpm, 30-hp axial-gap permanent magnet motor drive system for enrichment-related activity was designed, fabricated, and successfully tested, demonstrating the motor's ability to drive a compressor without using a gear box. Synchronous switching of the inverter was accomplished through Hall probe feedback of rotor position. Fixed-frequency pulse width control of the switching regulator was manually adjusted to achieve motor speed control. While fixed-phase angle switching was used on the inverter, power factor correction was achieved through passive components in the motor lines.

1.2.3.6 Radiation-Hardened Circuit Development

Support for radiation effects studies on semiconductor components and circuits has been led by an I&C Division engineer affiliated with The University of Tennessee, Knoxville (UTK) for the Consolidated Fuel Reprocessing Program (CFRP), primarily through subcontracts with UTK. Early work at ORNL involved the design and test of a radiation-hardened television camera system suitable for use in a low dose rate (less than 2×10^5 rad/h) environment. More recently, CFRP subcontracted to UTK for a continuation of radiation effects studies in two primary areas: (1) continuation of semiconductor electronic device irradiation tests for total dose (gamma) effects on voltage comparators, operational amplifiers, transistor arrays, pulse-width-modulated (PWM) control circuits, analog switches, buffers, and voltage references; and (2) several digital integrated circuits (ICs), such as Schottky transistor-transistor logic (TTL) and emitter-coupled logic (ECL) type circuits and arrays. Design, development, and testing of a radiation-hardened off-line 500-W switching regulator power supply were done through an agreement between DOE and the French CEA. The power supply system was irradiated at the HFIR containment pool at ORNL, using spent fuel elements as a radiation source. The dose rate was ~35 krad/h, with the system performing within all required specifications during the entire test, which exceeded a total gamma dose of 10 Mrad.

For fuel recycling, RIS has designed a rad-hard 12-bit analog-to-digital converter (ADC) and bit-slice processor to withstand >10 Mrad total accumulated dose. A major difficulty is the drift that occurs in the voltage reference because of radiation dose effects. Because the 1N827A zener diode has shown the least drift, it was chosen as the reference. By properly designing the system and using this one reference throughout, loss of accuracy due to reference drift may be minimized.

The bit-slice processor will be exposed to a severe radiation environment. Its function is to move data between a microwave link and a remotely controlled manipulator. Based on the Am2910 sequencer and the Am29116 ALU/μP, the processor is intended to operate through gamma doses in excess of 10 Mrad with minor degradation in performance, and possibly up to 50 Mrad before total failure. Processor components have been tested to 10 Mrad, but the processor itself is still in development. A processor that can withstand high doses of gamma radiation will give remotely controlled manipulators a limited amount of onboard intelligence, allowing manipulators to incorporate emergency routines. A rad-hard processor will also eliminate the need for heavy shielding. Radiation testing is scheduled for late 1988.

1.2.4 ELECTRO-OPTICS DEVELOPMENT

Electro-optics has been recognized by the I&C Division as an important area to pursue. Though the Division has done significant work in image analysis as well as scattered work in many other areas of electro-optics, no concentrated efforts were made until fall of 1987 when a new staff member was hired to provide leadership in this area. Goals are (1) to develop and expand I&C Division capabilities to measure physical properties using optical techniques; (2) to support I&C Division and ORNL programs in optical computing, image processing, and vision systems; and (3) to pursue electro-optic opportunities in general.

1.2.4.1 New Initiatives

With assistance from faculty members of Tennessee Technological University (TTU), RIS members have identified and pursued both short- and long-term funding for laser-based particle characterization. Research involves optically measuring sizes, density distributions, and aspect ratios of aerosol particles. While a large amount of research effort has already been expended in this area, the group's major contribution is in the use of multiple wavelengths for extending the resolution and accuracy of existing systems. Two immediate applications targeted for research are (1) measurement of the liquid phase of wet steam and (2) identification of asbestos, both airborne and in installed insulation. Papers on these promising areas for development, one for steam sensing and one for asbestos characterization, have been submitted to several potential funding sources including TVA, EPRI, and HAZWRAP, and a Field Work Proposal entitled "An Optically-Based Wet Steam Monitor" has been submitted to DOE.

1.2.4.2 High-Temperature Optical Strain Measurement

Research opportunities lie in the areas of high-temperature strain measurement in rotating equipment and advanced materials research. Technology does not exist for making these measurements above 1000°C. In collaboration with the ORNL Applied Technology Division (formerly ETAC), a RIS staff member is developing thermal phosphor techniques to measure surface temperatures and strain above 1000°C in combustor environments. Phosphors are bonded to a measurement surface in specific patterns. Strain in the measurement surface then results in pattern deformation, which is monitored optically by scanning or imaging the pattern. Temperature is also obtained from the same system due to phosphor decay rate dependence on surface temperature. Other techniques being investigated include using orthophosphate crystals as host material for the phosphor and looking for sensitivity of the fluorescent emissions to strain in the crystalline structure. This technique also provides strain and temperature information simultaneously from the same transduction system. Initial experiments have been performed in which phosphor bands were bonded to the surface of a tensile specimen. A dual fiber optic probe—one fiber to transmit the uv laser signal and one to collect the phosphor floresecence—(see Fig. 1.2-10) was designed to scan across the phosphor bands. Resolution of these initial tests was ~100 μstrain with gage length of 5 cm (2 in.). These concepts, which have been presented to the U.S. Air Force as a potential source of funding, are part of an ORNL Exploratory Fund proposal initiated by ATD entitled "Optical Sensing for Advanced Technologies Using Temperature and Pressure-Dependent Phosphors." The principal investigator would be a RIS staff member.

1.2.4.3 Program Support

Optical Johnson Noise. Members of the I&C Research Instruments and Reactor Systems sections are conducting experiments to determine whether or not there exists an optical equivalent to electrical Johnson noise. If Johnson noise is the lower noise limit of optical systems, fundamental noncontact temperature measurement would be possible simply by examining the noise imposed by a metal surface on an incident laser beam. One experiment consists of measuring noise imposed on a HeCd laser beam (325 nm) chosen to provide sufficient isolation of the signal from blackbody radiation when it is reflected

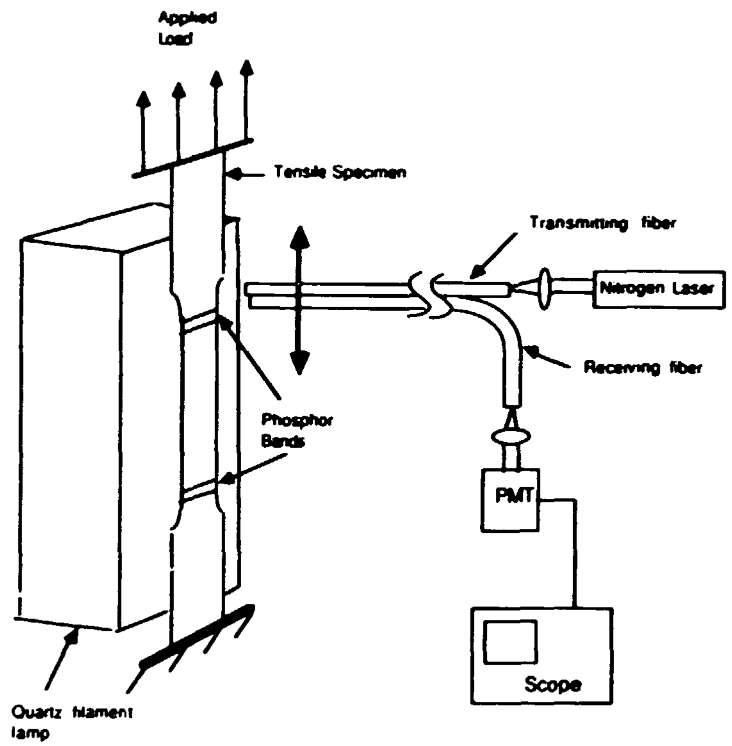


Fig. 1.2-10. Dual fiber optic probe for optical strain experiment.

from the filament of a tungsten reference lamp. A divider and correlation network are being designed to eliminate all sources of noise except that imposed on the photons by the filament surface. Initial experiments with a lower bandwidth divider showed that improvement in the divider design is necessary before the system noise rejection is acceptable for experiments. One improvement being investigated is to digitize the signal from the photodiode and process the resulting signals in the digital domain.

Optical Inspection. A RIS engineer, as task leader of advanced technologies for the U.S. Treasury's Bureau of Engraving and Printing (BEP) Stamp Program, has investigated several areas of optical inspection technologies: (1) adaptive classifiers, (2) optical processing, (3) invariant moment transformations (Fig. 1.2-11), and (4) textural descriptors. An extensive literature search was conducted to determine viable technologies for automated inspection. Image processing compares an image of a "perfect" stamp to the image of the stamp being evaluated. Image and color registration, however, are major problems for video frame rate in real-time inspection. One alternative is to use image transforms that are invariant to translation, rotation, and scale changes. Invariant moments, generated from Radon, Fourier, and Hough transforms among others, are advantageous in that many transforms can be implemented optically. A second alternative is to use textural descriptors such as image energy, entropy, and variance. One final area that has been investigated is the use of neural networks (perceptrons) in an adaptive classifier configuration.

In a related effort, the same engineer worked on a testing plan for optical inspection systems to be procured as part of the BEP Currency Program. A formal plan was designed

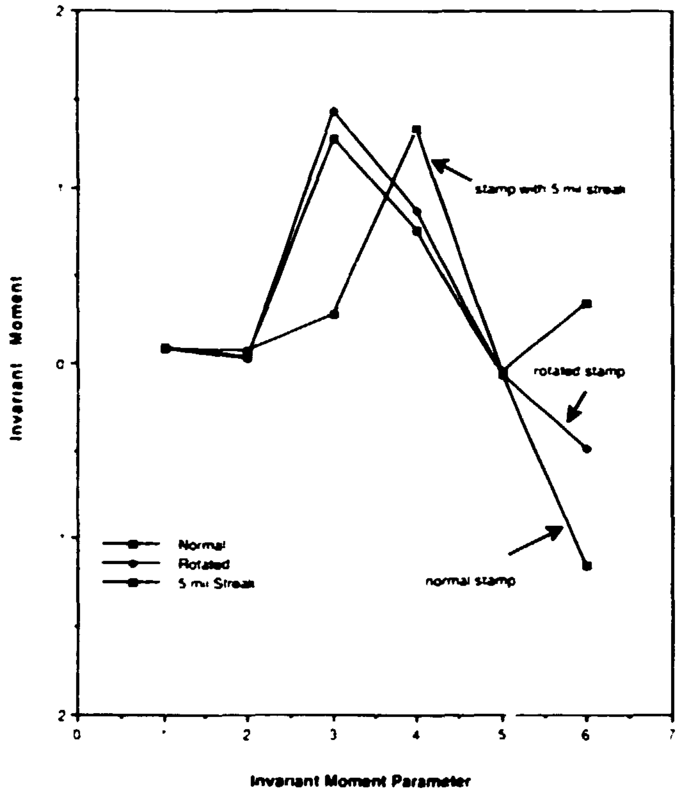


Fig. 1.2-11. Invariant moments of 22-cent U.S. flag stamp.

and distributed to potential inspection system vendors at a bidders' conference in January 1988. A test plan to verify the performance of a particular vendor's currency inspection system involves tradeoffs in available testing resources (rolls of currency exemplars, time, personnel, etc.) and Type I and Type II error probabilities. A Type I error is rejection of a device under test (DUT) that meets specifications, and a Type II error is the acceptance of a DUT that does not meet specifications. Error Types I and II in turn determine the sample size needed for verification of a particular specification. In the formal plan, individual tests were described for verifying specifications for both Phases I and II of the program.

1.2.5 INSTRUMENTATION SYSTEMS DEVELOPMENT

1.2.5.1 Measurement Systems Instrumentation

Measurement instrumentation was developed for a number of areas such as the U.S. Navy RADIAC Program, surface surveys and mapping for USRADS, the MEL initiative, spectrometer support of computer-based stepping motor control and motor position feedback to control systems, and gaseous diffusion support.

Multifunction RADIAC. Work on the multifunction RADIAC project was directed toward development of new-generation radiation detection instruments to replace those currently used by the U.S. Navy. RADIAC has a modular architecture consisting of smart microprocessor-based probes and display units that perform self-tests, are autocalibrated, and can be reprogrammed to incorporate new control and display concepts. A universal bus connection provides an identical electrical interface for all probe types (alpha, beta, gamma, neutron). Other advanced features of this instrument system include the integration of VLSI chips and portable/remote configurability.

RADIAC ARCADES Gamma Calibrator. A remotely controlled variable dose-rate gamma calibrator was designed for NAVSEA to provide varying levels of dose rates for calibrating gamma radiation instruments used aboard naval vessels (see Fig. 1.2-12). Four attenuator wheels, each having four positions, are driven by stepping motors and controlled by a computerized calibration processor. Made of a sintered tungsten alloy, the attenuators will provide incremental dose-rate steps of 1 mGy/h up to the maximum rate of 1 Gy/h. A ^{137}Cs source will be used.

USRADS Development. This ultrasonic range and data system (see Fig. 1.2-13) was developed to correlate a radiological surveyor's location with radiation data collected by a portable survey instrument. The objective was to develop a data collection and tracking system for radiological surveys performed in an urban environment through UMTRAP. Special computer algorithms were developed to distinguish between valid signal paths and error or echo signal paths from houses, trees, or utility buildings. During this past year the USRADS technology was purchased by ChemRad Corporation of Seabrook, Texas.

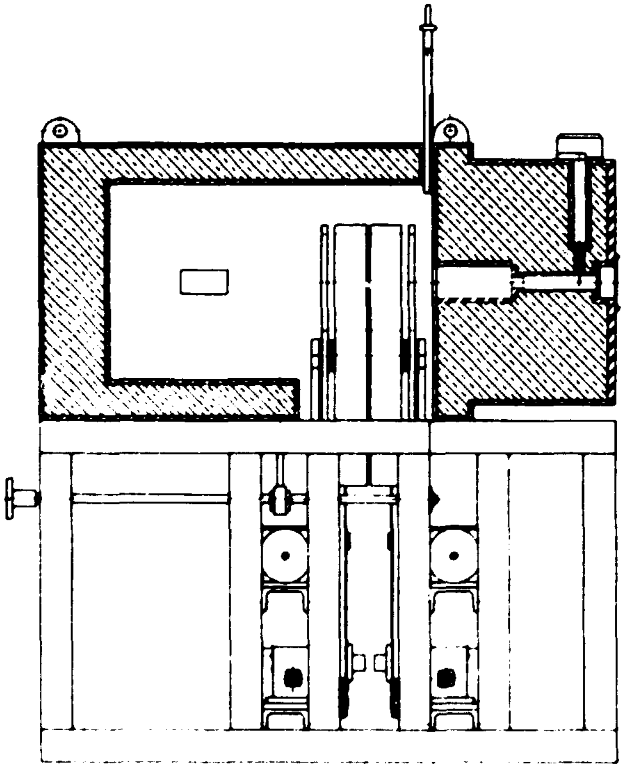


Fig. 1.2-12. RADIAC ARCADES Gamma calibrator assembly.

Fig. 12-13. USRADS system in use for property survey.

USRADS 3-D Mapping. A means of drilling shallow holes in the ground for insertion of radiation probes has been developed to provide three-dimensional maps of locations of radioactive mine tailings near residential and commercial properties. Earlier, USRADS generated a surface map of radioactive mine tailings used as backfill material. Using a gasoline-powered impact drill to install an aluminum conduit vertically into the ground, a computer-driven detector logs radiation intensity over the full depth of the hole. The system was used in Grand Junction, Colorado, to demonstrate that a small, two-wheel, cart-mounted drill can be used by two operators to successfully log commercial and residential properties.

Ultrasonic 2-D Mapping System. Studies are under way on the practical design and performance limitations of 3-D coordinate mapping systems on airborne ultrasound signals optimally encoded for measurement of both vector arrival time (relative to transmit time) and vector angle of incidence at a receiver. A flexible transmitter signal generator and a receiver system with quadrature demodulation have been built to study indoor and outdoor range capability and angle measurement accuracy as functions of signal waveform, microphone phase response, and digital signal processing methodologies. The easily reprogrammed signal generator has 5 switch-selectable codes, 4 switch-selectable window modulation waveforms, 5 jumper-selectable carrier frequencies, and 16 switch-selectable bandwidths for each window function. The receiver uses EPROM-generated sine and cosine reference signals, precision analog multipliers, and eight-pole low-pass filters with linear phase characteristics. Received signals are digitized and processed off-line on a PC. Our goal is to design custom VLSI hardware to perform the digital signal processing in real time.

Modular Electromagnetic Levitator Conceptual Design. Work is in progress to create a conceptual design of a MEL for NASA Marshall Space Flight Center, Huntsville Alabama (see Fig. 1.2-14 and Sect. 1.1.4).

The MEL will be used for containerless melting of niobium and other metals in space. Measurement and controls issues include heating a metal sample (i.e., niobium) to 2500°C using rf induction heating; levitating and translating the sample to different sections of the test vessel; noncontact measurement of the temperature of the sample; splat cooling of the sample; and measurement and control of the vacuum system to attain 10^{-7} Pa (10^{-9} torr) with minimal levels of oxygen.

Shaft Angle Encoders for Multiple Axis Neutron Scattering Spectrometer. Multiple-turn, absolute-position shaft-angle encoders were added to stepping motors used on three Solid State Division neutron scattering spectrometers. Encoders greatly reduce the chances for human error in setup and continually provide instant verification of the positions of all axes of the spectrometer, even in the event of power failure.

CAMAC Stepping Motor Control System. A stepping motor control system was designed for the ORNL Physics Division to retrofit a new CAMAC design control system on a foreign-built, poorly designed ion source analyzer. The old control system failed because of burned contacts on relays and shorted dc power supply, which resulted in failure of the discrete component motor drivers. Two CAMAC modules were used to duplicate functions, and a new control panel and wiring chassis for the interconnections were designed.

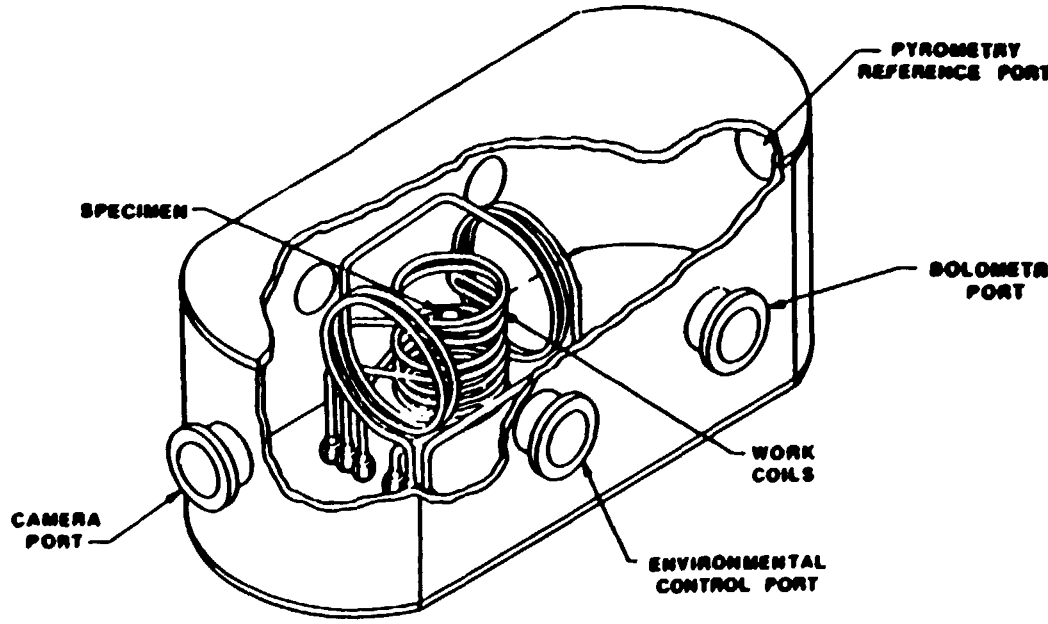


Fig. 1.2-14. Modular electromagnetic levitator (MEL).

Three-Frequency rf Power Stabilizer for an NMR Spectrometer. A system was developed for the ORNL Chemistry Division to stabilize rf fields at three separate frequencies simultaneously to permit long-duration nuclear magnetic resonance (NMR) experiments in solids. NMR experiments require stabilized constant-ratio rf magnetic fields at the probe. Long-term drifts in rf sources cause experiments to fail after short runs. Development was complicated by rf being generated in very narrow pulses (<50 μs) at very slow rates (0.1 to 10 s) with frequencies in the VHF range (50, 80, and 200 MHz).

Acoustic Gas Analyzer Project. A ruggedized streamlined version of an acoustic gas analyzer (AGA) was designed for the Oak Ridge Gaseous Diffusion Plant PLRTS. The analyzer measures the velocity of sound in a mixture of two known gases and thereby indicates the relative concentration of the mixture. This measurement technique, which can also be used to determine the average molecular weight of a multicomponent gas mixture, is particularly attractive in that it is independent of ambient pressure. It is, however, complicated by the presence of corrosive gases. In the streamlined version, delicate condenser microphones have been replaced with small dynamic microphones, which simplifies the electronic drive circuitry by eliminating the 200-V bias and the ±140-V high-voltage power amplifiers and associated power supplies.

1.2.5.2 Data Systems Instrumentation

Computer-Assisted Detection and Report Enhancement System. Development work was continued on the CADRE systems for the Immigration and Naturalization Service of the U.S. Department of Justice (see also Sect. 1.1.3).

The INS CADRE system had the following operational requirements: (1) to alert radio operators to sensor-detected intrusions, (2) to aid radio operators in tracking the status of remote sensors and field agents, (3) to provide statistical data to evaluate sensor effectiveness, (4) to maintain historical information on sensor and agent activities, (5) to allow radio operators access to INS national data bases, (6) to allow radio operators access to state and local law enforcement data bases, and (7) to provide information for INS required reports.

During this report period the prototype system, which had been installed in Tucson, Arizona, was extensively modified as a result of feedback from field installations and revised requirements from the INS. The task-scheduling and message-passing system allowed easy reconfiguration. The ORNL-developed multitasking software system was extended for transparent use over the PC network. All tasks were implemented as C language functions. The ORNL-devised multiwindow operator interface with real-time status displays was refined. Finally, software utility programs were written to support application software development and to assist field personnel in handling unusual situations such as those resulting from electrical power failures.

Following an initial test of prototype systems in Del Rio and El Paso, Texas, the basic system was installed for extensive testing at 10 sites on the southern U.S. border because multiple sitings were deemed necessary to ensure feedback from widely differing operations sites. Locations ranged from high-population, heavily industrialized border cities to low-population remote communities, and from many hundreds of remote rf-linked sensors and Border Patrol agents to relatively few agents and sensors. The expertise of operations and maintenance personnel varied greatly from site to site, as did agent dispatch and reporting requirements and operational links to state and local law enforcement agencies.

A reiterative process of test, review, and redesign followed. The additional installations required preparation of more polished and nearly automatic installation procedures so that inexperienced Border Patrol field personnel could install, maintain, and operate the CADRE system.

Computer-Controlled System for Laser Bonding. A computer-controlled system for laser bonding for USC in ATD was developed by a RIS member and an ATD member. The goal of this proof-of-principle system is to precisely maintain temperatures of composite tapes bonded with a laser. The closed-loop control system comprises an Nd-YAG laser, an infrared (IR) noncontact temperature probe, and a PC AT. The laser output is expanded through a series of lenses to obtain the desired width at the bonding surface. The IR probe monitors the temperature at the bonding surface and outputs an analog signal proportional to the temperature. This signal is digitized by an A/D converter and processed by the PC AT. The resulting control signal is passed through a D/A converter and applied to the laser control system.

ATD Mobile Field Data Acquisition System. A second instrumentation system developed by ATD with RIS support is a mobile field data acquisition system for the U.S. Air Force Armament Laboratory at Eglin Air Force Base. This system provides an instrumentation trailer for acquiring and processing data from conventional explosives. It is capable of digitizing 28 channels of data from various accelerometers and pressure gages at the test site. Data collection is orchestrated by one of two identically configured industrial grade IBM AT computers while data analysis is performed by the other. An integrated software package has been provided.

Interactive Video Instruction. An area of growing development is interactive video applications. An interactive video instruction (IVI) project to develop a prototype interactive instructional videodisk for the U.S. Navy Regional Data Automation Center (NARDAC) is near completion. The project, undertaken with assistance from HMP Systems, Inc. is to identify those factors that contribute to successful IVI and serve as a model for development of other state-of-the-art interactive instructional techniques. The IVI system will allow managers to learn standard applications of the U.S. Navy Fleet Modernization Program (FMP) and to identify and define FMP phases, roles, and personnel responsibilities. Main components of the interactive system include an IBM PC AT, a Pioneer LD-V6000 videodisc player, IBM Infowindow display, and locally written software.

Multichannel Compressor Monitor for Use in Gaseous Diffusion Cascade Area Control Rooms. As part of an ORGDP instrumentation milestone in FY 1987, amplitude and phase demodulation of motor current signals from fractional-horsepower single-phase motors and high-power polyphase motors (such as those used in the cascades) was demonstrated to be a viable means for analyzing mechanical vibrations in motor-driven systems. Recent work has proven that motor current monitoring can be used to detect unstable and potentially damaging operating conditions such as primary surge (gross flow oscillations) and secondary surge (rotating stall) in large axial cascade compressors. This approach to compressor monitoring is extremely attractive. Instruments employing this technique should be relatively inexpensive and provide improved monitoring capability over existing instruments. They should not require additional cabling because they use existing current loops that feed the stage motor ammeters in the process building control rooms.

During FY 1988, a specialized system was configured to monitor all 10 compressors in operating "00" (1700-hp stages) cells at the Paducah and Portsmouth plants. In addition to monitoring, this system is capable of retaining digital records of cascade upsets and other compressor-related events and communicating these conditions to the central cascade computer system.

Gaseous Diffusion Compressor Recycle Controller. As part of an FY 1987 ORGDP site milestone, a microprocessor-based compressor recycle controller was developed. This instrument was intended to eliminate major deficiencies associated with obsolete pneumatic controllers, minimize occurrences of wasteful recycle flow, eliminate the need for frequent adjustments, and provide greatly improved compressor protection. During FY 1988, the demonstration prototype was modified to (1) interface with existing ORGDP cell controls and monitoring hardware and (2) facilitate monitoring and recording of compressor surge and secondary operation during its field testing. Detection of abnormal compressor operating conditions via motor current demodulation, rather than by the vibration signal analysis method previously employed, will provide more reliable sensing and reduce long-term maintenance costs.

FEMA Pilot Production Facility Work Station. A computer program written for the Federal Emergency Management Agency calculates a production dosimeter's ionization volume, useful in reducing calculating time for "what if" conditions. For example, since ionization chambers are sealed at ambient pressure, what size chamber is needed for a dosimeter assembled in Colorado Springs, Colorado (elevation 6500 ft)? The internal shape of the ionization chamber is such that accurate calculations of its volume using the conventional calculator would be tedious and time-consuming.

FEMA Dosimeter Optics Computer Program. A second computer program models FEMA production dosimeter optics. Based on the thick-lens equations for accuracy, the program is useful when specifying dimensional tolerances for those components that would normally affect optical qualities such as lens radii of curvature, thickness, material, and component spacing. The program can be used to make design changes and to study "what if" conditions quickly, eliminating time-consuming and error-prone methods associated with traditional calculators.

Expert System for Computer-Aided Polymer Conversion. Expert systems instrumentation is being generated from a program in the ORNL Chemistry Division to find disposal methods for hydrocarbons. A project for the Energy Conservation and Utilization Technology (ECUT) Material Program in cooperation with MACES and Chemistry Division staff includes development of a rule-based expert system for computer-aided polymer conversion using LISP and OPS5 programming languages. The final goal of the project is to use the computer as a molecule testing tool in development of degradation and fabrication methods for polymers. The knowledge-based portion of the expert system which includes known chemical reactions and mechanisms, is being developed using OPS5. The rules locate atom groupings within a given molecule and produce a data base that describes the grouping chemically and identifies possible chemical reactions the molecule could undergo, given local environmental conditions. LISP, used to develop the inference engine, or driving program, includes a set of functions that manipulate the data base and inform the user of a possible conversion, if one exists.

Computer Data Acquisition and Control System for the Neutron Scattering Time-of-Flight Experiment. The data acquisition and control system of the neutron TOF experiment, operated by the ORNL Solid State Division at HFIR, is being upgraded with the help of the Computing and Telecommunications Division. This improvement and the accompanying replacement of obsolete equipment improves the facility for international users. The experiment computer interface will be replaced by CAMAC-standard modules, including six ORNL-designed CAMAC modules for TOF data acquisition. A new DEC GPX workstation and a DEC MicroVAX computer will replace the obsolete DEC PDP 15.

ORELA Data Acquisition Equipment Upgrade. An IBM PS-2 Model 80 computer was purchased for the ORNL Engineering Physics and Mathematics Division to provide program storage for the main data acquisition computers at ORELA and allow communication between these computers and the VAX 11/785 via an Ethernet link. A second Ethernet system has been installed on the VAX, and an Ethernet card will be installed in the PS-2 to allow high-speed communication between the VAX and other data-taking computers at ORELA.

ORELA Data Handler and Interface. A data handler and interface (DHI) for control of experiments and hardware at ORELA has been designed and constructed. Completely controlled by an IBM PS-2 computer, the system is presently under test. The DHI controls the experiment equipment and accepts, preprocesses, and stores experiment digital input data for further processing by the PS-2 computer.

ORELA High-Speed Computer Link. A second system augments an existing data acquisition system at ORELA by providing a parallel interface between an SEL 810B computer and a VAX 11/785. The original system consisted of three SEL 810Bs servicing up to 12 experimenters on 12 input ports. A fourth SEL 810B links the three data-taking computers to peripheral equipment. The newly designed high-speed link between the fourth 810B and the VAX enables transfers of data and programs between the old system and the VAX computer.

Computer Upgrade for Chemistry Division. Computing equipment specified and procured for the Polymer Group of the Chemistry Division replaces and upgrades existing equipment and links the group's computers to the ORNL central computing system.

SLAM Engagement Training Aid Statement of Work. RIS is cooperating with the Reactor Systems Section, ORNL Data Systems Research and Development, the Engineering Physics and Mathematics Division, and The University of Tennessee, Knoxville, to develop a Statement of Work for a SLAM (air-to-ground missile) engagement training aid for the Naval Air Systems Command (NAVAIR). To serve as a model in the preparation of procurement documents for operator-oriented air-launched missile engagement training aids, this system uses desktop, off-the-shelf, fleet-available microcomputer components. Such a software/image instructional system provides realistic training for operators who are restricted in actual missile firing training exercises because of the high cost of modern weapons systems.

Modified Waste Operations Control Center Count Rate Meter. WOCC autoranging count rate meter software was modified to provide smoother transitions between ranges. The existing coding was restructured, and software tools were developed to add averaging algorithms and enhance code maintenance.

1.2.5.3 Fuel Recycle Division Communication Systems

A major obstacle to successful implementation of dexterous servomanipulator systems in nuclear fuel reprocessing facilities has been the design of a reliable communications link that will withstand the rigorous environmental conditions of the reprocessing cell. Six areas of research have been undertaken to support the Fuel Recycle Division's experimental program to develop wireless rf communication within a hot cell: (1) theoretical studies of rf wave propagation in a hot cell. (2) an advanced integrated maintenance system (AIMS) 12-GHz microwave communication system, (3) development of a 94-GHz transmission system, (4) in-cell testing of the microwave systems, (5) microwave communication link tester design, and (6) radiation-hardened AIMS control system design.

Because experience and calculations predicted multipath-induced degradations in the microwave signals, several advanced techniques were developed to deal with the multipath: the use of special bandwidth-reducing digital coding schemes, antenna polarity adjustments, receiver/detector optimization, advanced transmission techniques, and millimeter wave frequencies (just under 100 GHz).

Theoretical Studies of rf Wave Propagation in a Hot Cell. A special theoretical study of rf wave propagation focused on calculation of effects of multipath transmission on signal-to-noise ratios of direct focused signals and on maximum data rates that could be broadcast with the multipath signal itself. Mathematical modeling of the rf environment in a metal-lined cell suggested the desirability of an operating frequency as high as practical. Multipath interference was reduced by approximately a factor of the frequency raised to the 1.5 power. A decade increase in carrier frequency would be expected to provide better than a 30-dB improvement in the overall cell signal-to-noise ratio (see Fig. 1.2-15).

AIMS 12-GHz Microwave Communication System. A prototype focused-microwave communications system that operated bidirectionally at 10 and 12 GHz with 60-cm (2-ft) antennae was designed and tested. Both television and bidirectional digital control transmissions were demonstrated in the ORNL Fuel Recycle Division AIMS facility, which is only partially metal lined. Periods of up to 6 h of error-free 1-Mbaud digital transmission were observed.

94-GHz Transmission System. The transportable reflective environment communications system (TRECS), a 94-GHz (W-band) microwave link, was designed for in-cell signal transmission. Short (3-mm) wavelengths provided higher wall interaction losses, thus reducing multipath interference in a closed metal-lined cell. A 15-cm (6-in.) Cassegrain dish antenna was used for communications up to 30 m (100 ft) to send bidirectional frequency-modulated digital data at 1 Mbaud and to send frequency-modulated video information (see Fig. 1.2 on p. 6).

In-cell Testing of the Microwave Systems. As part of the fulfillment of several international exchange agreements, testing of 10- and 12-GHz microwave systems was

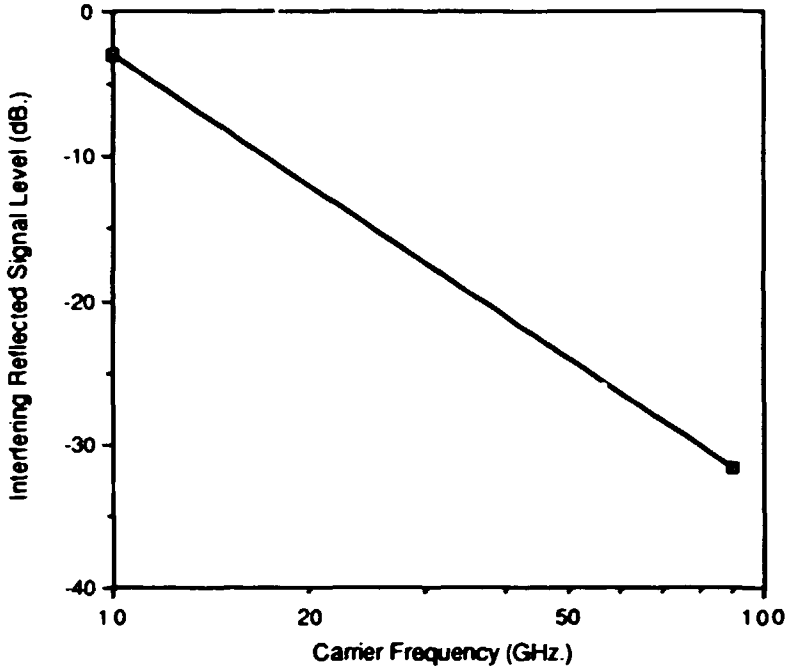


Fig. 1.2-15. The RECS interfering signal decreases by 30 dB per decade.

performed in a metal-lined reprocessing cell in France under a CEA agreement. Evaluation of both 10- and 12-GHz and 88- and 94-GHz systems was performed in a metal cell in Japan under agreement with the Power Reactor and Nuclear Fuel Development Corporation (PNC). Although neither cell was fully reflective, results confirmed that microwave signal transmission is feasible within a metal-lined cell and indicated advantages in multipath rejection using the 88- and 94-GHz system.

Microwave Communication Link Testers. Computer hardware and software for digital data link testing were developed for the ORNL Fuel Recycle Division for use in testing data integrity of microwave links designed for cooperative development programs with CEA of France and PNC of Japan. Random data are generated, encoded by a "link tester" module into a selected format and baud rate, and transmitted by microwave. Data retransmitted and beamed back from the far end of the microwave link are received, converted, and compared with the original data. Error data are displayed for the operator.

Radiation-Hardened AIMS Control System. As a major task in the development of a workable fuel reprocessing plant for DOE, design of a radiation-hardened in-cell AIMS control system was undertaken in support of the CFRP for cooperative development programs with CEA in France and PNC of Japan. The primary goals of this project have been design and verification of an electronic control and data acquisition system capable of sustaining a total gamma dose of 10^7 rads while maintaining high accuracy and data integrity.

A component testing program was undertaken to evaluate numerous analog and interface integrated circuit devices and identify those that performed adequately at the specified dose level. Devices selected for testing and specifically targeted toward the key subsystems required to implement a workable radiation-tolerant control system for AIMS include (1) a microcomputer, (2) an analog data multiplexer system, (3) D/A conversion systems, and (4) the serial digital interface to the microwave communications link.

1.2.5.4 Other Communication Systems

INS Receiver/Decoder. A low-data-rate PC AT computer-based receiver/decoder was designed for an INS remote sensor monitoring application in which serial data transmitted from intrusion sensors via rf communication are processed.

Data Isolation Analysis of a Broadband LAN. Analysis and testing of a broadband local area network (LAN) were performed to determine a cost-effective method for isolating data of nonassociated users. Results indicate that shared broadband LAN usage is possible without compromising data security when mixed modem techniques are properly applied. Theoretically predicted isolation was based on (1) frequency separation through the use of different rf channels, (2) a 20:1 difference in rf bandwidth, (3) incompatibilities in modulation and data encoding, (4) timing differences resulting from digital data rates and recovery techniques, and (5) incompatibilities in the packet transmission protocols. Mixed modems from two manufacturers deliberately introduced user incompatibilities during network testing to verify the isolation. No data were cross-coupled by the modems during 1600 h of heavy network transmission testing (242 Gbytes).

1.2.6 FACILITIES ENGINEERING

I&C Division engineering support to ORNL and to Energy Systems facilities ranges from planning, designing, and implementing to field engineering and supervising implementation. Activities for research facilities, environmental upgrades, security systems, operating facilities, and documentation are highlighted.

1.2.6.1 Research Facilities

Holifield Heavy Ion Research Facility Tandem Accelerator. An I&C Division team, in support of ORNL Physics Division operation of the Holifield Heavy Ion Research Facility (HHIRF), has been assigned to operate, maintain, and upgrade the Tandem Accelerator and control system to provide a variety of beam species befitting a world-class research facility, to minimize interruptions for maintenance, and to simplify tuning and operating. Highlights include 4162 h of research in FY 1987, a substantial decrease in unscheduled maintenance, and establishment of a world record by operating the experimental program at 23.4 MV. One team member has become a Tandem operations mentor and a gas-handling system supervisor. Support and engineering have been provided for the addition of new beam lines. Concepts for design and modifications to the Tandem control console have been formalized and breadboarded. Console upgrade will be completed in FY 1989.

Oak Ridge Electron Linear Accelerator Systems. A RIS engineer is responsible for supporting the operation of ORELA. Studies of bunching systems and photocathode electron sources have strongly suggested that the greatest gains in peak current and the most favorable time distribution of electrons will probably come from photocathode-type sources. Unfortunately, reaching the high vacuum requirements for these sources means reducing their reliability in large systems such as ORELA. Even so, most of the interest has shifted from bunching to photocathode techniques. At present the favorite technique is the standard oxide-type cathode, which we improved and with which we established new ORELA records for peak beam performance and reliability. A gun was constructed that produced 4.2 j/ns at 3 ns FWHM after 5000 h of use. This gun has logged more than 10,000 h and is still performing acceptably. The reliability of the injection system and other subsystems has been improved so that ORELA is able to log more than 4000 h/year in spite of staff reduction to about one-third and a corresponding budget reduction.

The goal of reducing beam afterpulsing has led to two significant and somewhat related developments. Both static and dynamic beam-sweeping techniques have been investigated, and it has been shown that both can be valuable in reducing the afterpulse by a factor of ~10. Consideration of these techniques is expected to continue as long as oxide-type cathodes are used.

A significant success was achieved toward the goal of diversifying ORELA with installation of the new Positron Facility on Flight Path 3. This facility has performed better than expected. With the addition of a Penning trap and other improvements, it has the potential to become the most practical and versatile positron source in the world. A feasibility study and a preliminary proposal to ORNL management have been made for converting ORELA to a driver for a free-electron laser while it continues its traditional role in neutron cross-section studies.

National Center for Small Angle Scattering Research. RIS staff members provided maintenance of the detector systems to the National Center for Small Angle Scattering Research (NCSASR). The small angle X-ray scattering facility detector was cleaned, resealed, pumped, and refilled. Preamplifiers were replaced with new units. One detector brought in for repairs was replaced with the standby detector. The gas was withdrawn and purified for later reuse. After two leaky seals were found on the detector, a secondary seal was designed and installed on all seals. The repaired detector was then pumped and leak checked.

1.2.6.2 Environmental Monitoring

Remote Air Monitoring Stations. An I&C Division team has upgraded a network of eight remote air monitoring stations. These stations have provided remote field services to the Laboratory for more than 25 years, at distances up to 120 km (75 miles) from ORNL, by monitoring background ambient air and sampling for any unexpected release of contamination from Oak Ridge operations. The new system design incorporates pneumatic flow regulators, placed in aluminum housings for improved weatherability, to ensure more constant sampling flow rates.

Eleven perimeter air monitor (PAM) station installations were completed, and a fully operational system was turned over to the ORNL Department of Environmental Monitoring. These stations produce continuous radiation counting and other monitoring data, which are then telemetered to manned control centers within ORNL on a round-the-clock basis. A station at one end of a playground site in the Scarboro community of Oak Ridge was aesthetically designed to please the community and totally enclosed (top and sides) in heavy fencing to make it more or less child-proof.

Environmental Restoration and Facilities Upgrade Program. In support of the Environmental Restoration and Facilities Upgrade (ERFU) Program, RIS engineers coordinated efforts to ensure that modifications and upgrades maintained system integrity. A data base was completed for the Waste Operation Control Center (WOCC), one of four operating and signal monitoring systems at ORNL. This data base records more than 360 signals at WOCC, their sensor sources, routes of collection, and signal-parameter characteristics. Although support for the data base has been discontinued, more work is still needed for all four ORNL monitoring centers.

Manhole Monitoring. A major upgrade of the process water manhole monitoring system has been carried out over the last several years as part of line item projects. RIS members have been instrumental in design, calibration, and installation support. New gross gamma and gross beta water-contamination monitors were designed, and these, along with previously designed watershed monitors, were installed in 10 manholes on the ORNL process waste system. Laboratory calibration was carried out to check the sensitivity of several ORNL-designed detectors to monitor radioactive contamination of groundwaters.

1.2.6.3 Security Systems

Safeguards and Security Badge Reader Project. Personnel from RIS, the Graphics Division (formerly the Information Resources Organization), the respective installation security organizations, and Computing and Telecommunications are engaged in a DOE-mandated program to replace employee badges. Project objectives are a new badge with design features compatible with the existing badge reader system and improvement of badge fabrication, enrollment, and assignment. Engineering design and system integration decisions involved procurement and/or deployment of Weigand wire-encoded modules, indium foil disks, badge packets, rephotography equipment, pouch laminators, film, photographic background screens, badge computer enrollment station equipment, and data communication encryption devices.

A newly designed Energy Systems logo has been added to the badge, and a three-of-nine bar code employee number (which may be used for other administrative purposes), has replaced the OCR (optical character recognition) employee number on the back of the badge. Use of a badge packet made by an outside vendor simplifies in-house fabrication requirements and eliminates delays now experienced in fabricating new badges. Individual badge and pass offices prepare inserts from the central data base using computer terminals. The front insert contains the preferred name of the employee and his badge number; the back insert contains the employee's badge number and surname with initials, along with a seven-character bar code. The leading character is "E" for employee, which is followed by the employee number, right-justified, and leading zeros as needed. These gummed inserts are affixed inside the packets, a photograph of the employee is placed in the recess inside the packet, the packet is laminated, and the badge is enrolled in the system and given to the employee.

Security Badge Reader Upgrade. The second-generation security badge reader system being developed by RIS reduces the number of communication lines to the access control host computer from facilities in material access areas. Hardware and operating system software were selected for a prototype controller to replace in-house designed equipment because of the maturity and increased functionality of board-level microcomputers, the commercial availability of CMOS system boards, and the emergence of real-time operating systems for microcomputers.

This project includes embedded real-time controllers and software for addressing a number of badge readers on a daisy chain. Software remains to be written for integrating the device driver modules in the badge reader. The communication protocol and command codes between the host and the multireader controller have been partially defined. Prototype hardware for communication routing in the multireader controller uses a commercially available real-time operating system. Operating controllers will have the application program in programmable read-only memory (PROM), and some controllers will have a bubble memory device for storage of collected badge reader data. Routing software is under development in parallel with the definition of the command codes for the defined communication protocol.

Portsmouth Gaseous Diffusion Plant. A plan to add the Portsmouth Gaseous Diffusion Plant (PGDP) to the Energy Systems badge reader system data base, developed by a team representing several Energy Systems organizations, allows gradual implementation of badge readers there. Equipment will be installed for badge enrollment via a leased telephone line to the central badge reader system computer at the Oak Ridge Y-12 Plant.

Y-12 Plant. I&C Division engineering personnel developed and tested a microcontroller-based selector for random vehicle searches, and two prototype units were sent to the Oak Ridge Y-12 Plant for evaluation at a vehicular portal. In addition, Division personnel assisted Y-12 Plant Security in preparing for a technical security audit conducted in the fall of 1987. As a result of increased DOE interest in a higher level of personnel accountability in emergency situations, another I&C Division engineer assisted Y-12 Plant Security in studying the feasibility of using badge readers at Y-12 Plant perimeter exit portals and emergency assembly points.

Laboratory Emergency Response Center Project Closure. RIS members assisted the ORNL Laboratory Protection Division in completing the Laboratory Emergency Response Center (LERC) project. This effort included tracking all instrument installation and support activities for both the Laboratory Shift Supervisors' data acquisition system and the Safeguards and Security backup system.

Safeguard Security Backup for LERC. RIS staff members have also worked on the safeguard security backup program for LERC. Objectives were to provide an on-line dual processor monitoring system, with automatic switchover to the hot-standby processor upon detection of a computer failure in the controlling processor, and transfer to dual operation while producing minimum interference with the operation of the single processor system. Security access control and monitoring system (SAM) operators were trained in the procedure for initializing the system to either master or slave operation. Software module documentation was written or modified to incorporate the changes for dual processor operation. Operating procedures were revised to include single-mode operation during scheduled maintenance or computer failure in either building and normal operation in the dual mode.

1.2.6.4 Operating Facilities

Facility Radiation and Contamination Alarm System Upgrades. The facility radiation and contamination alarm system (FRACAS) in Building 3019 was upgraded to improve the safety of high-level radiation chemical processing activities performed there. Monitoring units were relocated and rewired, and new monitors costing up to $30,000 each were fabricated and connected to the system to increase coverage and to comply with coincidencing requirements. Central and remote monitoring panels were rewired to reflect changes made in the equipment.

HHIRF/ORIC Safety Monitoring and Door Interlock Upgrades. Safety monitoring and door interlock systems for the ORIC and HHIRF accelerators were expanded to accommodate new experiment stations, doubling in-process monitoring instrumentation and safety interlocking requirements and necessitating redesign of the dose-auctioneering and dose-integrating circuits. The safety monitoring and door interlocking systems ensure the safety of operating personnel working in the high-energy physics experiment stations. These stations are monitored with ionization detectors having the unusual design characteristic of being as sensitive to gamma rays as to neutron fluxes. The original system designed by the I&C Division uses these detectors and associated monitoring instruments to allow facility personnel to attend to their experiments up to a point at which a preselected radiation dose is indicated. Then the station must be evacuated, closed, and secured before accelerator operations can continue. These safety systems have been redesigned as required, new detectors have been procured, additional wiring runs have been made to cover the new experiment stations, and new printed circuit boards are under construction.

Radio System Manager for ORNL. One RIS member has provided technical support and control for radio and paging systems at ORNL to ensure that all radio transmitting and receiving equipment used is in compliance with Federal Communications Commission and DOE regulations with respect to frequencies used and purity of signals generated. A set of transmitter and receiver specifications is maintained for use in purchasing rf equipment. An ORNL directory listing the 300 paging numbers allocated for ORNL use was updated and distributed.

Calibration Well Software. Software has been written in BASIC to operate a computerized source controller for a gamma calibration well for the ORNL Environmental Compliance and Health Protection Division calibration facility. This system provides gamma source positioning for calibration of radiation survey instruments used within ORNL.

Portsmouth Gaseous Diffusion Plant Radiation and Criticality Assessment. Under the direction of ORGDP, RIS and RSS personnel provided radiation monitoring instrumentation and served as operating personnel to assess holdup and criticality issues at PGDP. Measurements were made of ^{235}U content in process and recovery facilities.

DOE Emergency Response at Radiation Sterilization Incorporated. After a radioactive leak occurred, several radiation monitoring instruments were set up at Radiation Sterilization Incorporated in Decatur, Georgia, at the request of DOE to monitor water contamination, room air contamination, and other personnel hazards. Assistance was provided in the installation and operation of this equipment.

UMTRAP System Improvements. Special electrical utility service was designed and installed to improve the reliability of the electrical power system, and a LAN was installed for computer systems at the Grand Junction, Colorado, office of UMTRAP. Improvements included uninterruptable power, special grounding, improved lightning protection, and special power service to critical data systems.

A RIS engineer also provided technical expertise in the design and installation of improved electrical grounding and surge protection at 11 PAM sites. Improvements included additional ground rods, extra grounding of the perimeter fence, and grounding of all internal metal elements in the shelter. Surge suppression included metal oxide varistors on the power lines and high-surge current zener diodes on all low-level signals.

1.2.6.5 Documentation

Drafting Procedures. Drafting procedures have been revised to indicate more precisely how the I&C Division operates, and these procedures have been reissued. Changes were made in drawing format, and new information was added for preparation and control of CAD-produced drawings. The format, which now includes the Energy Systems logo, is similar to that used by Engineering. The number of approval signatures required on drawings has been reduced and made consistent for original and revised versions.

Drawing Conversion to AutoCAD. Approximately 250 FRACAS engineering drawings were upgraded and translated into AutoCAD electronic files with scanners by an outside vendor; final rework was performed by I&C Division drafting personnel. Another 150 drawings were redrawn using I&C Division terminals. Stored on an optical disk for easy retrieval, these electronic files allow changes and upgrades to be efficiently reflected in the drawing revisions.

I&C Data Base/PC Network. Three data base systems were developed for the I&C Division: (1) To automate the I&C Division purchase requisition office, a system using a PC data base replaces a system on the DEC-10 computer. Advantages of the new system are improved user and multiuser access, computer-generated purchase requisitions, and a data base that contains all information needed to reprint a requisition. Installed on a Novell PC network, the system provides Division-wide access over the I&C Ethernet. (2) To automate I&C safety office records, a program using a PC data base was written to replace an existing PC-based system. The new design is fully relational and does not require the user to reinitialize the data base for each new safety inspection or group of safety meetings. The system maintains data bases of I&C personnel, I&C buildings/rooms, safety meetings, safety inspections, and radioactive sources. Efficiency has been improved by simplifying data input for various safety requirements. The system can generate informational reports on safety meeting attendance, safety inspections, and radioactive sources. (3) To produce travel authorization and travel expense forms using a Hewlett-Packard laser printer, information is conveniently stored as an electronic file once a form is printed. For each travel expense form printed, the system stores a summary that can be easily edited and printed. Users may store form templates for employees who travel frequently. The data base provides a history of travel expenses by account, traveler, location, and date.

Printed Circuit Board and Metal Photograph Panel Layouts. I&C Division designers continue to produce high-quality printed circuit board layouts using various CAD systems.

The P870 program by Automated Images is a PC package currently replacing Applicon by Schlumberger, which is a mainframe system. Significant time is saved with the use of autorouting, networking, and schematic capture capabilities of software programs now in use. A partial listing of printed circuit board projects designed by this group includes a pellet injection system, a telerobotic manipulator arm, a microwave communication link, a wide-range radiation monitor liquid crystal display, a neutron spectrometer, and a large-scale vehicle (LSV) data acquisition system.

Specialties. Using an AutoCAD graphics system by Autodesk, Inc., design layouts and drawings were created for fabricating a dual camera pan and tilt package for the HERMIES III robot, retrofitting an existing five-axis manipulator control slave with differential transformers, fabricating an anti-Compton Ball detector housing and a velocity filter target for the ORNL Physics Division, and documenting a capacitor winding fixture for FEMA.

Using AutoCAD, a RIS designer has updated all FEMA dosimeter drawings, detailed FEMA fabrication fixtures, prepared electrical schematics for the telerobotic manipulator arm, and updated a number of Bulk Shielding Reactor (BSR) drawings and placed them in electronic files.

The computer-augmented design and manufacturing (CADAM) graphics system by International Business Machines, Inc., was used to create design layouts and drawings for fabricating a gamma calibrator, a wake rake velocity sensor probe and purge valve assembly, and a remote automated sampler.

1.2.7 NEW CAPABILITIES

Engineering Design Center. The Engineering Design Center (EDC) has been established to provide computer aid to Division engineers. EDC hardware resources include an IBM 5080 graphics workstation connected to IBM 4383, SUN, and Apollo engineering workstations; IBM-compatible PCs; Apple Macintosh II computers; Postscript and Imagen laser printers; an HPGL plotter; and connections to the I&C engineering Ethernet network. Emphasis has been on electronics design, software development, mechanical design, and electronic publishing. The center also serves as a demonstration, test, and integration point for engineering workstations and tools that will be distributed in I&C work areas (see Fig. 1.2-16).

VLSI TOOLS. An ambitious program of acquisition and integration of commercial and university-developed software has been undertaken to equip I&C with leading-edge VLSI design tools. Installed first was Mentor Graphics, a well-integrated commercial package that includes schematic capture, analog and digital simulators, and interactive full custom VLSI layout. Recently, university tools including SPICE and RELAX analog simulators; BSIM, ESIM, and RSIM digital simulators; COSMOS and THOR compiled digital simulators; and a CRYSTAL timing simulator have been installed. Tools developed by the University of California at Berkeley include interactive VLSI layout with automatic design rule checking (MAGIC), PLA minimization and synthesis, extraction and netlist conversion programs, and multiple simulators. A newer package from Berkeley is based on a common data base (OCT) and an X Windows-based visual editor (VEM). OCT/VEM tools unify all views of a VLSI design in a data base and allow various design tools to integrate without conversion programs. The 1988 OCT/VEM tools include symbolic layout, automatic standard cell layout, and a Mississippi State University CMOS standard cell library

HARDWARE RESOURCES

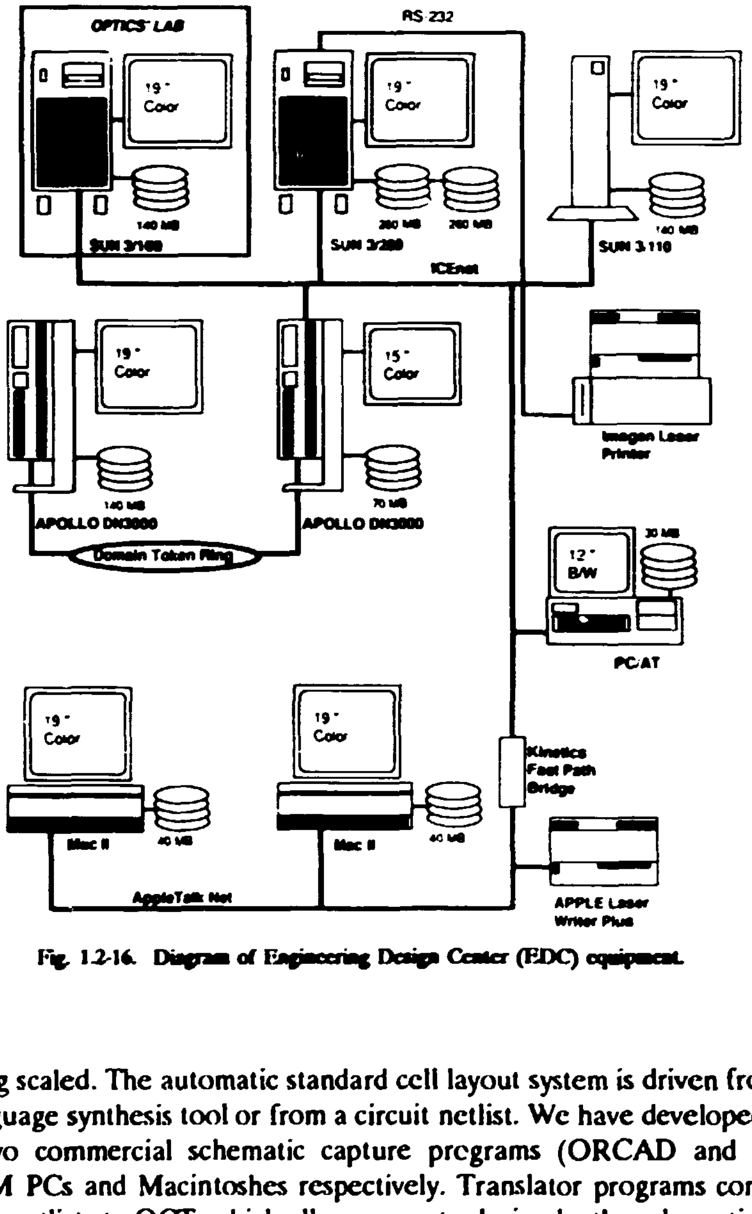


Fig. 1.2-16. Diagram of Engineering Design Center (EDC) equipment.

capable of being scaled. The automatic standard cell layout system is driven from a hardware description language synthesis tool or from a circuit netlist. We have developed standard cell libraries for two commercial schematic capture programs (ORCAD and Logic Works) running on IBM PCs and Macintoshes respectively. Translator programs convert ORCAD or Logic Works netlists to OCT, which allows users to design by the schematic entry method and to fabricate integrated circuits automatically under the OCT/VEM standard cell synthesis tools. Silicon compiler tools are being added to the OCT/VEM tool set.

Rapid Engineering Prototype of Printed Circuit Boards. The capability to fabricate prototype circuit boards rapidly is being developed to permit direct computer control of one-of-a-kind and prototype circuit boards by mechanical means (without using any photographic or chemical processing) and to allow quick response to support ORNL experiments. Reduced prototype circuit board fabrication time will drastically reduce evaluation time for test circuit topologies and layouts during system development.

Computer-Aided Design and Drafting. A computer-aided design and drafting (CADD) system has been installed in the I&C Division for mechanical and electrical-electronic design and drafting. The system is implemented on MS DOS-compatible PCs with high-resolution graphics displays. After a study of CADD packages, AutoCad from Autodesk, Inc., was selected for its capabilities (1) to easily duplicate features of existing manual drawings in electronic drawings, (2) to accommodate translation to and from CADAM drawings (CADAM is used in the Energy Systems engineering organization), and (3) to interface easily with CIMLINC (computer-integrated manufacturing LINC system), which is used in ORNL Plant and Equipment Division fabrication machine shops. All I&C drafting technicians in Building 3500 and most assigned to Y-12 use AutoCad for new drawings. Approximately 150 new drawings and 500 manual drawings needing revisions have been converted to electronic drawings on AutoCad; some 60% were converted directly by optical scanning, and 40% were redrawn using AutoCad PC workstations. In addition to AutoCad workstations, an IBM 5080 CADAM workstation is used to produce CADD drawings. Work is in progress to link CADAM drawings with CIMLINC.

Printed Circuit Board CAD. Computer-aided design of printed circuit boards in I&C has migrated from a time-shared minicomputer system from Applicon, Inc. (AGS-870) to a PC-based system running equivalent software from Automated Images, Inc. (P870). P870 provides functionality nearly identical to AGS-870 and performs better on PCs than the time-shared system. Data base conversion software has allowed easy transition to P870 and provides means to recover and update archived AGS-870 designs. Annual maintenance costs have dropped from ~$45K for three users to $4K for five users.

1.3 PUBLICATIONS AND PRESENTATIONS

D. J. Adams, D. L. Besbears, G. J. Capps, J. K. Jordan, G. W. Ott, M. B. Scudiere, C. P. White, R. N. Nodine, and R. A. Todd, *Naval Underwater Systems Center Torpedo Data Acquisitions System - Wet System Conceptual Design Report*, K/ETAC-64, April 1988.

B. P. Adkisson, *Maintenance Accountability, Jobs, and Inventory (MAJIC) Program Users' Manual*, ORNL/TM-10817, September 30, 1987.

G. T. Alley and M. L. Bauer, "Data Processing and Display Algorithms for Portable Instruments," *IEEE Trans. Nucl. Sci.* 35(1), 559-61 (February 1988).

R. G. Alsmiller, Jr., F. S. Alsmiller and T. A. Lewis, "Calculated Fraction of an Incident Current Pulse That will be Accelerated by an Electron Linear Accelerator and Comparisons with Experimental Data," *Trans. Am. Nucl. Soc.* **52**, 392 (1986); also *Nucl. Instrum. Methods Phys. Res.* **A256**, 409-417 (1987).

M. L. Bauer and J. A. Ramsey, "Some Solutions to On-Line Radiological Monitoring of Difficult Streams," IEEE Nuclear Science Symposium, San Francisco, Calif., October 22, 1987; *1988 IEEE Trans. Nucl. Sci.* 35(1), 571-74 (February 1988).

D. W. Bible, A. C. Morris, Jr., E. J. Kennedy, and S. F. Smith, "Radiation-Hardened Television Camera Development," France/USDOE Meeting on Remote Systems Technology, Oak Ridge, Tenn., May 5-9, 1986.

C. L. Britton, Jr., and E. Madden, "A PC-Based Receiver-Decoder for Remote Sensor Monitoring," Southeastcon '88, Knoxville, Tenn., April 10-13, 1988; *Proceedings*, 332-35 (April 1988).

T. W. Burgess, J. N. Herndon, S. L. Schrock, and C. H. Nowlin, *Summary Report of CFRP Experiences with Signal Transmission Techniques for Remote Applications*, ORNL/TM-10599, February 1988.

R. F. Carlton, R. R. Winters, G. W. Tweed, J. A. Harvey, and N. W. Hill, "^{189}Os + *n* s-Wave Mean Level Spacings and Strength Functions," American Physical Society, Crystal City, Va., April 20-23, 1987; *Bull. Am. Phys. Soc.* 32(4), 1110 (1987).

M. M. Chiles, S. A. McElhaney, and R. A. Todd, "Dual Scintillator with Pulse Shaping Electronics as a Wide-energy Range Neutron Detector," Health Physics Society 22nd Midyear Topical Meeting on Instrumentation, San Antonio, Texas, December 4-8, 1988; *Proceedings*, 186-89 (1988).

M. M. Chiles, J. T. Mihalczo, and E. D. Blakeman, "High-Efficiency Scintillation Detector for Thermal and High-Energy Neutrons and Gamma Radiation," IEEE Nuclear Science Symposium, San Francisco, Calif., October 21-23, 1987; *IEEE Trans. Nucl. Sci.* 35(1), 110-11 (February 1988).

R. K. Chohan and B. R. Upadhyaya, Review of *Advances in Two-Phase Flow and Heat Transfer*, vols. 1 and 2, S. Kakac and M. Ishii, Martinus Nijhoff Publishers, Boston, 1983; *Nucl. Tech.* 75, 253-55 (1986).

G. P. Coddens, J. A. Harvey, N. Salah, N. W. Hill, and N. M. Larson, "Resonance Structure of ^{33}S + *n* from Transmission Measurements," *Nucl. Phys.* **A469**, 480 (1987).

R. I. Crutcher, "Analysis of a Data Isolation Technique for a Broadband Local Area Network," Thesis presented for the Master of Science Degree, The University of Tennessee, Knoxville, June 1988.

R. I. Crutcher and P. D. Ewing, "Broadband Network Sharing by Different Sensitivity Levels," *USDOE Cent. Computer Security News*, 10-11, Los Alamos National Laboratory, Los Alamos, N.M. (December 1987).

R. I. Crutcher and P. D. Ewing, "A Mixed Modem Approach to Data Isolation on a Broadband Local Area Network," IEEE Southeastcon '88, Knoxville, Tennessee, April 10-13, 1988; *Proceedings* 36-39 (1988).

R. I. Crutcher and P. D. Ewing, "A Mixed Modem Solution for Sensitive Data Segregation on a Broadband Network," 11th DOE Computer Security Group Conference, Kansas City, Mo., May 3-5, 1988; *Proceedings*, 41-51 (1988).

R. L. Crutcher, P. D. Ewing, and T. W. Hayes, *Crosstalk Analysis of a Broadband Data Communications System*, ORNL-6431, November 1987.

R. Gwin, R. R. Spencer, and R. W. Ingle, "Measurements of the Energy Dependence of Prompt Neutron Emission from ^{233}U, ^{235}U, and ^{239}Pu for E_n = 0.0005 to 10 MeV Relative to Emission from Spontaneous Fission of ^{252}Cf," *Nucl. Sci. Eng.* **94**, 365 (1986).

B. S. Hoffheins, M. W. Seigel, and R. J. Lauf, "Intelligent Thick Film Gas Sensor," *Hybrid Circuit J.-Ayr, Scotland*, September 1987.

B. S. Hoffheins, R. J. Lauf, C. A. Walls, and M. W. Seigel, "Intelligent Thick Film Gas Sensor," Lecture at UT Engineering School Measurement Science Class, The University of Tennessee, Knoxville, March 30, 1988; also Texas Chapter of ISHM, Regional Symposium, Dallas, Tex., April 11-12, 1988.

B. S. Hoffheins, R. J. Lauf, and C. A. Walls, "Thick Film Gas Sensor," Measurement and Controls Engineering Center Information Meeting, University of Tennessee, Knoxville, July 20, 1988.

B. S. Hoffheins and R. J. Lauf, "Gas Sensor Arrays for Olfactory Sensing: Issues and Opportunities," Sensors Expo, Chicago, Ill., September 13-14, 1988.

L. D. Hulett, Jr., T. A. Lewis, R. G. Alsmiller, Jr., R. Peelle, S. Pendyala, J. M. Dale, and T. M. Rosseel, "A Design for a High Intensity Slow Positron Facility Using Forward Scattered Radiation from an Electron Linear Accelerator," *Nucl. Instrum. Methods Phys. Res.* **B24/25**, 905-908 (1987).

C. M. Jones, G. D. Alton, J. B. Ball, J. A. Biggerstaff, D. T. Dowling, K. A. Erb, D. L. Haynes, D. E. Hoglund, E. D. Hudson, R. C. Juras, S. N. Lane, C. A. Ludemann, J. A. Martin, M. J. Meigs, S. W. Mosko, D. K. Olsen, and N. F. Ziegler, "The Holifield Heavy Ion Research Facility," Seventh Tandem Conference, Berlin, West Germany, April 6-10, 1987; *Nucl. Instrum. Methods Phys. Res.* **A268**, 308-12 (1988).

R. C. Juras, "Tutorial on Computer Controls," XXI Symposium of Northeastern Accelerator Personnel (SNEAP), Tallahassee, Fla., September 28-October 1, 1987; World Scientific Publishing, Singapore, 1988.

R. C. Juras, N. F. Ziegler, M. J. Meigs, R. L. McPherson, D. E. Hoglund, and J. A. Biggerstaff, "Evolution and Development of the Oak Ridge 25URC Tandem Accelerator Control System," 7th Tandem Conference, Berlin, April 6-10, 1987; also, *Nucl. Instrum. Methods Phys. Res.* **A268**, 542-48 (1988).

R. C. Juras, N. F. Ziegler, G. D. Mills, M. J. Meigs, R. L. McPherson, C. M. Jones, D. L. Haynes, and G. D. Alton, "Oak Ridge 25URC Tandem Accelerator–SNEAP Lab Report," Symposium of Northeastern Accelerator Personnel, New Haven, Conn., October 24-27, 1988; *Proceedings*.

E. J. Kennedy, *Operational Amplifiers, Theory and Applications*, Holt, Rinehart and Winston, Inc., New York, 1988.

E. J. **Kennedy**, *Semiconductor Devices and Circuits*. Holt, Rinehart and Winston, Inc., New York (accepted for publication).

E. J. **Kennedy** and A. Wu, *Electronics Irradiation Testing*, TR-EE/EL-19, The University of Tennessee, Knoxville, February 19, 1988.

E. J. **Kennedy** and T. N. Blalock, Development of a Radiation Hardened 600 Watt Switchmode Power Converter, TR-EE/EL-20, The University of Tennessee, Knoxville, August 1988.

R. J. Lauf, R. F. Wood, P. H. Fleming, and M. L. Bauer, *New Applications of Silicon Micromachining*, ORNL/TM-10590, June 1988.

R. L. Macklin, G. De Saussure, R. B. Perez, and R. W. Ingle, "High Resolution Measurement of the ^{238}U Neutron Capture Yield for Incident Neutron Energies Between 1 and 100 keV," *Trans. Am. Nucl. Soc.* 5[illegible] 344 (1987).

R. L. Macklin, J. A. Harvey, N. W. Hill, and G. L. Tweed, "Neutron Capture and Total Cross Sections of ^{144}Sm + *n*," 1986 Fall Divisionsal Meeting of the American Physical Society, Vancouver, October 9-11, 1986.

J. A. Martin, D. T. Dowling, D. L. Haynes, E. D. Hudson, C. M. Jones, R. C. Juras, S. N. Lane, C. A. Ludemann, M. J. Meigs, W. T. Milner, S. W. Mosko, D. K. Olsen, and N. F. Ziegler, "Operational Experience for Coupled Operation of the Holifield Tandem Electrostatic Accelerator and Isochronous Cyclotron," Eleventh International Conference on Cyclotrons and Their Applications, Tokyo, Japan, October 13-17, 1986; *Proceedings*, 38-45 (1987).

S. A. McElhaney, M. M. Chiles, and M. L. Bauer, "Thin Film Techniques for Developing a More Rugged Alpha Scintillation Detector," Health Physics Society 22nd Mid-Year Topical Meeting on Instrumentation, San Antonio, Tex.; December 4-8, 1988; *Proceedings*.

S. A. McElhaney, M. M. Chiles, R. J. Lauf, and M. L. Bauer, "Ruggedized Alpha Radiation Detector," 1988 IEEE Nuclear Science Symposium, Orlando, Fla., November 9-11, 1988.

J. A. Moore, "Electronic Implementation of a Closed-Loop Gas-Flow Control System," Thesis presented for the Master of Science Degree, The University of Tennessee, Knoxville, December 1986.

J. A. Moore, *Electronic Implementation of a Closed-Loop Gas-Flow Control System*, ORNL/TM-10660, February 1988.

V. M. Morgenstern, B. R. Upadhyaya, and O. Glockler, "Signal Anomaly Detection and Characterization, DOE/NE/37959-18, August 1988.

A. C. Morris, Jr., M. L. Bauer, and R. E. Pudelek, "Improved Capabilities for Area Environmental Monitoring at Oak Ridge National Laboratory," IEEE Nuclear Science Symposium, Washington, D.C., October 27-November 1, 1986; *IEEE Trans. Nucl. Sci.* **NS-34**(1), 595-600 (February 1987).

A. C. Morris, Jr., M. L. Bauer, and R. E. Pudelek, "Improved Capabilities for Area Monitoring at Oak Ridge National Laboratory," Knoxville Ruritan Club, Knoxville, Tenn., May 14, 1987.

R. S. Ramsey and R. A. Todd, "Pulsed-Modulated Helium-Ionization Detection," *J. Chromatog.* **399**, 139-48 (1987).

D. Shapira, H. J. Kim, B. Burks, J. Blankenship, R. Varner, K. Teh, and R. Novotny, "HILI–A Heavy Ion-Light Ion Detection System," American Chemical Society Symposium on Nuclear Detectors for Nuclear and Radiochemistry, Denver, April 5-10, 1987.

M. L. Simpson, "Optoelectronic-Strain Measurement System for Rotating Disks," *Exp. Mech.* (March 1987).

S. F. Smith, "A Study of Universal Modulation Techniques Applied to Satellite Data Collection," Dissertation presented for the Doctor of Philosophy Degree, The University of Tennessee, Knoxville, June 1987.

S. F. Smith, "AIMS Radiation-Hardened Control System Conceptual Design," France/USDOE Meeting on Remote Systems Technology, Oak Ridge, Tenn., October 6-7, 1987.

S. F. Smith and E. J. Kennedy, "Radiation Hardening of In-Cell Electronics," France/USDOE Meeting on Remote Systems Technology, Marseilles, France, February 19-24, 1987.

R. R. Spencer, J. A. Harvey, N. W. Hill, and L. W. Weston, "Parameters of the 1.056-eV Resonance in ^{240}Pu," *Nucl. Sci. Eng.* **96**, 318 (1987).

D. K. Su and E. J. Kennedy, *The Effects of Gamma and Neutron Irradiations on Linear Integrated Circuits and Power Devices*, ORNL/TM-10480, June 1988.

R. A. Todd, "Pulsed Helium Ionization Detector Electronics System for Gas Chromatography," Dissertation presented for the Doctor of Philosophy Degree, The University of Tennessee, Knoxville, March 1988.

N. F. Zeigler, M. J. Meigs, and R. C. Juras, "Recent Electronic Improvements to the Oak Ridge 25 URC Accelerator," Seventh Tandem Conference, Berlin, West Germany, April 6-10, 1987.

N. F. Ziegler, G. D. Mills, M. J. Meigs, R. L. McPherson, R. C. Juras, C. M. Jones, D. L. Haynes, and G. D. Alton, "Status of the 25URC Accelerator," XXI Symposium of Northeastern Accelerator Personnel, Tallahassee, Florida, September 28-October 1, 1987, *Proceedings*, 5-10.

N. F. Ziegler, W. T. Milner, G. D. Mills, M. J. Meigs, R. L. McPherson, R. C. Juras, C. M. Jones, D. E. Hoglund, D. L. Haynes, J. A. Biggerstaff, and G. D. Alton, "Status of the ORNL 25URC Accelerator," Twentieth Symposium of Northeastern Accelerator Personnel, SNEAP XX, Notre Dame, Indiana, November 3-6, 1986; *Proceedings*, 483-86.

N. F. Ziegler, G. K. Schulze, J. W. Rochelle, W. T. Milner, M. J. Meigs, R. L. McPherson, and R. C. Juras, "Recent Electronic Improvements to the Oak Ridge 25URC Accelerator," *Nucl. Instrum. Methods Phy. Res.* A268, 509-512 (1988).

2. MEASUREMENT AND CONTROLS ENGINEERING

OVERVIEW

D. W. McDonald

The Measurement and Controls Engineering Section (MACES) provides advanced engineering and R&D on instrumentation systems for DOE, for other federal agencies, and for the research divisions within ORNL. The emphasis of our section is in instrumentation systems engineering and instrumentation systems integration. Our Section includes specialists in all areas of general instrumentation as well as in electronics, controls, automation, metrology, electro-optics, chemical processes, intelligent systems, image processing, advanced computer architectures, and computers for real-time data acquisition and analysis. Our Section management philosophy stresses technical excellence, project management sophistication, and sensitivity to sponsor needs. This approach allows us to successfully carry out large, complicated instrumentation-related projects requiring interdisciplinary skills.

ORGANIZATION

The Section currently consists of approximately 80 staff members in 8 development groups. Each group has technical specialty areas in which it develops and maintains section expertise. Three groups represent our main interface to other Energy Systems organizations. Two of the three groups, at Y-12 Process Systems Development and X-10 Process Systems Development, are staffed to support large engineering development projects. Emphasis is on requirements definition, estimating, scheduling, and systems integration. The third interface group, X-10 Research Support, is staffed to support the research divisions at ORNL. The scope of this work tends to be smaller than that of the other two groups. In addition, there are five technology groups, which are more technically focussed. While our interface groups require the skills of instrumentation generalists, the technology groups are made up more of specialists. The Instrument Research Group is presently involved primarily in electro-optics and image processing; the Electromagnetic Technology Group supports large projects with electromagnetic compatibility concerns; the Real-Time Computer Systems Group is extending the performance of high-speed data acquisition and analysis systems; the Advanced Architecture Group is investigating various software products and hardware systems for advanced computing systems and artificial intelligence use; and the Measurement Research Group is investigating extensions to measurement science for calibration and on-line metrology applications. Specialists from the various technology groups work on large laboratory projects in a matrix management arrangement. In addition, all the development groups have responsibility for projects from other government agencies as well as smaller projects from ORNL research divisions. The educational level of the engineering staff includes approximately 9% Ph.D., 46% M.S., and 44% B.S. degrees.

ACCOMPLISHMENT HIGHLIGHTS

- MACES personnel have attained national recognition by winning a prestigious R&D-100 Award in each of the past 2 years. These awards are given by *R&D Magazine* to the top 100 technical innovations in the nation each year. Our 1987 award was for a remote cable sensor identifier (Fig. 2-1), and our 1988 award was

ORNL Photo 9693-87

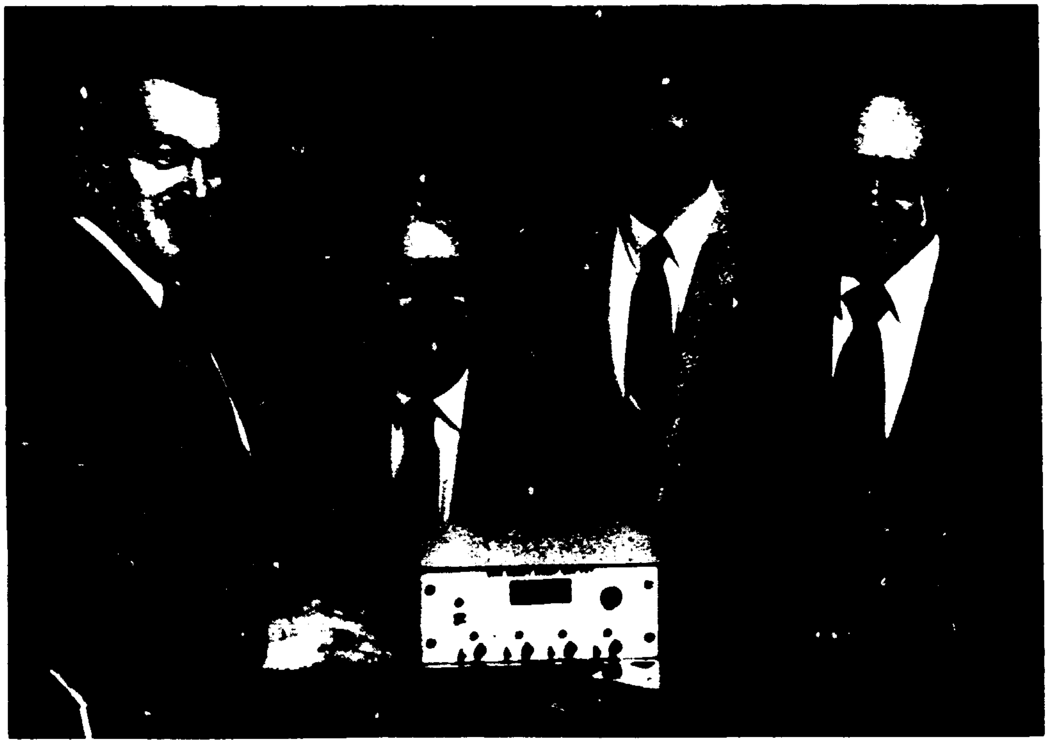


Fig. 2-1. 1987 R&D-100 Award winner: Remote sensor and cable identifier.

for the OPSNET parallel expert system computer (Fig. 2-2). These innovations are discussed more fully in Sects. 2.6.3 and 2.4.1 respectively.

- Developed a prototype personal rf dosimeter for the U.S. Navy (Fig. 2-3). This development is described in Sect. 2.7.5.

- Developed for the Bureau of Engraving and Printing a computer vision camera-based, high-speed inspection system for detection and quantification of printing flaws in U.S. currency (Fig. 2-4). This work is described in Sect. 2.6.1.

- Completed two major technical security assessment programs for DOE, which will result in the savings of millions of dollars nationwide in the areas of secure phone lines and broadband cable networks (Fig. 2-5). These assessments are described in Sect. 2.7.

- Continued significant contributions to major upgrades and automation of facilities and processes at the Oak Ridge Y-12 complex (Fig. 2-6). This automation work is described in Sect. 2.3.

- Developed for the U.S. Navy a system for measuring flight simulator parameters in support of new theories on motion sickness (Fig. 2-7). This development is described in Sect. 2.2.

ORNL Photo 4285-87

Fig. 2-2. 1988 R&D-100 Award winner: The expert system parallel computer OPSNET.

ORNL Photo 9141-88

Fig. 2-3. Early developmental prototype personal rf dosimeters.

ORNL Photo 7176-88

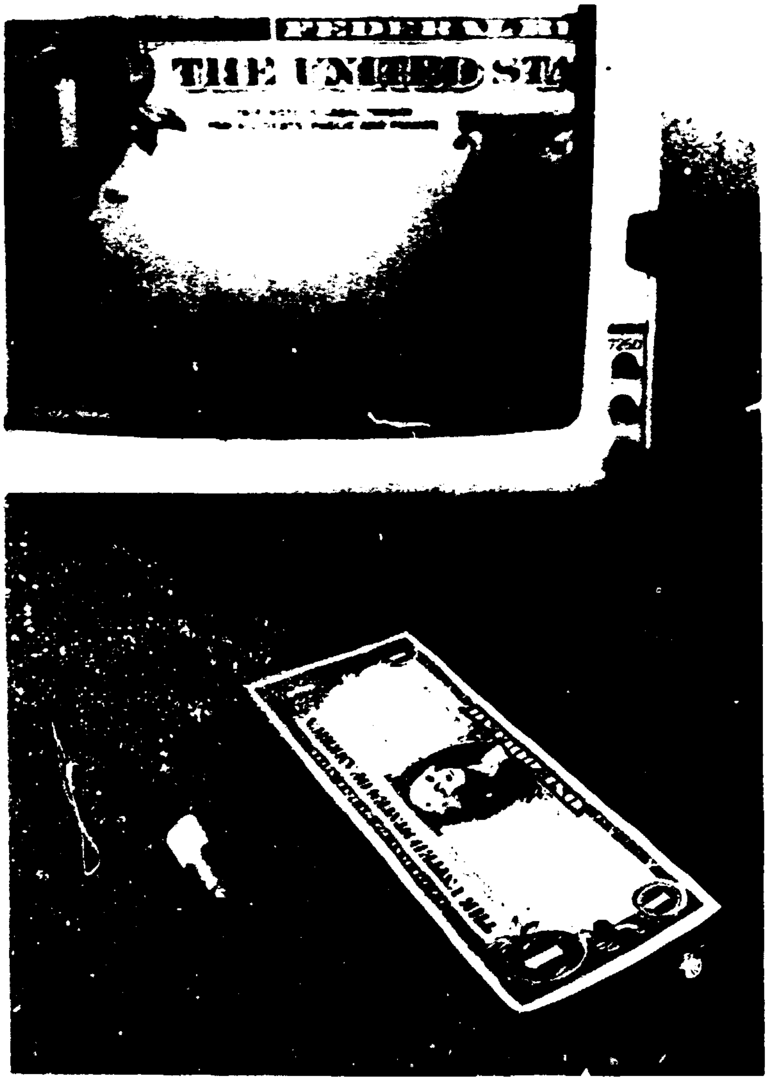


Fig. 2-4. Flaw isolation on U.S. currency.

- Developed and evalua veral computer architectures, systems, and software for implementa f expert system techniques in real-time applications (Fig. 2-8). These efforts are described in Sect. 2.4.

- Figure 2-9 is an example of the many PC-based instrumentation systems installed in user facilities throughout ORNL. These systems, which are described in Sect. 2.1, include the following:

  - Roof Research Facility
  - Melton Hill Monitoring System
  - Air Pollution Effects Field Research Facility
  - Advanced Neutron Source Corrosion Test Loop
  - Alternate Fuels Utilization Program Diesel Engine Test Facility
  - Contactor Test Stand
  - Walkers Branch Watershed Monitoring System

ORNL Photo 4404-87

Fig. 2-5. Broadband test network with associated instrumentation.

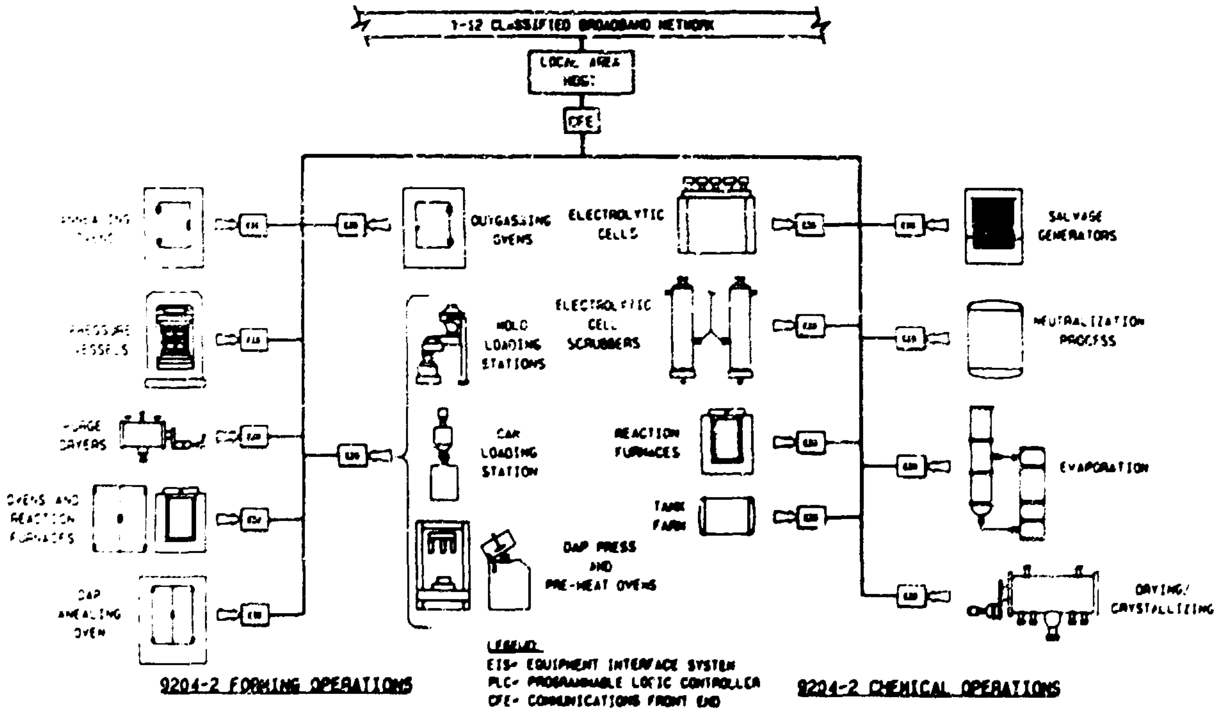


Fig. 2-6. Automation efforts in Y-12 Building 9204-2 chemistry and forming operations.

ORNL Photo 10377-87

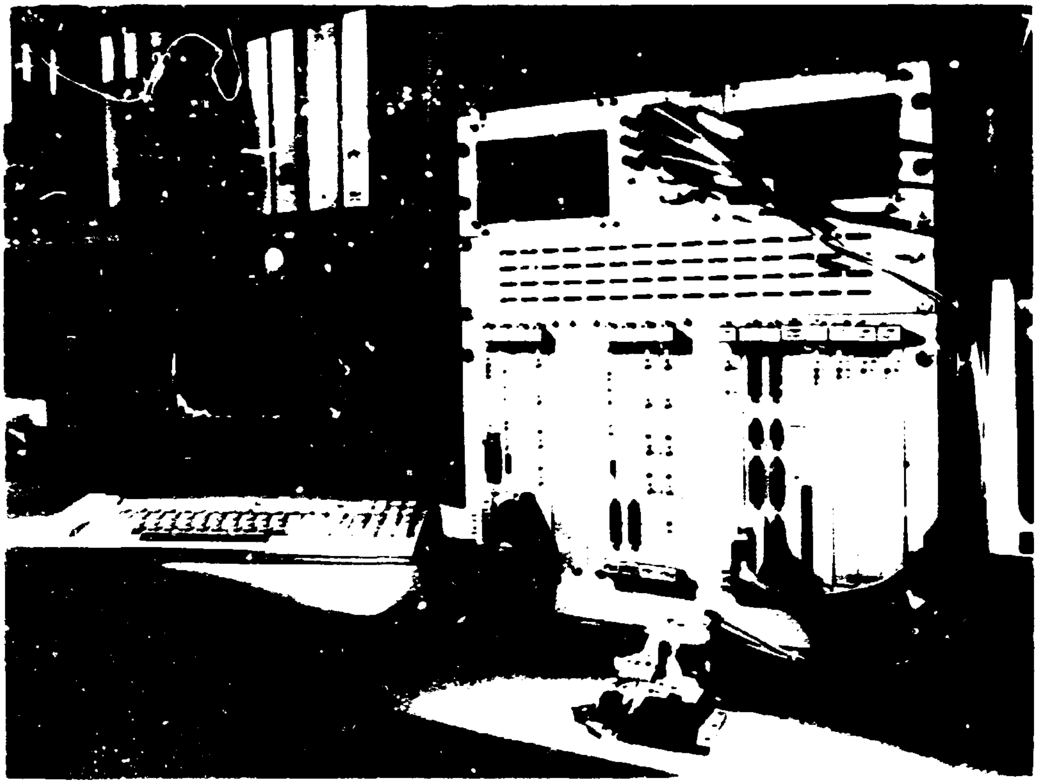


Fig. 2-7. Inertia measurement device and associated electronics.

ORNL Photo 3549-88

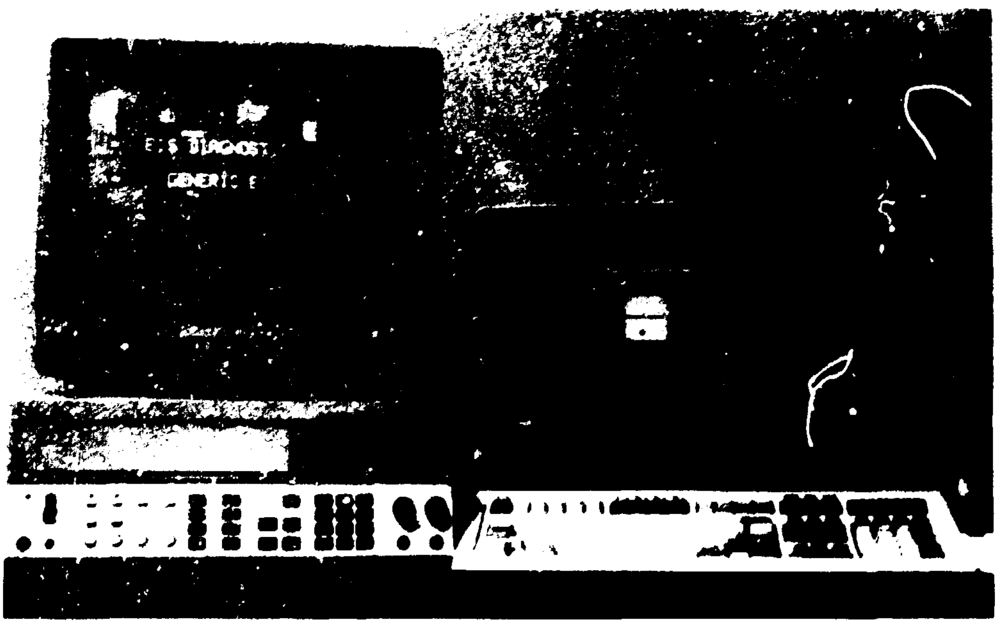


Fig. 2-8. The expert diagnostics systems use equipment photographs and clear instructions to guide the maintenance technician.

ORNL Photo 6830-86

Fig. 2-9. PC-based control and data acquisition and sampling and analysis subsystems.

- Completed an upgrade of the High Flux Isotope Reactor Experiment Facility (Fig. 2-10). This work is described in Sect. 2.2.1.

- Developed new diagnostic tools for assessing the performance of a "multilevel perceptron" neural network model (Fig. 2-11). This work is described more fully in Sect. 2.8.1.

FUTURE TRENDS

We will continue to pursue application of advanced data processing technologies to measurement and control as our primary technical thrust. Our advanced microprocessor, programmable logic controller (PLC), and superminicomputer background has formed the foundation for our entry into reduced instruction set computers, erasable programmed logic devices, n-tuple and multilevel perceptron neural networks, transputers, image processing pipelines, and high-performance array processors. As in the past, our emphasis will be on real-time applications. These technologies will be distributed throughout the spectrum of our applications from smart sensor projects to large automation programs.

We have seen a dramatic increase in our work for non-DOE federal agencies, and this trend is expected to continue. In addition, DOE plans to increase the scope of modernization efforts at Y-12, and continuing DOE support for the Advanced Neutron Source reactor and the Atomic Vapor Laser Isotope Separation Program bode well for continued challenging opportunities for our staff. We anticipate the following trends in funding from sponsors over the next 2 years:

ORNL Photo 7609-88

Fig. 2-10. Upgraded HFIR instrument panels.

ORNL Photo 7806-87

Fig. 2-11. Software emulation of a neural-like paradigm.

Advanced Neutron Source reactor	Increase
NASA	Increase
U.S. Air Force	Increase
MODIL	Increase
Strategic Defense Initiative	Increase
U.S. Navy	Increase
Atomic Vapor Laser Isotope Separation	Stable
Y-12 production modernization	Stable
Bureau of Engraving and Printing	Stable
ORNL research divisions	Stable
Fuel Reprocessing Program	Stable
Japanese fuel reprocessing	Decrease

New initiatives are planned in the areas of sensor research, environmental monitoring instrumentation, and precision surface measurements of large optical components.

2.1 X-10 RESEARCH SUPPORT

J. A. McEvers

T. L. Bowers*	J. L. Horton
R. M. Burnett	J. T. Hutton
J. A. Hawk	N. D. McCollough
J. S. Hicks	W. P. Murray†
M. S. Hileman	D. L. Senn‡

The X-10 Research Support Group is responsible for providing design and fabrication support in the areas of instrumentation and control for research divisions at ORNL. The divisions that have received direct support during the last reporting period include Energy, Environmental Sciences, Metals and Ceramics, and Chemical Technology. Support consists of interacting with the principal investigator during the initial conceptual design of an experiment or project, developing detailed designs for the instrumentation and/or controls equipment, specification and procurement of required components, and performing or overseeing fabrication and checkout activities.

2.1.1 ENERGY DIVISION SUPPORT

2.1.1.1 Energy Conservation Investment Program

This work included investigative and reporting support for the Energy Conservation Investment Program (ECIP) and design, fabrication, and installation of PC-based data acquisition systems for the Roof Research Facility.

ECIP-related support involved on-site evaluation of equipment and facility upgrades performed for the purpose of conserving energy at various U.S. Army installations within the continental United States. Energy consumption data (taken both before and after the upgrade) were analyzed along with supporting contract documents to determine the savings-to-investment ratio. This information was then used by the U.S. Army Facilities Engineering Support Agency to assess the relative merit of each energy conservation investment activity.

2.1.1.2 Roof Research Center Data Acquisition and Control Network

A major support activity for the ORNL Energy Division was the specification, design, fabrication, installation, and checkout of a multiunit, industrialized PC data acquisition and reporting system. This system was implemented using three IBM industrial AT-type computers, with a unit being placed at each of the following areas: (1) the roof panel fabrication and checkout area, (2) the large-scale climate simulator area, and (3) the central facility control room. The roof panel fabrication and checkout area system is equipped with multiple channels of low-level analog input and permits immediate sensor verification during sensor installation without the need for repetitive, manual sensor connection.

---

*Westinghouse Corporation.
†Midwest Technical, Inc.
‡AG Associates.

The large-scale climate simulator-related system, equipped with both high- and low-level analog input channels, provides direct display and logging of roof panel sensor data and specific chamber parameters. This system also communicates with dedicated, two-loop process controllers to define set points and obtain process variable values. A third system, which serves as the main operator interface to the facility and provides central data storage and analysis capabilities, may be operated alone or in direct communication with the other two systems, which continue to store and display data while the control room system is off-line.

2.1.2 ENVIRONMENTAL SCIENCES DIVISION SUPPORT

Pollutant Gas Generation, Distribution, and Monitoring System

This group has provided instrumentation and controls support to the ORNL Environmental Sciences Division by designing, fabricating, and supporting an atmospheric pollutant gas distribution and monitoring system (See Fig. 2.1-1).

The effects on terrestrial plant life of increased levels of ozone in the atmosphere have been and continue to be studied. In situ determination of effects on plants is of particular value because it essentially allows the plants to be exposed to otherwise normal conditions while also being exposed to elevated levels of specific pollutant gases.

A pollutant gas (ozone) generation, distribution, and monitoring system was developed for use in determining its detailed effects on plants (See Fig. 2-9 on p. 67). The system provides for both "ambient + fixed level" and "n times ambient" elevation of ozone levels in open field chambers. The plants to be exposed are located in specific exposure chambers (see Fig. 2.1-2).

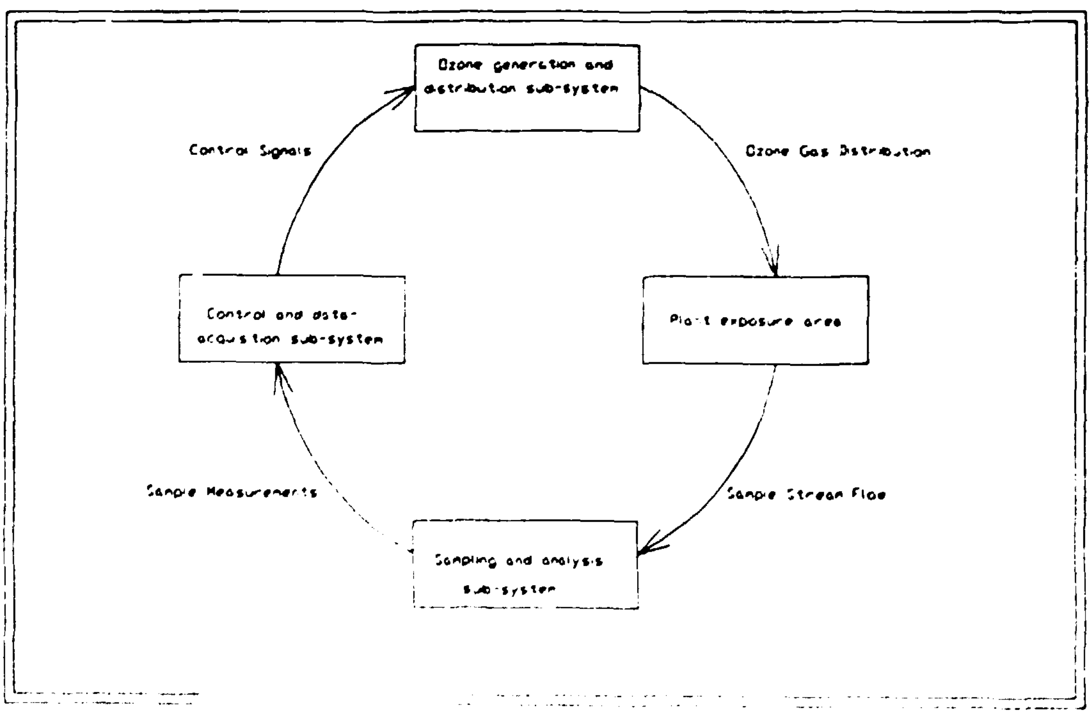


Fig. 2.1-1. Block diagram of atmospheric pollution flow control and monitoring system.

ORNL Photo 5063-86

Fig. 2.1-2. Aerial view of exposure area.

2.1.3 METALS AND CERAMICS DIVISION SUPPORT

Development of materials that can withstand the hostile and corrosive environments found within industrial flues is of major importance in fabricating waste heat recovery systems. Exposure tests in industrial furnaces have been used in recent years to compare the high-temperature corrosion of various candidate heat exchanger materials. Specimens have been placed in the flues of aluminum remelt furnaces, steel soaking pits, steel reheat furnaces, and glass furnaces. In most cases, specimens were exposed to ambient furnace conditions for a time determined by the production schedule. During exposure, temperatures sometimes could be monitored and a temperature-time history determined, but specimen temperature could not be controlled. Exposure conditions—maximum and minimum temperatures, heating and cooling rates, temperature-time history, and composition of combustion products—have been dependent on production requirements.

Research aimed at developing a controlled-temperature flue gas corrosion probe was performed in cooperation with the ORNL Metals and Ceramics Division. The objective of this work was to develop a conceptual design for an instrumented, temperature-controlled corrosion probe suitable for testing candidate heat exchanger materials (both metallic and ceramic) in high-temperature combustion environments. Computer models evaluated the characteristics of the probe prior to actual fabrication. The effects of size, spacing, cooling air flow rate, heating capacity, and flue gas temperature and flow rate were evaluated to determine possible ranges of temperature control. A photograph of the initial probe configuration is shown in Fig. 2.1-3.

The probe is cooled by conventional plant air (100 psig). Initially, heating was attempted using electricity, but this proved to be unsatisfactory. Currently, the probe is heated by a mixture of propane and oxygen, which yields a probe temperature >920°C in still air at 25°C.

2.1.4 CHEMICAL TECHNOLOGY DIVISION SUPPORT

ORNL's Tower Shielding Facility has been used for many years to conduct drop tests of large (up to 100-ton) shipping containers for radioactive material or hazardous waste. Drop tests and horizontal impact tests are part of U.S. Nuclear Regulatory Commission (NRC) licensing requirements for container designs.

A drop test usually consists of a series of 30-ft drops onto a steel pad with the container in a different orientation at each impact. Test containers are instrumented with various sensors which record data during the actual drop: accelerometers, strain gages, pressure transducers, displacement sensors, and thermocouples. A high-speed recording and analysis system has been developed to collect and study sensor data obtained during tests. The drop test facility also has a programmable logic controller-based countdown sequence controller to automatically coordinate operation of the recording instrumentation and

Photo No. YP-5986

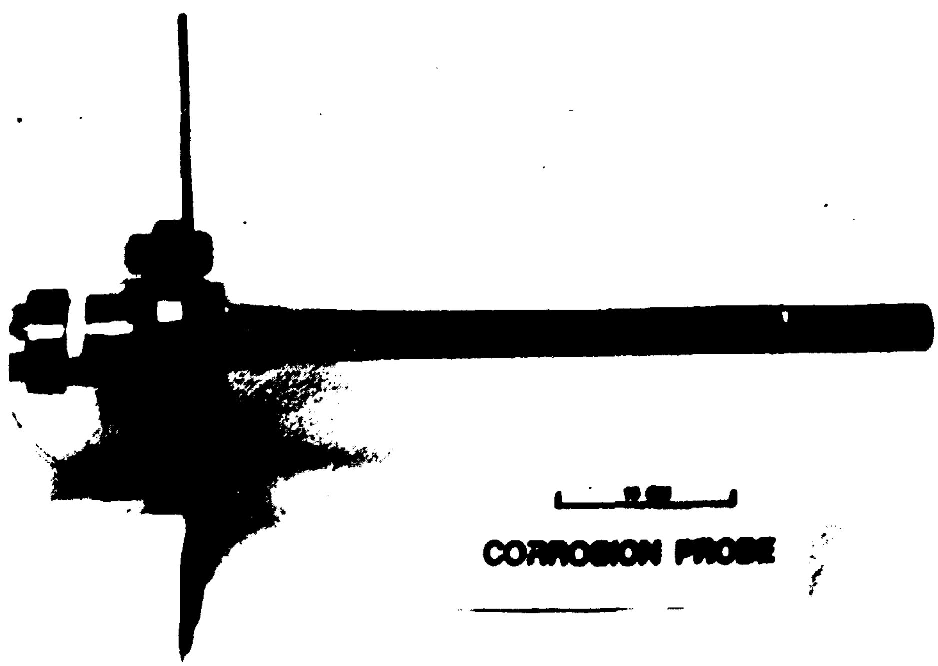


Fig. 2.1-3. Controlled-temperature flue gas corrosion probe assembly.

The most noteworthy test series conducted during this report period was for some specially designed canisters for shipment of damaged fuel rods from the Three Mile Island (TMI) reactor. Figures 2.1-4 through 2.1-7 illustrate some of the key features of the drop test facility.

2.1.5 SPECIAL TOPICS

2.1.5.1 PC-Based Data Acquisition and Control Systems

The X-10 Research Support Group has provided data acquisition and control capabilities for several applications through the use of industrialized, rack-mounted PCs. Although originally intended for office use, the personal computer–especially in the industrialized, rack-mountable configuration–is a very adaptable tool for field and laboratory data acquisition and control applications. The availability of field I/O hardware and multiple programming languages makes it quite advantageous to apply PCs to small- to medium-scale tasks. The X-10 Research Support Group has provided fully functional, turnkey systems for the following applications:

ORNL Photo 7870-85

Fig. 2.1-4. Countdown controller being prepared for TMI canister tests.

ORNL Photo 7880-85

Fig. 21-5. On-line recording and analysis instrumentation for TMI canister tests.

- Contactor Test Stand Data Acquisition and Control System (Fuel Recycle Division)

- Roof Research Center Large-Scale Climate Simulator Data Acquisition and Control System (Energy Division)

- Roof Research Center Roof Panel Fabrication Area Checkout System (Energy Division)

- Roof Research Center Central Control Room Data Acquisition and Control System (Energy Division)

- Air Pollution Effects Field Research Facility: Ozone Flow Control and Monitoring System (Environmental Sciences Division)

- Air Pollution Effects Field Research Facility: Environmental Data Acquisition and Control System (Environmental Sciences Division)

- Walkers Branch Watershed Monitoring System (Environmental Sciences Division)

- Melton Hill Monitoring System (Environmental Sciences Division)

ORNL Photo 7672-85

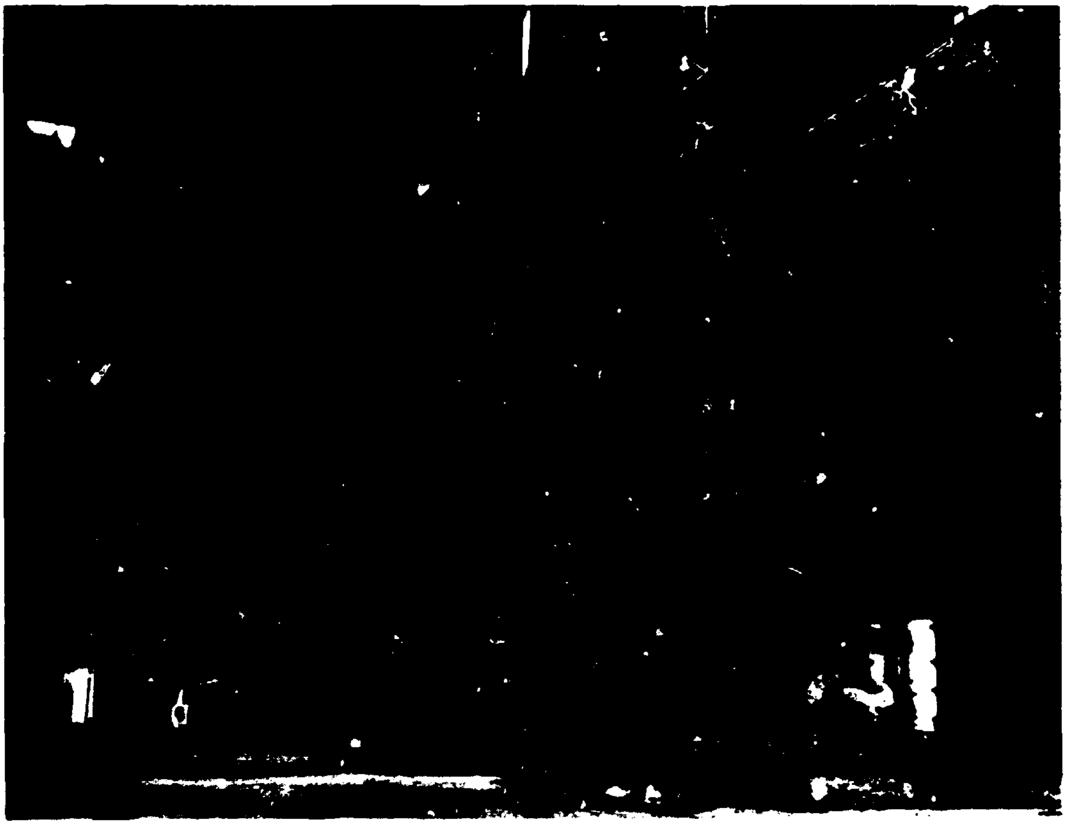


Fig. 2.1-6. TMI canister ready for 30-ft drop test.

2.1.5.2 U.S. Air Force Remote Advisory Panel Network

The need to communicate shelter status information from aircraft shelters to a central command location gave rise to development of a low-cost, microprocessor-based status panel reporting network for the U.S. Air Force Remote Advisory Panel (RAP) (see Fig. 2.1-8).

The system is based on establishment of remote aircraft shelter computer stations that report to a single central host computer over a multidrop two-wire, half-duplex communication network. A keypad and alphanumeric display serve as the user interfaces, and several keys are multifunctional. Keys are assigned a specific function corresponding to an action or status code. The ALPHA and NUMERIC keys alter the function of other keys to provide support for all letters of the alphabet, for the digits 0 through 9, for editing functions, and to initiate transmission of a message. As initially conceived, the system would use a smaller scale computer (e.g., personal computers) as the central system for periodically polling individual stations to gather status information and acknowledge receipt of information (See Fig. 2.1-9). Full battery backup supports operation for up to 24 h in the event of power failure. Each station is polled in turn and requested to report any change-in-status information. Information is then displayed at the central station for verification, and an appropriate confirmation message is sent to the remote station.

ORNL DWG 86-537

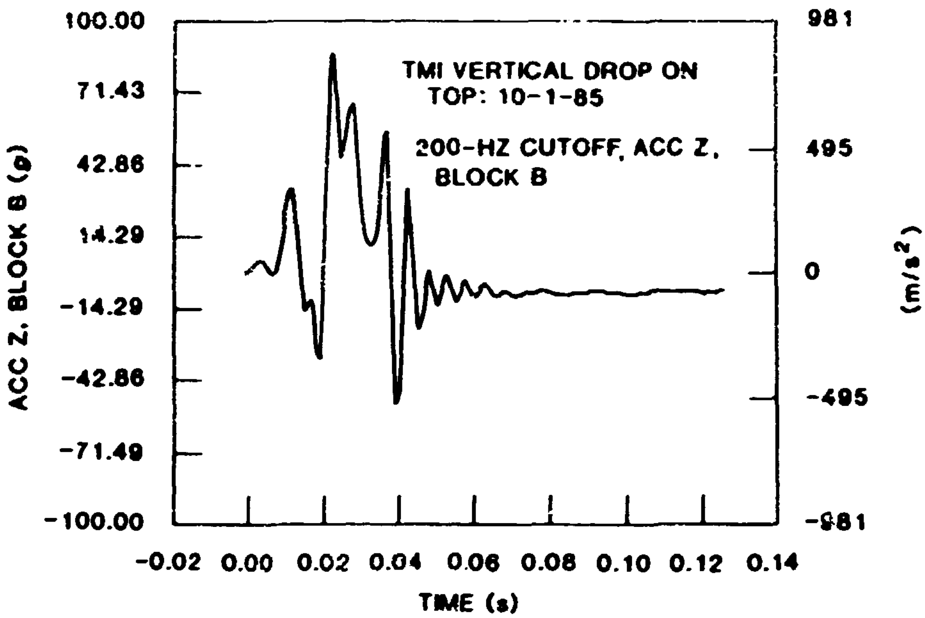


Fig. 2.1-7. Typical accelerometer signal from TMI canister impact.

ORNL Photo 3733-87

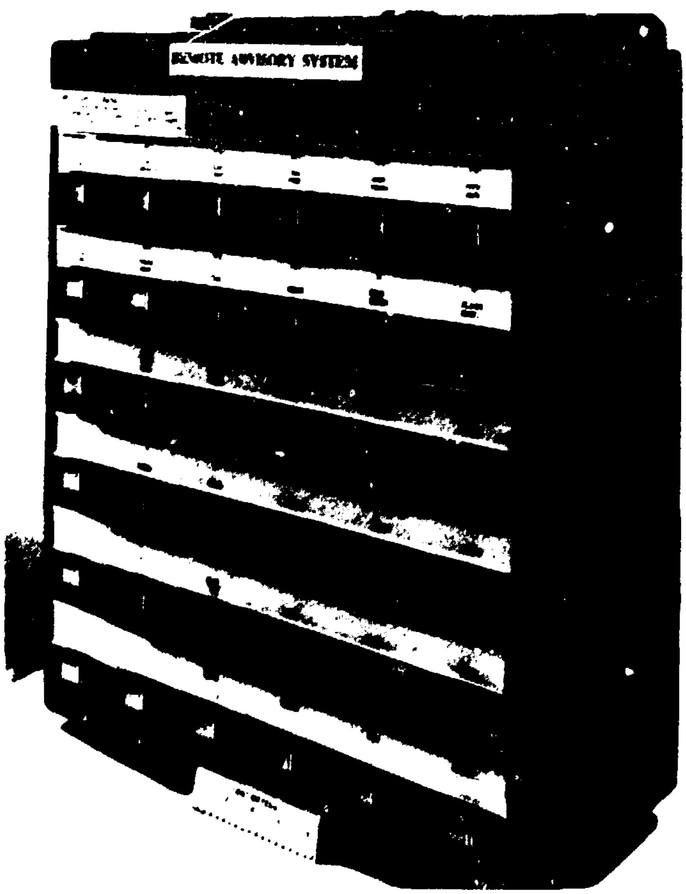


Fig. 2.1-8. Remote advisory system station.

ORNL Photo 3735-87

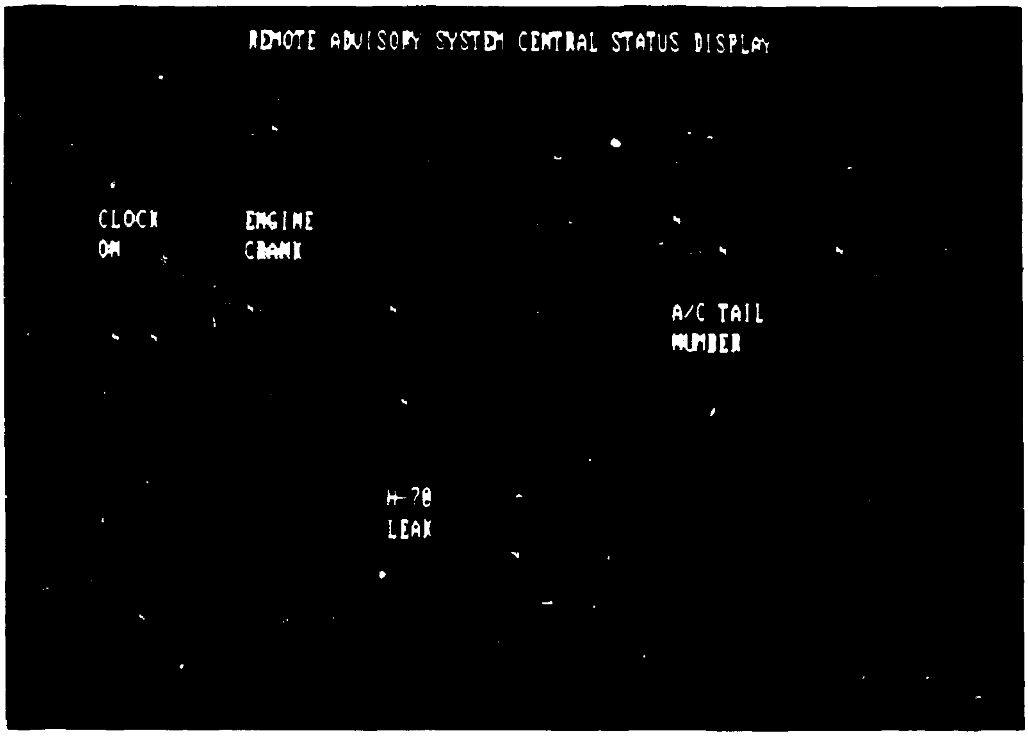


Fig. 2.1-9. Central station status display.

The network was developed through the prototype phase and demonstrated to be fully functional. Although funding cutbacks prevented full implementation of the system, the design has proven to be reliable, responsive, and suitable for any application in which information must be reported from remote sites in a timely and efficient manner. A prototype expert system developed in conjunction with this activity is based on Texas Instruments, Inc., Personal Consultant Plus expert systems software and was intended to aid U.S. Air Force field maintenance personnel in locating and correcting system faults.

2.2 X-10 PROCESS SYSTEMS DEVELOPMENT

J. O. Hylton

G. O. Allgood — R. E. Hutchens
A. V. Blalock — W. F. Johnson
C. L. Carnal — C. J. Remenyik
T. E. Gallegos — A. A. Shourbaji
J. E. Hardy

The Process Systems Development Group is involved in development, design, and installation of instrumentation and process control systems for ORNL facilities and research programs, and members have participated in a large variety of activities during this reporting period. We have significantly increased our involvement in projects for upgrading and modernizing ORNL operating facilities, reactors, and hot cells, generally by replacing obsolete instruments and improving the readability of display and control panels with digital or computer-driven displays. These projects have, in many cases, been joint efforts with the I&C Maintenance Management Department. The contributions of the Maintenance Field Engineering Group have been invaluable and must be acknowledged here. Some of these projects are discussed in more detail below.

Three major R&D programs started in previous periods have continued to require significant amounts of effort. Consolidated Fuel Reprocessing Program activity has increased, with much development related to a Japanese reprocessing plant. The Advanced Instrumentation for Reflood Studies (AIRS) Program is beginning to wind down as the last major system of the project has been installed at a West German test facility. The SIMSICK project for the Navy involves development of improved control systems for flight simulators to provide more realistic visual and motion effects and to reduce the amount of motion sickness experienced by pilots resulting from the artificial stimuli of the simulator.

2.2.1 FACILITY UPGRADE PROJECTS

2.2.1.1 HFIR Experiment Facility

The extended shutdown of ORNL reactors and the permanent closing of the Oak Ridge Research Reactor (ORR) during this period led to a major renovation of the experiment facility at the HFIR. The HFIR core has several tubes that permit insertion of test capsules in which long-term materials irradiation experiments can be conducted. These capsules usually are heavily instrumented, both to obtain experimental data and to monitor the condition of the capsule for problems that might affect the operation or safety of the reactor. Capsules are monitored and controlled from the experiment control room, which contains control panels, data acquisition systems, alarms, and reactor control interfaces for each experiment. The upgrade has involved complete removal and replacement of the old experiment panels and safety systems.

Because the experiment safety system can interact with the reactor controls, it is designed with a philosophy of three independent and redundant instrument channels for critical safety functions. Any section of the experiment system that will affect reactor controls requires a two-of-three coincidence from the safety channels.

Current plans for the facility include five separate experimental capsules, each with its own control panel consisting of monitoring instruments, annunciators, and a data logger. The data loggers will be linked on a LAN with an IBM PC AT host that will serve as the facility data acquisition system. The monitoring and voting logic required for reactor safety system interaction will be done by three PLCs (one per channel) that serve all five experiments. Figure 2-10 (p. 69) shows typical experiment instrument panels.

Several smaller upgrade projects were completed involving hot cell or other test facilities containing radioactive materials. The usual objectives of these upgrades were to replace obsolete instruments for which spare parts are no longer available and, at the same time, improve the human-machine interface for operators who have to respond to certain emergency or abnormal conditions. A few examples are described below.

2.2.1.2 DBA Paint Specimen Autoclave

The design basis accident (DBA) autoclave is a facility in which painted specimens are first irradiated in the HFIR and then tested in an autoclave under conditions that might exist inside the containment of a pressurized water reactor (PWR) during a loss-of-coolant accident (LOCA). The autoclave and its pumping system contain corrosive solutions at high pressure and temperature, and once a test has begun the system must be operated continuously for several days. The old system was manually controlled and required frequent operator adjustments during a test, whereas the upgraded system is fully automatic with a digital controller and a PC-based monitoring and data acquisition system. Figure 2.2-1 shows the new control panels for the system. Note the use of mimic panel displays to provide operators with an immediate overview of system status under automatic control and to provide for manual backup control. The system can be operated from either the computer terminal or the mimic panel.

2.2.1.3 TRU/TURF Safety System Monitor

Another safety system upgrade designed to provide centralized monitoring (at building level) was installed at the TRU Facility. The new system will monitor critical alarm signals throughout TRU as well as at the nearby TURF facility and will display them on computers located in the TRU and TURF buildings. The TRU controller also communicates with an industrial IBM PC AT, which displays the status of the two systems and provides operators with information and advice during alarm conditions.

2.2.1.4 Building 2025 Hot Cell Ventilation Monitor

Another example of a safety-related upgrade is the system installed to provide a centralized display of the status of the Building 2025 cell ventilation and off-gas system. The old system consisted of local gages and pressure switches mounted at each cell, whereas in the new system electronic draft gages are installed at each cell and the signals are routed to the central building display panel (Fig. 2.2-2).

2.2.2 CONSOLIDATED FUEL RECYCLE PROGRAM

This group's involvement in the CFRP integrated equipment test (IET) and the integrated process demonstration (IPD) has been a continuing effort for several years. Although most of the various IPD systems were intact and operational prior to this reporting period, efforts have continued to improve their performance by software and hardware modifications and additions. Support of system startup and operation has also been provided. System integration has been improved through the use of automation software developed by FRD, I&C, and C&TD.

2.2.2.1 CFRP Environmental Chamber

A major activity has been the environmental test chamber (ETC). Both hardware and software support (including development) were provided for control and monitoring of the ETC, which utilizes the unique concept of low-flow ventilation to maintain a desired environment within its 5000-ft^3 volume. Recently I&C has developed software and instrumentation to monitor exposure of typical fuel reprocessing equipment (electronics, motors, etc.) to a nitric acid environment in the chamber. This work was a result of a collaborative agreement between ORNL and PNC of Japan.

Other activities have included redesign of the small contactor test stand and instrument support for fluid transfer research.

ORNL Photo 7611-88

Fig. 2.2-1. Autoclave control panel for DBA tests.

2.2.2.2 Mechanical System–Disassembly and Cutting

Developmental support continues to be provided for the disassembly and cutting task, which is developing equipment and procedures to receive, prepare, and shear spent nuclear fuel. As previously described, the main components of the D&C equipment are a receiving station, a 9-kW CO_2 laser, a transfer station, a feeding station, a 300-ton shear, and a control system.

The equipment has been made fully operational and is being used routinely to determine optimum laser-cutting parameters such as cutting speed, laser power, cut assist gas pressure and composition, and shearing variables such as blade configuration and speed–all operated from the control console shown in Fig. 2.2-3. This development work establishes the baseline design requirements for similar systems to be used in the Recycle

ORNL Photo 7612-88

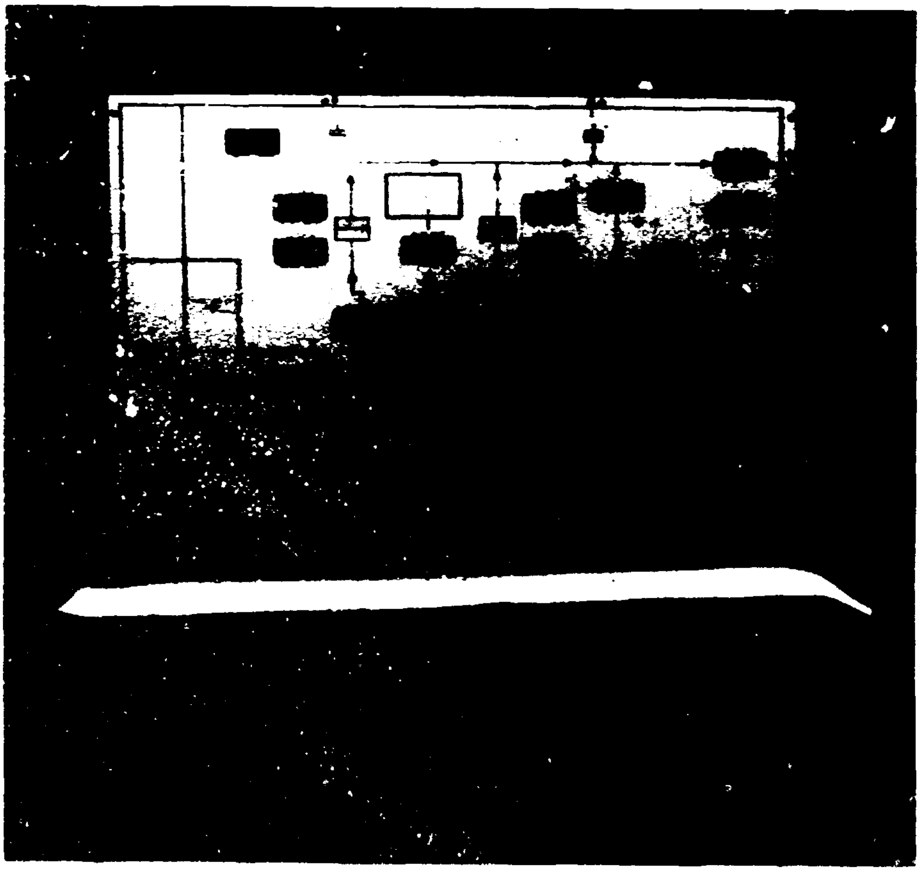


Fig. 2.2-2. Building 2025 cell ventilation monitor.

Equipment Test Facility (RETF) for the Engineering Technology Development Division of the PNC Tokai Works.

Current efforts center around preparation of control system criteria for the PNC D&C control system and the selection, application, and modification (if necessary) of suitable radiation-hardened sensors and actuators for use in operating the PNC equipment in the radioactive environment of the reprocessing hot cell.

2.2.2.3 Recycle Equipment Test Facility Prototype Rotary Dissolver System

The Fuel Recycle Division is developing a prototypical rotary dissolver system as part of the nuclear fuel reprocessing cycle. After test, a final design will be generated and used in the Recycle Equipment Test Facility (RETF), a radioactive pilot plant in Japan. This group is supporting FRD efforts in several areas of this project. Conceptual design of instrumentation and controls for the dissolver system has been completed. Final design has been initiated, with two major tasks to be addressed. The first is final specification of all sensors, actuators, and motors. Many of these items need to be prototypical, which means they must be radiation hardened. The second major effort is in the area of control for the dissolver motor and the overall system. The overall control system will include the ability

ORNL Photo 0898-85

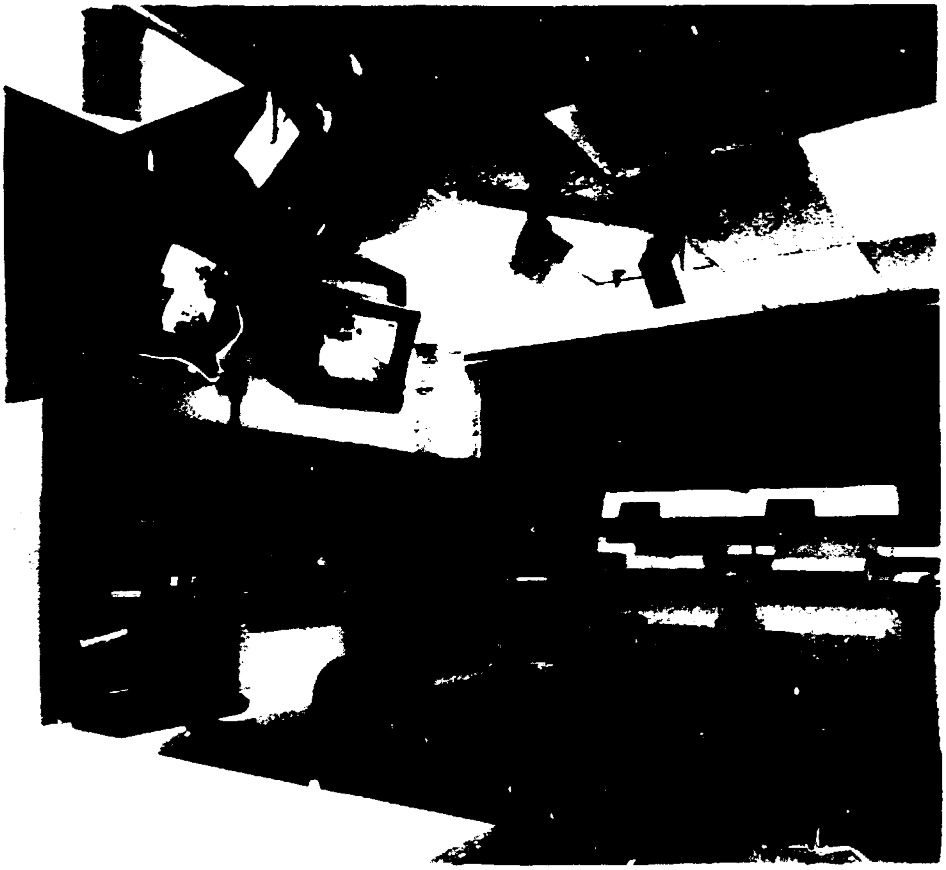


Fig. 2.2-3. Control console for disassembly and cutting.

to provide remote automatic operation, data acquisition, and archival alarming operator interfaces.

2.2.3 NAVY FLIGHT SIMULATOR PROJECT

Flight simulator systems are an integral part of U.S. Navy training programs, and represent a significant capital investment. These systems are used extensively to familiarize pilots with aircraft operations, emergency procedures, and tactics. The importance of these systems can be assessed when one considers the cost savings in fuel, airframe time, and no loss of aircraft in emergency situation training.

Simulator hardware and software architecture vary according to training and the particular aircraft being emulated. For instance, fighter aircraft such as the F-14 Tomcat have an air combat maneuvering simulator consisting of a graphic display system for visual cues and g-seat/helmet loading for inertia cues. Helicopter systems, on the other hand, can have a six-degree-of-freedom synergistic motion system to provide rotational and linear acceleration (see Fig. 2.2-4) as well as a display system for visual cues. This architecture is further complicated by the fact that the visual system can vary to support daylight, dusk, or night operations with presentation ranging from dot matrix to vector calligraphics with raster scan.

Photo K/PII 86-2046

Fig. 2.2-4. U.S. Navy helicopter simulator SH3 Sea King.

In all of these simulators the most important aspect of system performance is training effectiveness. This parameter identifies qualitative as well as quantitative attributes and is complicated by the fact that evaluation can be subjective as well as objective.

One of the key parameters in effectiveness assessment is a malady known as simulator sickness. It is a disease that affects students as well as experienced aviators with varying degrees of symptomatology, which can affect a system through self-imposed limitations. The characteristics of simulator sickness have close parallels with those of motion sickness. Unlike the latter, however, it can be precipitated through simple visual presentation.

Many theories have been developed to explain the causal effects of motion and visual cues in the genesis of this disease. In particular, research directed at motion dynamics and its impact (motion sickness) has led to human factors standards being adopted by the U.S. Navy as a military standard. This milspec identifies levels of acceleration (G_{rms}) for certain spectra and particular lengths of time that should be avoided to reduce the incidence of simulator sickness. Of particular importance is the 0.2-Hz region, in which humans exhibit the greatest sensitivity. This recommended human exposure limit for very low-frequency vibrations was first published in September 1976 and was adopted as a military standard (MILSTD 1472C) in May 1981. It should be noted that the standard was developed from tests conducted using a single linear axis of acceleration and has been cited extensively in criteria and requirements documents for motion-based flight simulators.

Although the standard has existed for 7 years, no experiment had been conducted to support the theoretical base from which it was developed. This was due in part to the complex nature of the problem and the fact that the U.S. Navy did not possess the equipment or techniques necessary for measuring motion-based dynamics and symptomatology response. The U.S. Navy therefore requested that ORNL provide the analytic skills and measurement capabilities to carry out an experiment at one of their operational facilities to validate the milspec. The system used in the experiment was the 2F64C SH3 Sea King helicopter simulator located at the Naval Air Station at Jacksonville, Florida. This particular simulator had been identified as one that produced a high incidence of simulator sickness.

An experiment conducted over a 4-week period recorded the neurophysiological effects of use along with the motion-based dynamics of the system. As seen in Fig. 2.2-5, the results support the hypothesis that 0.2-Hz acceleration is a critical region that needs to be avoided. These efforts led to the conclusion that with pilot-in-the-loop, pilot-induced oscillations limit the inherent capability of the pilot to control the simulator and introduce the low-frequency vibration that is guarded against by MILSTD 1472C.

This experiment gained international recognition* and has become the definitive study on motion-induced sickness in U.S. Navy flight simulators. The findings are now being incorporated into design specifications for next-generation operational flight trainers and have formed the basis for development of a Tiger Team for test, evaluation, and acceptance of simulator systems delivered to the U.S. Navy.

Consequently, the U.S. Navy has requested that ORNL develop an inertia measurement device (see Fig. 2-7 on p. 67) to measure, record, and analyze the motion base dynamics of flight simulator systems. In addition, a symptomatology reporting device is being developed to establish differential measures of human tolerance to low-frequency vibrations. These two systems will be integrated into a device that enables the U.S. Navy to measure susceptibility to simulator use based on a vestibular paradigm developed by ORNL.

Research is now being directed toward investigating the visual systems used in these simulators to determine what aspect of scene content precipitates simulator sickness. The hypothesis is that vection, the perceived motion through space solicited from visual presentation, is the major contributor to the malady. Experiments will be conducted to determine what aspects of vection act as the catalyst for this disease. These findings will provide measures of performance for ascertaining the nauseoginicity of dynamic visual scenes.

2.2.4 ADVANCED INSTRUMENTATION FOR REFLOOD STUDIES PROGRAM

The AIRS Program is part of the International 2D/3D Refill and Reflood Experimental and Analytical Research Program, whose objective is to study steam binding, flow distribution, and flow hydrodynamics during the refill and reflood phases of a simulated LOCA. Three countries are involved in this program: West Germany (FRG), Japan, and

*G. O. Allgood et al., "Motion Sickness Symptoms and Postural Changes Following Flights in Motion-Based Flight Simulators," 4th International Meeting on Low Frequency Noise and Vibration, Humanisthuset, Sweden, also G. O. Allgood et al., "Etiological Significance of Equipment Features and Pilot History in Simulator Sickness," AGARD Conference, Brussels Belgium, invited papers

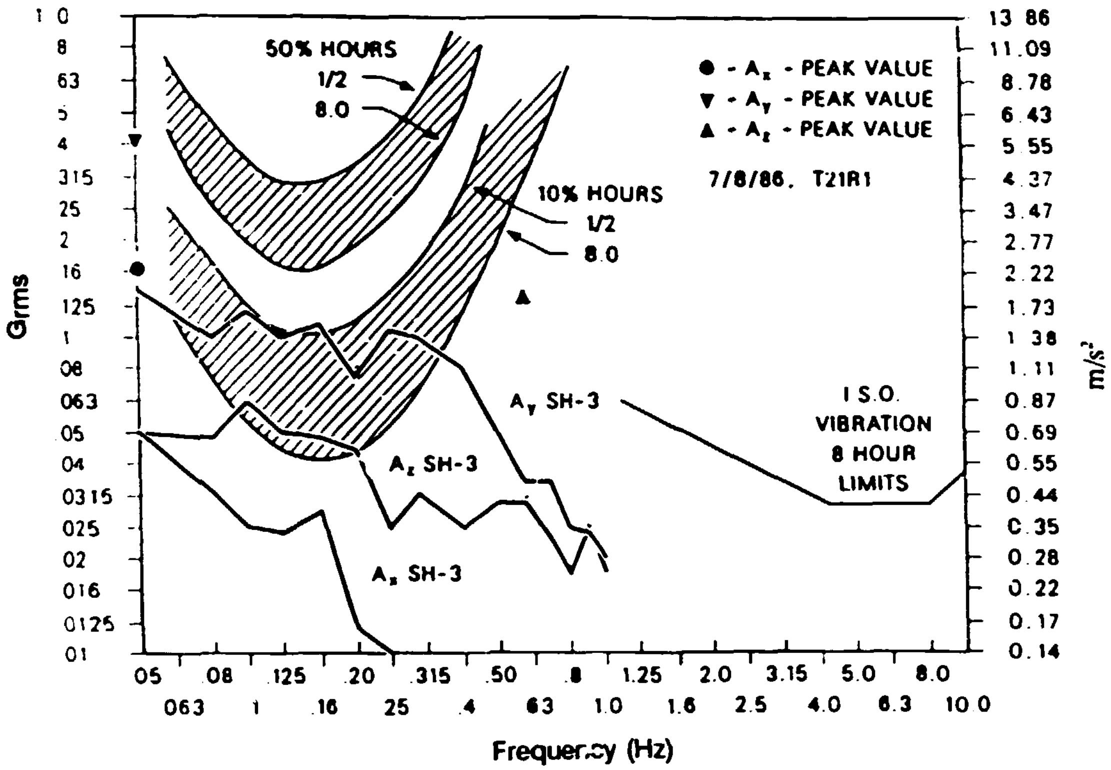


Fig. 2.2-5. Critical acceleration/frequency regions relative to simulator sickness.

the United States. Representing the United States, NRC furnishes advanced instrumentation and analysis of results to obtain improved computer codes that simulate PWR LOCAs, and West Germany and Japan provide test facilities and conduct the experiments. Through the AIRS Program, ORNL has developed instrumentation to measure in-vessel, two-phase flow parameters such as film thickness and velocity, phase velocities, void fraction, fluid momentum, and differential pressure measurements not made previously in reflood test facilities. The AIRS Program used a threefold development effort to obtain these measurements: (1) new instrumentation sensors were designed, (2) sensitive signal-conditioning electronics were designed, and (3) sophisticated software and analysis techniques were developed to process instrumentation responses and convert the signals to usable engineering values.

Because of the harsh environmental conditions—high-temperature steam (900°C) and severe thermal transients (-200°C)—new Cermet materials (0.5% platinum in aluminum oxide) were created. A new brazing alloy (49% copper, 49% titanium, 2% beryllium) was developed previously. These materials were used in fabricating film and impedance probes to measure two-phase flow velocities, film thickness and velocity, and the void fraction of steam and water mixtures. Strain gage-based instruments were developed to measure momentum flux in the end box (core/upper plenum interface region). A fast-responding differential pressure measurement was developed to measure flow losses and head changes in several locations in the upper plenum. Software routines were created for each instrument type and incorporated into a main program (provided by the facility owner) to produce data in engineering units.

Film and impedance probes have been installed in the Japanese Slab Core Test Facility (SCTF), Cores I, II, and III; in the Japanese Cylindrical Core Test Facility CCTF), Core II; and in the German PKL-II Facility. Strain gage-based instrumentation has been installed in the SCTF Core III, in the Upper Plenum Test Facility (UPTF), in the Kraftwerk Union (KWU) Test Facility, and at the Technical University at Hannover (TUH). Differential pressure measurement systems have been installed at the UPTF and at the KWU Test Facility.

2.2.4.1 Instrument Performance in the Slab Core Test Facility, Core III

Testing at SCTF Core III was completed in 1987. At the time (after 26 experiments), the status of AIRS-provided instrumentation was that 80% of the probes not in the core region remained operational whereas most of the in-core sensors had failed. Failure was most often caused by cracks in the Cermet insulator. These cracks were caused by the severe in-core environment (300°C/s thermal shocks).

All functioning sensors produced high-quality data for all the testing. Electronics supplied by the AIRS Program was very reliable, requiring only minimal maintenance over the 2-year testing program.

The completion of testing at the SCTF Core III essentially finishes AIRS Program involvement with the Japanese Reflood Test Facilities. ORNL instrumentation has produced valuable data that have, and will continue to be, useful in understanding and predicting PWR behavior during the reflood and refill stages of a LOCA.

2.2.4.2 Instrumentation Performance in the Upper Plenum Test Facility

During the previous reporting period, 4 tests were conducted along with all facility commissioning tests. During this reporting period, ~15 tests have been run. Generally, ORNL instrumentation has functioned very well and has produced excellent data which have been useful for providing a better understanding of PWR behavior during the reflood and refill stages of a LOCA.

All 50 differential pressure measurement systems have operated flawlessly since their installation in 1984. Signal-conditioning electronics for all AIRS sensors has continued to work very well with only minimum maintenance required. Dragbody (DB) force transducers have continued to exhibit strain gage encapsulation leakage, whereas breakthrough detectors (BTDs) have not had a new problem since November 1985.

Two facility outages occurred during this reporting period in which ORNL replaced defective DBs and BTDs. In the first outage, 15 DBs and 4 BTDs were replaced. The failed strain gages were examined by several laboratories. After numerous discussions between engineers and metallurgists in both the United States and West Germany, the consensus on failure mode was high-cycle fatigue cracking of the strain gage encapsulation. Most cracks occurred at high-stress locations. Several steps were taken to modify strain gage design and reduce stress at critical locations. New DBs were fabricated in time for the second outage. In this outage, five DBs were replaced with the modified design, but no BTDs required replacement.

It is too early to tell whether the new design for DBs will be effective in reducing failure rates. However, it is encouraging that the overall force transducer degradation rate decreased from the first to the second outage. ORNL is keeping a close watch on the status of DB performance for each test.

A second improvement to the dragbody system was the change to ac-excited signal-conditioning electronics. Once a leak occurs, ac excitation allows the DB unit to function and produce quality data for numerous tests. The previous dc excitation units caused sensor failures within hours after a leak.

Overall, more than 90% of the ORNL systems have been operational for each test and have produced high-quality, useful data.

2.3 Y-12 PROCESS SYSTEMS DEVELOPMENT AND RESEARCH SUPPORT

G. N. Miller

A. H. Anderson
S. P. Baker
J. D. Belcher*
W. F. Bethmann
A. H. Bost†
N. C. Bradley
T. M. Cate
R. M. Childs
R. L. Durall
J. T. Farmer†
F. R. Gibson
S. S. Gould
G. W. Greene
P. G. Herndon
J. M. Heidle‡
B. L. Lienhart†
R. F. Lind
R. L. Moore
F. R. Ruppel
P. A. Tapp
J. T. Thornton†
R. W. Tucker, Sr.†
K. A. Wakefield
B. R. Whitus

Traditionally the Y-12 Process System Development and Research Support Group has supported ORNL divisions located at the Y-12 site. The amount of ORNL-sponsored work has decreased over the last several years, but in its place a significant amount of work has been performed for the Oak Ridge Y-12 Plant in support of its computer-integrated manufacturing (CIM) upgrade. These support activities include procurement, systems engineering, communications networking, and installation and startup. During this period work has been performed for the following Y-12 production and support divisions and programs: Metal Preparation, Development, Engineering, Computer Integrated Manufacturing, Computing and Telecommunications (C&TD), and Security. The work in support of ORNL divisions, although not large in size, has included instrumentation and controls support for several crucial experiments and projects, two of the more important being the Advanced Neutron Source Corrosion Test Loop and Strategic Defense Initiative (SDI) shielding studies.

2.3.1 Y-12 METAL PREPARATION DIVISION PROJECTS

A Metal Preparation/Instrumentation and Controls team structure was established to accommodate the vast range of engineering capabilities required to support the "shop-of-the-future" automation plans of the MPD in compliance with overall Y-12 Plant computer-

*Tennessee Technological University.
†Midwest Technical, Inc.
‡Y-12 Plant Engineering.

integrated manufacturing initiatives. The MP/I&C team receives funding and directives as a resident matrix subgroup of the MPD Computer Utilization Group. Strategic directions and review of automation design philosophies, project proposals, and design standardization are provided by the I&C Management Review Committee.

2.3.1.1 Distributed Control System Procurement and Installations

The MPD/I&C team has been instrumental in establishing standards in distributed control system design and implementation philosophies through an aggressive program in which MPD operational requirements were established and modeled. The prevailing control philosophy was adopted by MPD after in-depth internal and external review by individuals, committees, and organizations and four successful technology demonstrations on the shop floor. An extensive market survey was conducted to identify all necessary system components that required testing and evaluation. A comprehensive specification and procurement plan was developed to address the needs of major operations, funded from multiple sources and incrementally committed over extended procurement schedules. The apparent low bidder for the equipment was selected through rigorous procurement analysis, and the equipment required for the system was placed on order with provisions for close monitoring and acceptance testing at the vendor's shop after installation.

These practices have been followed in the design implementation and procurement of major distributed control systems for three metalworking operations, a chemical forming facility, and two metal-casting process shops with full, coordinated participation by Y-12 CIM, Engineering, Development, C&TD, Procurement Engineering, Purchasing, and Security support divisions. The distributed control computer on the shop floor (Fig. 2-6 on p. 66) networks up to 64 equipment interface systems (EISs) to provide full inventory processing and tracking status information details to Y-12 Plant operating personnel. This information is used for automatic scheduling and production monitoring while controlling production equipment on the shop floor via operations monitoring, data display and analysis, inventory tracking, report generation, procedure posting, and process scheduling of all production equipment and processes. Individual EIS controllers were designed to control up to 640 local I/O devices while providing full data acquisition, data analysis, data and process procedure display, inventory tracking, fault and failure analysis, and operations security on the shop floor.

In addition, the MP/I&C team has been instrumental in developing a number of CAE tools for EIS design customization and cost estimating and for automated configuration documentation for board-level jumpers and switch details. The team also has designed and developed expert systems techniques for diagnostic analysis and fault detection in complex control systems, expert trainers for maintenance on complicated stack monitoring equipment, and a maintenance response methodology for servicing advanced control system technologies.

2.3.1.2 Metalworking Operations Improvements

The MP/I&C team has completed the detailed design for the automation and plant integration of two metalworking operations and is currently in the process of installation, checkout, startup, and production commissioning of major equipment and processes. A third metal-forming pilot facility is currently in the conceptual design stage.

Early in our implementation plans for metalworking operations, we identified training as a strategic goal and focus for successful implementation of advanced control technologies. We have conducted two complete training sessions (8 weeks each) for engineers, programmers, operators, and maintenance personnel associated with the implementation and maintenance of the automated systems.

Other improvements were as follows:

- A survey of background electrical noise and a study of the effects of electromagnetic interference/electromagnetic compatibility (EMI/EMC) on the selected Bristol Babcock control systems were conducted in the metalworking shop areas. The study confirmed the need for a clean and reliable power source, an isolated instrument ground system, and proper connection of signal cable shields to avoid induced noise, ground loops, high common-mode voltages, and other potential performance degradation from electrical noise.
- A procedural standard was generated and accepted by Y-12 organizations for use during installation of new electronic equipment within the shops.
- The difficulty in measuring traces of moisture in atmospheric furnaces was eliminated by use of a General Eastern optical dewpoint hygrometer system, which was successfully demonstrated over a year of operation. The dewpoint hygrometer system is now being applied to other atmospheric quench furnaces as a standardized solution.
- Successful training technologies have been demonstrated in both metalworking shops for the past year and have become valuable tools in providing technological familiarization for operating and maintenance personnel.

Activities in Building 9204-4 metal-forming operations include procuring a Bristol Babcock distributed control system with dual supervisory consoles (Fig. 2.3-1), a DEC microVAX-II computer system, and 14 EIS control systems. Application software as outlined in the functional design specification document is about 60% complete for the full shop design implementation. Supervisory graphics and data base entries were completed for seven EIS controllers. To date, four furnaces and EIS control systems have been installed and are in various stages of startup and production certification and commissioning. A new G-M preheat furnace has been successfully producing parts for 2 months (Fig. 2.3-2), and a vacuum quench furnace has been fully integrated to the supervisory console for data collection, report generation, and inventory tracking. The MP/I&C team is also responsible for application software configurations for the Wellman rotary hearth furnace and associated robotic billet handling, two Rogers molten salt baths, an existing horizontal annealing furnace, and two existing vacuum quench furnaces. The remaining installation activities will be tracked by the MP/I&C team, which expects to make significant technical contributions.

A new metal-forming pilot facility is being designed to investigate the use of pressure/temperature stress curves for forming metallic parts. The new Bristol Babcock DPC-3330 controller, selected as the furnace and press controller for this process, has passed the test and evaluation stages, and requisitions are being prepared for procurement of the first of two furnace and press sets having these controllers. The operator-machine

ORNL Photo 8582-88

Fig. 2.3-1. Metal-forming operations control system.

Y-12-Photo 2561-84

Fig. 2.3-2. Y-12 metal preparation preheat furnace and control panel.

interface will be a Nematron 80286 terminal with the ICONICS Genesis display monitoring and display software attached to a Bristol Babcock UCS-3380 data concentrator. This facility will be integrated with the existing Building 9204-4 distributed control system through the UCS-3380 data concentrator.

In Building 9215 metal rolling and forming operations, we have procured a Bristol Babcock distributed control system with dual supervisory consoles, a DEC microVAX-II computer system, and two EIS control systems. Additionally, we have purchased an AVS vertical vacuum annealing furnace and a Wellman ferrous heat treat furnace. Application software for the supervisory consoles and the computer system is being designed by the MP/I&C team. The EIS software configuration has been purchased from Bristol Babcock and will be upgraded by the team.

2.3.1.3 Metal Casting Automation

Functioning as part of a multidivisional casting furnace automation technology startup team, our major roles in the two metal casting operations were in temperature measurement, power control, and operator-machine interfacing. Early attempts to control power to the induction furnaces using programmable logic controllers (Gould Modicon 584) indicated that power would be very difficult to control because of changing furnace parameters during run time and large variances in load sizes. Modeling the process determined that power could be controlled, and, as an initial proof-of-principle experiment, we installed expert single-loop power controllers (Foxboro EXACT Model 760) to establish run-time tuning constant variance with vastly differing load sizes. The EXACT tuning parameters were then translated for use in the Modicon 584 controllers and fine-tuned for optimal control and power limiting. Temperature measurement of the melt was improved by converting from maintenance-intensive, ceramic-protected Pt-10% Rh vs Pt thermocouples to two-color optical pyrometry. Extensive investigation, testing, evaluation, and statistical analysis of operational data were performed in selection of the Ircon pyrometer for standardization within Y-12 metal preparation casting operations. Replacing the Burr-Brown miniterminal operator-machine interface with Canberra graphics terminals has accelerated operator acceptance of the new automation technology in casting operations. Already purchased and installed, this equipment is currently being placed into operation for 22 induction casting furnaces.

2.3.1.4 Chemical Process Systems Improvements

A very successful technology demonstration conducted on a lithium reaction furnace in chemical forming operations has paved the way for the lithium process restoration (LPR) program ($51-M line item) to use the Bristol Babcock distributed control system as the basis of prototype process automation activities. The MP/I&C team has participated in the feasibility study, conceptual design, and process prototype demonstrations on the lithium hydride forming furnaces. The Bristol Babcock distributed control system purchased has dual supervisory consoles, a microVAX-II computer, and two EIS control stations. The MP/I&C team is responsible for application software for the supervisory consoles and the computer system. We are providing technical direction for installation of two existing EIS control systems and those currently in design. We are investigating alternative controller solutions that utilize the manufacturing automation protocol (MAP 3.0) for networking in the final distributed control system design for the LPR Program. Several industrial (NEMA 4)

PC-based graphics workstations have been evaluated along with process control and monitoring software packages. Nematron and Xycom 80286/80386 terminals and the ICONICS Genesis package have been recommended for standardization within the LPR Program. A Nematron IBM PC AT with an ICONICS Genesis package purchased and installed for the first prototype demonstration is being evaluated by operations personnel for adoption as a standard. Bristol Babcock controller drivers for the Genesis package are being developed under a subcontract with ICONICS.

2.3.2 Y-12 DEVELOPMENT DIVISION PROJECTS

Over the past decade, a major activity at the Oak Ridge Y-12 Plant has been restoration and upgrade of existing manufacturing capabilities to meet future regulations and production needs. Working with the Y-12 Development Division, this group has been involved with design, checkout, and startup for the last of these upgrades as well as for several large chemical processing facilities. Current efforts involve writing detailed integrated test plans (ITPs) and performing system checkouts using completed ITPs.

2.3.2.1 Enriched Uranium Recovery Improvements Program (EURI)

ITPs were completed for two primary extraction systems (PRIMEX) and for one secondary extraction system (SECEX) for the EURI Program. ITPs are used for preoperational testing phases and are composed of vendor/shop/installation tests, field inspection check lists, loop function tests, and a system integrated test. After checkout, each ITP will become a quality assurance (QA) record for the project. Checkout of SECEX is 50% complete. As a result of our experience and knowledge in the operation of SECEX, a large number of problems have been found and corrected. Checkout for SECEX will be finished after completion of construction in the fall of 1988. Checkout of PRIMEX will begin in the spring of 1989 after construction is well under way.

Software support has been provided for the Texas Instruments D/3 distributed control system (DCS) for EURI. A portion of the continuous control data base, including PRIMEX and SECEX, and the sequencing and batch language (SABL) were completed.

2.3.2.2 Enriched Uranium Conversion Facility Modifications

An in-house investigation was undertaken to find a method of detecting releases of UF_6 into air that could be applied to the enriched uranium conversion facility modifications (EUCFM) project. The results of release tests performed at K-25 are discussed in ORNL/TM-10341.* This report indicates that attenuation of a laser beam propagated through a vessel containing UF_6-into-air release products is a very sensitive method of release detection. Therefore, EUCFM autoclaves, the portion of the facility in which there is potential for release, were modified to accept a laser-based release detection system. Application of another technology (sampling tubes) was investigated. We coordinated testing

*W. D. Bostick and D. P. Bostick, *Evaluation of Selected Detector Systems for Products Formed in the Atmospheric Hydrolysis of Uranium Hexafluoride*, ORNL/TM-10341, March 1987.

and recommended a design of a hydrogen fluoride Draeger sampling tube for application to the autoclaves as a backup instrument.

We actively participated in development and implementation of software for the Texas Instruments D/3 DCS for EUCFM. We were involved in software design, coding, and checkout of the entire continuous control data base, which consisted of about 1500 I/O points.

2.3.2.3 Centrifugal Contactors

An alternative to pulse columns for separation of uranium is centrifugal contactors—a newer, less proven technology, but one that offers a number of significant advantages. Centrifugal contactors are compact in size and therefore result in significantly reduced inventory holdup, have high throughput and fast response time, and can be controlled by traditional PID control algorithms. A set of centrifugal contactors will be placed into service in parallel with the SECEX pulse columns, and an integrated test plan for their checkout and startup has been written.

2.3.2.4 Pilot Plant Support

Ongoing instrumentation and controls support was provided for development activities at the Building 9731 Development Pilot Plant. We have provided software and hardware support for equipment reliability, extraction pulse column, and centrifugal contactor testing.

2.3.3 Y-12 PLANT ENGINEERING PROJECTS

This group augments the Y-12 Engineering staff with a variety of design, cost estimate, peer review, and support services in conjunction with ongoing Y-12 Plant upgrade projects. In addition, we participate in internal quality assurance audits of the X-10 Instrument Engineering, X-10 Fusion Engineering, Y-12 Instrument Engineering, and Y-12 Computer Applications departments and associated projects.

2.3.3.1 Computer Networking Design and Installations

This group provided engineering design assistance for the draft document on an overall Y-12 broadband networking design for operation and support organizations. We performed a number of broadband bridge evaluations based on Y-12 internetworking requirements, and our recommendation for bridge communications equipment was accepted by the Oak Ridge Y-12 Plant for equipment standardization for general business systems networking. Design and installation assistance was provided for the classified broadband network taps.

Investigation of MAP technology is still progressing. An initial laboratory demonstration has been successfully conducted with version 2.2, and testing is under way with version 3.0. A number of pilot demonstrations have been investigated and costed. Design activities are under way to upgrade the existing Bristol Babcock controllers to include a MAP channel for PLC (programmable logic controller) integration, and the MAP solution is being considered as a production internetworking technology for the shop of the future.

2.3.3.2 International Fusion Superconducting Magnet Test Facility

Engineering field design and support assistance were provided during the final toroidal array testing of the six 8-T superconducting magnets in the International Fusion Superconducting Magnet Test Facility. All domestic and foreign participants considered the experiments very successful. The facility has been shut down while its future is contemplated.

2.3.3.3 Y-12 Manufacturing Facility Improvements

Significant support has been provided on a number of facility improvement projects for the Y-12 Metal Preparation Division. An estimate was prepared and accepted, and design and procurement activities have been initiated to convert all electrical instruments and equipment in Building 9404-11 to National Electrical Code Class I, Division I conformance. Design and procurement engineering have been completed for a replacement hydrogen fluoride (HF) system for Building 9212 and are in progress for a new HF system for Building 9206. Engineering assistance is being provided for caustic fusion, extraction solvent recovery, reduction salvage dissolvers, and reduction furnaces in Building 9212 and for salvage generators in Building 9204-2. Installation and checkout are complete, and startup commissioning support has been given for two Y-12 Steam Plant boilers that now use natural gas startup burners with automatic switchover to coal fuel.

2.3.4 Y-12 SECURITY PROJECTS

As a part of the general Y-12 Plant upgrade, Y-12 Security is actively involved in a number of plant security system modifications. This group has provided instrumentation and controls support for several vehicle access control projects.

2.3.4.1 Exclusion Area Barrier Control

The Y-12 Plant area contains a number of "pop-up" road barrier systems intended to control vehicle access during emergencies. Modifications were made to the West Gate system to prevent an operator from inadvertently raising a barrier while a vehicle is on it, and a relay latching system has been installed in which both entrance and exit photocells must be tripped in proper sequence to raise or lower the barrier.

2.3.4.2 Biology Gate Access Control

A number of accidents have occurred in which the ORNL Biology Division gates accidently struck vehicles while opening or closing. A control system of inductive ground loop detectors in the entrance and exit lanes at the gates has been designed, fabricated, checked out, and installed. This system has interfaces with the existing gate control system to prevent an operator from opening or closing a gate if a vehicle is in its path.

2.3.5 ENGINEERING TECHNOLOGY DIVISION SUPPORT

This group provided instrumentation and controls support for the ORNL Engineering Technology Division (ETD) in the areas of advanced reactor research and development, materials research, and alternate fuels utilization. A wide variety of expertise has been applied in these areas to provide data-gathering and control capabilities for a number of experiments.

2.3.5.1 Diesel Laboratory Data Acquisition System

Instrumentation and controls support was given to the Alternate Fuels Utilization Program Diesel Engine Test Facility. This facility is used to evaluate the effects of various grades and types of diesel fuels on the tolerance of uncooled diesel engines and their materials of construction. To collect data from test engines, an IBM PC AT host-based data acquisition system (DAS) was designed, purchased, installed, and tested. The DAS itself is a moderately high-speed CAMAC-based system that communicates on a parallel data link to the PC AT. It consists of two data collection modules, one low speed and one high speed. The high-speed module can collect data at an aggregate rate of up to 100,000 samples/s. For making very high-speed engine temperature measurements, the high-speed module is interfaced with an optical fiber temperature measurement system with a 10-KHz bandwidth manufactured by Accufiber.

2.3.5.2 Advanced Neutron Source Corrosion Loop

A very important area of work has been the design, construction, and installation of instrumentation and controls for the Advanced Neutron Source corrosion test loop. This is an out-of-reactor high-pressure water loop for experimental evaluation of proposed reactor fuel element cladding materials for the ANS, the next-generation ORNL research reactor. The entire loop, including piping and instrumentation, was designed and procured as a skid-mounted system. Instead of using type K thermocouples, which are susceptible to short-range ordering in chromel, type N thermocouples were used to measure the inlet-to-outlet temperature profile of a simulated HFIR-type fuel element. The simulated fuel element test section consists of a 25.4-cm- (10-in.)-long Al 6061 test section with a 0.127-cm × 1.27-cm (0.050-in. × 0.5-in.) coolant flow gap. A 600-kW dc power supply is connected across this test section to provide the heat source for the heat transfer tests. Loop parameters controlled are the test section inlet temperature, test section outlet temperature, loop water pressure, and loop water flow.

2.3.5.3 Heavy Section Steel Technology

As part of the Heavy Section Steel Technology (HSST) Program, a series of experiments has been performed to study the influence of cladding on crack behavior in reactor vessels. Four thermal shock-type experiments have been run on a test cylinder instrumented with thermocouples and crack opening displacement gages. The inner surface of the cylinder was subject to a severe thermal transient, producing a temperature gradient through the cylinder wall and causing subclad and surface flaws to propagate. Program effort is directed toward obtaining cladding-related flaw-behavior data and applying them to reactor pressure vessel design. This group designed and delivered Nova-based DAS hardware and software and provided field engineering support for these experiments.

2.3.5.4 Thermal Shock Testing

The Pressurized Thermal Shock Facility located at K-25 was restarted after being shut down for over 2 years. The facility was designed to subject an instrumented thick-walled test vessel to conditions of thermomechanical stress and fracture that are characteristic of realistic nuclear reactor overcooling accidents. The system consists of 38 loop sensors and 145 specimen sensors connected to a PDP-11/34 DAS and 37 specimen sensors connected to a redundant data logger. Before restarting, all instrumentation and control systems were checked out and calibrated. Operational support was provided during the PTSE-2A and PTSE-2B experiments, both of which were completed successfully.

2.3.5.5 Shielding Studies

The Fast Track Program (FTP) is an SDI program for development of lightweight passive shielding to protect space assets from damage by kinetic energy weapons. A series of experiments was performed at Arnold Engineering Development Center (AEDC) in Tullahoma, Tennessee. In these experiments, targets were fired upon with small hypervelocity projectiles from a light gas gun. The targets were instrumented with strain gages and connected to wideband signal conditioning and a high-speed DAS composed of several LeCroy Model 9400 digital oscilloscopes controlled by an IBM PC AT. The studies also involved the use of various trigger circuits, X rays, and integrated timing techniques. This program has successfully developed a multilayer composite shield that weighs only a small fraction of an equivalent solid shield.

2.4 ADVANCED ARCHITECTURE GROUP

W. L. Zabriskie
J. D. Allen, Jr.[*] P. L. Butler
W. H. Andrews L. C. Williams

The Advanced Architecture Group was formed in December 1987 to consolidate work in advanced computing technologies. The mission of the group is to perform R&D related to advances in the computing field and to expedite transition of those developments into measurement and control applications. The current interests and activities of the group encompass advanced microprocessors, parallel computing, rule-based and object-oriented programming, and neural networks.

A computer security study, funded primarily by the U.S. Department of State (DOS), was a responsibility of the group that has since been passed on. This program provided assistance to DOS in planning, analysis, evaluation, demonstration, and development of techniques related to computer security, with emphasis on existing and planned DOS computer hardware and software. The program emphasized software analysis and testing that was inconsistent with the long-term goals of this group.

[*]A.G Associates.

2.4.1 OPSNET EXPERT SYSTEM PARALLEL PROCESSING COMPUTER

Implementation of a computer for high-speed execution of expert system programs was completed during this reporting period (Fig. 2.4-1). A host microcomputer and 64 microprocessors, operating in a unique parallel architecture called OPSNET, give this computer rule-processing horsepower unsurpassed by dedicated expert system computers currently being developed elsewhere.

Programs written in the popular OPS5 rule processing language for serial computers can be executed on this computer without modification, and the OPS5 compiler on this special-purpose machine is designed to exploit the language's intrinsic parallelism. The hardware is expandable_the OPSNET architecture imposes no inherent limit on the number of parallel processors that can be employed.

Functionally, the host and all rule processors are connected by a common bus (Fig. 2.4-2). The host uses this bus to (1) distribute the OPS5 rule conditions at compile time and (2) send working-memory element (WME) changes to all rule processors simultaneously during program execution. The host then monitors the "wired-or" completion flag and begins the next recognize-act cycle when the flag is raised, indicating that each of the rule processors has completed its evaluation and stored its results in its host-accessible local memory.

The host is a single-board Motorola MC68000-based computer on a Multibus-I backplane and has 1 Mbyte of memory on board. The rule processors also use MC68000 processors, and each has 512 Kbytes of local memory. They reside four to a card on custom Multibus printed circuit boards.

The full advantage of the 64-processor OPSNET computer is realized with very large (>2000-rule) systems. Smaller systems can be run efficiently on scaled-down versions, as shown in Fig. 2.4-3.

An eight-processor desktop OPSNET computer has been designed and fabricated, and performance is consistent with that predicted by the trends evident in Fig. 2.4-3. On a moderately sized OPS5 benchmark system with 228 rules, OPSNET provided an order-of-magnitude gain in performance over a VAX 11/780 serial minicomputer.

The significance of this innovative OPSNET development, which was an internally funded project, was recognized with the only 1988 R&D-100 Award received by ORNL.

2.4.2 EXPERT SYSTEMS

A prototype is under development to demonstrate the capabilities of expert systems in diagnosing faults in complex systems. It will be applied to the equipment interface systems (EISs) being installed for furnace control in the Oak Ridge Y-12 Plant. The prototype is a portable system for use in troubleshooting malfunctioning equipment by a technician unfamiliar with the design or operation of the particular system. The technician's interaction with the prototype system has been reduced to a series of "point and shoot" operations in response to simple instructions and queries by the diagnostics "expert."

The expert system consists of a personal computer, two color displays, a videodisk player, input devices, software, target system data, and sets of rules that capture the diagnostics expertise for pinpointing the source of the problem in the target system. One color screen will display still photographs, automatically selected from hundreds stored on a videodisk (Fig. 2-9), that show portions of the EIS system at varying levels of detail or reproduce diagrams or drawings from users' manuals. Some photographs have highlighted

ORNL Photo 4284-87

Fig. 2.4-1. R&D-100 Award-winning OPSNET computer.

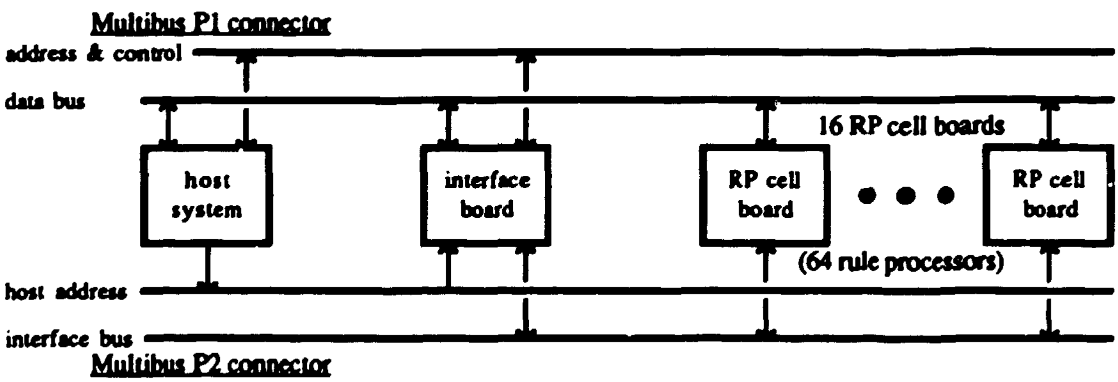


Fig. 2.4-2. OPSNET architecture.

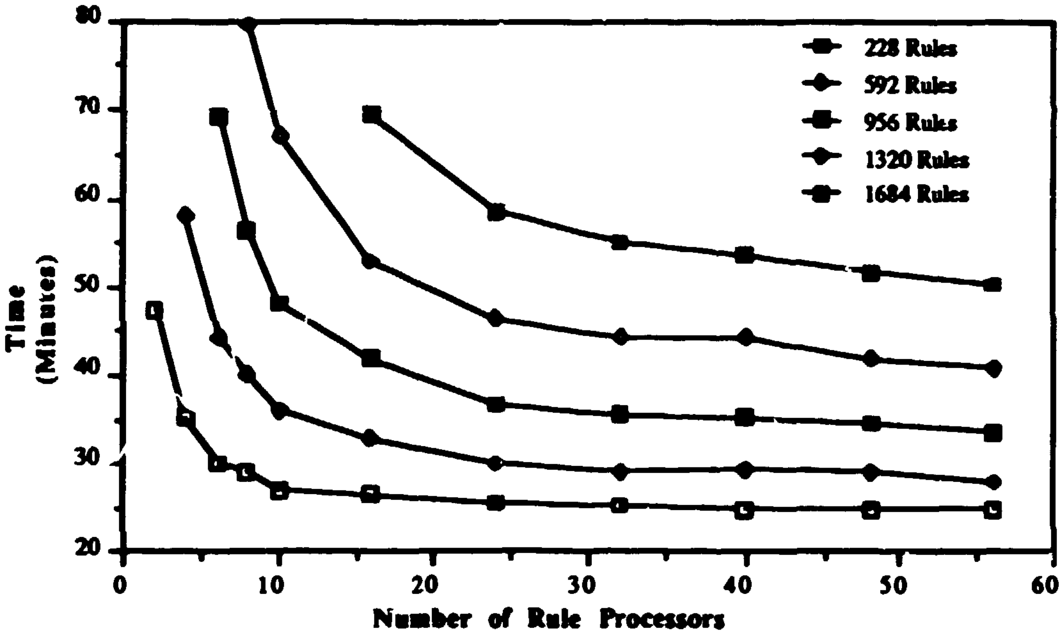


Fig. 2.4-3. Effect of the number of rule processors on execution time.

areas and superimposed text that clarify instructions or information given on the second display.

The expert system guides the technician through a series of tests and inspections, locates the malfunctioning component or subassembly, and instructs the technician in effecting repair. An audit log of operator responses and system diagnoses is maintained.

2.4.3 REAL-OPS ON A RISC

Interest in rule-based programming and in reduced instruction set computer (RISC) technology has made the marriage of these two technologies an almost inevitable alternative for applying artificial intelligence (AI) techniques to real-time computing tasks. The Advanced Architectures Group has accomplished this union by implementing rule-based expert system software on a Novix NC4016 RISC CPU. The software written is a derivative of the widely used OPS5 rule processing language. The resulting inference engine is capable of executing small (less than 100 WMEs and 20 rules) systems at the real-time speeds required for many automatic control and signal-processing applications.

The development system consists of a PC and an extension card incorporating the Novix processor. The PC acts as an incremental compiler and as an I/O slave, allowing the Novix processor to be fully devoted to the match-fire cycle of the language. Communication between the two computers is accomplished through a switched-memory, message-passing protocol. Because the system is intended for application to ROM-able rules, it does not support run-time rule creation as does the standard OPS5 language.

Real-OPS on a RISC executes benchmark tests ~15 times faster than a 16-MHz 80386 processor-based system executing the same OPS5 code. Real-OPS on a RISC is currently being applied to correlation of radar contacts with passive emissions data for target prioritization in a U.S. Navy command and control aircraft. Performance of Real-

OPS when it is attached to simulated radar and sensor signals has demonstrated its capability for real-time processing in this application.

2.5 REAL-TIME COMPUTER SYSTEMS GROUP

J. M. Jansen, Jr.

R. R. Bentz	R. L. Simpson
E. R. Broadaway	J. D. Stanley*
D. A. Clayton	R. M. Tate
J. B. Cordts	R. M. Tuft
J. T. Glassell	G. R. Wetherington, Jr.
J. A. Jefferis	R. W. Wysor
R. B. Rochelle	W. D. Zuehsow

The Real-Time Computer Systems Group provides research, development, and applications engineering in the areas of high-speed data acquisition, analysis, and processing for real-time measurements. The group also provides expertise in development and deployment of integrated networking systems.

During this 2-year reporting period, much of our funding has come from Work for Others programs. We have developed and delivered a system for the Naval Sea Systems Command (NAVSEA) for the Large-Scale Vehicle (LSV) model, including both an onboard submarine data acquisition system and a retrieval/analysis system. We have acquired two similar but unique projects from the David Taylor Research Center (DTRC) involving high-speed signal processing systems for underwater acoustics and sonar development. We anticipate further development activities, with this sponsor demanding higher processing rates, more complex sensor structures, and increased sensor/processing fusion requirements. Development of parallel processing architectures for application-specific signal processing and advanced man-machine interfaces for improved operator system response are new target areas. We have broadened our digital signal processing expertise through an in-house course and consulting contracts with UT and The University of Tennessee Space Institute (UTSI).

Our emphasis on networking, which began in an effort to meet computational capacities required with distributed measurement systems, continues and has been expanded into more global communications areas. We have expanded the ICENET VAX computing environment and distributed Ethernet throughout the Division's three-building complex.

The Athens Automation and Control Experiment and the Four-Plant Medical and Industrial Hygiene Computer System (FPMCS) have been supported by four full-time equivalents. Major expansions and accomplishments are described below. Three group members have been assigned to support other activities involving major projects for real-time systems. These activities are described elsewhere in this report.

In addition to supporting 20 FTEs, the group has provided support for 4 FTEs in other parts of the I&C Division and the Laboratory. We have purchased $2.5M worth of hardware to support our projects during this period. We have received letters of

*Midwest Technical, Inc.

commendation for the Large-Scale Vehicle Data Acquisition System. The sections which follow describe our major accomplishments in more detail.

2.5.1 ATHENS AUTOMATION AND CONTROL EXPERIMENT

The Athens Automation and Control Experiment (AACE) is an ongoing, large-scale electrical distribution automation project sponsored by the DOE Office of Energy Storage and Distribution. The experiment site is the Athens Utilities Board (AUB), a Tennessee Valley Authority (TVA) power distributor in Athens, Tennessee. Volt/VAR (reactive power) control, load management, and system reconfiguration are the three experimental areas that the AACE is designed to test. Monitoring points for parameters such as voltage, power, temperature, and switch states are located in the 3 AUB substations and at selected points along the 12 distribution feeders. Automation also includes control of capacitor banks, load tap-changing transformers, feeder switches, breakers, and residential space and water heating appliances. Data acquisition and control for the approximately 10,000 I/O points is accomplished at the AUB office with a dual minicomputer configuration which provides fail-over redundancy. Operator interaction with the computer is through rapid-update color CRT screens, light pens, and specialized keyboards.

A development system, the Athens Automation and Control Experiment Test System (AACETS), is located at ORNL and is used for development and testing of all project software before it is installed on the AACE computers at AUB. This preinstallation testing allows the software to be implemented at AUB with a high degree of confidence that it will perform as desired.

Residential load management and automatic, computer-initiated capacitor control programs are two areas that utilize the AACETS for software testing. To minimize the power factor on individual feeders and the power factors presented to TVA, the capacitor control program uses real-time reactive power data to determine which capacitor banks should be switched and then initiates the commands via computer to actually switch the capacitor bank. The algorithm used for determining which capacitors to switch is designed to minimize the reactive power on each feeder while maintaining a lagging power factor. Since all feeders at AUB are radial, the program works from the end of each feeder back to the substation to determine which capacitors to switch. No attempt is made to switch a capacitor that is out of service or has been switched too recently to have discharged properly. Capacitor bank switching is accomplished by commands injected at each substation as a ripple signal on the power line. The command is received by uniquely addressable distribution control receivers at each capacitor bank.

Figure 2.5-1 shows the real power (kW), reactive power (kVAR), and voltage (kV) for a capacitor switching operation. The decrease in reactive power and increase in voltage when switching in a capacitor bank are as expected. The increase in real power is not predicted by the commonly used constant-power model for the distribution system. Analysis of the actual data and models determined that a power flow model sensitive to the voltage is required to properly represent the dynamics of the system. Concurrent use of two I&C-developed high-speed, portable computer-operated data acquisition systems (CODAS), one of which is shown in Fig. 2.5-2, provides the additional data acquisition capability necessary to develop and verify this voltage-sensitive power flow model. The high-speed data acquisition capability these systems provide is not required for daily operation of the AUB

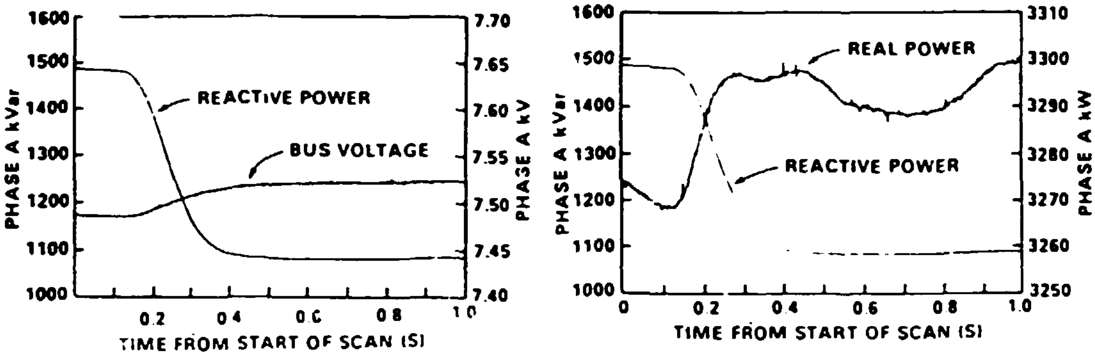


Fig. 2.5-1. Plots of data recorded during capacitor switching tests.

Fig. 2.5-2. Portable high-speed computer-operated data acquisition system.

distribution system, but it is essential for experiments that result in small, millisecond-duration changes in power line phenomena.

A Unix-based workstation is used at ORNL to develop and test artificial intelligence software to aid operators in system reconfiguration decisions. Data to aid in these decisions are acquired via a serial link with the AACE computer at AUB.

A primary goal of the AACE is transfer of experimental results to the utility industry. The I&C staff has assisted ORNL Energy Division project team members in this effort by preparing and presenting technical papers on AACE equipment and test results.

2.5.2 ACOUSTIC MEASUREMENTS FACILITIES IMPROVEMENT PROGRAM

The Acoustic Measurements Facilities Improvement Program (AMFIP) is an effort sponsored by the U.S. Navy and carried out by David Taylor Research Center to improve its testing and measurement capability. The RTCS Group of the I&C Division, a key participant in this important program, is developing an advanced signal processing and analysis system called the Multichannel Narrowband Noise Analysis System II (MNNAS-II) for use by DTRC.

The MNNAS-II is a multichannel, high-speed signal processing and analysis system. The system, pictured in Fig. 2.5-3, is based on the latest technological offerings in super-minicomputer, array processor, low-level analog signal-conditioning, and graphic-processing technologies. It provides over 800 kHz of real-time signal processing bandwidth with 121 dB of signal-to-noise rejection and 115 dB of dynamic range. Reliability is improved by configuring the system into two functionally independent halves, which allows 50% of the system to be available in the event of any single-point equipment failure. The MNNAS-II can process up to 32 channels of incoming analog data and store up to 4 Gbytes of processed spectral data. The spectral data are normally stored as sixty-four 8-K point basebands that cover the frequency range from dc to several hundred kilohertz. In addition to basebands, one-third-octave and transient processing are also performed in real time.

A block diagram of the system is shown in Fig. 2.5-4. Incoming test signals interface with the system by way of a 64-input crossbar switch matrix, which allows up to 32 signals to be selected for processing. From the matrix switch, the analog signals travel to two banks of programmable low-pass antialiasing filters. After filtering, the signals travel to ADCs where they are converted to 15-bit digital data at a nominal rate of 1.1 M samples/s/ADC. The digital data are then directed into the first array processor of each system half. Each Star ST-50 array processor passes the ADC data on to the next array processor so that all these units share the same input data and process the data in parallel. At this point the array processors transform the time domain data into frequency domain data and also perform other real-time signal processing functions.

Each array processor buffers its output data into the mass memory of the Aptec IOC-24 I/O computer, which acts as a high-speed bus for each system half. From here the data are routed to any one of the high-speed Fujitsu disks or to the special electrographic recorders (EGRs) for production of high-resolution spectral plots. Each system half is controlled by a VAX host computer, which also provides disk-service functions for a number of VAX workstations used by the operator and the analysts via an Ethernet/DECNET local area network.

A key feature of the MNNAS-II design is its "split" architecture, which allows 50% of the system to be available in the event of any single-point failure. Its distributed design allows for significant future expansion. To accomplish real-time signal processing, the system

ORNL Photo 7077-88

Fig. 2.5-3. The MNNAS-II array processing and analysis system.

utilizes 400 Mflops (million floating point operations/s) of computational power by way of its eight array processors that operate in parallel. Two high-speed buses provide an aggregate data bus bandwidth of 48 Mbytes/s for control and distribution of spectral data after they are produced by the array processors. The system provides 4 Gbytes of short-term data storage on disks that can sustain a read/write rate of 16 Mbytes/s. VAX computers serve as hosts for each system half, and as disk servers and boot-nodes for a number of VAX workstations. Clustering the VMS operating system allows complete software system maintenance at a single point. The system will be completed in FY 1989 and installed on a seagoing vessel.

2.5.3 LOCAL AREA NETWORK DEVELOPMENT, DESIGN, AND SUPPORT

LAN technologies facilitate information exchange and resource sharing within local work environments. Interconnecting an increasing number of computer systems permits increasing integration of all aspects of information processing in the workplace—including word processing, data processing, electronic mail, and data base management. I&C is developing the tools to meet Energy Systems' organizational networking needs including developing designs for installations, product evaluations, status monitors, and compliance tests that ensure successful networking.

To support the large distribution system of the widely dispersed, 25-mile Energy Systems interplant broadband cable network, I&C has developed a signal level/status monitoring system. This system continually monitors remote amplifiers at strategic locations. The status monitoring system allows a centrally located PC to alert telecommunication personnel of any broadband signal level changes, and it has greatly improved our ability to troubleshoot the network.

Major needs of such a large distributed system, which is maintained by a dozen or more employees at three different sites, are adequate documentation, training, and

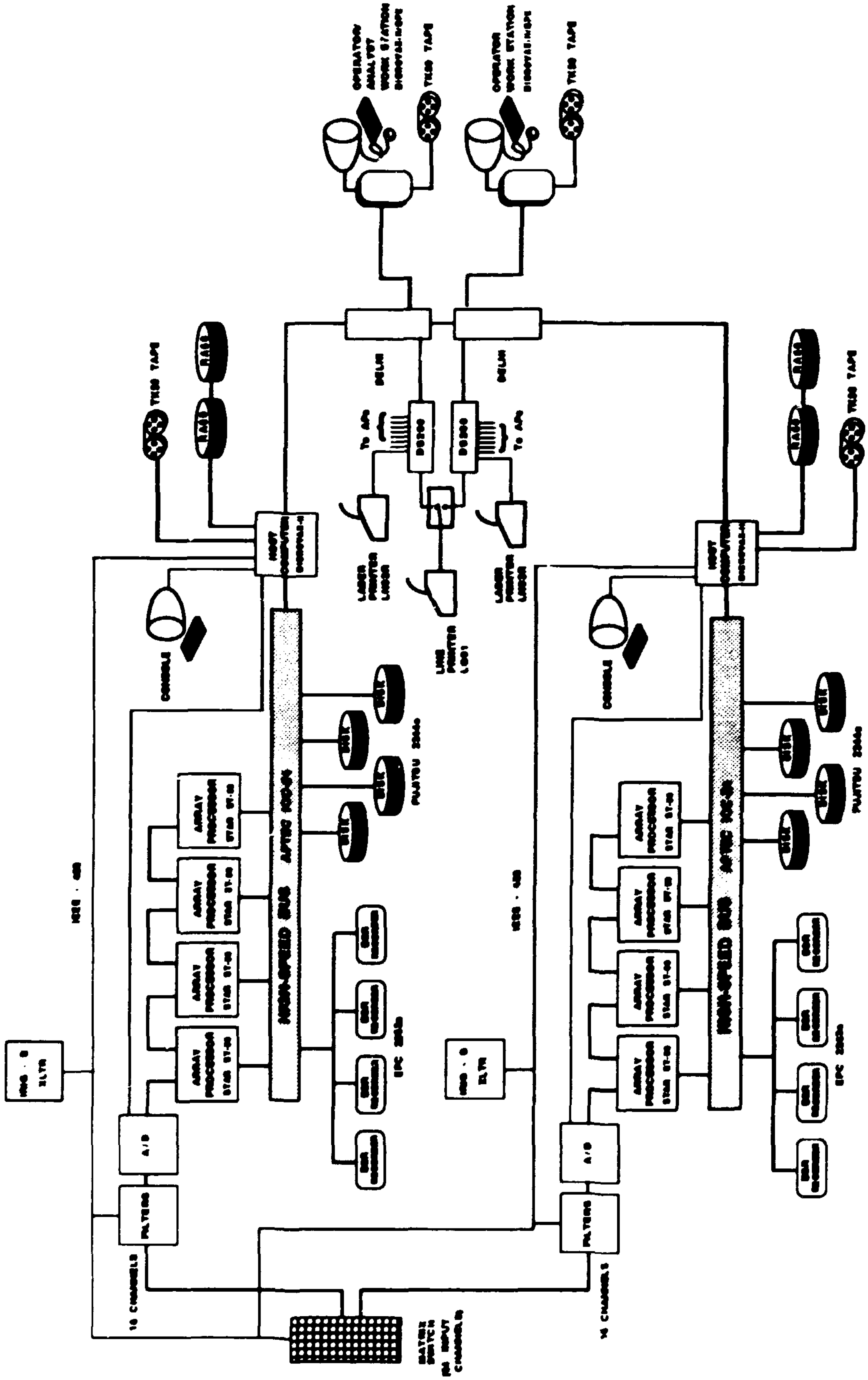


Fig. 2.5-4. Diagram of the MNNAS-II processing and analysis system.

maintenance procedures. I&C has produced new drawings for the headend room and selected distribution networks and a single-line network diagram. I&C also has designed distribution networks for several additional building installations and has issued a report on design criteria.* Realignment and recertification procedures have been developed to aid in maintenance and operation of the system. In addition, training for telecommunication and maintenance personal was provided for the realignment project.

With such large cable networks, which can cover more than 30 buildings, another major concern is identifying equipment emitting out-of-specification rf signals that could compromise the entire network. Incoming inspection procedures were developed by I&C for Sytek's desktop modem, interchannel bridge, multiplexer, and translators. These inspection procedures are used by maintenance personnel to ensure proper operation of the new devices before placement on the broadband network.

I&C has evaluated point-to-point modems such as Sytek's 56-Kbit/s synchronous broadband modem, Halley's (Zeta Laboratory) 19.2-Kbit/s and 56-Kbit/s synchronous broadband modems, and Scientific Atlanta's T1 broadband modem.

To improve the interconnectivity of computer systems, personal computers, and networks, two products called bridges (from Bridge Communication and Applitec) that interconnect Ethernets via the interplant broadband system were evaluated. The test procedures developed by I&C evaluated the bridges' throughput, reliability, and maintainability to ensure proper operation as specified in IEEE Standard 802.3. A report was issued documenting the evaluation.†

Networking as a technology is changing with the introduction of many new products. Large companies with large networks, trying to lower the cost of networking computer systems, are interested in new developments. Since networking is a fundamental part of Energy Systems' ability to transport data between sites, new products are continually investigated by I&C. This group has evaluated new products that implement Ethernet and IBM's token-ring over unshielded twisted-pair (telephone wire) cable. Using IBM's token-ring, synoptic communication's LATTISNET, and Lannet's LE-6 equipment, this group tested the feasibility of using twisted wire in new construction by ensuring that equipment met IEEE Standards 802.3 or 802.5. During the testing, three cable vendors' products were evaluated: Accutech, Teledyne, and AT&T.

Networking involves design, installation, evaluation, maintenance, documentation, status monitoring, training, security, and much more. I&C is committed to developing networking tools to meet Energy Systems needs.

2.5.4 INSTRUMENTATION AND CONTROLS ENGINEERING NETWORK

The ICENET computer system is a heavily used Division-wide resource to support the large-scale engineering R&D efforts of more than 250 I&C staff members.

To support I&C project efforts, the ICENET computer system has been expanded by the installation of four additional VAX CPUs, new-technology Winchester disk drives (for total storage capacity of more than 3 Gbytes), three laser printers, a streaming

*R. W. Hayes et al., *Building Distribution System Design Criteria for the ORNL/Interplant Broadband Network*, ORNL/TM-10118, December 1987.

†R. W. Hayes and J. T. Farmer, Jr., *An Evaluation of Ethernet Connectivity via Broadband Bridge*, ORNL/TM-10177, November 1987.

magnetic tape cartridge drive, and a 2.3-Gbyte, 8-mm magnetic tape storage device for backing up the disk volumes.

The ICENET computer system now consists of one VAX 11/780, one MicroVAX II, and four VAXstation 2000s with associated peripherals (Fig. 2.5-5). The ICENET VAX 11/780 and four VAXstation 2000 computers are connected in a local area VAX cluster network to provide extensive peripheral sharing and load distribution across the CPUs. This arrangement has increased the total CPU power of ICENET to five times its previous capacity.

The ICENET computer systems provide support for development of high-level language software, AI programming, engineering drawings, control system modeling software, and tools such as data base management, spreadsheet, and text processing programs for timekeeping, personnel, procurement, and plant-wide instrument maintenance records. Spice, ACSL, $MATRIX_X$,* and the NAG library provide engineering tools for circuit and control systems modeling and analysis, while OPS5 and LISP provide tools for designing AI and expert systems applications. System 2020 and System 1032 provide tools for spreadsheet and data base management. The list of high-level languages supported includes FORTRAN, C, Pascal, Ada and BASIC.

Thick-wire and thin-wire Ethernet systems have been distributed throughout three I&C buildings, and bridges to connect the I&C Ethernet to the interplant Ethernet have been installed. The port contention device, an electronic switch that connects user terminals to computer systems, has been expanded to access the interplant broadband (IPBB) and Ethernet. We now have 10 incoming and 4 outgoing terminal lines to the IPBB network via Sytek terminal connections for users and systems throughout Energy Systems. We have added 8 incoming and 12 outgoing terminal lines to permit access via Ethernet terminal servers. These latest additions provide higher speed access to users outside the Building 3500 complex. This combined network provides easy access to both I&C and non-I&C Energy Systems computers for such purposes as electronic mail, file transfer, and data sharing.

The I&C Ethernet connects more than 60 computers ranging from PCs running PC-DOS, assorted workstations running Unix and VMS, PDP-11 computers running RSX-11M, to VAX computers running VMS and Unix. The ICENET disk system offers virtual disk storage for more than 40 IBM PCs for LAN data sharing between PC users and VAX users across Ethernet. The ICENET distributed print queues offer the use of three laser printers, one high-speed impact printer, and one dot matrix printer to I&C minicomputers and PCs connected to the Ethernet (Fig. 2.5-6).

2.5.5 FOUR-PLANT MEDICAL AND INDUSTRIAL HYGIENE COMPUTER SYSTEM

The four-plant medical and industrial hygiene computer system was developed by the RTCS Group to support the needs of Energy Systems medical and industrial hygiene organizations at Oak Ridge and Paducah. The system has recently been upgraded by providing additional memory capacity and improved processor performance through the addition of a new CPU/memory board that emulates a DEC PDP-11/84. The two system disks were replaced with disks that double the capacity for programs and temporary data

*$MATRIX_X$™ by Integrated Systems, Inc., Palo Alto, California.

ORNL-DWG 88-16556

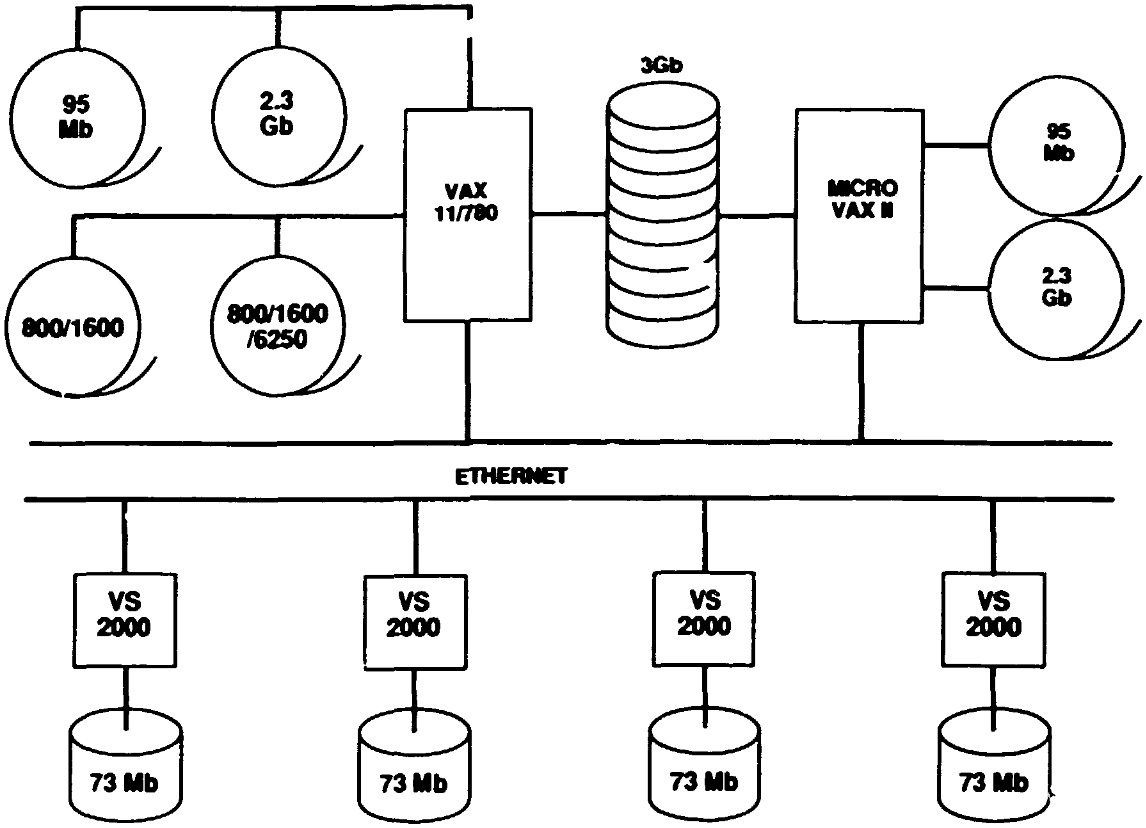


Fig. 2.5-5. Diagram of expanded ICENET system.

storage, a backup terminal-line multiplexer, and spares to improve system availability. A new terminal and printer were installed at DOE nurses' stations to display and print DOE employee data. Improvements to physical security were made, and the security plan has been updated recently.

A new blood chemistry analytical instrument was integrated in the system at ORNL. New limits, based on updated laboratory methods, were incorporated into the data displays and limit-checking programs to denote out-of-tolerance values.

To meet Occupational Safety and Health Administration (OSHA) standards for hearing conservation, audio baselines were established for each employee. Software was developed to display the original baseline and most recent audiogram. A printout is made for the employee if the standard threshold shift exceeds OSHA standards. Programs were written to maintain baselines with criteria for checking terminations, transfers, and rehires.

New software was developed to provide additional information displays for physicians. The new displays include audio screening criteria, cholesterol risk factors, respirator use criteria, and a list of Energy Systems Health Care Plan physicians and hospitals by location. Programs were written to set up the Health Care Plan/Physicians and Hospital Data Base with display/print menus for use in the medical centers at all three Oak Ridge sites.

To assist in assessment of services and activities, new software was developed to collect and archive data for monthly reporting to the Energy Systems Medical Director.

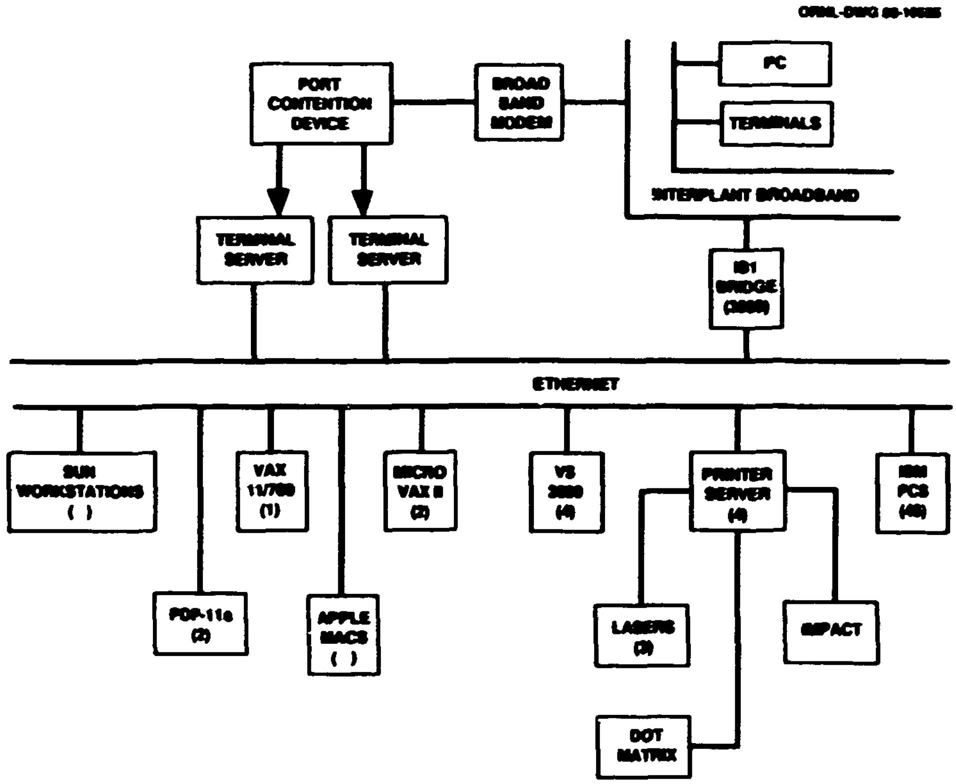


Fig. 2.5-6. Diagram of ICENET Ethernet system.

Numerous survey programs were developed to support the needs of the plant and Energy Systems medical directors.

A program was written for the ORNL Laboratory Protection Division's physical fitness data base, which is administered through the Health Division. Quarterly run tests, push-ups, and curls are recorded, and output programs print individual profile analysis reports and a report of key areas of the test, comparing the most recent test with the three previous ones.

A survey was made of all musculoskeletal injuries for 1985, 1986, and 1987 at the Oak Ridge and Paducah installations. The musculoskeletal system was divided into the cervical, upper and lower extremities, and mid- and lower back. The survey determined the total yearly occupational and nonoccupational injuries in each category and total days lost per category.

The system has now stored clinical data for 73,451 Energy Systems, DOE, Oak Ridge Associated Universities (ORAU), Rust Engineering, and other contractor employees, and laboratory data for 31,872 Energy Systems, DOE, ORAU, and Rust employees. All data for each employee are available for display or print.

Files are maintained for special hazardous occupation groups such as security, Materials Access Area (MAA), beryllium, asbestos, laser, and former coal workers who need special schedules for physicals or examinations by specialists.

A manual has been written to describe and document system procedures for the medical/industrial hygiene computer system.

2.6 INSTRUMENT RESEARCH GROUP

W. L. Zabriskie

Hal Beck* W. B. Jatko
Dragana Brzakozic* D. D. McCue
Jim S. Goodard† R. N. Nodine
Paul H. Hight‡ Ken Tobin**
M. A. Hunt R. W. Tucker, Jr.

The Instrument Research Group has returned to a small core group, concentrating on its traditional mission of providing "invention-on-demand" services to ORNL research projects having unique instrumentation requirements not met by commercial vendors. The current activities of the group include heavy involvement with machine vision, electro-optic design, chemical assay, and electronic circuit design for sensor development, signal acquisition, and data recording.

2.6.1 BUREAU OF ENGRAVING AND PRINTING PROGRAMS

A major new role for ORNL is that of technology integrator for the U.S. Treasury Bureau of Engraving and Printing as it plans for its next generation of high-speed stamp and currency printing systems. I&C Division expertise is being applied to the critical process of real-time, on-line inspection of the printed material in support of the Automation in Security Printing Program being led by the ORNL Chemistry Division. The ultimate goals for this effort are (1) to demonstrate the feasibility of performing detailed on-line inspection while maintaining overall system throughput and (2) to transfer the technology assembled and developed during the demonstration to the BEP in a manner that will facilitate the specification of its actual manufacturing systems.

Current targets for the inspection processes include detecting and flagging flaws as small as 5 mils and registration errors as small as 1 mil on paper moving through the presses at rates up to 1200 ft/min. Producing consistently high-quality stamps and currency is crucial to the BEP as it strives to (1) provide a visually attractive product to users, (2) meet the stringent demands of the numismatic and philatelic communities, (3) prevent the release of obviously flawed products (which invariably become prized collectors' items), and (4) deter counterfeiting by raising standards to levels that are difficult for unauthorized operations to meet.

The resolution, accuracy, and throughput criteria for these inspection systems impose hardware and software requirements that are beyond the current state of the printing art. In addition, fundamental issues concerning flaw definition and severity grading, human vs

*The University of Tennessee, Knoxville.
†Y-12 Computer Applications Engineering.
‡X-10 Instrument Engineering.
**ORNL Technology Division.

machine perception, and security and accountability must be addressed in the course of this effort. The systems developed must be able to be phased into BEP facilities and therefore must be partially compatible with existing equipment.

2.6.1.1 Currency Inspection and Finishing

The goal of the web currency inspection and finishing systems development effort is to build a prototype system based on machine vision technology that can recognize and mark flaws in currency as it moves continuously at speeds up to 600 ft/min. The system must detect the full spectrum of flaws typical of the processes used in currency printing including streaks, spots, gaps, setoff (unintentional transfer of undried ink occurring when note surfaces contact each other), front-to-back and image-to-edge registration errors, and others. Two inspections are required—one before and one after the overprinting process that adds the serial numbers, the U.S. Treasury seal, and the Federal Reserve Bank seal to the front of each blank engraved note. Provisions must be made to reject and handle notes receiving unacceptable flaw-severity grades. Sequentially numbered good notes must be packaged for delivery to Federal Reserve banks. All good notes, rejected notes, and even unused paper scraps must be accounted for in a material balance procedure.

A currency flaw model (a quantitative description of flaw severity based on flaw size, intensity, and location) was developed by Chemistry Division personnel, and the I&C Division has incorporated this model into a statement of work issued in a request for proposals to build the prototype system. The responsive proposers for the inspection system prototype have been identified, and the subcontract for this system should be awarded late in CY 1988. The I&C Division has also applied the model to development of the flaw calibration device (Fig. 2.6-1), which will grade the rolls of currency to be used in evaluating the performance of the demonstration inspection system delivered by the subcontractor. The I&C Division has developed specifications for and is procuring a web transport to serve as a test platform for in-house development activities and for evaluation of the demonstration inspection system(s).

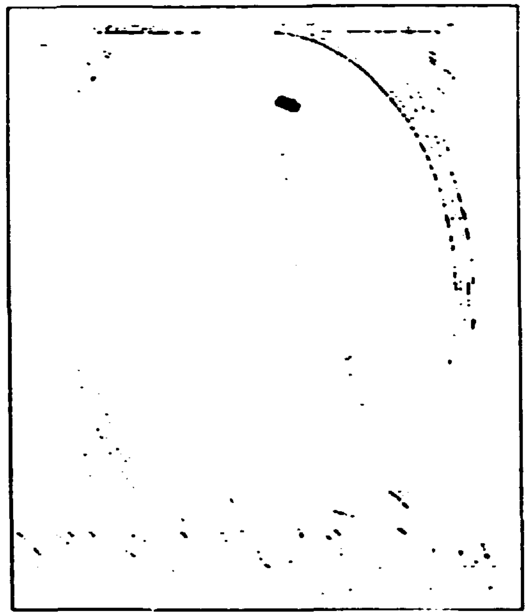
2.6.1.2 Stamp Inspection

The purpose of the Postage Stamp Inspection Program is to develop a technical foundation for the BEP in automatic postage stamp inspection technology. The objectives are (1) to develop standards for stamp quality that can be used by machines to perform automatic stamp inspection, (2) to develop sensors capable of measuring the characteristics of stamps that influence their perceived quality, (3) to investigate how best to integrate these sensors into the existing BEP manufacturing system, and (4) to build prototypes that demonstrate how automatic inspection can lead to increased production efficiency.

The project is divided into two phases. The current phase, technology development, focuses on analyzing the requirements for the inspection system and on developing sensors (or suites of sensors) to provide real-time measurements of the stamp characteristics that have been identified as useful in detecting perceived flaws. The second phase, technology integration, will develop prototype inspection systems (Fig. 2.6-2) that incorporate the technologies identified in Phase I and tie them together in a way suitable for installation and operation at BEP facilities.

Stamp inspection difficulties are compounded by several constraints not encountered by currency inspection systems.

(a) Difference image with no registration



(a) Difference image with registration

Fig. 2.6-1. Flaw calibration device processing: difference image after (a) simple alignment and (b) first-order registration correction. Note the intentionally introduced flaw on the forehead.

1. Stamps are multicolored, and a single stamp may be printed with as many as six different inks. The inspections system must be able to measure the uniformity of a wide variety of colors and measure color-to-color registration.
2. Stamp size, images, and sheet layouts vary on a routine basis.
3. Stamps are smaller and move faster on the presses than do currency notes.
4. Stamps are perforated. The image-to-perforation registration problem replaces the obverse-image-to-reverse-image registration and image-to-edge registration problems in currency production.
5. Stamps may be printed with any of three different types of press. Each has its own features such as characteristic flaw types, tolerances, minimum feature size, and control methods.

2.6.2 PHOTOMETRIC PROCESS ANALYZER

Previous progress reports described development of an optical instrument that measures the selective absorption of ultraviolet light by solutions bearing uranyl compounds (Fig. 2.6-3). By measuring the attenuation of monochromatic light as it passes through the solutions, dissolved uranium concentration can be determined with good accuracy. This instrument is now finding widespread use in several Energy Systems programs.

In the Y-12 EURI upgrade project, a prototype system that was installed on the secondary extraction system 5 years ago was retired from service, and new three-channel systems were installed on each secondary extraction process line and on a new centrifugal contactor. A new three-channel system was installed at the Building 9731 Pilot Plant for use

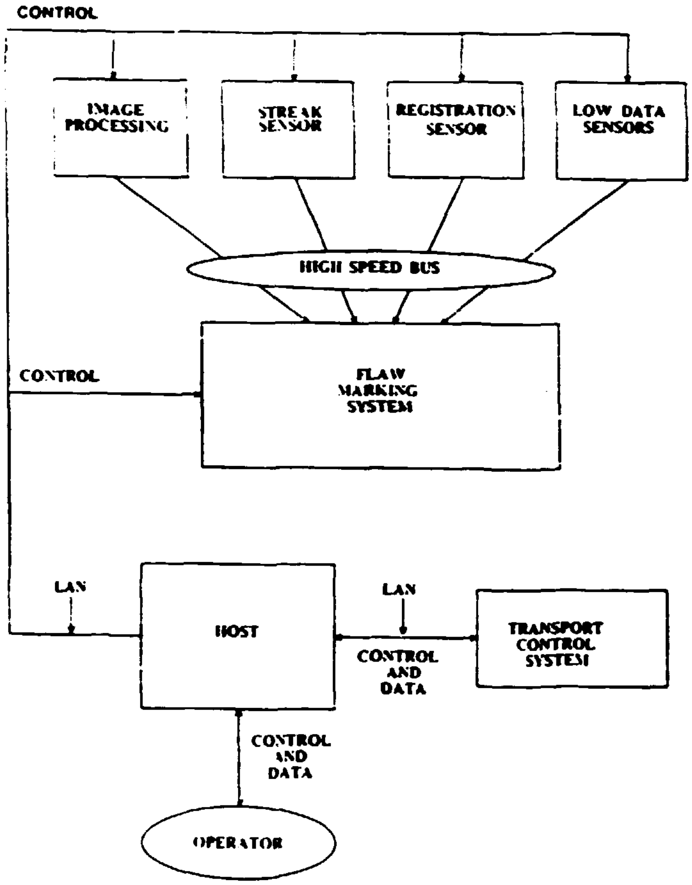


Fig. 2.6-2. Proposed postage stamp inspection system.

in testing pulse column devices and operations strategies for developing centrifugal contactor control algorithms. The monitor also has been applied to centrifugal contactors in support of the ORNL Consolidated Fuel Recycle Program. Two three-channel units have been provided, one for a multistage contactor and one for a single-stage version. Development is under way to adapt the system for use at infrared wavelengths so that water vapor concentration can be measured. The intended application for this version of the device is to detect the end of a UO_2-to-UF_4 batch conversion process. When water vapor is no longer present in the process off-gas, the reaction is complete and the HF feed to the process should be terminated. Successful application of the photometric monitor to this process will have several benefits, including (1) more efficient use of expensive, high-purity HF, (2) extended equipment life due to reduced exposure to unreacted HF and HF vapor, and (3) improved environmental safeguards by preventing releases of HF vapor.

2.6.3 REMOTE SENSOR AND CABLE IDENTIFIER

In 1987 MACES staff received an R&D-100 Award for a remote sensor and cable identifier system. The sensor-identifier system consists of small, passive identifier circuits and an interrogator. The identifier circuit is permanently connected to a remote sensor (such as a thermocouple) but is electrically isolated so that normal sensor operation and

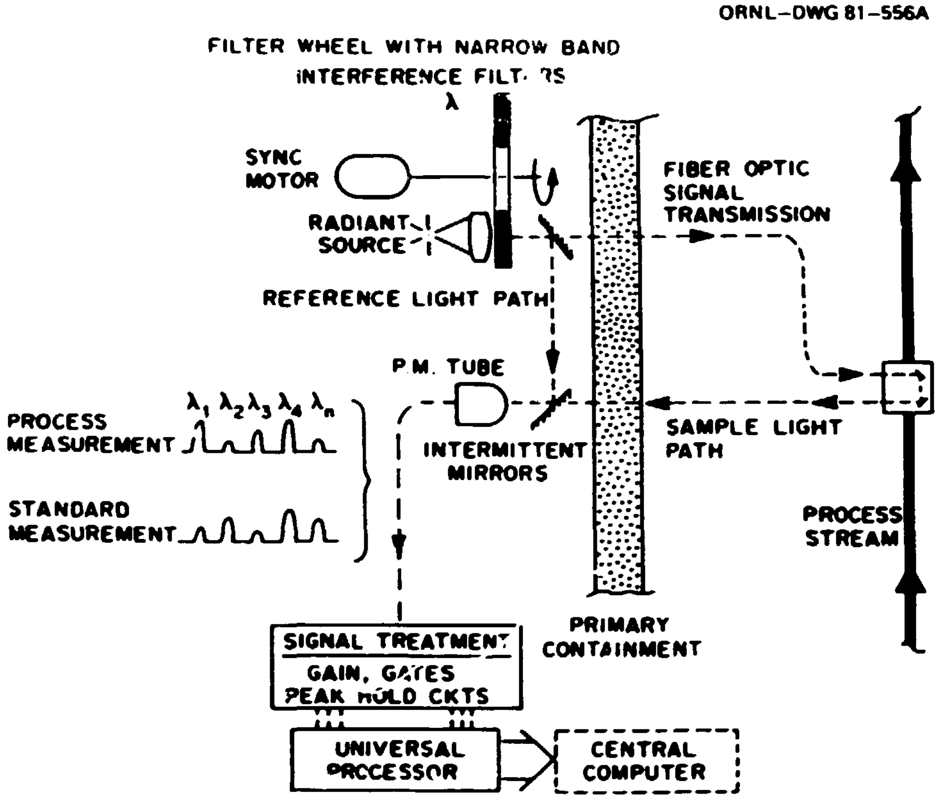


Fig. 26-3. Diagram of the photometric uranium monitor.

accuracy are not affected. The identifier circuit remains passive until queried. The circuit is queried by connecting the interrogator to the sensor cable at the termination point, typically in a control room. The identifier circuit will reply with a preset identification code for the attached sensor. The interrogator matches the identification code with the corresponding sensor type, model, and location from a look-up table and displays this information to the operator. Alternatively, the sensor data can be sent to a host computer for electronic generation of a facility's "as-wired" schematics. A single interrogator can be multiplexed to read an arbitrary number of identifier circuits. The identifier circuit will ultimately be miniaturized to an integrated circuit chip.

This device is unique because it can use the sensor's existing wiring to send identification data to the interrogator, thus eliminating the need for costly additional wiring. The system uses a proprietary method of transmitting energy to the identifier circuit, enabling it to reply by sending the sensor identification signal back to the interrogator. This process can generally be done even while the sensor is operating.

The system was developed from transmission-line theory and has been verified with cable lengths up to 5000 ft using various types of cables (2-wire, thermocouple lead wire, coax, etc.), sensors, and open and shorted terminations.

NASA has begun funding an additional multiyear development on this system for its Advanced Launch Facility at the Kennedy Space Flight Center.

2.7 ELECTROMAGNETIC TECHNOLOGY GROUP

R. A. Hess
P. D. Ewing — M. R. Moore
J. M. Googe — R. W. Rochelle
J. H. Holladay — E. E. Waugh
D. J. Marshall

The I&C Division Electromagnetic Interference/Electromagnetic Compatibility Engineering/Test Team became a separate line organization, the Electromagnetic Technology (EMT) Group, during this reporting period. This newly formed group has assumed the responsibilities of the former engineering/test team as well as the responsibility for providing service to ORNL research projects having electromagnetic problems or concerns.

The group has gained considerable expertise in all aspects of electromagnetic environmental effects (E^3) including electromagnetic interference (EMI), electromagnetic compatibility (EMC), electrostatic discharge (ESD), lightning effects, and electromagnetic pulse (EMP). The group also has expanded its involvement in TEMPEST (a study of compromising emanations) programs and was instrumental in the startup of a new technical surveillance countermeasures (TSCM) program.

The group is actively involved in work for government agencies other than DOE, including the U.S. Navy, U.S. Army, and Department of State.

2.7.1 U. S. NAVY

As part of the Electromagnetic Environmental Effects (E^3) Branch team of the Naval Air Systems Command (NAVAIR), the group has become involved in many aspects of this program including the following:

EMP Testing. The group serves as project manager for EMP testing of naval aircraft. This work has involved all aspects of testing from reviewing and upgrading test methodology to scheduling tests and preparing the test, safety, and security plans.

High-Speed Digitizer Evaluation. An in-depth evaluation of the LeCroy 6880A modular waveform digitizer was performed to determine its suitability for use in recording EMP-induced waveforms. The effort closely examined its conformance to quoted specifications and sought to identify any operational anomalies.

Novix Evaluation. The EMT Group performed a technical assessment of the Novix, Inc., FORTH engine for possible use in the navy EMP data acquisition and analysis system. Results of the assessment indicated significant technical advantages of the FORTH engine chip over more traditional microprocessors. However, from a systems viewpoint (software, support chips, etc.), we recommend against using the chip in this program.

Composite Connector. The group was involved in a joint effort with NAVAIR and G&H Technologies, Inc., to develop a composite connector that would conform to military specification MIL-C-38999, be lightweight and highly corrosion-resistant, and have good

EMI characteristics. An extensive search failed to identify any promising candidate materials suitable for this application.

Shielding Effectiveness. This program grew out of the need for a standard methodology for measuring the shielding effectiveness of composite materials. The group conducted studies of various current methods of testing composites and a correlation of the values obtained from these different methods. The group has acquired the expertise and equipment required to perform testing according to formal procedures of the National Institute of Standards and Technology (formerly the National Bureau of Standards).

Rf Monitor. The need for a personal rf radiation dosimeter with cumulative dose recording capabilities was addressed. This project is described in greater detail in Sect. 2.7.5.

2.7.2 U. S. ARMY

This study was undertaken to address the army's concern for the safe operation of the Harry Diamond Laboratories (HDL) EMP simulation facilities, which in turn led to concern for the safety of medical electronics equipment in general and electronic medical device wearers in particular. The primary issue addressed by this study was the adequacy of existing standards and regulations regarding susceptibility of these devices to transient electrical overstress. The study revealed that no standards, regulations, or industry-wide guidelines deal specifically with susceptibility of medical electronics to EMI from radiative sources. Although awareness of this issue in the professional community is increasing, none of the organizations that usually promulgate such standards have committees active in this specific area.

2.7.3 U. S. DEPARTMENT OF STATE

This DOS project was an in-depth study of the state of the art in rapid and complete destruction and/or sanitization of computer storage media. The following techniques were considered.

Destruction Techniques	Sanitization Techniques
1. Cutting action	1. Degaussing
2. Abrasive action	2. Overwriting
3. Explosives	3. Encryption
4. Chemical action	4. Magnetic bubble erasure
5. Incineration	

These techniques were evaluated against criteria supplied by the State Department.

2.7.4 TEMPEST PROGRAMS

The TEMPEST testing program for all DOE facilities under DOE/ORO is the responsibility of the EMT Group, which has been charged with zone testing, field testing, and equipment assessment. TEMPEST testing determines the extent to which conducted or radiated electromagnetic leakage of potentially compromising information reaches nonsecure areas. Zone testing is a characterization of the attenuation of rf fields between the area being tested and a predetermined zone boundary, whereas TEMPEST assessment characterizes emanations from a particular piece of equipment. Based on zone testing and equipment assessment, guidelines are developed concerning what equipment can be used safely in which areas of a facility.

The EMT Group performed a telephone line attenuation study for the Department of Energy. DOE communications security requirements specify a minimum physical separation between computer equipment (including cabling) that handles classified information and unprotected telephone lines to prevent compromising emanations outside the controlled area via telephone lines. If rf attenuation of telephone lines is high enough between the point of coupling and the exit from a controlled area, this separation requirement can safely be waived. A major EMT Group test effort characterized the rf attenuation of telephone lines to determine the lengths of cable required to provide sufficient attenuation.

The first phase of testing was to simulate electromagnetic radiation from a source computer terminal and its coupling onto nearby telephone lines and develop a procedure for measuring telephone line attenuation between buildings. In the second phase, attenuation at three different DOE/ORO sites (Y-12, ORGDP, and PGDP) was measured. Results are being used to obtain waivers of the placement rule in areas sufficiently isolated from noncontrolled areas.

In a related project, group members served on an evaluation team that conducted an overall security evaluation of a U.S. Air Force base. They were responsible for the TEMPEST portions of the evaluation.

A broadband cable system represents a significant resource for data transmission within a facility, but duplicate broadband networks to provide services of varying sensitivity levels within the same area is an inefficient use of capital resources. Different data services sharing a single network is financially attractive, provided that sensitive data are inaccessible from nonsensitive ports. Testing performed in the I&C Division indicates that significant isolation can be obtained by using equipment from two separate vendors to introduce a deliberate incompatibility.

Vendor systems from Sytek and Ungermann-Bass were chosen for analysis because they are in use in DOE networks and because system specification differences initially indicated that isolation would exist. The two vendor products use different protocol, modulation, and bandwidth schemes to process information transmitted between users, and it was believed that the two systems could operate independently to provide maximum isolation.

To verify the isolation, an experimental broadband test network was constructed that allowed simultaneous operation of both systems. By using an independent system, total control over the network could be exercised without interfering with ongoing broadband operations. Figure 2-5 (p. 65) shows the test network along with the associated computers and monitoring instrumentation, and Fig. 2.7-1 shows the layout for the broadband test setup. The broadband network was a 300-MHz midsplit system configured to represent a typical system except for the use of variable attenuators to alter network operating levels. Sytek 2502 frequency-agile modems were chosen as the nonsensitive interface, and Ungermann-Bass NIU-180 modems were selected as the sensitive interface.

Theoretical analysis indicated that a minimum of four independent levels of isolation were achievable. These levels were (1) frequency separation on the broadband cable, (2) differences in rf modulation and bandwidth, (3) detection of the broadband signal to

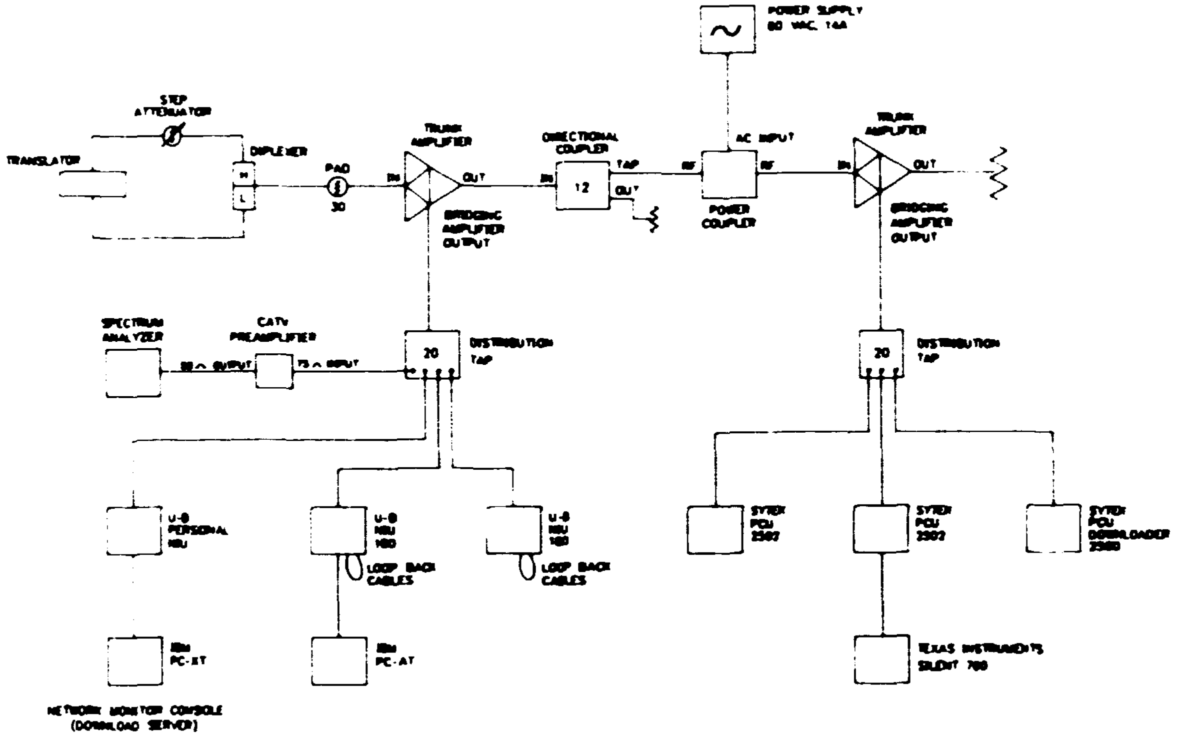


Fig. 2.7-1. Block diagram of the broadband test network.

recover digital data, and (4) software protocols implemented for packet transmission control by each system. When implementing the test system, the two modem types were assigned :o the same frequency on the broadband network. Cochannel operation is not normally implemented in an operational system, but in this case it was necessary in order to obtain sufficient signal strength to test the isolation of levels two and three.

Results of the testing show that significant data protection can be achieved by using different vendor products to obtain multilayered isolation. The mixed-modem technique provides a cost-effective method of sharing a broadband network while maintaining isolation of data with different sensitivity levels. This method can be implemented without concern for breach of security provided that the level of protection for the modems is commensurate with that of a secure broadband network, that administrative control is exercised over the sensitive modems, and that normal security is maintained.

2.7.5 PERSONAL RF DOSIMETER

The I&C Division is developing a personal rf dosimeter for the Electromagnetic Environmental Effects Branch of NAVAIR. This portable instrument is a cumulative dose recording device designed to detect and record the strengths and durations of electric fields present in the work areas of naval vessels. The device is designed to be worn by individuals to detect and record electric fields that exceed permissible levels set by ANSI. This dosimeter should increase present knowledge of the levels of electric fields to which naval personnel are exposed.

The design of the personal rf dosimeter is illustrated in Fig. 2.7-2. The electric field sensor for the dosimeter consists of three orthogonal printed-circuit dipole antennas designed to cover the frequency range of 30 MHz to 10 GHz (Fig. 2.7-3). Beam-lead Schottky-Barrier diodes are used to convert the rf fields to dc voltages, and readings of the sensor's dc outputs are fed into an Intel 80C196 16-bit CMOS microcomputer for conversion into digital signals. Readings are averaged over a 6-min period corresponding to the rise time of the core body temperature, and these values are stored for a 6-month period, after which the data are retrieved by a host computer via the dosimeter serial port.

The feasibility of the personal rf dosimeter has been demonstrated, and its effectiveness in measuring field strengths is presently being evaluated. A prototype unit is being used to measure known electric fields for extended periods of time to determine device accuracy. Upon completion of this evaluation, a production prototype will be built to demonstrate the type of instrument that could be fabricated in quantity.

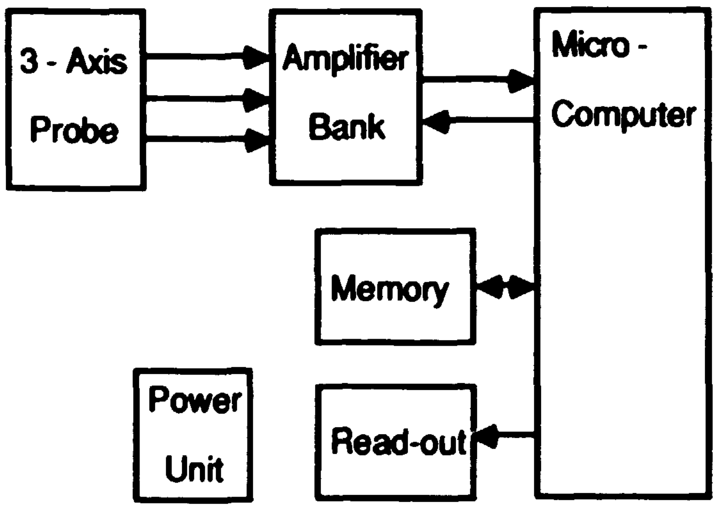


Fig. 2.7-2. Diagram of a personal rf dosimeter.

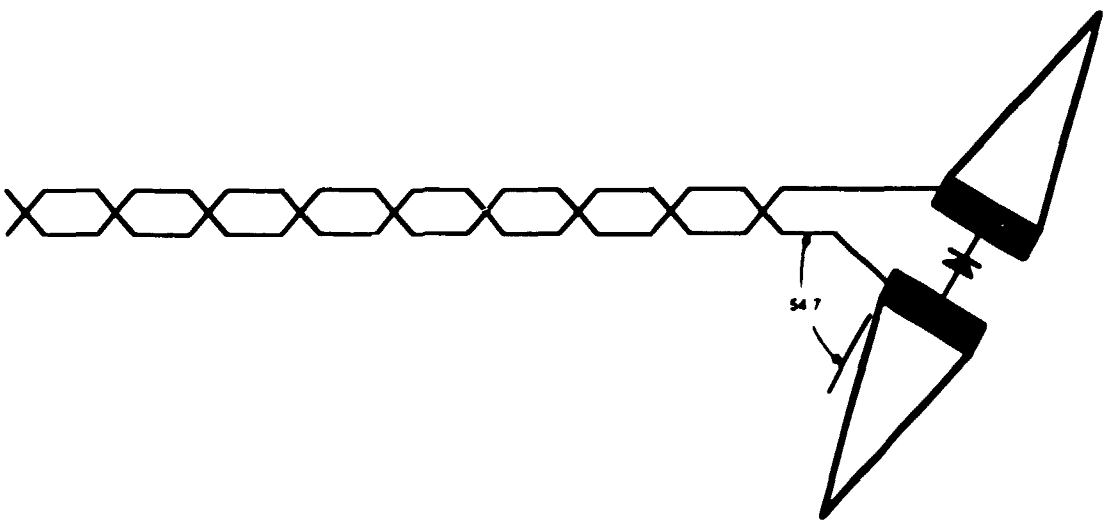


Fig. 2.7-3. Dipole antenna used in rf dosimeter sensor.

2.8 MEASUREMENT RESEARCH GROUP

R. L. Anderson
M. H. Cooper
W. B. Dress, Jr.
J. D. Lyons

The Measurement Research Group specializes in fundamental measurement and metrology research, sensor development, and applications of artificial intelligence concepts to measurement problems. The group also operates the Standards Laboratory for ORNL through which measurement traceability to the National Institute of Standards and Technology (formerly the National Bureau of Standards) is maintained. Major projects and activities of the group during this reporting period are summarized below.

2.8.1 NEURAL NETWORK RESEARCH

The use of neural metaphors for problems in autonomous system design, pattern recognition tasks, and machine learning has been investigated over the past 2 years. Of particular interest is a methodology, based on Darwinian principles, for autonomous design of complex systems.

2.8.1.1 Pattern Recognition

The ability to recognize, store, and recall complex patterns has long been of interest in engineering and computer science. Work from the late 1950s was brought up to date in several pattern-recognition systems. A 10 × 16 element tactile pad (used in robotic sensing applications) served as the input device for one of the algorithms. The resulting system could be trained to recognize various objects (hex nuts, coins, rods) by touch. A computer-based system for recognizing handwritten characters was likewise demonstrated.

2.8.1.2 Methods in Machine Learning

A project undertaken for the Materials Laboratory at Wright-Patterson AFB involved examining various artificial neural network models with the goal of identifying learning methods appropriate for machine discovery systems. The first result of this work was a categorization of various learning mechanisms. In the process, we had to examine the various artificial neural systems used. The second result was subsequent classification of the several neural net "paradigms." This classification contains the major popular models as well as some relatively unknown ones. The final result of this project was identification of the type of learning central to the needs of any true discovery engine.

2.8.1.3 Autonomous Design of Complex Systems

Beyond a certain level of complexity, both hardware and software solutions for systems required to function in the natural world become impossible problems to solve with standard methodologies of structured design (engineering project management and software engineering). The exact level of this complexity is not known, but examples currently being debated as candidates include control systems and software for the strategic defense system, the NASA space station, and advanced reactor systems. As the demands of the next century will certainly place exponentially greater strains on our methodologies, which are currently advancing at a linear pace, achieving a breakthrough in design principles is one way to guarantee our ability to keep pace with the demands. Work has been undertaken over the past 2 years to attempt to achieve such a breakthrough. The proposed methodology is described in a published paper.*

In simplest form, the idea is to let the systems design themselves in both simulation and actuality. Methods are taken from the natural world and include neuron and brain models and methods found in natural selection and molecular genetics. This approach has proven successful in the few cases tried thus far, and it seems to have general validity. A plausible argument for a guarantee of success is presented every time we see another living organism, each of which has been designed to a point of optimality for a specific set of functions and tasks. Nature has even designed what appears to be a very general system for coping with a broad range of problems. (See Fig. 2.8-1.)

2.8.1.4 ORAU Traveling Lectures and ORNL Speakers' Bureau Activities

Recognition of the rapid advances being made in computer science and engineering in the general field of artificial intelligence and connectionist architectures has led to a large number of invitations for speaking engagements at secondary schools, colleges, universities, and various professional symposia in the Southeast. More than 20 presentations have been undertaken during the last 2 years under the auspices of the Oak Ridge Associated Universities Lecture Program and the ORNL Speakers' Bureau, and the pace seems to be accelerating.

2.8.2 METROLOGY FOR THE SURVIVABLE OPTICS MODIL

The Survivable Optics Manufacturing Operations Development Integration Laboratory (MODIL) is a program to improve optical manufacturing technologies for the Strategic Defense Initiative Office (SDIO). Oak Ridge National Laboratory was selected as the site for this first MODIL by SDIO in mid-1988. Metrology for the survivable optics MODIL encompasses all measurements that affect the quality of the optics produced. Insofar as possible, it is desirable to use deterministic metrology–that is to say, on-process or in-process measurements–with the objective of reducing or even eliminating separate gaging steps in the manufacturing process. Ideally this procedure would require real-time measurements that can be used as feedback in control of the fabrication processes. At the present time, most optical fabrication employs gaging as a separate and often time-consuming process. A recent study by Perkin-Elmer estimated that inspection took up >75% of the total time spent in final figuring and polishing of beryllium optics. Clearly a significant savings in processing can be realized by moving toward real-time, in-process inspection and gaging. Metrology methods are considered in five categories: (1) starting material parameters, (2) substrate parameters, (3) machining/polishing parameters, (4) coating parameters, and (5) final inspection/test measurements. The status of

*W. B. Dress, "Electronic Life and Synthetic Intelligent Systems," *Mathematics and Computers in Medicine* (Fall 1988).

ORNL Photo 2477-88

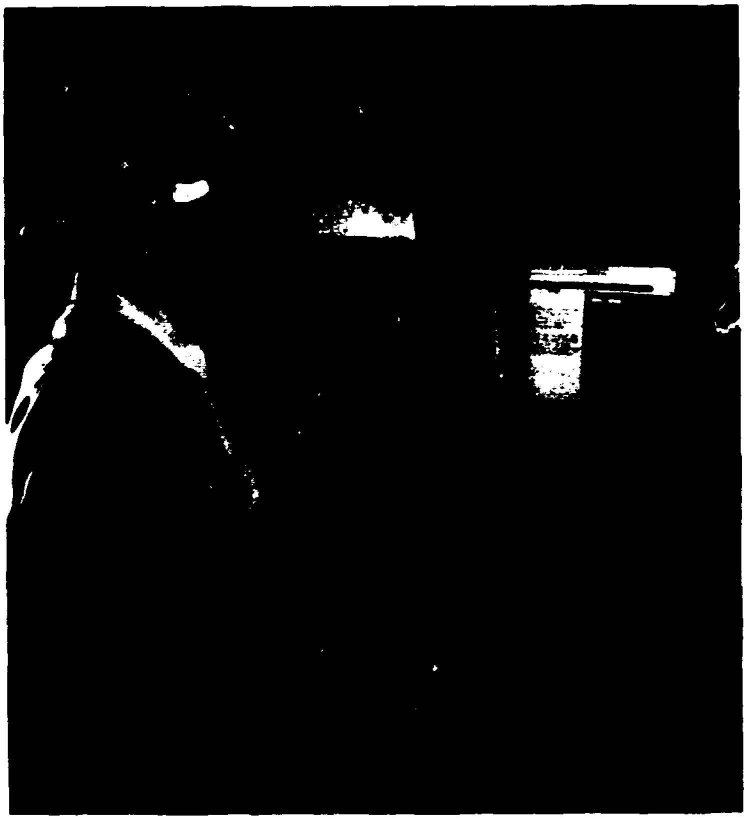


Fig. 2.8-1. Electronic life model in action.

industry capabilities and the technology issues in industry have been studied in each of these categories. Major program funding is expected to begin early in FY 1989.

Development of in-process measurement technologies is anticipated to include surface figure measurement using interferometry and other noncontact technologies for sensing the optics surface (ultrasonics, eddy current, capacitance, air gaging); subsurface damage and residual stress; surface microprofile and reflectance or ellipsometry and determining of the relationship of these measurements to scatter; in-process coating thickness measurement; and nondestructive, noncontact measurements of coating adhesion.

2.8.3 EXERCISE AND MONITORING PROGRAM FOR ELECTRONIC TEST INSTRUMENTS

Failures of instruments in nonoperating storage prompted the Navy Calibration Laboratory (NCL) at the Seal Beach Naval Weapons Station to seek methods to reduce these failures. A Navy subcontractor, C.A.C.I., thereupon developed an "active storage" procedure–the exercise and monitoring (EAM) program–for a large batch of electronic test instruments destined for the Royal Saudi Navy Calibration Laboratory in Al Jubayl, Saudi Arabia.

The I&C Division has conducted an independent assessment of the EAM program for NCL including a literature survey to gather data on failures of nonoperating electronic equipment. Since the early 1960s, several of the armed services and their contractors have been concerned with storage failures and shelf life of missile materials. These studies developed models for nonoperating failures at the component level. Analysis of failures of operating components gives some insight into nonoperating failure mechanisms, but the quantity of data available for their analysis is sparse. In many cases the cause of failure is not clearly attributable to storage, and the number of documented failures available for analysis is so small that application of standard statistical methods is questionable. These models, therefore, have not been used to calculate nonoperating failure rates for specific electronic test instruments, but they do provide insight into probable causes of such nonoperating failures of electronic test instruments. Many of the conclusions concerning the causes of these failures tend to support the strategy developed for the EAM program. With minor modifications, the EAM approach could be applied to electronic equipment and mothballed facilities to reduce storage-related failures. This application can be a very cost-effective measure to ensure equipment availability when reactivated.

The introduction of electronic systems on U.S. Navy ships is accelerating. The reliability and availability of these shipboard systems at sea depend on maintenance and repair capabilities on the ship. Electronic test instruments used to maintain ship systems are carried as a part of each ship's inventory of equipment. A recently completed carrier, the Theodore Roosevelt (CVN-71), carries well over $1M in some 500 items of general-purpose electronic test equipment. Although redundant instruments may be carried, they are located in different workstations distributed throughout the ship so that failure of a test instrument, while rarely dehabilitating, can impair operating efficiency. As a part of the Seal Beach Naval Weapons Station, the NCL is responsible for outfitting many ships with electronic test and calibration equipment. When possible, test instruments for each ship are drawn from navy stores at the Ship Parts Control Center in Mechanicsburg, Pennsylvania, even for new construction. Over the years NCL has experienced a high percentage of failures (typically 25%) of instruments returned to use after storage.

In 1984, NCL was assigned the responsibility for supplying test and calibration equipment for an upgrade of the Saudi Arabian Navy's calibration and standards laboratory. Because of the high visibility of this international program, NCL decided to see what could be done to reduce the number of operating failures in instruments delivered on this program. Working with a subcontractor who collected and stored the instruments for this program prior to delivery to the Saudis, NCL devised EAM active storage.

EAM maintains electronic instruments in a temperature- and humidity-controlled environment. Periodically (on the average of once a month), each instrument is powered up and all switches and other controls operated. As a result of this program, the failure of instruments delivered to Al Jubyal was reduced from 25% to less than 1%.

2.8.4 NETWORKING IN THE METROLOGY LABORATORY

We have begun setting up a shared resource management (SRM) system in our laboratory. This is a data network (see Fig. 2.8-2) to interconnect all computing facilities in the Metrology Research and Development Laboratory (MRDL). When the new network is in place, all four MRDL computers can share programs, data, and printing and plotting facilities. This is an initial step toward replacing aging HP-9825 computers whose tape drives are wearing out and are no longer supported by Hewlett Packard. (The HPL language is also being phased out.)

Of particular interest is a new HP-Vectra, which includes a 68000 coprocessor and HP-BASIC in ROM. With this machine it will be possible to move data from other HP

Series 9000 computers in the system to the IBM PC environment for word processing or spreadsheet calculations. The new network can communicate with other systems via Ethernet through HP-UX (HP's UNIX). This will allow us to ship data from the local SRM to one of our VAX systems and hence to the Maintenance Management Department data base. We can also tie to the Navy Gage and Standards Center in Pomona, California, to exchange programs and data through ARPANET.

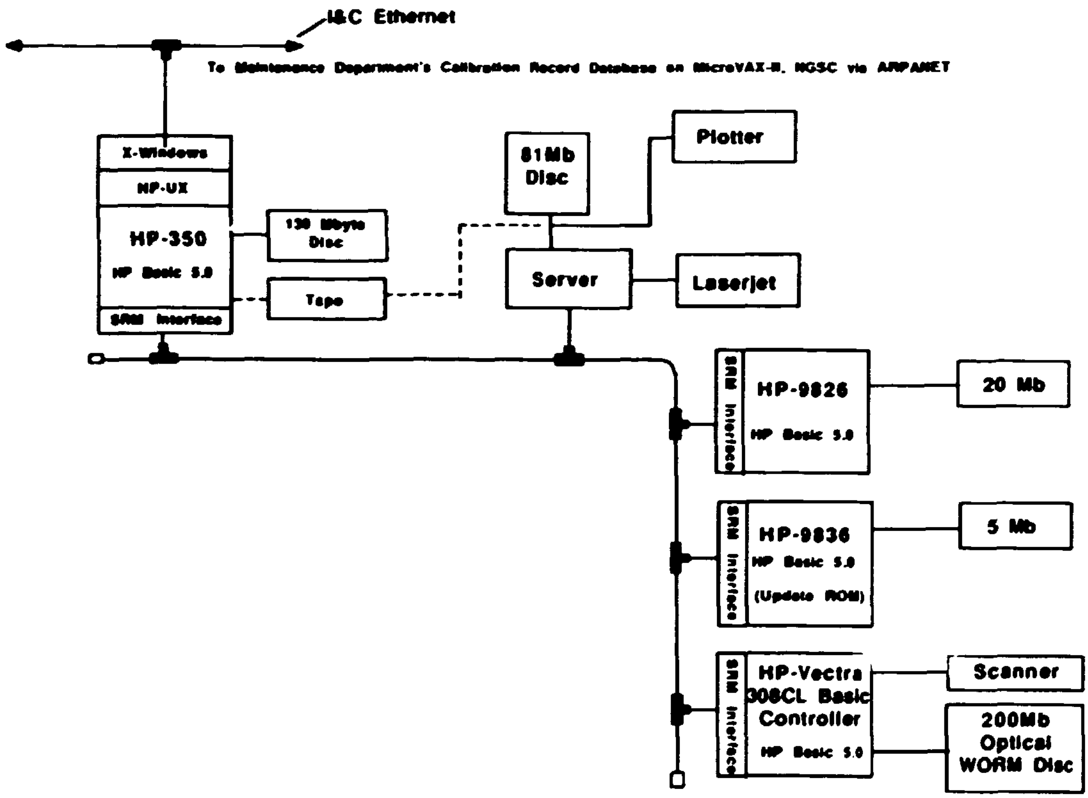


Fig. 2.8-2. Block diagram of MRDL data network system.

2.9 PUBLICATIONS AND PRESENTATIONS

D. J. Adams, D. L. Beshears, G. J. Capps, J. K. Jordan, G. W. Ott, M. B. Scudiere, C. P. White, R. N. Nodine, and R. A. Todd, *Naval Underwater Systems Center Torpedo Data Acquisitions System - Wet System Conceptual Design Report*, K/ETAC-64, April 1988.

J. D. Allen, Jr., and P. L. Butler, "The Implementation of a Parallel Architecture for the OPS Expert System Language," Rochester FORTH Conference, Rochester, N.Y., June 9-13, 1987; *J. Forth Appl. Res.* 5(1), 235 (1987).

J. D. Allen, Jr., and W. E. Thiessen, *A Useful By-Product Expert System*, ORNL/TM-10178, August 1987.

G. O. Allgood, F. R. Gibson, D. H. Gray, and W. W. Manges, "The Implementation of a Hierarchical Control Strategy in the Development of the AVLIS Thermal Control Subsystem," 1988 International Symposium on Communications and Controls, Baton Rouge, La., October 19-21, 1988.

G. O. Allgood, F. R. Gibson, and W. W. Manges, "Development of an Optimal Control Strategy for the Startup and Outgassing of Material Handling Demonstration Module," 1988 International Symposium on Communications and Controls, Baton Rouge, La., October 19-21, 1988.

G. O. Allgood and D. S. Hartley, "Enhanced Utility of War Games Through AI - From Basic Constructs To Synthetic Intelligence," Joint National Meeting of the Operations Research Society of America and The Institute For Management Science (ORSA/TIMS), St. Louis, October 25-28, 1987.

G. O. Allgood, J. M. Hooper, M. G. Lilienthal, R. S. Kennedy, and B. W. Van Hoy, "Inertial and Control Systems Measurements of Two Motion Based Flight Simulators for Evaluation of the Incidence of Simulator Sickness," Image IV Conference, Phoenix, Ariz., June 23-26, 1987.

G. O. Allgood, R. S. Kennedy, K. S. Berbaum, N. E. Lane, and M. G. Lilienthal, "Etiological Significance of Equipment Features and Pilot History in Simulator Sickness," AGARD Conference, Brussels, September 1987.

G. O. Allgood, R. S. Kennedy, B. S. Van Hoy, M. G. Lilienthal, and J. M. Hooper, "Very Low Frequency Vibrations and the Incidence of Simulator Sickness," 1987 Annual Scientific Meeting of Aerospace Medical Association, Las Vegas, Nev., May 10-14, 1987.

G. O. Allgood, B. W. Van Hoy, R. S. Kennedy, and M. G. Lilienthal, "Motion Sickness Symptoms and Postural Changes Following Flights in Ground-based Flight Simulators," 4th International Meeting on Low Frequency Noise and Vibration, University of Umea, Humanisthuset, Sweden, June 9-11, 1987.

G. O. Allgood and L. C. Williams, "Basic Constructs for a Weapons Platform/Weapons Suite Mapping Onto Mission Profiles - A Classifier For JTLS ATO Expert System," Office of Joint Chiefs of Staff Military Aides Planning Conference, Hurlburt Field, Ft. Walton Beach, Fla., November 16, 1988.

J. L. Anderson, R. L. Anderson, E. W. Hagen, T. C. Morelock, T. L. Huang, and L. E. Phillips, "Post Implementation Review of Inadequate Core Cooling Instrumentation," IEEE 1988 Nuclear Science Symposium, Orlando, Fla., November 9-11, 1988; proceedings to be published.

R. L. Anderson, and G. N. Miller, "Selection of Sensors for Measurement and Control," Sensors Expo, Chicago, Ill., September 13, 1988.

W. H. Andrews, Jr., "Hardware for Improved Crossing Signal Visibility," Annual Meeting of Transportation Research Board, Washington, D.C., January 13, 1987.

W. H. Andrews, Jr., "Improving the Visibility of Railroad-Highway Grade Crossing Signals," *FHWA J. Public Roads* 51(2), 25-35 (September 1987).

W. H. Andrews, Jr., "Vulnerability Assessment: PC-Network Connectivity," *Cent. Comput. Security News* 6(3), 18-22 (December 1987).

W. H. Andrews, Jr., G. A. Armstrong, and T. L. Bowers, *Railroad-Highway Grade Crossing Signal Visibility Improvement Project Final Report*, vol. I; *Data and Hardware Details*, vol. II; *User's Guide*, vol. III; ORNL Reports FHWA/RD-86/186, 187, and 188, October 1986.

J. Barhen, W. B. Dress, and C. C. Jorgensen, "Applications of Concurrent Neuromorphic Algorithms for Autonomous Robots," NATO Advanced Research Workshop on Neural Computers, Dusseldorf, West Germany, September 28-October 2, 1987; *Proceedings 1988 NATO ARW Neural Computers*, p. 321, Springer-Verlag, 1988.

E. R. Broadaway and G. R. Wetherington, Jr., "A High-Speed Data Acquisition System for Distribution Level Monitoring," IEEE Power Engineering Society, New York, N.Y., January 31-February 5, 1988; *Proceedings, IEEE Transmission and Distribution Meeting, Winter 1988.*

C. A. Burtis, W. F. Johnson, and W. A. Walker, "Development of a Simple Automated Rotor for Processing and Aliquoting a Single Whole Blood Specimen into Multiple Aliquots of Plasma," Oak Ridge Conference on Advanced Analytical Techniques for the Clinical Laboratory, San Antonio, Tex., April 9-10, 1987; *Clin. Chem.* **33**, 1558 (1987); also *J. Autom. Chem.* **10**, 6-9, (1988).

P. L. Butler, "Design and Implementation of a Parallel Processing Machine for Artificial Intelligence Applications," Thesis presented for the Master of Science Degree, The University of Tennessee, Knoxville, December 1987.

P. L. Butler, "Design and Implementation of a Parallel Processing Machine for Artificial Intelligence Applications," Monthly Meeting of the East Tennessee/Oak Ridge Chapter, IEEE Computer Society, Knoxville, Tenn., January 12, 1988.

P. L. Butler, J. D. Allen, and D. W. Bouldin, "Design and Implementation of a Parallel Computer for Expert System Applications," Applications of Artificial Intelligence VI, sponsored by SPIE and IEEE, Orlando, Fla., April 4-8, 1988.

P. L. Butler, J. D. Allen, and D. W. Bouldin, "Parallel Architecture for OPS5," 15th Annual International Symposium on Computer Architecture, Honolulu, May 30-June 2, 1988.

R. I. Crutcher and P. D. Ewing, "Broadband Network Sharing by Different Sensitivity Levels," *USDOE Cent. Computer Security News*, 10-11, Los Alamos National Laboratory, Los Alamos, N.M. (December 1987).

R. L. Crutcher and P. D. Ewing, "A Mixed Modem Approach to Data Isolation on a Broadband Local Area Network," IEEE Southeastcon '88, Knoxville, Tennessee, April 10-13, 1988; *Proceedings* 36-39 (1988).

R. L. Crutcher and P. D. Ewing, "A Mixed Modem Solution for Sensitive Data Segregation on a Broadband Network," 11th DOE Computer Security Group Conference, Kansas City, Mo., May 3-5, 1988; *Proceedings*, 41-51 (1988).

R. L. Crutcher, P. D. Ewing, and T. W. Hayes, *Crosstalk Analysis of a Broadband Data Communications System*, ORNL-6431, November 1987.

W. B. Dress, ed., *Proceedings of NeuroCon-I*, Neurocon-I Conference, San Jose, Calif., July 27-30, 1986.

W. B. Dress, "AI Goes FORTH," *Int. J. Telem. Inf.* 3(3), 191-97 (December 1986).

W. B. Dress, "Alternative Knowledge Acquisition: Developing a Pulse-Coded Neural Network," Long Island University 1987 Computer Technology Symposium, Brookville, N.Y., January 23, 1987; *J. Forth Appl. Res.* 5(2), 1-10 (1987).

W. B. Dress, "Handling Complexity: A New Approach to Systems Engineering?" IEEE-Rochester Section-Chapter Joint Seminar, Rochester Institute of Technology, Rochester, N.Y., February 26, 1987.

W. B. Dress, "Real-Time Engineering Applications of Artificial Intelligence," 1987 IEEE-Rochester Section Joint Seminar Series, Rochester Institute of Technology, Rochester, N.Y., February 26, 1987.

W. B. Dress, "Artificial Intelligence: Past, Present, and Future," Independent Computer Consultants Association, Nashville, Tenn., May 2, 1987.

W. B. Dress, "High-Performance Neural Networks," 1987 Rochester FORTH Conference on Applications of Real-Time Artificial Intelligence, University of Rochester, Rochester, N.Y., June 12, 1987; *J. Forth Appl. Res.* 5(1), 137-140 (1987).

W. B. Dress, "Darwinian Optimization of Synthetic Neural Systems," IEEE 1st Annual International Conference on Neural Networks, San Diego, Calif., June 21-24, 1987; *Proceedings.*, vol. III, 769-75 (Fall 1987).

W. B. Dress, "Frequency-Coded Artificial Neural Networks: An Approach to Self-Organizing Systems," IEEE 1st Annual International Conference on Neural Networks, San Diego, Calif., June 21-24, 1987; *Proceedings*, vol. II, 47-54.

W. B. Dress, "NeuroCon-I," *Novix Regis.* 2, 2 (August 1987).

W. B. Dress, "Two Biological Metaphors for Synthetic Neural Systems," ISA/IEEE Joint Meeting, Knoxville, Tenn., March 3, 1988; also Seminar, University of North Carolina, Chapel Hill, November 19, 1987; also 17th ASIS Mid Year Meeting, Ann Arbor, Mich., May 17, 1988.

W. B. Dress, "Artificial Intelligence or Synthetic Intelligence?" University of Tennessee Computer Science Seminar, Chattanooga, March 24, 1988.

W. B. Dress, "Synthetic Intelligence or Biology and Computers," IEEE Southeastcon '88, Knoxville, Tenn., April 11, 1988; *Proceedings*; also Western Kentucky University Physics and Astronomy Seminar, Bowling Green, April 18, 1988.

W. B. Dress, "Artificial Intelligence and Autonomous Robots," also Roane State Vocational Technical Center, Harriman, Tenn., April 25, 1988.

W. B. Dress, "Comment on Breakdown of the Bicameral Mind," American Philosophical Association, Cincinnati, Ohio, April 29, 1988.

W. B. Dress, "Electronic Life and Synthetic Intelligent Systems," 1988 Military Computing Conference, Anaheim, Calif., May 4, 1988; *Advances in Mathematics and Computers in Medicine* (Fall 1988).

W. B. Dress, "Two Biological Metaphors for Synthetic Intelligent Systems," Special EE and Biomedical Seminar Series, University of North Carolina, Chapel Hill, November 19, 1987; also Roane State Vocational School, Technical Writing Class, Harriman and Knoxville, Tenn., May 20, 1988.

W. B. Dress, "Intelligent Machines," National Mu Alpha Theta Convention, Knoxville, Tenn., August 3, 1988.

W. B. Dress, "Electronic Life," Virginia Commonwealth University College of Medicine, Richmond, Va., October 13, 1988; also Y-12 Computing and Telecommunications Division Seminar, Oak Ridge, Tenn., October 25, 1988; also Auburn University, Auburn, Ala., November 10, 1988.

W. B. Dress, "Real-Time Neural Nets," Real Time Computing Conference, Anaheim, Calif., November 17, 1988; also Auburn University, Auburn, Ala., November 1988.

W. B. Dress, "Introduction," *Proceedings, 1986 Conference on Artificial Neural Systems (NeuroCon-1)*, Oak Ridge National Laboratory Report CONF-8607100, pp. 1-4, 1988.

W. B. Dress, J. Barhen, and C. C. Jorgensen, "Applications of Concurrent Neuromorphic Algorithms for Autonomous Robots," NATO Advanced Research Workshop On Neural Computers, Dusseldorf, West Germany, September 28-October 2, 1987; in *Neural Computers*, NATO ASI Series F, Vol. 41, Springer-Verlag, New York.

W. B. Dress and J. R. Knisley, "A Darwinian Approach to Artificial Neural Systems," 1987 IEEE Systems, Man, and Cybernetics Annual Conference, Washington, D.C., October 22, 1987; *Proceedings* II, 572-77.

P. D. Ewing, "Gain and Electric Field Radiation Pattern Approximations for the E-Plane Horn Antenna," Thesis presented for the Master of Science Degree, The University of Tennessee, Knoxville, Tenn., June 1988.

P. D. Ewing and R. A. Hess, *Emergency Media Destruct Techniques, Survey of Media Storage Devices*, K/DSRD-25/V1, June 1988.

P. D. Ewing and R. A. Hess, *Emergency Media Destruct Techniques, Assessment of Existing Techniqes*, K/DSRD-25/V2, June 1988.

J. M. Googe and R. A. Hess, *Shielding Effectiveness Against Electromagnetic Interference*, ORNL/TM-10512, October 1987.

J. M. Googe, R. A. Hess, P. D. Ewing, and D. C. Agouridis, *Task 2: Examination of Specifications and Standards Relating to the Susceptibility of Medical Electronic Devices to Transient Electrical Overstress*, ORNL/TM-10769, April 1988.

J. H. Hannah, W. F. Johnson, and D. C. Watkin, *Integral Fast Reactor Program Fuel Pin Processor Conceptual Design*, ORNL/TM-10871, July 1988.

J. E. Hardy, *Phases I and II: ECIP Project Validation Design Plan Energy Monitoring and Control System Upgrade and Expansion*, ORNL/TM-10110, May 1987.

J. E. Hardy, "Advanced Instrumentation for PWR Reflood Studies: An International Cooperative Effort," WATTec 88, Knoxville, Tenn., February 17, 1988.

J. E. Hardy, T. L. Bowers, and F. D. Boercker, *A Post-Installation Evaluation of the Energy Monitoring and Control System at Fort Rucker, Alabama*, ORNL/TM-10646, December 1987.

R. W. Hayes and J. T. Farmer, Jr., *An Evaluation of Ethernet Connectivity via Broadband Bridge*, ORNL/TM-10177, November 1987.

R. W. Hayes, T. W. Hayes, D. A. Clayton, and J. M. Jansen, Jr., *Building Distribution System Design Criteria for the ORNL/Interplant Broadband Network*, ORNL/TM-10118, December 1987.

R. A. Hess, I. E. Williams, and R. W. Rochelle, *Telephone-Line Attenuation Tests at Oak Ridge Y-12 Plant*, ORNL/TM-10594, November 1987.

W. B. Jatko, "Computer Vision Applied to Workspace Intrusion Detection Systems," WATTec 88, Knoxville, Tenn., February 19, 1987.

W. B. Jatko, *A Microcomputer-based Averaging Flowmeter Using Forth Programming Language*, ORNL/TM-10657, April 1988.

W. W. Manges, G. O. Allgood, and D. H. Thompson, "Mapping a Hierarchical Control Strategy onto a Distributed System Architecture," 1988 International Symposium on Communications and Controls, Baton Rouge, La., October 19-21, 1988.

D. J. Marshall, R. A. Hess, and P. D. Ewing, "Technical Evaluation of the LeCroy Waveform Digitizer," Technical Evaluation Report for U.S. Navy, November 1987.

J. A. McEvers, "Design of a Controlled Temperature Flue Gas Corrosion Probe," Thesis presented for the Master of Science Degree, The University of Tennessee, Knoxville, August 1988.

J. A. McEvers and J. L. Federer, "Design of a Controlled Temperature Flue Gas Corrosion Probe," ASME 1988 National Heat Transfer Conference, Houston, Texas, July 24-27, 1988; *Proceedings*, HTD-96(1), 423-28 (1988).

G. N. Miller, "Sensor Selection for Measurement and Control," Sensors Expo, Chicago, September 13-15, 1988.

G. N. Miller and R. L. Anderson, "Selection of Sensors for Measurement and Control," Instrument Society of America-86, Houston, Tex., October 14, 1986.

R. C. Muller, G. O. Allgood, and B. Van Hoy, "Prototype Data Acquisition and Analysis System for Navy Operational Flight Simulators," 1988 Meeting of the American Institute of Aeronautics and Astronautics Simulation Technology Conference, Atlanta, September 7-9, 1988.

L. L. Odette and W. B. Dress, "Engineering Intelligence into Real-Time Applications," *Expert Sys.* V4(IV4), 228-39 (November 1987).

J. H. Reed, W. R. Nelson, G. R. Wetherington, and E. R. Broadaway, "Monitoring Load Control at the Feeder Level Using High Speed Monitoring Equipment," Athens Advisory Committee, Athens, Tenn., September 23, 1988; also Institute of Electrical and Electronic Engineers/Power Engineering Society Winter Meeting, New York, January 31-February 5, 1988.

C. J. Remenyik, "Presence and Absence of a Water Film Between Moving Air Bubbles and a Plate," 3rd International Colloquium on Drops and Bubbles, Monterey, Calif., September 1988.

R. W. Rochelle and I. E. Williams, *ORNL System for Measurement of Telephone-Line Attenuation*, ORNL/TM-10668, June 1988.

F. R. Ruppel, "Development of a Smart Temperature Measurement System Based on a Self-Calibrating Thermocouple," Thesis presented for the Master of Science Degree, The University of Tennessee, December 1988.

G. R. Wetherington, "Athens Automation and Control Experiment - The Impact of Load Control on a Feeder," IEEE Power Engineering Society Meeting, Anaheim, Calif., September 17, 1986.

L. C. Williams, "Implementation of an OPS5 Derivative on the Novix RISC Processor," 1988 Rochester FORTH Conference, Rochester, N.Y., June 14-17, 1988.

R. W. Wysor, "Coordinated Control of Relay Feedback Control Systems for Electrical Power Cost Reduction," Thesis presented for the Master of Science Degree, The University of Tennessee, Knoxville, August 1988.

G. L. Yoder, E. D. Brewer, J. E. Hardy, W. B. Jatko, and R. N. Nodine, "Experimental Investigation of Low Gravity Two-Phase Flow Behavior," ASME Winter Annual Meeting, Boston, December 17, 1987.

3. REACTOR SYSTEMS

OVERVIEW

D. N. Fry

The primary mission of the I&C Reactor Systems Section (RSS) is development of instruments, components, systems, and techniques for control and protection of nuclear reactors. This Section has been involved in all phases of design and installation of control and protection systems for every research reactor constructed at ORNL. Furthermore, the Section has made substantial contributions to the design and fabrication of systems for a number of other research and test reactors built in the United States. Because of the cumulative staff knowledge gained through experience in the design of measurement, control, and protection systems for virtually all types of reactors, the Section has been retained as the responsible authority for maintenance of the control and protection systems of all ORNL reactors and for upgrading these systems as components and techniques improve.

The scope of the Section's primary mission has been enlarged during the past decade to include research and development engineering in support of both advanced power reactor systems and nonnuclear systems. Activities include simulation of reactor systems in order to perform design analysis, and design of a wide spectrum of systems analyses for various branches of the armed services. Staff members are also engaged in research and development of new concepts, theories, and advanced techniques for radiation detection, monitoring, and measurement systems; for surveillance and diagnostic systems; and for subcriticality measurement of fissile systems.

Section staff members have provided technical assistance to the U.S. Nuclear Regulatory Commission (NRC) in a wide variety of areas including safety research and licensing support. Section staff members have also participated in reactor operations review and in development and review of industry standards.

Section staff expertise developed in the process of finding solutions to nuclear reactor problems has been applied more recently to nonnuclear problems in innovative and creative ways. For example, noise analysis techniques are being applied to a systems and equipment monitoring project for surface ships and to an entomology project for identification of Africanized bees.

SECTION ORGANIZATION

Defining the major programs for which the Section has responsibility is a good point of reference for describing the activities of the RSS. In the context of the matrix management scheme organized under the heading of the major programs, some tasks are being supported by RSS groups only, while others are supported by RSS staff members as well as staff from other sections in the I&C Division and from other Energy Systems organizations. The following major technical programs are being managed and/or supported by Section staff personnel and are described in Sects. 3.6 through 3.9.

- Advanced Controls Program (ACTO)
- Advanced Measurement and Controls Program
- Advanced Neutron Source (ANS) Reactor
- Acoustic Instrumentation Research and Development (AIRD) Program
- Federal Emergency Management Agency (FEMA) Program
- UTK/ORNL Distinguished Scientist Program
- American Institute in Taiwan/Coordination Council of North American Affairs (AIT/CCNAA) Program for Civil Nuclear Cooperation

In addition to support of major programs for which the Section is responsible, each group within the RSS has a well-defined technical area of responsibility and pursues specific technical projects within this realm. The exception is the Special Assignments Group, whose activities encompass a variety of technical subjects and are conducted by teams possessing diverse experience and academic backgrounds. These activities are described in group summaries (see Sects. 3.1 through 3.5).

At the end of this section is a bibliography of documents authored by RSS staff members and presented at technical meetings or published in scientific journals or as formal reports.

ACCOMPLISHMENT HIGHLIGHTS

- Advanced Controls Program

  - Demonstrated a prototype scheme for digital feedwater control.

  - Demonstrated a supervisory control scheme for a modular liquid metal reactor (LMR).

  - Developed a proof-of-principle intelligent workstation for control system design featuring artificial intelligence (AI) and graphical interfaces.

  - Developed and linked a prototype model of a human operator to an existing computer simulation of an advanced LMR (ALMR).

  - Translated ALMR control system design models from other computer codes into modular modeling system (MMS) format.

  - Developed and evaluated advanced control strategies for application to nuclear plants.

- Advanced Measurement and Controls Program

  - Developed two major components of a flux monitoring system for advanced liquid-metal-cooled reactors (ALMRs):

1. Designed and fabricated a high-temperature, high-sensitivity fission counter that is 100 times more sensitive than those currently available and that can operate in a 550°C environment.

2. Designed a 10-decade, single-mode reactor flux monitoring system, which includes a high-temperature, high-sensitivity fission counter and takes advantage of its unique features to provide a single instrumentation channel that is expected to meet or exceed the performance capabilities of currently used multichannel flux monitoring systems.

  - Developed a plan for upgrading the automated noise surveillance and diagnostic system installed in the Fast Flux Test Facility (FFTF) reactor.

  - Adapted Johnson noise thermometer technology to the SP-100 space reactor.

- Advanced Neutron Source (ANS)

  - Developed a dynamic model of the ANS to test performance of control and plant protection systems and thus determine acceptability of the preconceptual design of the ANS.

- Acoustic Instrumentation Research and Development (AIRD) Program

  - Developed a three-dimensional flow measurement system.

  - Completed a 54-channel, wideband acoustic signal acquisition and recording system (Fig. 3-1) for use aboard an unpowered underwater vehicle.

- Federal Emergency Management Agency (FEMA) Program

  - Developed an extended-range, low-cost dose rate meter for the FEMA Engineering Support Program.

  - Developed a wide-range meteor burst gamma monitoring system for the FEMA Engineering Support program.

  - Developed a very simple, very inexpensive dose rate meter for the FEMA Engineering Support Program.

  - Developed a new type of piezoelectric dosimeter capable of meeting the performance specifications of currently available chargers but at significantly less cost. A patent disclosure was filed.

FUTURE TRENDS

RSS will continue to be the ORNL focal point for nuclear plant instrumentation and control research and development. We anticipate many new challenges as digital

ORNL Photo 4039-86

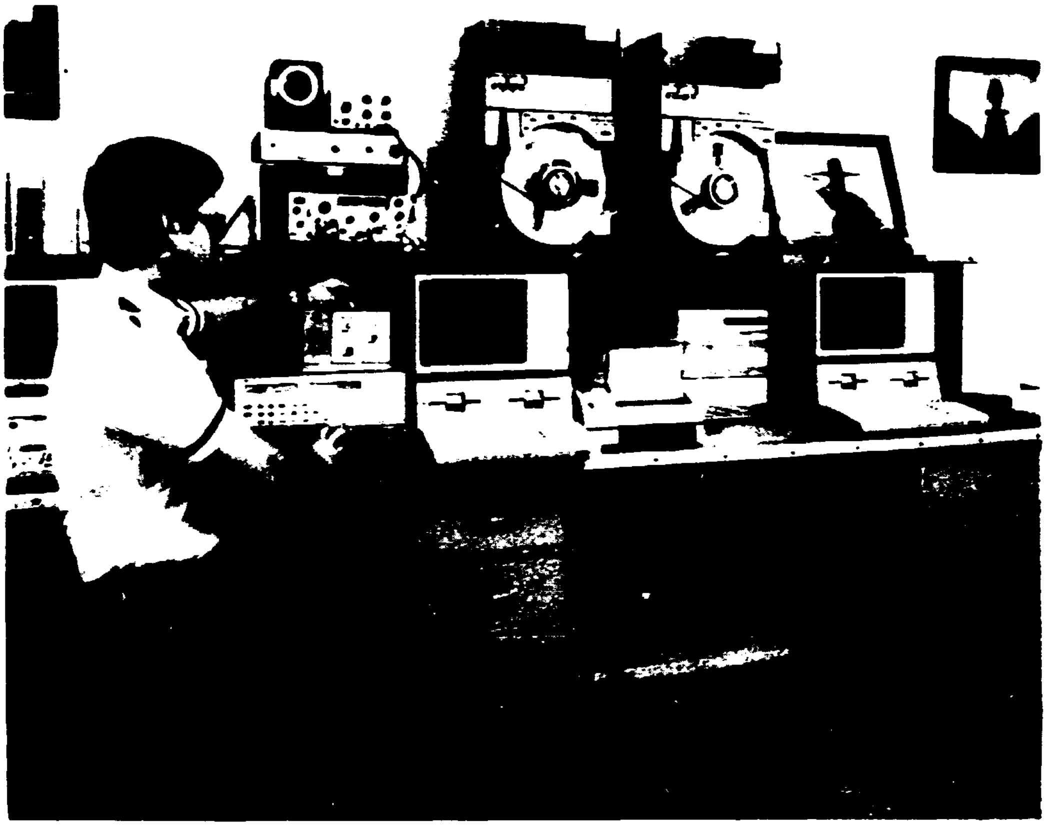


Fig. 3-1. Remote automatic data acquisition system.

computers are introduced into nuclear plants for protection and control systems and as operator aids.

Research and development performed by RSS personnel will provide the technological basis for I&C systems for such future reactors as the ANS, the New Production Reactor (NPR), and nuclear power sources for space (SP-100). The ACTO, when fully implemented in 1992, will be a world-class facility for design and evaluation of advanced control systems and operator aids based on artificial intelligence and expert system technology.

Other important missions of the RSS are to provide state-of-the-art instrumentation for space nuclear power sources such as SP-100 and NASA space laboratory experiments (see Fig. 3-2) and to support arms verification programs with advanced measurement techniques developed in the Section. Surveillance and diagnostic methods based on transient analysis will be applied to the fields of agroacoustics and underwater sound to improve the ability to identify the sources of noises produced by insects and underwater vehicles.

The ANS Reactor

L. C. Oakes

The I&C Division is participating in feasibility studies aimed at developing the Advanced Neutron Source (ANS) Reactor. The objective of the ANS is to produce a nigh-intensity source of thermal neutrons for all kinds of physics experiments. The peak thermal

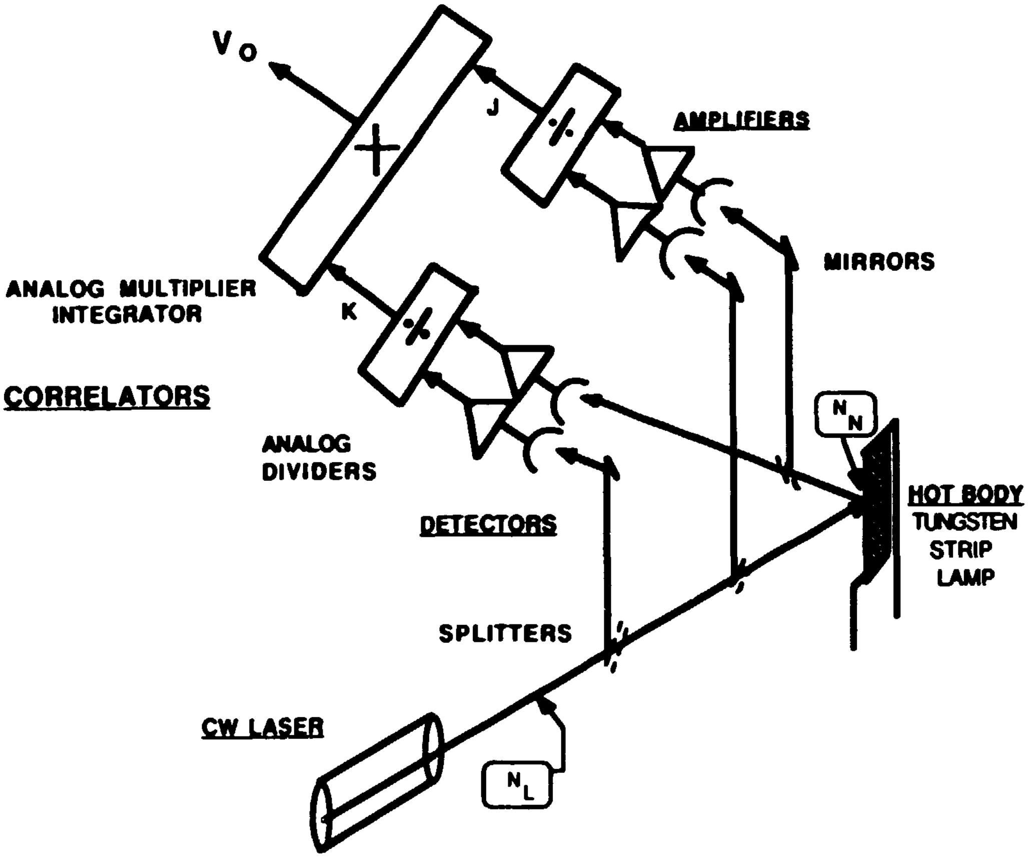


Fig. 3-2. Conceptual design of a laser-based system for noncontact temperature measurement of a levitated body.

flux in the ANS will be 5 to 10 times greater than its predecessor, the High Flux Isotope Reactor, giving it unique characteristics.

The I&C Division has been involved in developing control philosophy, the control mechanisms, and the plant protection system. The control mechanisms must be able to manipulate sufficient reactivity over a wide range of conditions to provide the desired control and protection system response characteristics. The control philosophy studies, involving development of an extensive dynamic model of the system, will provide information on the proper operating modes and safety system response needed to accommodate both routine operation and off-normal conditions.

A control rod configuration has been chosen which appears to meet the needs of both control and plant protection. A dynamic model of the ANS reactor has been placed in operation, and preliminary results have been obtained. The model will be refined as more detailed information on the plant design becomes available.

Studies are now beginning on determining the state of the art of systems and equipment for balance-of-plant control and instrumentation.

UTK/ORNL Distinguished Scientist Program

In January 1986, Dr. Robert E. Uhrig was appointed to the joint position of Distinguished Professor of Nuclear Engineering at the University of Tennessee, Knoxville, and Distinguished Scientist in the I&C Division at ORNL. Since joining the I&C Division, he has interacted with various ORNL groups and staff members of the I&C Division on a broad range of topics. However, his principal contributions have been in the area of AI and expert systems applied to nuclear power reactors. Dr. Uhrig

- Has been an active participant, both as advisor to management and as a senior researcher, in the ACTO program, where he has helped introduce expert systems into the control and operational management of nuclear power plants, using probabilistic risk assessment results as criteria for decision making and advice to the operators;
- Helped organize a joint UT/ORNL "Utility Center" as a vehicle for transferring expertise and technology from ORNL to the utility industry;
- Is principal investigator of an NRC project on review criteria for human factors aspects of advanced controls and instrumentation in which safety issues associated with the innovative use of digital computers and automation are studied;
- Assisted DOE in its evaluation of advanced inherently-safe reactor designs proposed by General Electric Co. and Rockwell International (PRISM and SAFR);
- Organized a Utility Advisory Committee consisting of utility executives and senior managers to advise ORNL on its reactor-related R&D programs, especially those being conducted in the I&C Division;
- Served on the Review Committee of the ORNL Engineering Technology Division and on the Board of Governors of the DOE Robotics Program for Advanced Reactors;
- Helped promote ORNL's ACTO program through personal contacts with leaders in the nuclear industry (reactor designers and utilities);
- Vigorously pursued the transfer of AI and expert system technologies developed for space program applications to the benefit of the commercial nuclear power industry;

American Institute in Taiwan/Coordination Council for North American Affairs Program for Civil Nuclear Cooperation

C. W. Ricker

In 1984, an agreement for civil nuclear cooperation was entered into by the American Institute in Taiwan (AIT) and the Coordination Council for North American Affairs (CCNAA). The Department of Energy and the Nuclear Regulatory Commission (NRC) of the United States provide technical support to the AIT in cooperative activities involving organizations in Taiwan represented by the CCNAA. The Taiwan organizations represented by the CCNAA include the Chinese Atomic Energy Council (Institute of Nuclear Energy Research, Taiwan Radiation Monitoring Center, and Radwaste Administration), the Ministry of Education (National Tsing Hua University), and the Ministry of Economics (Taiwan Power Company).

Being a DOE laboratory that provides considerable support to the NRC, ORNL has been actively involved in this cooperative program since its inception and is represented on the AIT/CCNAA Joint Standing Committee for Civil Nuclear Cooperation. This committee meets annually to review and evaluate the effectiveness of the program and to plan and initiate new activities.

Twenty-one engineers and scientists from Taiwan have worked in residence at ORNL for periods ranging from 3 to 12 months. The divisions or programs to which the participants were assigned are Nuclear and Chemical Waste Program (2); Health and Safety Research Division (5); Chemical Technology Division (3); and Instrumentation and Controls Division (11). Five ORNL staff members have likewise visited Taiwan as part of this program.

During this reporting period, ORNL, through Martin Marietta Energy Systems, Inc., and under the aegis of the AIT/CCNAA cooperative agreement, entered into a 3-year contract with the Taiwan Power Company for a joint study of groundwater. The ORNL Environmental Sciences Division will provide services and support to the Taiwan Power Company on numerical modeling of groundwater. The services and support will consist of technical consultations, review of reports prepared by the Taiwan Power Company, participation in technical meetings in Taiwan, presentation of a workshop in Taiwan, and training of a Taiwan Power Company engineer at ORNL. It is anticipated that this program will expand, and others like it are expected to be put in place in the future.

3.1 DESIGN AND EVALUATION

J. L. Anderson

J. M. Bailey*	R. A. Kisner
R. E. Battle	T. C. Morelock
R. C. Berkan†	G. V. Murphy†
G. C. Corbett	G. V. S. Raju††
E. W. Hagen	B. K. Swail‡‡
C. A. Hendrich‡	T. L. Wilson
M. Jamshidi**	

The goal of the Reactor Systems Design and Evaluation Group is direct participation in research and development programs involving generic instrumentation and control problems faced by designers, fabricators, operators, and regulators of nuclear power plants. The technical activities of this group fall into four major areas: (1) advanced control and protection system development and design, (2) design assistance for ORNL reactors and experimental facilities, (3) conceptual designs for new facilities and experiments, and (4) technical assistance to NRC.

3.1.1 ADVANCED CONTROL TECHNOLOGY

A program is under way for applying improvements in control technology to modular liquid-metal nuclear power plants. Several Design and Evaluation Group members and university consultants are involved with this task. This work, which is part of the Advanced Controls Program (formerly known as ACTO, the Advanced Control Test Operation Program), focuses on developing new control techniques and applying them to computer models of power plants.

3.1.1.1 Traditional vs Multivariate Control Studies Using EBR-II Model

The nuclear utility industry is particularly conservative in its adoption of new technologies. Only recently have digital control systems come under consideration for nuclear power plants. Because of this approach, modern control techniques (such as optimal and adaptive) are relatively unexplored for nuclear power plant applications. The industry's apprehension toward advanced control techniques has led I&C staff to explore the differences and advantages of modern control theory. Comparisons have been made between traditional three-element level controllers and optimal multivariate controllers, considering operational performance and ability to maintain control with deviated plant parameter values (i.e., robustness).

---

*The University of Tennessee, Knoxville.
†Graduate Student, The University of Tennessee, Knoxville.
‡Coop student, The University of Tennessee, Knoxville.
**University of New Mexico, Albuquerque.
††Ohio University.
‡‡Coop student, University of Kentucky.

Perturbation tests run on a steam generator model indicate that optimal multivariate control offers advantages in robustness and performance. Comparisons were made between a three-element (proportional-integral) controller and a multivariate (optimal) controller. Results show that the optimal controller yields better performance and can be made more robust. The three-element controller is more sensitive to changes in plant parameters (e.g., the three-element controller must be retuned whenever plant characteristics are varied). Also, while the three-element controller does a commendable job of maintaining steam generator level, the optimal controller is able to maintain several other variables at set point as well.

The three-element PI controller was designed using a linear EBR-II steam generator model. A linear-quadratic-Gaussian (LQG) compensator was designed using the $MATRIX_x$* development environment. The LQG compensator was augmented to include an integral term to drive the steady-state error to zero.

An optimal regulator design maximizes the closed-loop performance by minimizing a predefined criterion such as steady state errors. This form of regulator is expected to achieve very small steady state errors by appropriately choosing state and input weights in the quadratic cost function. However, the basic LQG regulator is not guaranteed to reduce steady state errors to zero but rather to find a minimum value. The basic LQG regulator can be augmented to eliminate steady state errors by introducing additional state variables as integrals of those for which zero steady state error is desired. The 19 x 19 steam generator model (which includes actuator dynamics) is appended to a dummy integrator state, and the closed-loop system is designed using the $MATRIX_x$ routines.

The simulation results plotted in Figs. 3.1-1 and 3.1-2 were obtained using the modified regulator designs in which the steady state errors are driven to zero.

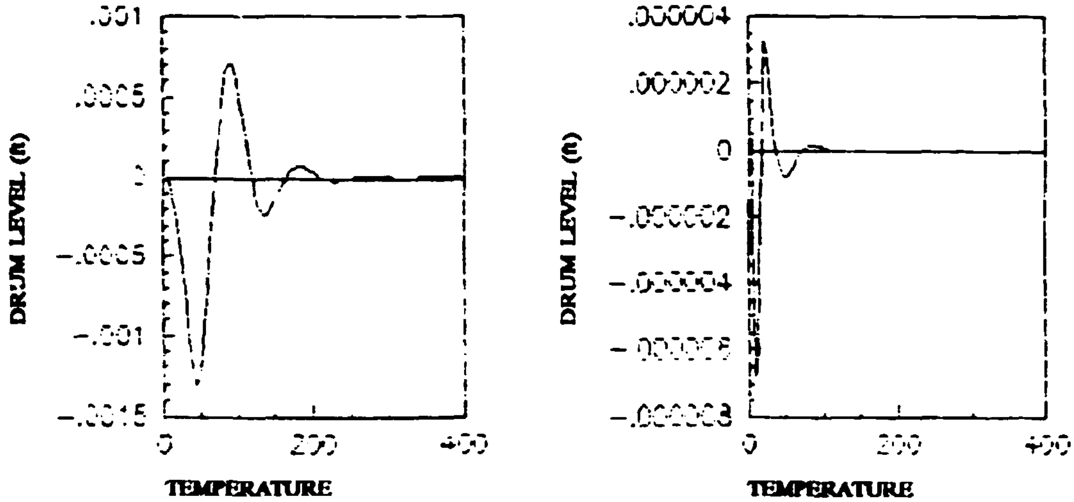
3.1.1.2 FUZZY CONTROL STRATEGY

Another controller design method under study is the "fuzzy control strategy," which is based upon a set of fuzzy rules obtained from the time responses of the process under consideration. According to the number of measurements used for control purposes, a signal to actuation devices is generated by a multidimensional interpolation table (look-up table) in which the measurements are used as the controller inputs. This strategy is known to be effective when the system includes nonlinearities.

A simple application of the fuzzy controller for the EBR-II steam generator level-control problem was examined. The goal was to replace the existing PI controller with a fuzzy controller and obtain a similar closed-loop performance. Figure 3.1-3 shows the computational environment prepared by using a $MATRIX_x$/System Build combination. The super block contains a linear dynamic system, a time-delay block, a gain block, an interpolation table, and algebraic conjunctions. The actuation signal (Fig. 3.1-4) was created using this super block.

---

*$MATRIX_x^{TM}$, © 1985 by Integrated Systems, Inc., Palo Alto, California.



(a) Three-element controller design

(b) LQG compensator design

Fig. 3.1-1. Drum level responses to a 10% feedwater temperature increase using three-element and LQG compensator designs.

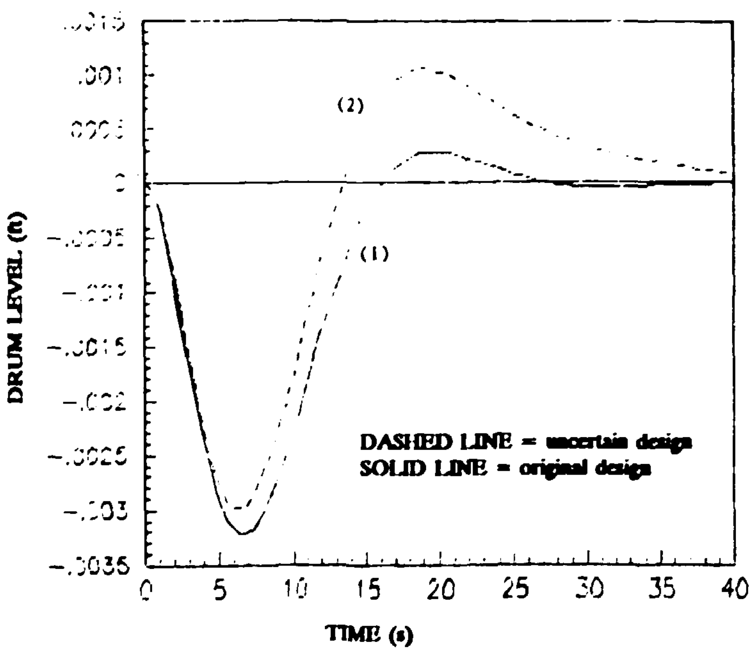


Fig. 3.1-2. Drum level responses to a 10% increase in steam valve opening using the LQG compensator design. This is done while the drum volume is decreased by 5% from the original design value to test the robustness of the controller to uncertainty in the actual plant parameters.

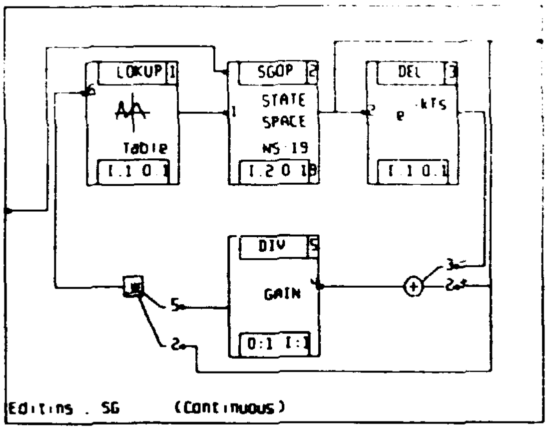


Fig. 3.1-3. Superblock SG created in System Build environment. Fuzzy control strategy implemented using EBR-II steam generator model.

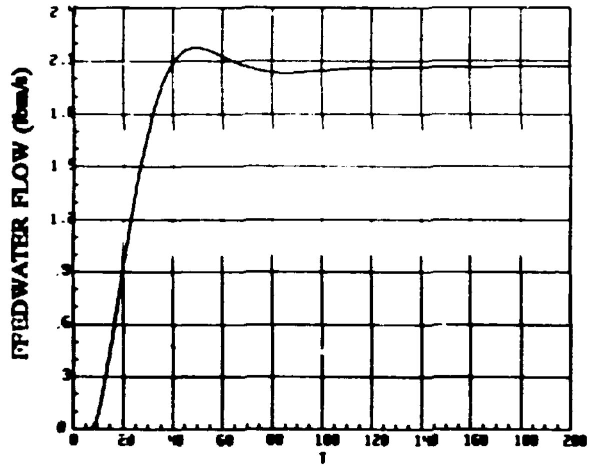


Fig. 3.1-4 Actuator output signal; 10% steam valve opening perturbation.

3.1.1.3 ROBUST CONTROL STRATEGIES

Robustness refers to the ability of a system to maintain performance standards even with shifts in plant parameters, which might occur because of a lowering of heat transfer capability due to scaling or crud buildup. Methods for improving robustness of control have been developed including the loop-transfer-recovery (LTR) technique. This technique shapes the system's frequency response to maximize command following and process disturbance rejection and to minimize effects of sensor noise.

A frequency-domain approach that allows the user to design and measure the robustness of LQG and LQG/LTR control systems has been condensed to a design procedure. A comparison was made of three control techniques (PI, LQG, and LQG/LTR) applied to a feedwater deaerator model that consisted of three state variables, one control variable, and one output variable. Results indicate that the LQG/LTR design procedure is effective in placing (1) low-frequency closed-loop response in the correct region for good command following and process disturbance rejection and (2) high-frequency closed-loop response in the correct region for minimization of the detrimental effects of sensor noise. The use of an input precompensator to meet transient response performance requirements is independent of the criteria for robustness.

For the system shown in Fig. 3.1-5, the output is given by the following expression:

$$Y(s) = \frac{L(s)K(s)R(s)}{I + L(s)K(s)} + \frac{D(s)}{I + L(s)K(s)} - \frac{L(s)K(s)N(s)}{I + L(s)K(s)} . \qquad (1)$$

From this expression, sensitivities to command following, disturbance rejection, and minimization of effects of sensor noise are studied. Without benefit of derivation, the gain requirements to achieve these system attributes are given below:

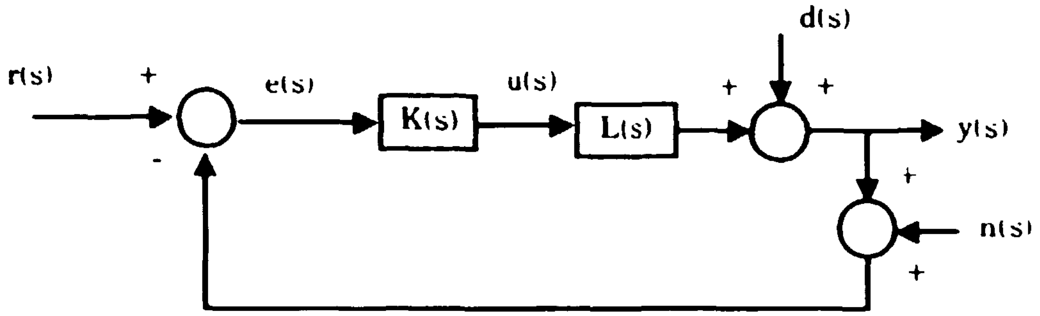


Fig. 3.1-5. Unity feedback MIMO control system.

COMMAND FOLLOWING: L(s)K(s) >> 1;
DISTURBANCE REJECTION: L(s)K(s) >> 1;
MINIMIZATION OF EFFECTS OF SENSOR NOISE: L(s)K(s) << 1.

Low-frequency gain requirements are analyzed by studying the singular-value plot of the return ratio of the compensated system. High-frequency gain requirements can be analyzed by studying the singular-value plot of the inverse return difference of the compensated system. Several singular-value plots of a system are shown in Fig. 3.1-6 to illustrate controller tuning to achieve the requirements stated above.

A control system is described as robust and having good robustness properties if it has large stability margins (gain and phase margins), good disturbance rejection/command following, and stability and low sensitivity in the presence of model uncertainties. One means of evaluating the robustness of a system is to use singular-value plots. There are three types of singular-value plots: return ratio $\{\sigma_{max}[L(j\omega)]\}$, return difference $\{\sigma_{min}[I+L(j\omega)]\}$, and inverse return difference $(\sigma_{min}\{I+[L(j\omega)]^{-1}\})$. The robustness of these controllers was examined using the singular-value plots for the PI, LQG, and LQG/LTR control system designs for the deaerator.

The PI design used in this study was based on a three-element controller used in previous deaerator studies. The LQG controller design was based on a trial-and-error modification of the state weighing matrix to shape the system's output transient response. The LQG/LTR controller was designed to specific requirements for disturbance rejection/command following and for stability in the presence of high-frequency modeling errors.

Comparison of the robustness of the PI, LQG, and LQG/LTR controllers is based on design specifications shown in Table 3.1-1. The results of the singular-value analysis of the three control systems are shown in Table 3.1-2.

In general, PI and LQG control system design techniques do not arbitrarily meet specific requirements unless several trial-and-error design iterations occur, and even then the specifications may not be met. In contrast, the LQG/LTR control system design technique offers a systematic manner for obtaining a system with good robustness properties.

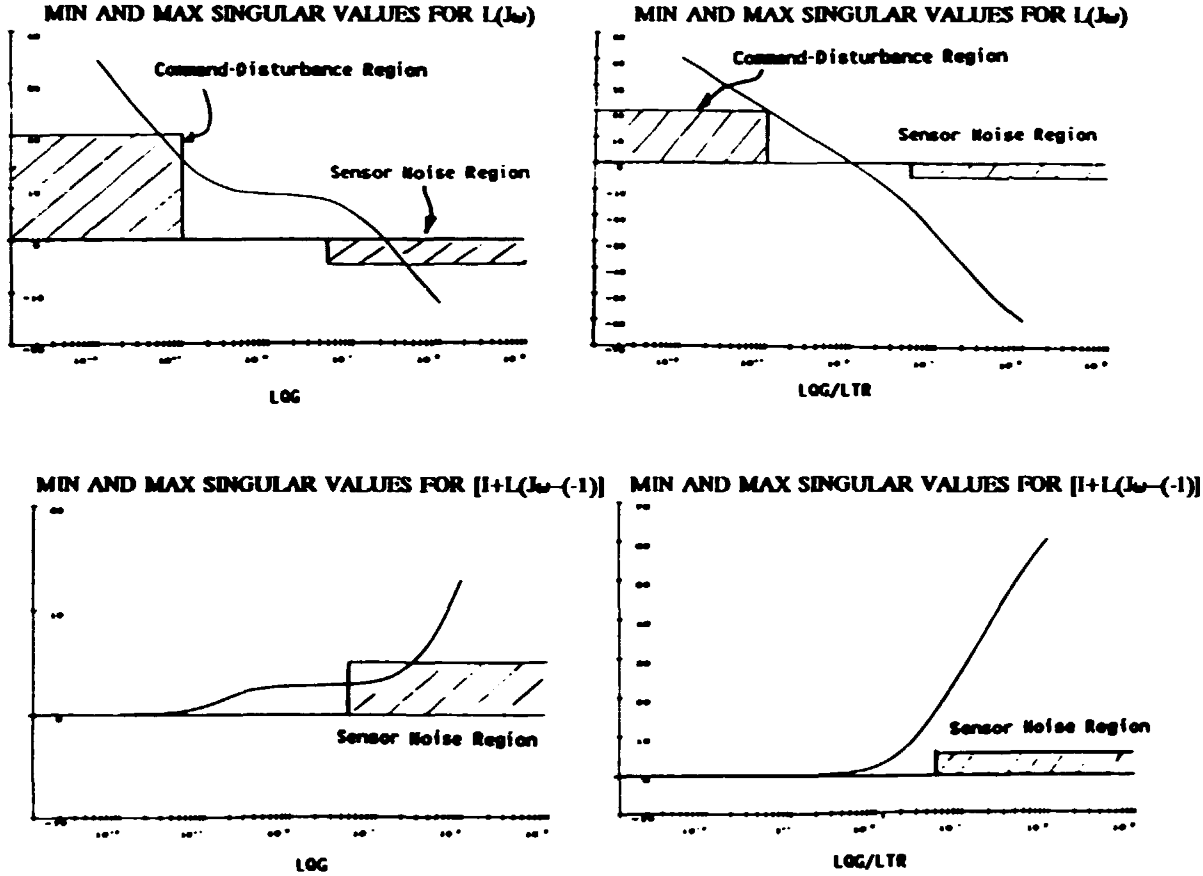


Fig. 3.1-6. Singular value plots that illustrate controller tuning.

3.1.2 DESIGN ASSISTANCE

The Design and Evaluation Group provides design assistance for ORNL research reactors and experimental facilities. In addition to preparing original designs for control and protection systems, this group also designs replacements for aging and obsolete components and systems as the need arises. This activity is conducted jointly with the Research Reactor Support Group (see Sect. 3.4). Several major modernization and upgrade projects are in progress for ORNL reactors.

3.1.2.1 High Flux Isotope Reactor

In late 1986 it was determined that the pressure vessel for the HFIR had suffered more embrittlement in some regions than had been predicted. To continue operation and extend the life of the vessel, it has been necessary to institute some new operational procedures and control features. A new maximum power level and operating pressure have been defined to allow a predictable life extension for the reactor vessel. To ensure vessel integrity, it is now necessary to maintain the vessel temperature above 29.5°C (85°F) when system pressure is above 2.1 MPa (300 psi). Changes in the control and protection instrumentation to meet the new requirements are

Table 3.1-1. System design specifications

System requirements	Range
Good command following/disturbance rejection	$\sigma_{min}[L(j\omega)] > 20$ dB $\forall\omega \leq 0.1$ rad/s
Good system response to high-frequency modeling error	$\sigma_{min}[I + L(j\omega)^{-1}] \geq \|\Delta L\| = 5$ dB $\forall\omega \leq 5$ rad/s
Good insensitivity to parameter variations at low frequencies	$\sigma_{min}[I + L(j\omega)] \geq 26$ dB for low frequencies
Good immunity to noise $\omega \geq 5$ rad/s	$\sigma_{max}[L(j\omega)] << 0$ dB for high frequencies

Table 3.1-2. Performance and robustness results

System properties	PI control system	LQG control system	LQG/LTR control system
Command following/ disturbance rejection	$\sigma_{min}[L(j\omega)] = 0$ dB $\forall\,\omega \leq 0.01$ rad/s	$\sigma_{min}[L(j\omega)] \geq 20$ dB $\forall\,\omega \leq 0.01\bar{7}$ rad/s	$\sigma_{min}[L(j\omega)] \geq 20$ dB $\forall\,\omega \leq 0.1$ rad/s
System response to high-frequency modeling error ($\omega \geq 5$ rad/s)	$\sigma_{min}(I + [L(j\omega)]^{-1})$ ≥ 43.0 dB	$\sigma_{min}(I + [L(j\omega)]^{-1})$ ≥ 30 dB	$\sigma_{min}(I + [L(j\omega)]^{-1})$ ≥ 16.7 dB
Insensitivity to parameter variations at low frequencies	$\sigma_{min}[I + L(j\omega)] \leq 26$ dB $\forall\,\omega \leq 0.0055$ rad/s	$\sigma_{min}[I + L(j\omega)] \geq 26$ dB $\forall\,\omega \leq 0.008$ rad/s	$\sigma_{min}[I + L(j\omega)] \geq 26$ dB $\forall\,\omega \leq 0.055$ rad/s
Immunity to noise ($\omega \geq 5$ rad/s)	$\sigma_{max}[L(j\omega)] \leq -42.5$ dB	$\sigma_{max}[L(j\omega)] \leq -30$ dB	$\sigma_{max}[L(j\omega)] \leq -16$ dB

1. Relocate the safety system pressure switches and sensors from the primary inlet piping to a new header extending directly from the vessel.
2. Install redundant depressurization valves to allow rapid depressurization when vessel walls are cooled below allowable temperatures.
3. Initiate pressurizer pump trip when low reactor vessel inlet temperature is sensed.
4. Modify the servosystem to control reactor power automatically at low levels to preheat the primary system at low pressure.
5. Adjust safety system set points for the new operational limits.
6. Add redundant pressure switches for higher pressurizer pump trip reliability on high discharge pressure.
7. Install thermocouples to measure water temperature inside and outside the vessel wall near the beam tube nozzles (where maximum embrittlement has occurred).
8. Increase the size of the cooling tower bypass line to allow operation of one main secondary pump in the tower bypass mode in order to prevent excessive system cooling after reactor shutdown.
9. In order to limit the cooling rate of the secondary (and primary) systems, revise the control logic for the secondary heat removal system to trip the main pumps, open the cooling tower bypass valve, and start the auxiliary pump on high speed when reactor scram occurs.
10. Add a steam injection system to the secondary side of the pool heat exchanger to preheat the pool prior to pressurization.
11. Modify the primary pump control circuits to trip the pumps on high pump motor bearing temperatures.

A digital simulation program, HFIRSYS, was developed using the modular modeling system (MMS) to analyze small-break loss-of-coolant (LOCA) events in the HFIR. The code evaluates the response of the primary reactor system, including automatic control actions resulting from breaks in auxiliary piping connected to the primary. The primary output of the code is the margin to the onset of nucleate boiling expressed as a ratio of heat flux that would cause boiling to the current hot channel heat flux.

3.1.2.2 Critical Experiment Facility

Upgraded protection, control, and instrumentation systems were designed and fabricated for the CEF, which is used to determine the water-submerged shutdown margin for each HFIR fuel assembly. Installation of this upgrade has been delayed pending HFIR restart and evaluation of a californium neutron noise method for measuring the actual shutdown margin without requiring criticality.

3.1.2.3 Bulk Shielding Reactor

Two projects at the BSR are to upgrade the reactor protection system from vacuum tube equipment with 1-of-3 trip logic to solid-state equipment with 2-of-3 trip logic and to design and install a control system for operation of the BSR from the HFIR control room.

The BSR protection system is being upgraded to a system similar to those used in the Oak Ridge Research Reactor and the HFIR. The purpose of this upgrade is to (1) replace old equipment that is difficult to maintain because of the unavailability of vacuum tubes and (2) increase system reliability by providing the capability of on-line testing. The protection system has three flux level channels and one period channel. The period information is derived from a new solid state, 8-decade logarithmic amplifier. The protection system includes isolation modules to provide analog signals and channel status to the proposed remote control system for monitoring and testing.

A remote control system will be installed between the BSR and the HFIR to reduce operating costs and improve reactor reliability. A fault-tolerant PLC and operator workstations are programmed to replace the hard-wired relay control system currently in the BSR. In addition to the PLC and remote and local operator workstations, auxiliary systems include a high-resolution video surveillance system, an intercom system, and a fiber optic communication system. The system is designed with reliability, redundancy, and fail-safe features as important considerations. A block diagram of the system is shown in Fig. 3.1-7. Fail-safe features include a watchdog timer in the PLC that will trip the reactor if communication to the control station fails. Redundant and diverse reactor trip channels from the HFIR–one via dedicated telephone lines and one via fiber optic cable–will trip the reactor if either signal is interrupted. Three methods verify that the shim rods are seated: workstation display, a monitor system using telephone lines, and indicator lamps that can be viewed by the room camera.

3.1.2.4 Tower Shielding Facility

A conceptual design plan was initiated for a major upgrade of TSF control, protection, and instrumentation systems. It was determined that the facility will be operated for only a limited time; therefore, the scope of the upgrade has been reduced to replacing a few vital instruments and replacing the deteriorated aerial cables with new cables in fixed conduits.

3.1.2.5 Health Physics Research Reactor

A new protection system and modified burst monitoring instrumentation are being designed for the HPRR to improve performance and permit a wider range of burst operation needed for certain experiments. This work was initiated earlier but was delayed by the extended shutdown of ORNL reactors.

3.1.2.6 Pool Critical Assembly

A design was initiated for replacement of the protection system of the PCA with a system very similar to that designed for the BSR. New scram magnets have been designed and fabricated. The upgraded facility was to be used for operator training for other reactors, but this project has been delayed indefinitely by funding constraints.

3.1.3 CONCEPTUAL DESIGNS

3.1.3.1 Advanced Neutron Source

Several group members have participated in research and development activities related to control and protection concepts for the ANS by interacting with other project personnel to establish control and protection requirements and limitations. These include considerations such as control rod worth and location, shutdown margin, required

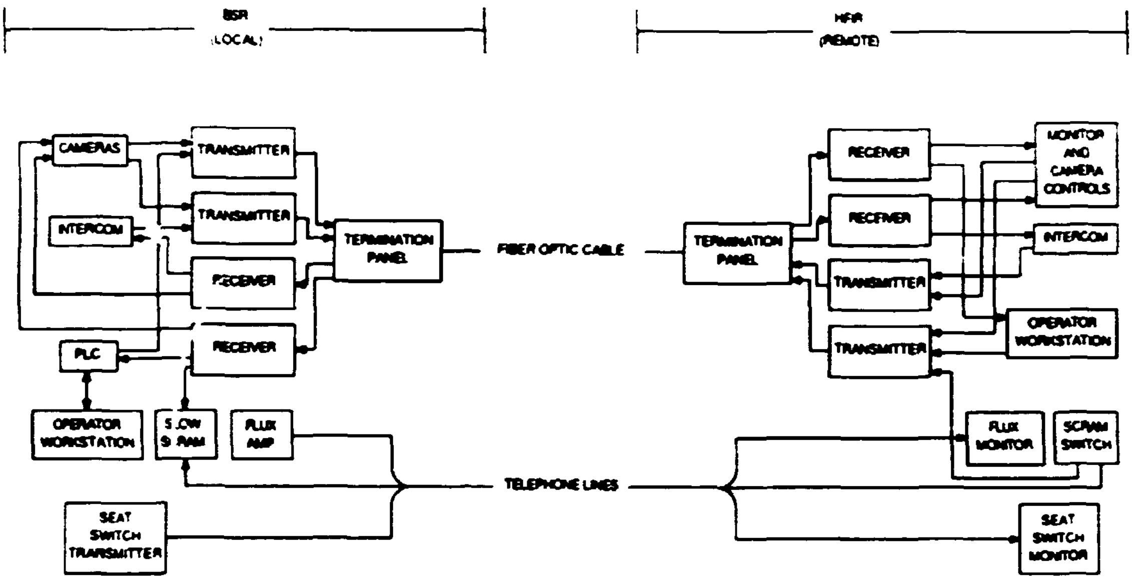


Fig. 3.1-7. Diagram of the Bulk Shielding Reactor remote control system.

accelerations for adequate shutdown response, mechanical latches, and scram release magnets. A dynamic model has been developed for control system design and transient analysis. The modules of the model use "advanced continuous simulation language" (ACSL) macros to provide modularity and good documentation and to facilitate refinement of the model as better information is developed.

Studies have been initiated to optimize the conceptual design of scram electromagnets and mechanical latches for the confined spaces available in the central core region. Surveys have been initiated to evaluate state-of-the-art process instrumentation, digital control concepts, and interfaces between reactor system and experiment controls. Ultrasonic level/temperature probes are being evaluated for possible application to the cryogenic environment of the ANS cold source. The probe must be able to measure liquid deuterium level and bulk temperature. Several size, material, and sensitivity restrictions apply to this specific environment. Experiments are being prepared to determine functional and electrical requirements for a complete, dedicated measurement system.

3.1.3.2 EPRI Advanced Light-Water Reactor Project

EPRI is developing a model requirements document for ordering and constructing an advanced light-water reactor (ALWR). ORNL staff have participated in development of Chapter 10 requirements, which address control systems and man-machine systems. Research has been performed to establish standards that apply to computer code development and implementation.

3.1.3.3 Babcock & Wilcox Owners' Group

The Babcock & Wilcox Owners' Group has created a task force to develop an advanced digital control system that can replace the existing analog-based integrated control system (ICS). The older ICS, which exhibited operational reliability problems, is rapidly becoming obsolete as parts become more difficult to find. The advanced control system

(ACS) will be computer based, feature a fault-tolerant architecture, and have levels of diagnostics and data validation incorporated in it. Several I&C staff members are involved as advisors to the ACS task force and as task participants.

3.1.4 NUCLEAR REGULATORY COMMISSION SUPPORT

Technical assistance is provided to NRC in a wide variety of areas including assessment of the adequacy and reliability of reactor control systems, technique development, and recommendations for regulatory positions and guides. Some current projects include

- evaluation of instrumentation to predict and detect inadequate core cooling,
- evaluation of the effect on reliability of potential interactions between control systems and protective systems to identify both philosophical and hardware techniques for minimizing adverse interactions to improve both features,
- application of digital computers to power plant protection systems,
- review and assessment of off-site power source reliability for nuclear power plants and performance of emergency power supplies,
- evaluation of performance of diesel generators in nuclear power stations and assistance in developing regulatory guides.

3.2 SURVEILLANCE AND DIAGNOSTIC METHODS

N. E. Clapp, Jr.

B. Damiano **F. J. Sweeney**
J. March-Leuba **J. A. Thie***
J. A. Mullens **B. R. Upadhyaya**
L. D. Phillips **R. T. Wood**
C. M. Smith

The Surveillance and Diagnostic Methods Group is the ORNL center for development of methods to extract information from noise signals. In this context, noise is defined as fluctuations in neutron or process signals from nuclear plants and acoustic noise obtained with accelerometers, hydrophones, and microphones. Significant accomplishments in the past 2 years have been in real-time noise data acquisition systems, noise signature screening methods based on pattern recognition, data bases built on spectral features, and automated diagnostic method developments based on information extracted from noise signals.

This group has more than 100 years' collective experience in various aspects of noise analysis: dynamic modeling of nuclear plants, structural vibration modeling, sensor response

*Consultant.

time analysis, statistical analysis of steady state and transient noise data signals, pattern recognition, artificial intelligence/expert systems, data base systems, and automated noise data acquisition. Group members include nuclear, electrical, and mechanical engineers.

3.2.1 BWR STABILITY PROGRAM

As part of an ongoing effort, this group has provided technical support to NRC staff on issues in three general areas related to BWR thermohydraulic stability: numeric calculations of dynamic parameters, stability tests in commercial reactors, and review of stability calculation/measurement methodologies submitted to NRC by utilities and reactor vendors. The most significant accomplishment resulting from this effort has been development of a portable BWR stability monitoring system capable of producing on-line estimates of the degree of reactor stability by analyzing normally occurring fluctuations in reactor power (i.e., neutron noise). The capabilities of this system were successfully demonstrated during two stability tests in commercial BWRs.

3.2.2 ANS PROGRAM

The group has contributed to research and development efforts in support of the Advanced Neutron Source reactor. As part of these efforts, members of the group are currently working on issues related to control and plant protection systems for the ANS reactor. A dynamic model of the ANS has been developed and implemented in a computer code to test performance of control and plant protection systems (PPS) concepts and to determine their acceptability as part of the preconceptual design. Parametric studies of the preliminary design for the ANS control rod drive/scram system have resulted in development of holding force performance curves for electromagnets of the type currently proposed for use in the ANS. These studies have developed predictions of rod motion during scram for various combinations of coolant flow rate, acceleration spring rate, control rod mass, and control rod diameter.

3.2.3 REACTOR INTERNALS MODELING

A dynamic model of a PWR fuel assembly was developed as a first step toward creating a comprehensive PWR internals model. This model will predict natural frequencies and modeshapes and will be used to aid in interpretation of neutron and process signal noise signatures. A method was developed to obtain from the detailed fuel assembly model a dynamically equivalent single-rod model that can be used to represent fuel assemblies in the larger reactor internals model, vastly reducing the size and computational complexity of the analysis.

3.2.4 ROTATING MACHINERY VIBRATION ANALYSIS

A lumped-parameter mathematical model simulating the vibrational response of a motor/pump unit has been developed to aid in interpreting measured vibration signatures. Forces that simulate flaws in rolling element bearings have been applied to the model to predict the effect on vibration signatures. A comparison of simulated and measured responses due to defective bearings has shown good qualitative agreement. Further studies will involve development of forcing functions to correspond to a wide variety of motor/pump faults.

3.2.5 FFTF DATA COLLECTION

A data base has been created using a personal computer to organize and store significant features of Hanford Fast Flux Test Facility (FFTF) neutron and process signal noise data. The data base entries consist of peak frequencies and amplitudes as well as rms values calculated using 20 frequency bands for over 8000 spectra. Data have been collected during full-power operation, control rod tests, and between-cycle shutdowns.

3.2.6 NAVY NOISE METHODS DEVELOPMENT

The group has been doing research to develop and demonstrate the ability to detect and classify transient signals from submarines. Initial efforts on recorded submarine signals have been encouraging, and our efforts constitute a substantial fraction of the U.S. Navy's work in this area. Intensive efforts to acquire a broad background in navy acoustic work have included participation in submarine acoustic sea trials with various DTRC groups and consultation with them on various noise and vibration monitoring systems for existing and advanced submarines.

3.2.7 ARTIFICIAL INTELLIGENCE PROJECT

As part of a demonstration of artificial intelligence applications, this group has developed an expert system to monitor the HFIR startup and report unexpected plant events to the operator. While an extended HFIR shutdown has made installation impossible, preparations to move this work from the laboratory to the reactor have continued. In addition, experimental conversion of the software to an object-oriented programming language was undertaken.

3.2.8 EQUIPMENT INTERFACE SYSTEM CONTROLLER DIAGNOSTIC EXPERT

A member of this group has worked with the Advanced Measurement and Control Programs staff to create a portable expert system to diagnose faults in a very complex controller used in the uranium metal preparation process at the Oak Ridge Y-12 Plant. This effort was both an application of AI and an evaluation of object-oriented programming.

3.2.9 NAVY BASELINE MODEL PROJECT DATA ACQUISITION SYSTEM

This group's expertise in signal acquisition was applied toward designing and implementing a remote, automatic data acquisition system (Fig. 3-1 on p. 138) for use by DTRC personnel during acoustic noise tests on a reconfigurable submarine model (see Fig. 3.2-1). During an acoustic test, the onboard system must dynamically control all aspects of data acquisition automatically, without operator interaction. The responsibilities the system assumes include powering up and shutting down equipment as necessary; setting up programmable amplifier/filter banks and calibrating signal paths; preparing tape recorders for analog data acquisition; initiating control actions on various programmable components based on time, model speed, or depth; supervising digital data acquisition by the A/D converter; performing on-line signal analysis on selected key digital data; and storing a test log and important test status results for later review. Additional advanced capabilities permit remote manual operation of any component of the onboard system and remote dubbing of

ORNL Photo 4037-86

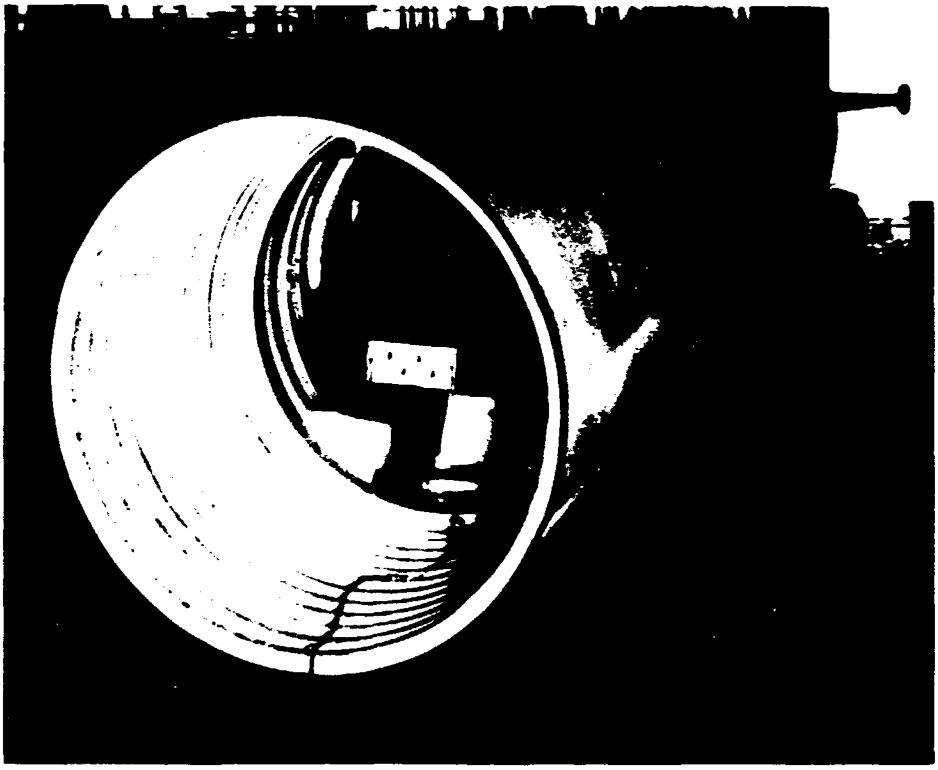


Fig. 3.2-1. Reconfigurable submarine model.

data from tapes on the model to surface tape recorders. This task involved acquisition and alteration of the necessary hardware to permit battery-powered operation, performance tests of each component, installation of hardware in racks on the submarine model, design of required control software (more than 50,000 lines of code), and implementation of the system on site. Final discharge of this group's responsibilities for the baseline project was accomplished with delivery of a two-volume user's manual.

3.2.10 ADVANCED CONTROLS PROGRAM: STUDY OF METAL FUEL INHERENT REACTIVITY OPERABILITY FOR THE LIQUID METAL REACTOR

Group members working on the Advanced Controls Program have assisted in developing a modular model of the SAFR using the Advanced Continuous Simulation Language (ACSL). First-principle mathematical descriptions of various reactor system components were coded and parameterized to make them representative of the SAFR design. These models were then combined to simulate the behavior of the SAFR system. A major goal of this work is to simulate the inherent reactivity feedback characteristics of a metal-fueled core. Simulation results will be used to investigate the controllability of the reactor system using inherency rather than direct reactivity control for normal load-following duty-cycle events. Group expertise in reactor systems modeling has been enhanced through this effort by developing a familiarity with ASCL, which offers powerful simulation capabilities without requiring advanced knowledge of numerical integration techniques.

3.2.11 MENU-DRIVEN KNOWLEDGE RETRIEVAL SYSTEM ACCESSING ASCII DATA

Acquiring a knowledge base and networking the elements in the knowledge base using rules are the two major tasks required in developing an expert system. A knowledge retrieval system was developed for the Navy to cover selected areas of procurement as the first step toward developing an expert system. The knowledge base was obtained by reviewing and abstracting procurement information from DOD and Navy documents. With the aid of an expert in the area of Navy procurement, a data-driven layered menu system was developed to display the abstracted information.

3.2.12 SPECIAL MEETINGS

Because of our expertise in signal analysis, a member of this group was invited to attend the first National Agroacoustics Symposium, which was a forum to transfer information regarding the use of acoustic signals in the field of entomology. The same member of the group, invited to attend an EPRI meeting at Northeast Utilities to review EPRI-sponsored programs for reducing instrument calibrations and response time testing in power plants, was asked to become a member of the advisory committee for that program. Yet another group member was invited to participate in the Advanced NATO Workshop on Nonlinear and Stochastic Phenomena held in Valencia, Spain. Contact has been made with a Spanish National Laboratory (CIEMAT) to start a cooperative program in the area of reactor noise and signal processing methods. Once established, this program will be funded by NRC.

3.3 DYNAMIC ANALYSIS

S. J. Ball

C. R. Brittain	P. J. Otaduy
F. H. Clark	A. W. Renshaw
C. E. Ford	J. T. Robinson
R. M. Harrington	O. L. Smith
J. K. Munro, Jr.	R. S. Stone
C. E. Murphy	

The Dynamic Analysis Group is involved in a wide range of systems analysis projects, expanded from an original narrow focus on the control and safety design of the ORNL research reactors. The expertise developed in that early work has since broadened in scope to cover similar control and safety development for the wider interests of U.S. nuclear programs. Further, the systems analysis tools and capabilities developed for fission reactors have also proven useful for other programs, including simulation of nuclear waste isolation, desalination, fossil fuel combustion, energy conservation, biological dynamics of the environment, and, most recently, projects involving computer programs for the military. Major program involvement during this reporting period is described.

3.3.1 BWR SEVERE ACCIDENT TECHNOLOGY

The BWR Severe Accident Technology program is an NRC-sponsored project of the ORNL Engineering Technology Division, to which the I&C Dynamic Analysis Group provides consulting and occasional analysis support. The objective of the program, which began 8 years ago, is to develop computer models and to determine the timing and sequence of events in severe accidents at BWRs. In-depth studies have been conducted of hypothetical anticipated transients without scram (ATWS), loss of control air, and station blackout accidents.

The BWR-LTAS (long-term accident simulation) computer program, which was developed by an I&C staff member for the BWR Severe Accident Technology Program, is used to study accident evolution leading up to and including a permanently uncovered core. One of the most valuable features of this code is that it enables the investigator to assess the effect of operator action to delay or prevent severe fuel damage. The code has enjoyed remarkable success and is currently being used by a number of other agencies, including NRC and several utilities.

3.3.2 ADVANCED NEUTRON SOURCE

ORNL staff members are currently developing design and technical bases for a new DOE research reactor proposed for Oak Ridge. During this reporting period, I&C has provided management of the safety function including safety analysis, containment requirements, design basis accidents, and regulatory approval. As the ANS design has matured over the past 2 years, this task has expanded to involve other I&C staff members who perform dynamic analyses and calculations relating particularly to design of the reactor control and protection systems.

3.3.3 HFIR/AI PROJECT

The project sponsored by ORNL Exploratory Fund was concluded in September 1987. Its purpose was to develop and learn how to apply expertise on AI to reactor systems to improve monitoring, diagnostics, and control capabilities. As a demonstration project, programs developed would be demonstrated at the HFIR.

Expertise was gained in a number of areas including advanced programming techniques and languages, expert systems, and machine learning. The planned demonstration on the HFIR was not carried out because the reactor was unavailable, but programs generated were demonstrated on a HFIR simulator developed as part of the project. Funding of a follow-on project is expected in FY 1989.

Several AI programs developed to provide HFIR operators with expert assistance include design and implementation of data bases of nuclear reactor alarm procedures and analog and digital signals, both developed on the VAX using the relational data base program Rdb and on the IBM AT using Arity/SQL. Part of this development included the prototype DCG9, a Prolog parser that allows "natural language" queries of the data base.

Another AI development was BSR3, a small (6 to 21 rules) expert system for "hot restart" of the BSR, a 2-MW(t) nuclear research reactor eventually to be controlled from the HFIR control room. BSR3 was implemented on an IBM PC AT in each of the following 10 expert system "shells": MicroExpert, CxPert, KDS, KES, Insight 2+, EXSYS, 1stClass, FLOPS, Arity/Expert, and KnowledgePro. A separate report* describes BSR3 and the various tools.

An object-oriented simulation package was developed and used for simulation of the HFIR. This package, which allows a simulation to be built from icons and modified interactively by the user, was developed on a Lisp machine and is now being ported to a SUN workstation as part of the Advanced Controls Program.

A C-language data manager was designed and implemented on the VAX for storing the 132 digital and 49 analog signals from the CAMAC data system at the HFIR, or alternatively, from the HFIR simulator, thus enabling access to these data by other software. A follow-on development was HFIR7, a simulation of an interactive alarm panel including scrolling display of alarm procedures for the HFIR using Arity/Prolog on the PC AT. Via the data manager, HFIR7 processed data from the reactor simulator on the LMI Lisp machine and an "alarm filter" on the VAX.

A machine learning program was developed as part of this project. This general-purpose program learned how to predict the initial critical rod position of a new HFIR core based on previous cycles.

3.3.4 ADVANCED CONTROLS PROGRAM

Several members of the Dynamic Analysis Group contributed to the DOE Advanced Controls Program in the areas of simulation and model development, expert systems, workstation design, software development issues, computer (workstations and parallel processor) acquisition, and program planning and management support.

A considerable effort in the program was directed toward acquiring the hardware and software needed to support software development activities. The 32-bit processor workstation technology will allow integration of two development activities that have proceeded along independent paths in the past: (1) algorithmic applications using languages such as FORTRAN, C, Pascal, and Ada, and (2) symbolic processing using languages such as LISP and Prolog. Workstations will be used as the basic development environment system.

Part of the Advanced Controls Program is to investigate different nuclear plant control strategies using advanced computing capabilities. One of the areas of interest is use of distributed processing, which leads into the related areas of parallel and networked computing. One of the parallel architectures that is very useful for process control applications gives all processors the capability to address the same global (shared) memory. Figure 3.3-1 shows the current network architecture for the Advanced Controls Computer Laboratory incorporating the shared memory parallel computer (ENCORE) and the workstations in the network.

Experience gained as part of the HFIR/AI project is now being used on advanced controls projects. Supervisory and intelligent controls are being investigated and demonstrated via simulation for use in advanced power reactor systems, which are expected to undergo a significant increase in level of automation compared to current-generation plants. Techniques are being developed and tested to improve the performance of plants in normal load-following conditions as well as during off-normal events.

---

*C. E. Ford, *Evaluation of Some Expert System Development Tools for the IBM-PC*, ORNL/TM-11047 (in preparation).

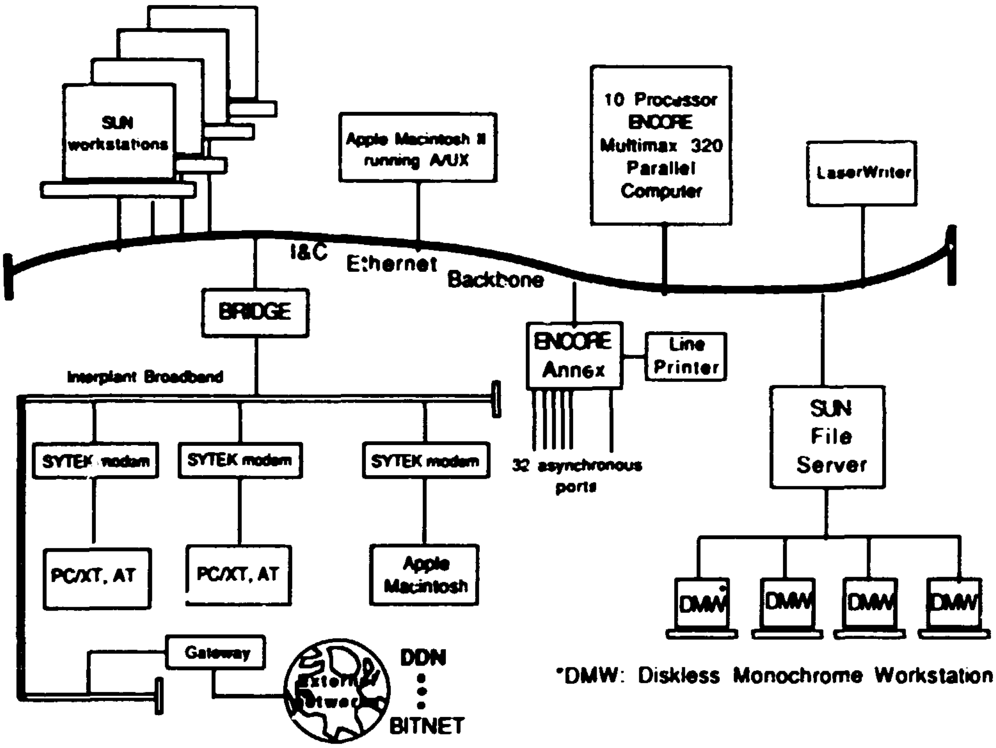


Fig. 3.3-1. Diagram of network architecture for the advanced controls computer laboratory.

Data bases for advanced controls reference material were designed and implemented using Rdb on the VAX and Superbase, Oracle, and dBase III on the AT.

3.3.5 DIRECTOR'S REVIEW COMMITTEE

Two members of the Dynamic Analysis Group served on the ORNL Reactor Operations Review Committee (RORC), one as RORC Chairman and the other as Chairman of the HFIR Subcommittee. This committee provides Laboratory management with technical oversight of safety-related issues of ORNL operating reactors.

3.3.6 HTGR SAFETY PROGRAMS

HTGR safety research and licensing support activities are sponsored by the NRC offices of Nuclear Reactor Regulation (NRR) and Nuclear Regulatory Research (RES) to study safety issues related to high-temperature gas-cooled reactors, both generic and plant-specific. The work began in 1974 and is funded for continuation through FY 1989. The safety program for HTGRs has been directed mainly at analysis of postulated HTGR accident sequences. One continuing effort has been technical assistance to NRC on licensing-related questions for the Fort St. Vrain HTGR, located near Denver. Other advanced HTGR concepts studied over the course of the program include General Atomics large commercial HTGRs planned in the 1970s, a plant design rated at 2240 MW(t) and adaptable to cogeneration, and the current DOE-sponsored modular HTGR reference design. In all of these cases, detailed dynamic simulations were developed to analyze accident scenarios and assist NRC in evaluating licensing-related problems.

Specific licensing support tasks for Fort St. Vrain included independent analyses of postulated accident scenarios using the ORNL-developed ORECA-FSV code. These analyses were performed to confirm the adequacy of several new and modified safety-related systems and other recent plant equipment changes resulting from more stringent environmental qualification requirements. Other studies were carried out in support of a major upgrade to the technical specifications.

Most recently, support was provided to RES in its review of the DOE reference design of the modular HTGR. This support included development of the MORECA code and application of it to independent analyses of design basis and severe accidents. ORNL was also a major contributor to the NRC safety evaluation report for the MHTGR.

3.3.7 MODEL DEVELOPMENT FOR MODERN AIDS TO PLANNING PROGRAM

The Modern Aids to Planning Program is sponsored by the Department of Defense to provide commanders in the field with sophisticated computer-aided assistance in developing and analyzing strategies for combat situations. As part of this program, ORNL was asked to perform research to upgrade and expand the State-of-the-Art Contingency Analysis Code, a tool for low-intensity combat evaluation that originated at other installations.

After a detailed assessment of the improvements needed, a broad range of both software and hardware alternatives was investigated, including (1) reconceptualization of the fundamental mathematical basis of the model—especially power, vulnerability, and attrition formulations—with the objective of increasing theoretical rigor and increasing dependence on field or other data sources; (2) a sensitivity analysis to permit identification of those parameters whose values and uncertainties most affect battle outcome; (3) a stochastic methodology that complements the deterministic approach and assesses the impact of combat (parameter) uncertainties on battle outcome; (4) a range of new graphics capabilities to increase the usefulness of display and improve the user-friendliness of the model; (5) advanced hardware with the capability to use satellite, atlas, or other rasterized data in map display; and (6) three data input options to allow the input format to be matched to the quality and detail of the data source.

The revisions were synthesized into a full stand-alone model that may serve as the basis of a next-generation code. Initial comparisons indicate that the new approaches may provide greater detail and accuracy of conflict representation while improving running time by an order of magnitude and requiring a smaller amount of coding. The code is written in FORTRAN-77, and the graphics are supported by the low-cost PLOT-10 standard Tektronix interface language.

3.3.8 POST-CHERNOBYL ACCIDENT ANALYSES

Following the Chernobyl-4 accident of April 26, 1986, DOE assembled a team of experts from four national laboratories to study the accident. This DOE team, which included representatives from Argonne National Laboratory, Brookhaven National Laboratory, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory, provided analytical support to the U.S. delegation for the August 1986 meeting of the International Atomic Energy Agency (IAEA) and to subsequent U.S. and international meetings.

The DOE team analyzed the accident in detail, assessed the plausibility and completeness of the information provided by the Soviets, performed studies relevant to understanding the accident, and published the results in a DOE Report.*

The accident at Chernobyl-4 occurred while the control room operators were running a test to determine a turbogenerator's ability to provide in-house power after its steam supply was shut off. The accident was the result of a large, destructive power excursion. In the Soviet-designed RBMK reactor, there are certain operating regimes in which an increase in power is likely to lead to an increase in reactivity, which in turn will further increase power because of a design feature called the positive void coefficient of reactivity. A large positive void coefficient of reactivity was the major design-related factor in the accident; this cannot occur in U.S. nuclear power reactors as they do not have this design feature. In addition, a series of procedural and operator errors occurred. The combination of these errors put the Chernobyl-4 reactor into a very unstable operating condition.

The first phase of the accident was a gradual power increase caused by the coastdown of the four main coolant pumps that resulted in increased void formation and a positive reactivity addition. The second phase was a rapid power excursion in which the void formation began to accelerate. The third phase was the energetic phase during which fuel coolant interactions, fission product vapor expansion, and destruction of the reactor occurred.

The DOE team used relatively simple point kinetics computer models to analyze the first two phases of the accident. Subsequently, three-dimensional analyses were performed using both static and dynamic models. The third phase was modeled using accident analyses codes modified to depict the Chernobyl-4 system and conditions. As a result of these analyses, a number of important conclusions were reached as to what caused the accident. In addition to analyzing the accident, the DOE team assessed the actions identified by the Soviets as fixes to improve the safety of RBMK reactors. Finally, the DOE team determined that the potential for a similar kind of accident in U.S. nuclear power plants was nil because of major differences in design.

Three members of the Dynamic Analysis Group participated in this work.

3.3.9 U.S. NAVY KNOWLEDGE RETRIEVAL SYSTEM

Acquiring a knowledge base and networking the elements in the knowledge base using rules are the two major tasks required in development of an expert system. The knowledge retrieval system provides the capability for generating, in a usable way, the knowledge base required by an expert system. The knowledge retrieval system uses a network of layered menus to access knowledge elements arranged in ASCII files. Because ASCII files are used, any word processing product that generates ASCII files can be used to develop the data required by the system. The knowledge retrieval system provides a tool to evaluate the knowledge base before the rules are added.

The knowledge base for this U.S. Navy system was obtained from two sources: printed material and a human expert. The human expert in the subject domain first identified the major topics and key documents that contained the information required by the system. The

*Report of the U.S. Department of Energy's Team Analyses of the Chernobyl-4 Atomic Energy Station Accident Sequence, NE-0076, November 1986.

knowledge engineer developing the knowledge base then outlined and abstracted knowledge from the documents chosen and queried the human expert for specific information needed to make the input data more nearly complete and precise. From this collection of information, the knowledge engineer was then able to build the ASCII files knowledge data base used by the expert system computer program.

3.3.10 SAFETY IMPLICATIONS OF CONTROL SYSTEMS PROGRAM

The SICS Program was sponsored by the NRC RES to provide analysis of the effects on plant safety of control failures in nuclear power plants. This program was designed to help resolve NRC unresolved safety issue USI-A47, "Safety Implications of Control Systems." ORNL was assigned to study PWRs built by B&W and Combustion Engineering. The study began in 1981 with the following objectives:

- Assess the safety implications of control (i.e., nonsafety-grade) system failures.
- Formulate a methodology for assessing failure modes and effects of failures of control systems on the basis of common cause, common mode, and other multiple failures such as cascade failures.
- Develop criteria for establishing the relative importance to safety of control systems and recommend design and operational criteria and modifications, if required, for these systems based on their relative importance to safety.

ORNL made major contributions to the NRC evaluation reports (NUREG-1217[*] and NUREG-1218[†]), which have been issued for public comment. The program has been completed except for occasional assistance provided to NRC in the final reviews.

3.3.11 DATA BASE MANAGEMENT APPLICATIONS

A project exploiting modern data base management capabilities culminated in a report[‡] outlining our experiences in building prototype nuclear cross-section data bases on the PC AT with the Oracle relational DBMS package and Arity/Prolog. In the process, we also utilized Arity/SQL, a set of Arity/Prolog predicates providing relational data base capabilities from within Arity/Prolog.

3.3.12 COMPUTING FACILITY REFURBISHMENT

The hybrid computer laboratory, which functioned under the auspices of the Dynamic Analysis Group, has been completely renovated. The PDP-10 digital and the AD-4 analog

---

[*] *Evaluation of Safety Implications of Control Systems in LWR Nuclear Power Plants*, NUREG-1217, U.S. Nuclear Regulatory Commission, April 1988 (draft).

[†] *Regulatory Analysis for Proposed Resolution of USI A-47*, NUREG-1218 U.S. Nuclear Regulatory Commission, April 1988 (draft).

[‡] Raquel Paviotti-Corcuera and C. E. Ford, *Designing a Nuclear Data Base Prototype with Oracle and Prolog* ORNL/TM-10984 (in press).

ORNL Photo 6563-88

Fig. 3.3-2. New computing facility parallel processor.

machines and their interfaces were removed, and a shared-memory parallel computer (Encore Multimax) and several high-performance workstations were acquired (see Fig. 3.3-2.). These are to be used primarily by the DOE Advanced Controls Program for reactor simulation, control system design, and controller testing.

3.4 RESEARCH REACTOR SUPPORT AND MAINTENANCE

K. W. West
D. S. Asquith
J. A. Ray
J. N. Smith

The Research Reactor Support Group (RRSG) renders assistance to the Research Reactors Division (RRD) by providing routine surveillance and maintenance of reactor instrumentation and control systems and initiating design changes to maintain the systems in state-of-the-art condition. With the assistance of I&C Maintenance Management Department personnel, this group is accountable for maintenance of instruments and control systems for ORNL reactors and associated experiments and for the Critical Experiments Facility. The group also prepares test and calibration procedures for plant control systems (PCS) and plant protection systems (PPS) as well as for individual instrument calibration. The group assists RRD in determining appropriate schedules for implementing procedures and assimilating test data. Under the auspices of the RRD Training Section, the group also provides instruction and materials for training programs for qualification of I&C maintenance personnel.

Some RRD facilities were shut down in November 1986 and the remainder in April 1987, and thus the group has not been able to apply the usual effort in automating routine functions to free operators for more significant tasks. During shutdown, reactor instrument maintenance and surveillance calibrations have continued on a regular schedule. The group has actively participated in RRD efforts to correct managerial problems as delineated by DOE/ORO, and group members have assisted RRD in editing administrative procedures that affect I&C operations.

Other group responsibilities include revising and maintaining up-to-date reactor controls drawings and preparation and approval of new drawings for reactor facilities. All new drawings are prepared and stored in the AutoCAD computer-aided design system, and drawing revisions are being placed in the computer system as time permits. The status and location of drawings and design documents associated with modifications are stored in a computer data base for easy review and retrieval.

The group continually reviews its operations and documentation to verify adherence to DOE, Energy Systems, and ORNL regulations. It is a group responsibility to promote facilities' conformance to mandates of the Reactor Operations Review Committee, the Reactor Experiment Review Committee, and the ORNL Office of Operational Safety as they are interpreted by RRD.

REACTOR MAINTENANCE ACTIVITIES

Engineering support and maintenance activities also have been performed at ORNL reactor facilities.

Bulk Shielding Reactor and Pool Critical Assembly

The BSR has not operated during this reporting period because of the DOE order. A project has been approved and funded to provide for design, procurement, installation, and testing of replacement BSR and PCA protection system components with functionally equivalent devices of modern and proven design. The project will provide more operating flexibility between the BSR and PCA as well as decrease maintenance needs and permit interchangeability of instruments and control rod components. A project has also been implemented to control the BSR remotely from the HFIR facility, which is ~3 km away. The project will utilize fiber optic links and state-of-the-art instruments for interfacing control and monitoring functions.

Reactor instrument surveillance testing and calibration were performed on a regular schedule. Programmed maintenance activities were performed as scheduled by the computerized I&C MAJIC system. One reactor design change memorandum was implemented and one addendum completed for the BSR during this reporting period.

Oak Ridge Research Reactor

The Department of Energy informed ORNL that there is no further programmatic need for the ORR and that it should be placed in permanent shutdown. Even though the ORR has been shut down, certain surveillance systems require calibration and testing, and these have been serviced on a regular cycle. RRSG is assisting in implementing the ORR shutdown plan, which involves removing instrument systems and measuring channels and relocating instruments needed for continued personnel radiation monitoring and building surveillance.

Health Physics Research Reactor

Instrumentation and controls systems for the HPRR have been maintained in a state of readiness during the period the reactor has been shut down. Considerable effort has been dedicated to safeguards and security of the reactor, and installation of the new safeguards and security system has caused an inordinate amount of time to be spent on reactor maintenance. A hydraulic system installed to provide orderly storage of the reactor requires that control circuits be compatible with reactor protection and controls requirements.

Reactor instrument surveillance testing and calibration have been performed on a regular schedule, and routine maintenance was performed on various instruments and systems.

Tower Shielding Reactor

Although the TSR continues to be used only for the cask drop testing program, reactor instrument surveillance testing and calibration have been performed on a regular schedule. Routine maintenance was performed on various instruments and systems while unscheduled maintenance activities centered on the remote monitors, fission counting channel, and Log N channel. Instrument improvements are planned, and, to eliminate badly weathered and noisy signal and control cables, aerial cables will be replaced by installing conduit directly from the reactor to junction boxes in the control room.

Two Reactor Design Change Memoranda were implemented during the reporting period.

High Flux Isotope Reactor

Maintenance activities at the HFIR have been in three major areas: (1) preparation and implementation of instrument and system calibration procedures in response to the surveillance requirements of reactor technical specifications, (2) modifications to the reactor instrument and control systems brought about by the reactor vessel embrittlement problem and additional operating requirements, and (3) provision of input to the various reactor review committees establishing a more formalized and regimented maintenance program at the HFIR.

To ensure compliance with the instrument surveillance requirements of HFIR technical specifications, a program was initiated to provide system calibration procedures for instruments and instrument systems identified as required for reactor operation. This group expended ~3 work-months in preparing 30 system procedures and check sheets encompassing 336 instruments. The second phase of this program was to apply these procedures prior to startup of the reactor. This effort, requiring 500 h of I&C HFIR maintenance staff, was completed well within the allotted time.

Nearly all of the >1000 instruments associated with HFIR are now on automatic recall for calibration. Those instruments not scheduled by system calibration procedures are accounted for through the I&C MAJIC system. Individual instrument calibration procedures have been prepared for those instruments designated in surveillance test procedures, representing about half of the 60 classes of instruments in use at the HFIR. All instruments are being reviewed as to their functions to establish or revise calibration schedules and procedures.

Major modifications were made to the reactor instrument and control system to prevent the primary system from being pressurized if the coolant temperature should become less than 90°F. This change, brought on by the pressure vessel embrittlement problem, necessitated a number of additional modifications. Four Mechanical Design Change Memoranda and four Instrument Design Change Memoranda were required for authorization of the various changes. These changes required some 12 months to complete and resulted in revision of more than 100 instrument and control drawings.

A number of work-hours were expended in meetings with various committees and teams brought in to review the overall operation of the HFIR. The major area of concern expressed in the findings was the lack of approved instrument and system calibration procedures for use within the reactor safety system. This concern has been addressed. Additional I&C procedures will be prepared and issued for other areas within the reactor complex.

3.5 ADVANCED MEASUREMENTS

C. W. Ricker

D. C. Agouridis	E. B. Johnson
E. D. Blakeman	J. T. Mihalczo
T. V. Blalock	V. K. Paré
R. M. Carroll	M. J. Roberts
D. D. Falter	R. L. Shepard
K. G. Falter*	L. H. Thacker
R. J. Fox	K. H. Valentine
T. M. Gayle	

The Advanced Measurements Group was established during this reporting period. Two former groups, Detector Research and Development and Process Instrument Development, were combined with part of the Special Assignments Group to form an integrated group of broad technical scope. The Advanced Measurements Group is engaged in instrumentation research and development of new concepts, theories, and advanced techniques for radiation detection, monitoring, and measurement systems for temperature and flow measurement and calibration systems, plasma diagnostic systems, subcriticality measurements of fissile systems, and aerosol and toxic gas measurement systems. The group also is involved in theoretical and analytical studies of electromagnetic interference (EMI) and electromagnetic pulse effects (EMP), electro-optics, and stability studies on boiling water reactors. The diversity of the group is further exemplified by the continuing development of a tracking system for Africanized bees, a staff member's service as an administrative judge on the Nuclear Regulatory Commission's Atomic Safety and Licensing Board Panel, management of ORNL

*A. G. Technical Associates, Inc.

activities in the American Institute in Taiwan/Coordination Council of North American Affairs Program for Civil Nuclear Cooperation, and active participation in development and review of industry standards for the American Nuclear Society and the American Society for Testing and Materials.

The Advanced Measurements Group provided technical support to the ORNL Advanced Measurement and Controls Program, the FEMA Program, the AIRD Program for the U.S. Navy David Taylor Research Center, the National Aeronautics and Space Administration, the Harry Diamond Laboratories of the U.S. Army Laboratory Command, and the Defense Programs Office of DOE. Significant work performed for some of these programs is discussed in Sects. 3.7, 3.8, and 3.9.

In addition to in-house activities, this group provides technical support to the ORNL Analytical Chemistry and Fusion Energy divisions by full-time assignment of staff members to these divisions.

3.5.1 NEUTRON DETECTORS AND FLUX MEASUREMENTS

3.5.1.1 High-Temperature, High-Sensitivity Fission Counter

A prototype high-temperature, high-sensitivity fission counter (HTHSFC) for advanced liquid metal-cooled reactors was designed and fabricated. It was designed to have a sensitivity of 5 to 10 cps/nv (counts/second/unit flux) at an operating temperature of 550°C. Testing of the counter has been initiated and is expected to be completed by mid-FY 1989 (see Sect. 3.7).

3.5.1.2 Ten-Decade, Single-Mode Reactor Flux Monitoring System

A 10-decade, single-mode reactor flux monitoring system was designed that includes the HTHSFC and takes advantage of its unique features to provide a single instrumentation channel that is expected to meet or exceed the performance capabilities of multichannel flux monitoring systems currently in use. A prototype system will be fabricated and tested before completion of the work in FY 1989 (see Sect. 3.7).

3.5.1.3 Detector Design Optimization Program

A computer program for optimization of design parameters of fission counters was converted for use on a personal computer (see Sect. 3.8).

3.5.2 X-RAY AND GAMMA RADIATION MEASUREMENTS

3.5.2.1 Wide-Range Meteor Burst Gamma Monitoring System

A wide-range meteor burst gamma monitoring system (WRMB-1) was developed (see Sect. 3.8). This system is unique in that it provides the capability to remotely monitor unmanned stations for gamma radiation levels when conventional lines of communication fail or are otherwise unavailable.

3.5.2.2 Extended Range, Low-Cost Dose Rate Meter

An inexpensive dose rate meter having a dynamic range from background to 500 R/h was developed for use by the general public. In a single instrument this meter is capable of measuring dose rates over a broad range without manual adjustments (see Sect. 3.8).

3.5.2.3 Very Simple, Very Inexpensive Dose Rate Meter

A VSVI dose rate meter was developed using innovative concepts and design techniques to meet the sponsor's performance and cost criteria. The elegance of this rate meter lies in its simplicity of design that results in significant cost reductions. A patent disclosure has been filed on this development (see Sect. 3.8).

3.5.2.4 Dosimeter Charger

A new type of piezoelectric dosimeter charger was developed that is capable of meeting the performance specifications of currently available chargers but which can be produced for less money. This hand-held, lightweight dosimeter charger is trigger actuated. Figure 3.5-1 shows seven configurations of the charger. The significant reduction in production costs achieved with this new charger could have a major financial impact on large-scale procurement of these devices. A patent disclosure was filed on this development (see Sect. 3.8).

3.5.3 FLUID FLOW MEASUREMENTS

This group provided technical support to the U.S. Navy AIRD Program in development of a three-dimensional flow measurement system. This assistance included development, installation, and operation of a support and positioning system for performing sensor characterization and calibration tests on a tow tank at DTRC; development of a sensor containment and pressure equilibrium system; development of analog signal processing electronics for two-tank tests and the water velocity measuring system; and development of a digital data processing system for a wake flow measurement system (see Sect. 3.7).

3.5.4 TEMPERATURE MEASUREMENTS

3.5.4.1 SP-100 Program

Technical support for the application of Johnson noise thermometry to the SP-100 reactor was provided during this reporting period and is continuing. Focus is on the use of a series RLC-tuned circuit in the preamplifier input circuit to produce a Johnson noise voltage signal that is independent of the material and resistance value of the temperature-sensing resistor and that does not require compensation (see Sect. 3.7).

3.5.4.2 NASA Noncontact Thermometry Project

A study was initiated to determine the feasibility of measuring the temperature of molten metals levitated in space, either by analysis of laser beams reflected from the surface

ORNL Photo 5474-88

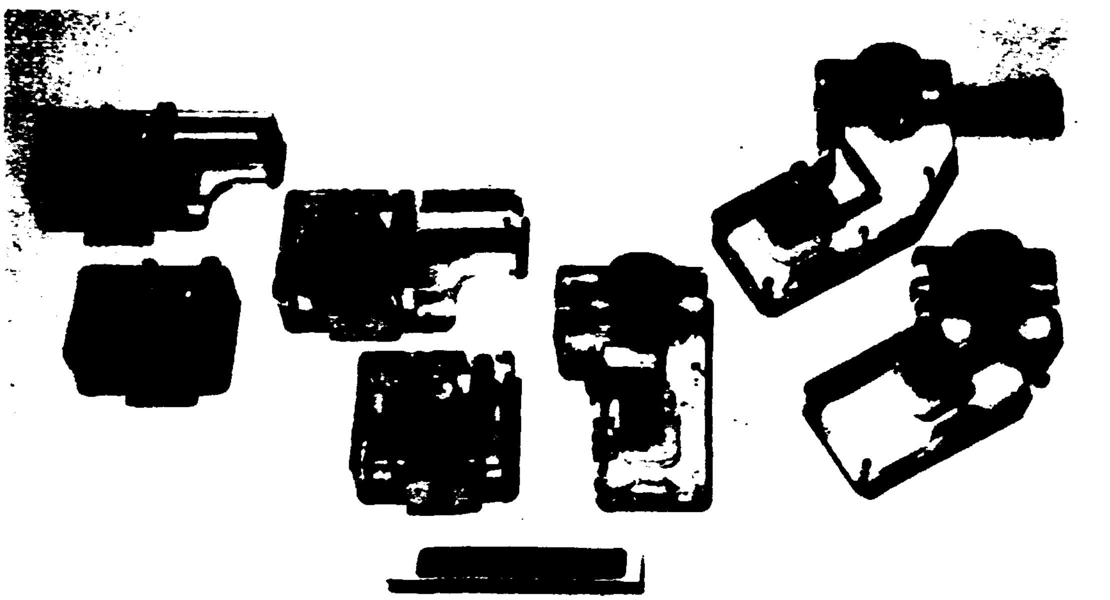


Fig. 3.5-1. Seven configurations of the piezoelectric dosimeter charger. (A dosimeter is installed in the charger at the upper right.)

of the metals or by analysis of thermal radiation from the molten metals in a manner that is independent of the emissivity of the metal (see Sect. 3.7.5).

3.5.5 SUBCRITICALITY MEASUREMENTS

A method for measuring subcriticality that obviates calibration at the delayed critical state (k_{eff} = 1.0) and is also independent of neutron detection efficiency would be a significant technological advance. A project to develop such a method has been under way in the I&C Reactor Systems Section for a number of years. The result of these efforts has led to development of the ^{252}Cf-source-driven neutron noise analysis method.* Because a broad range of geometries is encountered in the application of this subcriticality measurement method, a comprehensive series of proof-of-principle measurements on various geometries are required to establish the method's scope of applicability. To date ~20 different geometries have been measured, and the ^{252}Cf source method has proven valid for all of them.

During this reporting period, subcriticality data on three geometries acquired at the Pacific Northwest Laboratories and ORNL under the USDOE/Power Reactor and Nuclear Fuel Development Corporation (Japan) Program for Criticality Data Development were

*J. T. Mihalczo, W. T. King, and E. D. Blakeman, "^{252}Cf-Source Driven Neutron Noise Analysis Method," Workshop on Subcritical Reactivity Measurements, Albuquerque, New Mexico, August 26-29, 1985, pp. 254-85.

comprehensively analyzed and final reports published.*†‡ Planning for future measurements, which includes extensive computer calculations, procurement of new equipment; and design, fabrication, and testing of special detector/sources, was a major undertaking during this reporting period. This effort was in preparation for subcriticality measurements to be taken during the loading of an LWR fuel cask and measurements of the subcriticality of interacting tanks containing fissile solutions.

3.5.6 OTHER RESEARCH AND DEVELOPMENT

3.5.6.1 Postage Stamp Inspection

Support was provided to the I&C MACES Section on the U.S. Bureau of Engraving and Printing project for quality control of postage stamp production. A method was developed and demonstrated to detect production flaws by real-time comparison of video images of adjacent rows of stamps on a fast-moving web. This method required development of a system for suppression of the paper noise generated in the scanning process (see Sect. 2.6).

3.5.6.2 NASA Electromagnetic Levitation Project

A system for levitating molten metals in space, the Modular Electromagnetic Levitator, is being developed for NASA. In support of the MEL Program in the I&C Research Instruments Section, this group designed and fabricated levitation coils suitable for use on a space shuttle. Coils were tested and coil design verified by magnetic field mapping (see Sect. 1.1).

3.5.6.3 Acoustical System for Identification of Subspecies of Honeybees

An acoustical peak identification system (APIS) for differentiating between European and Africanized bees was developed during this reporting period. The instrument is based on the differing acoustical signatures of the two species of honeybees. APIS indicates the spectral content of the fundamental power peaks for sounds made by the bees in flight, which can be correlated to characteristic taxonomical features such as wing size, body weight, and thorax dimensions, and to physical behavior.

Other salient features of APIS are its simplicity, field portability, and low cost (see Fig. 3.5-2). With the growing concern about the proliferation and migration of the aggressive Africanized honeybees and their potential negative impact on agricultural productivity, APIS can be a valuable tool to beekeepers, regulators, and researchers.

---

*J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, and E. B. Johnson, *Dynamic Subcriticality Measurements Using the ^{252}Cf-Source-Driven Noise Analysis Method*, ORNL/TM-10122, August 1988.

†J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, R. C. Kryter, H. Seino, and R. C. Robinson, *^{252}Cf Source-Driven Neutron Noise Measurements of Subcriticality for an Annular Tank Containing Aqueous Pu-U Nitrate*, ORNL/TM-10138, August 1988.

‡J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, R. C. Kryter, H. Seino, and R. C. Robinson, *^{252}Cf-Source-Driven Neutron Noise Measurements of Subcriticality for a Slab Tank of Aqueous Pu-U Nitrate*, ORNL/TM-10139, March 1988.

ORNL Photo 3083-88

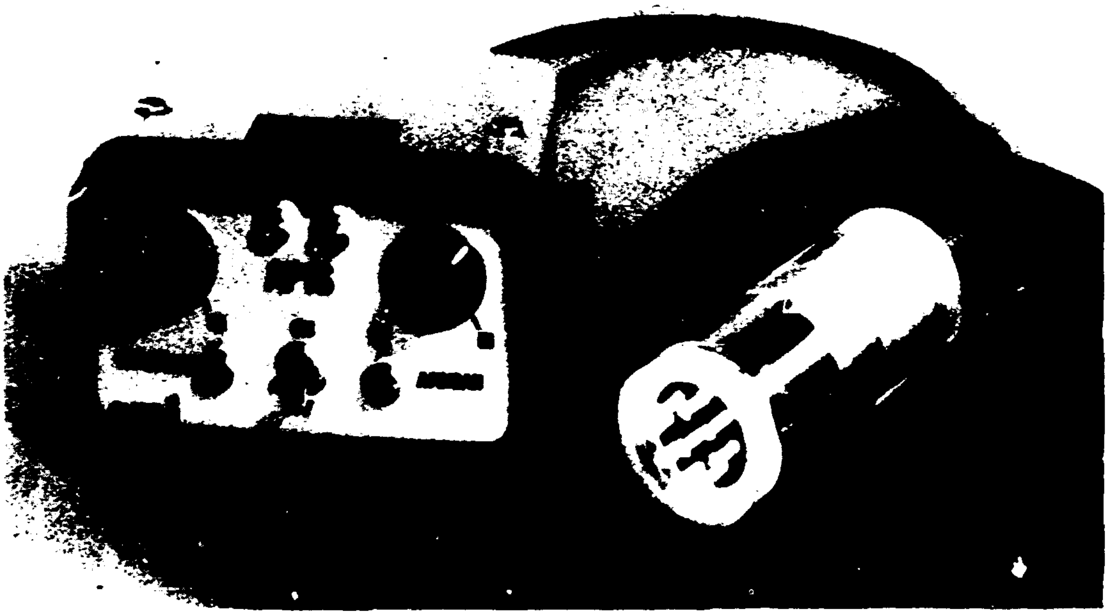


Fig. 3.5-2. Acoustical peak identification system for differentiating between European and Africanized bees.

This work was supported by the Office of Technology Applications, Martin Marietta Energy Systems, Inc.

3.5.6.4 Microminiature IR LED Transmitter/Tracking System

The concept of a tracking system that would allow entomologists to track and study the mating and foraging habits of insects, particularly Africanized honeybees, was formulated during this reporting period. Funded by the ORNL Exploratory Fund, this project addresses the feasibility of designing and fabricating a solar-powered transmitter small enough to be affixed directly to the thorax of a bee and capable of generating a series of infrared pulses through two laser diodes. The concept being developed calls for the infrared signals so generated to be optically amplified, collected, and analyzed by a microprocessor-controlled receiving station located up to 2 km from the source of the signals. An electronic chip of the size and weight of the proposed transmitter was attached to the thorax of a bee. The bee was able to carry this burden without adverse effects. This investigation, a cooperative effort with the RIS Monolithic Systems Development Group, is under way and scheduled for completion in FY 1989.

3.5.6.5 Electromagnetic Pulse Effects and Electromagnetic Interference

This group provided technical support in the areas of EMP and EMI to the MACES Electromagnetic Technology Group and to the ORNL Health and Safety Research Division. The former was responsible for evaluation of electromagnetic effects on medical electronics and the latter for bioelectromagnetic effects of EMP. Both projects were conducted for the

Harry Diamond Laboratories, U.S. Army Laboratory Command. Similar analyses and theoretical evaluations were provided in support of FEMA programs.

3.5.7 TECHNICAL SUPPORT TO OTHER ORNL DIVISIONS

This group provides research, development, and application engineering support to other ORNL divisions in the form of full-time staff assignments. During this reporting period, two staff members were assigned to other divisions. Their activities in those divisions are discussed below.

3.5.7.1 Analytical Chemistry Division

As a member of a team in the ORNL Analytical Chemistry Division, the assignee works on aerosol and toxic gas measurements as well as measurement R&D.

Characterization of Rocket Propellant Combustion Products. The purpose of this work is real-time chemical and physical characterization of exhaust products of solid fuel rocket motors of interest to the military. Work is conducted via range-finding studies on free burns of propellant at ORNL and via on-line characterization of exhaust atmospheres generated at the U.S. Army Signature Characterization Facility (ASCF) at Redstone Arsenal, Huntsville, Alabama.

Sampling and Analysis of Diesel Engine Exhaust and Military Motor Pool Atmosphere. Diesel engine exhaust and motor pool workplace atmospheres were sampled and analyzed for organic compounds to better define the fuel-related workplace atmosphere contamination to which military personnel are exposed. Extended field trips were made to the U.S. Army's Fort Carson, Colorado, Armored Division Base to make instrumental measurements involving both time-averaged and time-resolved collections of particulate phase and gaseous organic compounds.

Development of a Solids/Petroleum-Based Aerosol Generating System for the Military Obscurant Studies Program. A laboratory-scale generating system has been developed for a binary (solid/liquid) aerosol in connection with U.S. Army tactical military obscurant programs.

Design of Smoke Dosimeter for Human Smoking Studies. A real-time smoke dosimeter was developed under sponsorship of the National Cancer Institute. Successful demonstrations at ORNL have been followed by installation of the unit for extended field evaluation at a medical facility in San Francisco.

Development of Marijuana Smoke Chemistry/Inhalation Exposure Systems. Support continued for a program sponsored by the National Institute of Drug Abuse to develop animal exposure systems. These systems involved extensive ORNL-developed instrumentation and controls.

Scoping Studies on Techniques and Methodologies for Evaluating Chemical and Toxicological Properties of Combustion Products of Rifle and Gun Systems. This design study, sponsored by the U.S. Army Biomedical Research and Development Laboratory, included a detailed design of the facility, controls, and instrumentation to quantify toxic exposures from various gun systems. These studies are continuing.

3.5.7.2 Fusion Energy Division

The staff member assigned to the Fusion Energy Division has major responsibilities associated with fluctuation diagnostics for the Advanced Toroidal Facility* (ATF). The ATF is a type of magnetic plasma confinement device known as a stellarator. In this machine, the principle of plasma confinement is the same as that of the more familiar tokamak devices, but in a stellarator the needed twist in the toroidal magnetic field is generated by helical magnet coils rather than by current induced in the plasma. In all confinement experiments that achieve plasma parameters of interest in the fusion program, the plasma develops instabilities which, although they normally saturate in amplitude, may severely degrade the quality of confinement. Standard diagnostic methods for studying instabilities are (1) measurement of magnetic fluctuations using pickup ("Mirnov") coils outside the plasma and (2) observation of internal temperature variations using arrays of collimated X-ray detectors. Conceptual designs have been prepared for a set of these types of diagnostics to be built and installed on ATF over the next few years.

In working out the designs, it was necessary to allow for some features that are unique to stellarators and some that are unique to ATF itself. The cross section of the plasma is not constant around the torus, as in a tokamak, but rather twists and changes shape with toroidal angle, completing a cycle every 30°. The ATF coil and power supply system permits a wide variety of plasma shapes and positions within the vessel. Thus, the position of the plasma boundary will vary widely with both location in the vessel and operating mode. In a stellarator, fast particles escaping from the plasma tend to be spatially concentrated in localized helical bands whose positions are uncertain; the resulting high energy flux could damage diagnostic devices within the vessel, even if they are not close to the plasma. To illustrate integration of these considerations with physics measurement objectives, the features and design criteria of two of the diagnostics systems are described.

Because magnetic fluctuations from plasmas have been observed at frequencies up to several hundred kilohertz, a high-frequency Mirnov coil assembly will be built. To obtain maximum bandwidth with adequate sensitivity in a compact package, a multiturn Mirnov coil design was optimized for minimum inductance. Since the coils and wiring would degrade the vessel vacuum and thus plasma purity, the coils will be encased in stainless steel cans made as small and thin as possible to minimize their electromagnetic shielding effect. To receive sufficient high-frequency signal, the coils need to be very close to the plasma edge. Because of the hazardous environment and the variability of plasma position, the high-frequency Mirnov assembly will be radially movable and shielded with graphite armor. Thermocouples and a Langmuir probe will be incorporated to indicate proximity to the plasma edge. Considerable heating could occur nevertheless; therefore, during long plasma pulses the coils and wiring will not contain any organic materials.

Collimated semiconductor diode X-ray detectors receive radiation from all along their lines of sight, with emphasis on the most strongly emitting (that is, the hottest) parts of the plasma. Thus they are useful for observing large-scale internal instabilities. Because most of the variability of plasma shape in ATF consists of horizontal shifts and distortions, the X-ray

---

* J. F. Lyon et al., *Fusion Technology* 10, 179 (1986)

array to be used for fluctuation studies is being installed with a horizontal view so that the region of dominant emission along each detector line of sight will remain at approximately the same radius from the plasma center. Small ion-implanted detectors mounted on ceramic substrates will be used, and organic materials will be excluded from the detector assembly; thus, the device can be located within the vessel vacuum (though not near the plasma), and it will not require either cooling or a separate vacuum system. Heavy electromagnetic shielding and careful wiring layout will be employed to reduce EMI. The EMI environment is being studied with the aid of a three-axis antenna.

3.6 ADVANCED CONTROLS PROGRAM

J. D. White

In 1985, DOE established a task team to determine the need, assess the feasibility, and recommend an approach to the introduction of automation and advanced controls into the nuclear power industry. This team was one of four established as a result of a high-level workshop of DOE and key nonnuclear industry executives to solicit ideas for advanced reactor technology programs with potential for a big payoff. The task team report, published in September 1985, recommended an advanced controls test operation program with a centralized, multiuser capability. Quoting from the task team report:

> The purpose of the Advanced Control Test Operation (ACTO) Program is to provide the nuclear industry with a control design, test, and qualification capability for current and advanced LWR, LMFBR, and HTGR designs. The design and development of this integrated software and hardware environment will provide multi-user testing and qualification support capabilities throughout the nuclear plant design life cycle from the initial interactive first-principle dynamic model development for the process, systems, components, and instruments through advanced control room qualification. This support capability is not currently available, and though needed, is not likely to be provided by industry due to its long-term high financial risk implications. The structure of the industry, the market, and competitive realities do not make it financially viable for any commercial organization to provide this capability or to combine with others to do so. The lack of this capability prevents the use of new technology that could reduce power plant operating cost and could increase plant availability. The establishment of this capability will allow industry to test and qualify control advances, and thus use this technology.

As a result of this report, DOE has provided support to ORNL to pursue research leading to advanced, automated control of new, innovative liquid metal reactor (LMR) power plants. The goal is to provide a national center of excellence in research, development, and testing of nuclear control systems employing the latest advances in automation, artificial intelligence, expert systems, hierarchical structure, and optimal control. This program will provide an integrated environment to support rapid and confident design and testing of advanced control systems providing improved operability, reliability, and safety for advanced LMRs. A long-range plan for R&D in advanced controls was written in FY 1988 for the DOE Advanced LMR Program (the sponsor of this activity).

Transition is from today's nuclear control systems, with some analog control at the subsystem level and significant operator integration, to designs for complete automation under human supervision. The transition may be described in terms of four levels, as shown in Fig. 3.6-1. Level 1 is essentially automated data management at a plant, which is actually occurring now to a limited extent in U.S. LWRs and is planned for U.S. LMRs. Also at this level is replacement of some analog controllers with more reliable digital controllers performing basic proportional-integral-differential control. As mentioned previously, EPRI is already sponsoring some of this work at existing LWR sites.

Level 2 is automation of routine procedures such as startup, shutdown, refueling, load changes, and certain emergency response procedures. Significant assistance will be given to the operator in the form of expert systems and control room displays of plant status. Control strategies will be predetermined choices selected from hierarchical, optimal, linear, robust multivariate options. Advanced LMR concepts now being studied fit within this phase.

Level 3 is a significant advance toward automation, with capability for full automation of all hierarchical levels of control. The operator's role will be to interact with and monitor the intelligent, adaptive supervisory control system. Smart sensors will validate their own signals and communicate with robust, fault-tolerant process controllers, which in turn will be able to reconfigure control logic to meet operational objectives selected by the supervisory control system. Control strategies will be adaptive, uncompromised by nonlinear effects in the processes, and very robust to off-normal conditions. Plant designs will be completely automated, with plant data bases available to the control system and to the operator. Operational experience of all plant systems and components will be tracked in an automated data base. The control system will recommend maintenance schedules and outages to the operator. Human performance modeling will indicate allocation of function decisions in a way that keeps the operator motivated and informed about plant status.

Level 4 is total automation of the plant: an intelligent control system aware of operational status and in interactive communication with the operator to keep him apprised of operational status, any degraded conditions, likely consequences of degradations, and possible (recommended) strategies for minimizing deleterious consequences. At this level, plant designs will have many functions automated and robotized including maintenance and security surveillance. The control system will be an integral part of not only the total plant design but also the national network of commercial power plants. The control system computer will learn from the network relevant information concerning other plants and component operational experience and will alert the operator if that experience is relevant to his plant.

To help provide the necessary national leadership in this transition, Advanced Controls Program personnel will support four major kinds of activities:

1. demonstrations of advanced control system design using current developments in control theory, automation, artificial intelligence, information management, modeling and simulation, and man-machine interaction research;

2. establishment of a design environment that allows designers to formulate and test various control strategies on a plant of interest quickly and economically;

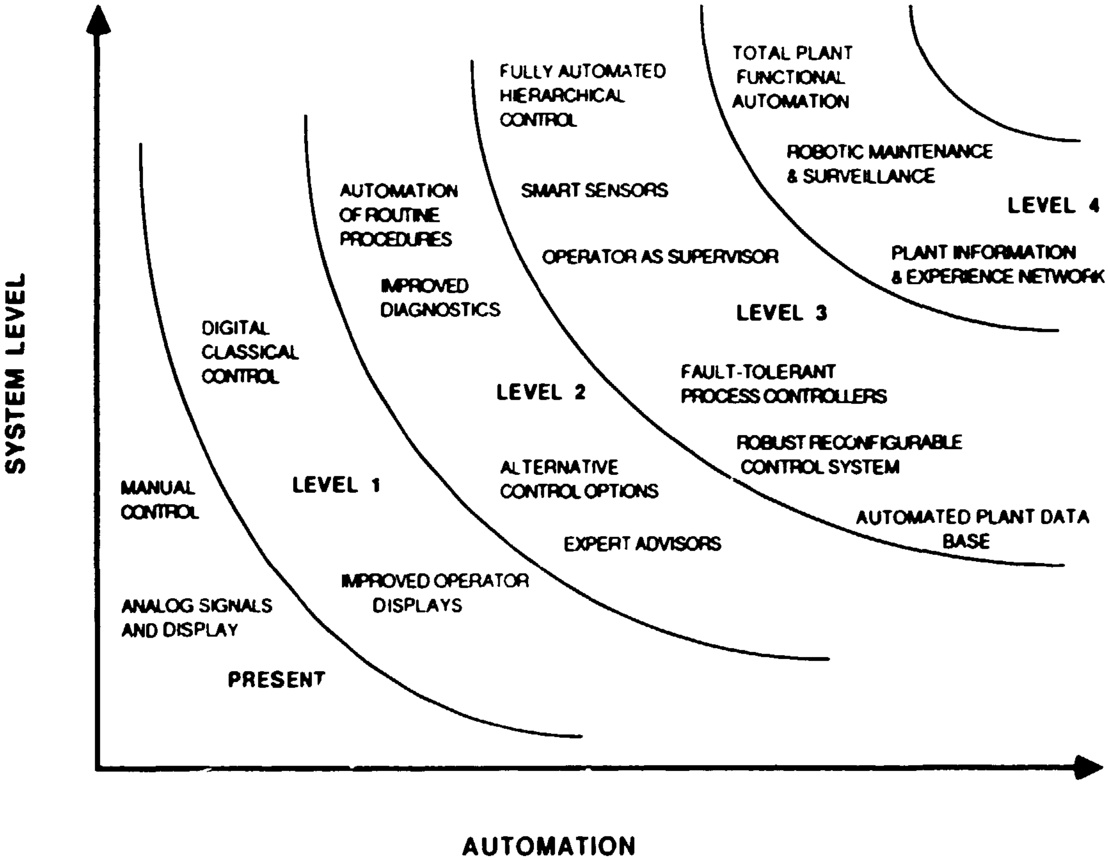


Fig. 3.6-1. Levels of transition envisioned to move LMRs from manual to automatic control.

3. testing and validating advanced control system designs by simulation; and

4. guiding control software and hardware specifications.

3.6.1 DEMONSTRATIONS

The Advanced Controls Program provides national leadership in control system design by providing demonstration examples of advanced control system designs for nuclear reactors. These demonstrations are designed to show how state-of-the-art research can be used to help accelerate the transition to fully automated control. For example, the first demonstration, planned for November 1988, will be an advanced, automated control system design for a feedwater system for an advanced LMR using a robust, optimal, hierarchical control strategy. The demonstration will include incorporation of smart sensors into a hierarchical control system and will include an expert advisor system for the operator. The feedwater train is a complex system that is the origin of incidents causing a significant fraction of lost plant availability in conventional LWRs. Although this demonstration will be based on a multimodular LMR, it will be useful to control system designers of all types of steam-producing power plants such as the Power Reactor Inherently Safe Module

(PRISM), the Sodium Advanced Fast Reactor (SAFR), the Modular High-Temperature Gas-Cooled Reactor (MHTGR), and LWRs.

In late FY 1989, a second demonstration will exemplify a supervisory control system for an advanced LMR. It will show control of multiple modules using a robust nonlinear control algorithm developed as part of the program. The control strategy will be hierarchical with adaptive control features.

These and other demonstrations in following years will help to transfer to the reactor industry the benefits of the latest proven advances in control systems strategy; control system and whole-plant simulation; computer-aided software engineering for control system and whole-plant simulation; computer-aided software engineering for control systems design, man-machine interaction, modeling and analysis; and other technologies. Further demonstrations will include (1) automated startup and shutdown, (2) automated load following, (3) control systems with state prediction, (4) control systems transparent to and interactive with human operators, and (5) others as required.

3.6.2 DESIGN ENVIRONMENT

The program will provide a centrally located, user-friendly design environment for control system designers within the DOE community and, later, for other qualified users. The environment will consist of (1) networked, intelligent computer workstations into which have been integrated software tools, graphics capabilities, on-line design guidance, on-line documentation, and interfaces to the large-plant simulation capability at ORNL; (2) plant/component models and data bases useful for control system design and plant simulation; (3) information resources concerning control system strategies for automated control; and (4) man-machine interaction models and guidelines for designing control system interfaces with operators. The center at ORNL will be electronically linked to participating universities and institutions, and all information will be in electronic form for easy accessibility. ORNL professional staff members will be available to assist in transfer of the technology to users.

3.6.3 TESTING AND VALIDATION BY SIMULATION

The ability to simulate an entire plant in real time is critical to the design of a fully automated plant. For certain types of studies, only high-level simulation is needed, but for testing and validation of automated control systems, significantly more detailed models are required. The technical community and ORNL will use their capabilities to test example control systems designed in the program and provide simulation capability to other DOE program participants. State-of-the-art advances in computer architectures, software engineering, very high-level languages, area networking, artificial intelligence, and data base management will be integrated into a whole-plant, real-time nuclear power plant simulation capability. This capability will be linked to the design workstations described previously, but it will also be addressable by telecommunication networks. Design organizations will be able to simulate, test, and demonstrate their own designs to the utility community. Since these designs will include actual controller software and hardware specifications, the simulator can be linked to actual (or prototypical) controller hardware and run the software.

3.6.4 CONTROL SOFTWARE AND HARDWARE

The program will provide standards, guidelines, and specifications for control software and hardware. ORNL will acquire or develop tools and methods for generation of large software programs for automation of nuclear reactors. Methods for locating logical faults and errors in software programs will be acquired or developed. Program participants will develop standardized software programs that accommodate computer hardware system and plant component failures. Software verification and validation procedures will be acquired or developed and used.

3.6.5 ACCOMPLISHMENTS IN THE REVIEW PERIOD

Accomplishments from September 1986 to September 1988 are in four primary program tasks: demonstrations, design environment, testing and validation by simulation, and control software and hardware R&D.

3.6.5.1 Demonstrations

Although no demonstrations are to occur before the end of September 1988, progress to date has been substantial. Primary emphasis has been on demonstration of a prototype for digital feedwater control. Completed work includes conceptual design, preliminary design description, and detailed design. The final step, which is almost complete, is systems integration and testing.

The feedwater system controls and expert advisor project is an example that encompasses a vertical slice of an advanced control system. The heater strings, pumps, valves, and other components constitute a relatively large, complex system to control and monitor, one on which Advanced Controls Program capabilities can be demonstrated. The expert advisor will provide advanced monitoring functions to detect degraded or failed components and take actions to continue operation of the plant.

This design demonstration project advances development of the Power Reactor Inherently Safe Module (PRISM) design because control and operation of the feedwater system of the PRISM have not yet been designed or analyzed in depth. This study develops models and collects engineering design information necessary for construction of the plant. Moreover, since the feedwater system in PRISM has a great deal in common with feedwater systems in other power plants, the lessons learned and control features developed will be directly applicable to other plant designs.

The second demonstration project is a supervisory control scheme for a multimodular LMR. A digital, distributed, hierarchical control system is proposed for the PRISM multimodular concept. The control strategy requires a supervisory control scheme in which a top level controller coordinates the other controllers. While ORNL plans to demonstrate such a strategy in FY 1989, much of the preliminary work has been completed. The first subtask was a hierarchical decomposition of the large-scale system. A new approach to this decomposition has been developed and tested by a new technique based on optimal control theories for systems with uncertain dynamics. Each subsystem has an autonomous optimal controller, which treats interactions with the rest of the plant as unknown contributions determined from plant sensor readings. The supervisory controller establishes the demand distribution strategy among subsystems' performance and the behavior of their unknown terms. This technique is mathematically consistent with the nonlinear algorithms developed in the Advanced Controls Program for multivariate control, parameter identification, and tracking. Application of this technique to a multimodular advanced liquid-metal cooled reactor (ALMR) is nearly complete. A mathematical formulation of the dynamics of the ALMR has been completed, and testing to date has been satisfactory. ORNL presented a paper on this work at the Third IEEE International Symposium on Intelligent Control.*

3.6.5.2 Design Environment

A proof-of-principle intelligent workstation for control system design featuring AI and graphical interfaces has been developed. This work provides the Advanced Controls Program staff with an ability to easily produce and evaluate certain ALMR control system strategies and techniques. The simulation environment has been developed on an LMI Lisp machine using the FLAVORS object-oriented language. The class library contains generic descriptions of objects that define the domain of the simulation environment. The user interface provides the means to build, run, and interact with simulation models using interactive graphics. The goal of this work is to construct a workstation-based simulation environment that is user friendly and powerful and that can support development of advanced control systems through interactive experimentation.

3.6.5.3 Man-Machine Interfaces

ORNL Engineering Physics and Mathematics Division personnel developed and linked a prototype model of a human operator to an existing computer simulation of an advanced LMR to enable a rough qualitative assessment of operator workload and operator performance during operational upsets. This model of a human operator will require several more years of development to complete, but already it addresses to some degree the operator's (1) qualitative simulation model of the plant process, (2) error detection and recovery capability, and (3) motivational factors. To the best of our knowledge, no other such model exists. Our plan is to make the model more complete and to integrate it into the design and testing capabilities of the Advanced Controls Program.

3.6.5.4 Plant Models

Development of control system designs requires plant models. Existing models of conceptual ALMRs are embedded in computer codes (typically averaging 500,000 lines), written by other organizations. These codes are written for detailed calculations of plant behavior during accidents. To design control systems with them would require a great deal of central processing unit (CPU) and designer time. Therefore, a team effort has been made to reduce the models embedded in these codes into a set of reconfigurable, fast-running models in an easy-to-use format standardized for control system design and analysis. Two important blocks of this work have been completed: translations into MMS format of the models in the General Electric computer code ARIES-P and in the Rockwell International computer code SASSYS. These accomplishments have resulted in development of models of cores, pipes, heat exchanges, centrifugal sodium pumps, and other advanced

*C. R. Brittain, P. J. Otaduy, L. A. Rovere, and R. B. Perez, "A New Approach to Hierarchical Decomposition of Large-Scale Systems," *3rd IEEE Internat. Symp. Intelligent Control*, Arlington, Va., August 24–26, 1988.

LMR components and linking them to form fast-running plant simulations that compare very well with test case runs on ARIES-P and SASSYS.

3.6.5.5 Advanced Control Algorithms and Strategies

The mathematics of control theories and strategies is an area in which the I&C Division and its subcontractors have considerable strength. An ongoing R&D effort in classical and advanced control theories has resulted in significant advances in theory and applications. I&C staff members and UTK graduate students have developed and evaluated (using EBR-II data) several strategies showing that certain advanced control techniques are better than classical PI techniques for steam generator control. Techniques using multivariate optimal algorithms in a LQG and LQG with LTR provided a significant degree of robustness with respect o changes in performance due to such factors as fouling.

A promising technique for hierarchical control using nonlinear optimal control theories for systems with uncertain dynamics has been developed and testing has begun. Early results indicate that algorithms developed in this work can be utilized in real-time control of systems to improve (1) capability to adapt to changes in plant performance, (2) performance even in the case of noisy plant signals, and (3) performance in regions of nonlinear behavior. Work to date on simple low-order models has been very encouraging.

3.6.5.6 Testing and Validation by Simulation

The most important work done in simulated test and validation has been development of the first phase of the computer laboratory (see Fig. 3.3-1). Requirements have been developed, specifications written, and competitive bids evaluated for the automated data processing (ADP) equipment planned. As a result, an ENCORE parallel processor and several SUN workstations have been procured to host the software and models necessary to test and validate the prototype control system designs developed within the program. These pieces of ADP equipment will be integrated next year, and their capabilities will be expanded as needed. They will be available for testing the control system designs of others.

Acknowledgments

Participants in the work reported here who are not members of the I&C Division include J.M. Bailey, C. March-Leuba, and R.B. Perez of The University of Tennessee, Knoxville; and H.E. Knee, P.J. Otaduy, and J.C. Schryver of the Engineering Physics and Mathematics Division.

3.7 ADVANCED MEASUREMENT AND CONTROLS PROGRAM

R. I. Shepard

3.7.1 FLUX MONITORING SYSTEM DEVELOPMENT

Two major components in development of flux monitoring systems for advanced liquid metal-cooled reactors (ALMRs) have been designed. First, a high-temperature, high-sensitivity fission counter that provides a sensitivity of 5 to 10 cps/nv and an operating temperature of 550°C was designed and assembled. (See Fig. 3.7-1.) This counter is 100 times more sensitive than other counters that can operate at these temperatures. It allows designers of ALMRs to install a single detector in the sodium-filled reactor vessel to monitor reactor flux from the initial fuel loading of the reactor to full power operation. Cooled thimbles such as those used in the FFTF reactor are not required. A prototype detector will be tested at temperature in mid-1989, prior to irradiation testing of the EBR-2 reactor.

Second, an improved measuring channel for the reactor flux monitoring system to be used with the HTHSFC was designed to use a new method of variable-threshold counting detection. This extended wide-range channel design provides more than 10 decades of coverage with a single measurement mode. It also eliminates the traditional use of three overlapping modes–counting, campbelling, and dc current–each with its own set of electronics, and avoids the customary operational problems of alignment of the three modes. The channel design utilizes the particular features of the HTHSFC to provide wide-range self-checking burnup life estimates and trimming to reactor thermal power, and, relying on microprocessor-based digital technology, it provides reactor operators and control and safety systems with the required flux signals. A prototype measuring system will be tested in mid-1989. (See Fig. 3.7-2.)

A detailed design description was written for the flux monitoring system of the Rockwell International SAFR modular ALMR using these two developments. The design of the General Electric PRISM modular reactor also is based on these ORNL developments.

3.7.2 AUTOMATED NOISE SURVEILLANCE AND DIAGNOSTICS

For the fifth year, an automated noise surveillance and diagnostic system (ANSDS) continued to acquire data from 21 process sensors (6 neutron flux, 3 pressure, 6 temperature, and 6 flow) installed in the FFTF reactor. The data have been analyzed and summarized.* A data base management system was designed to organize these data. Work was started on development of a physical model of the in-vessel components of the FFTF for interpreting the noise signals and on development of improved data reduction methods that would permit on-line analysis of noise signals. A new computer was ordered to replace the 10-year old FFTF system and support on-line data analysis. A plan was developed for upgrading the ANSDS system to expert advisor for the FFTF reactor operators and for its

*Summary of ORNL Long-Term Surveillance at the FFTF, ORNL/TM-10767, to be published.

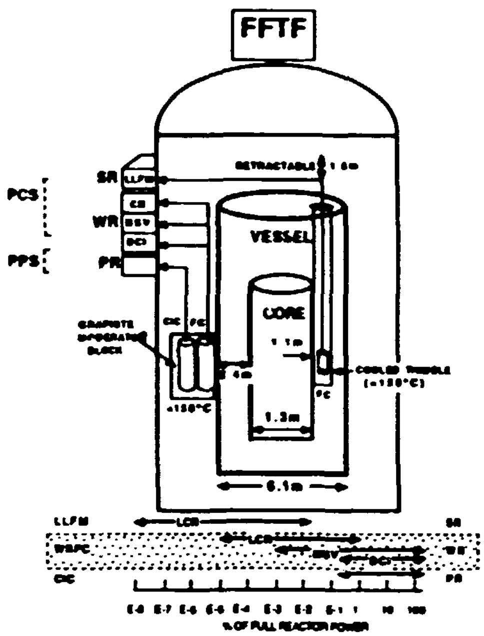
ORNL Photo 0453-86

Fig. 3.7-1. Conceptual model of HTHSFC, 10 cpsav, 550-650 °C, 11.4 cm (4.5 in.) OD, 76.2 (30 in.) overall.

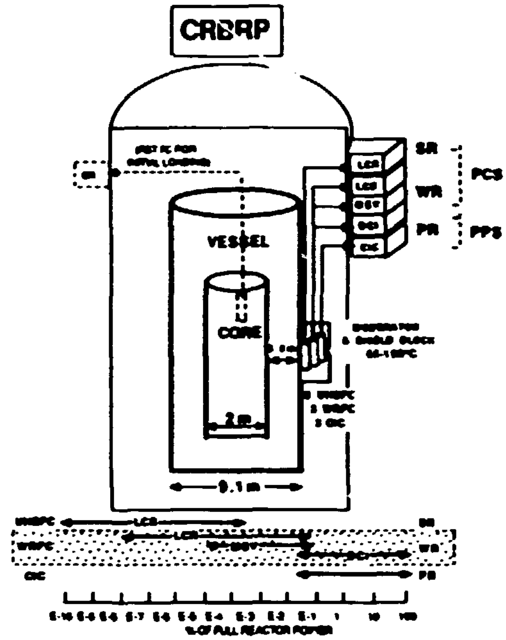
becoming, ultimately, a part of the diagnostic system for an automated control system for ALMRS. (See Fig. 3.7-3.)

3.7.3 AIRD WAKE FLOW MEASUREMENT INSTRUMENT

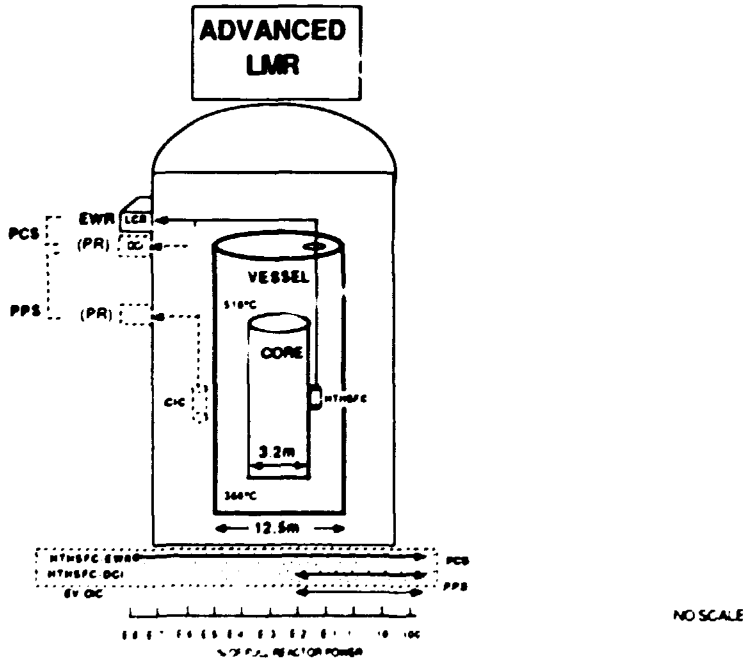
A new flow vector instrumentation system for the AIRD Program was developed for making precision measurements of three-dimensional fluid flow in open channels, tunnels, and pipes using fixed 7-port Pitot probes with a cone of acceptance angle of ±30° in both pitch and yaw (see Fig. 3.7-4.) For water speeds of 6 to 18 m/s (20 to 60 ft/s), velocity magnitudes can be resolved to ±0.1% and angular differences to 0.1°. A multiprobe measuring system, signal processing electronics, and a computer-based data acquisition system were designed for the U.S. Navy David Taylor Research Center. The entire system is mechanically and electrically integrated, automated, and remotely operated. Several prototype probes were tested in DTRC flow facilities, and fabrication of a field measurement system was begun. The project was suspended by DTRC for FY 1988, but it can be resumed readily when funding is restored.



- THREE FLUX DETECTORS
- ONE IN-VESSEL DETECTOR
- FIVE MEASURING CHANNELS
- TWO EX-VESSEL DETECTORS



- THREE FLUX DETECTORS
- LOW-TEMERATURE (150°C)
- FIVE MEASURING CHANNELS
- EX-VESSEL LOCATION



- ONE FISSION COUNTER
- HI-TEMPERATURE (550°C)
- ONE MEASURING CHANNEL
- IN-VESSEL LOCATION

Fig. 3.7-2. LMR flux monitor system installations.

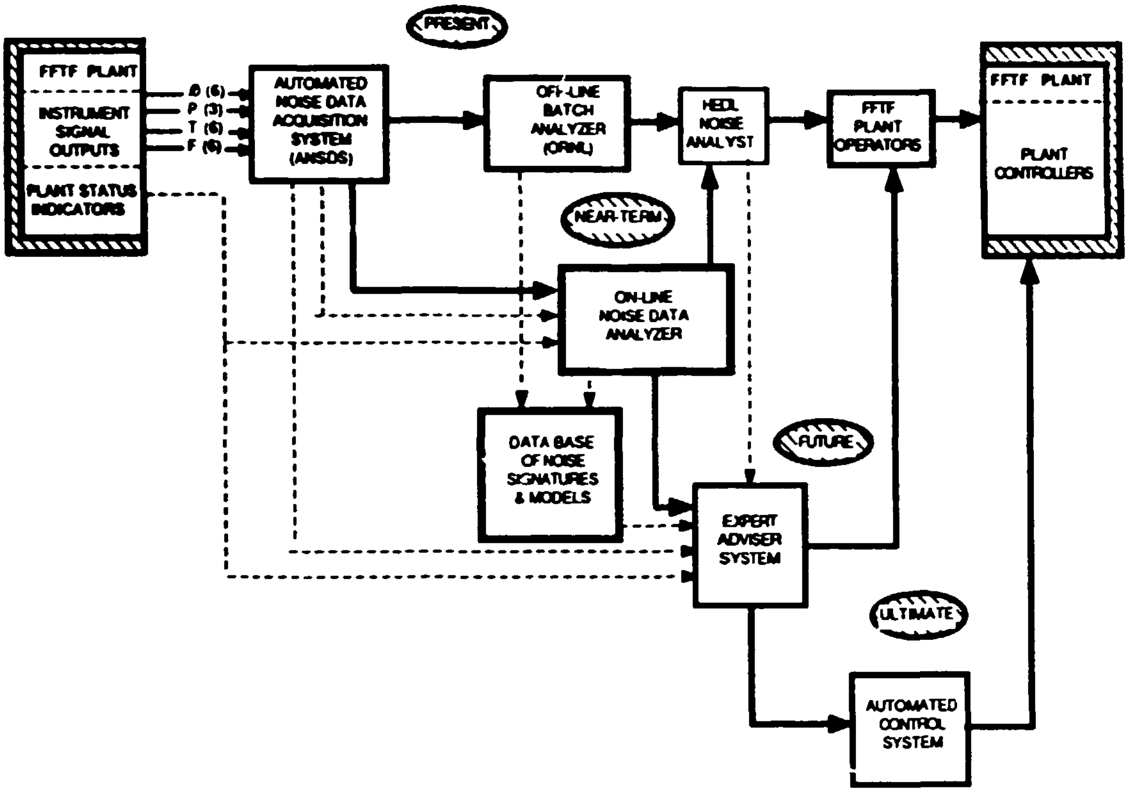


Fig. 3.7-3. Automated on-line diagnostic system development.

3.7.4 SP-100 TEMPERATURE MEASURING SYSTEM

The Johnson noise thermometer has been selected as a diverse temperature-measuring instrument for monitoring the lithium coolant exit temperature in the SP-100 reactor. Accuracy must be maintained at <1.5% to 1350 K for a decade in a remote, unattended system that is to be tested in the mid-1990s for deployment in space. It was recognized that only an absolute thermometer such as the Johnson noise thermometer could provide drift-free operation in this space environment, which is accompanied by a significant radiation field (see Fig. 3.7-5). ORNL is adapting Johnson noise technology, previously demonstrated in ORNL test reactors, to the SP-100 application and joining with General Electric-San Jose in designing noise temperature sensors and a prototypic measuring system. This project began in the spring of 1988 and will continue into FY 1993.

3.7.5 NASA NONCONTACT THERMOMETRY DEVELOPMENT

ORNL is exploring the measurement of the noise content of laser signals reflected from, or the Planck radiation emitted by, incandescent metal surfaces to provide a measurement of surface temperature independent of the metal's emissivity. The goal of this study is to evaluate the feasibility of an optical equivalent of the (electrical) Johnson noise thermometer. (See Fig. 3-2 on p. 139.) Of interest to NASA are control of the temperature of molten materials levitated in a space environment and terrestrial applications for

ORNL Photo 7959-87

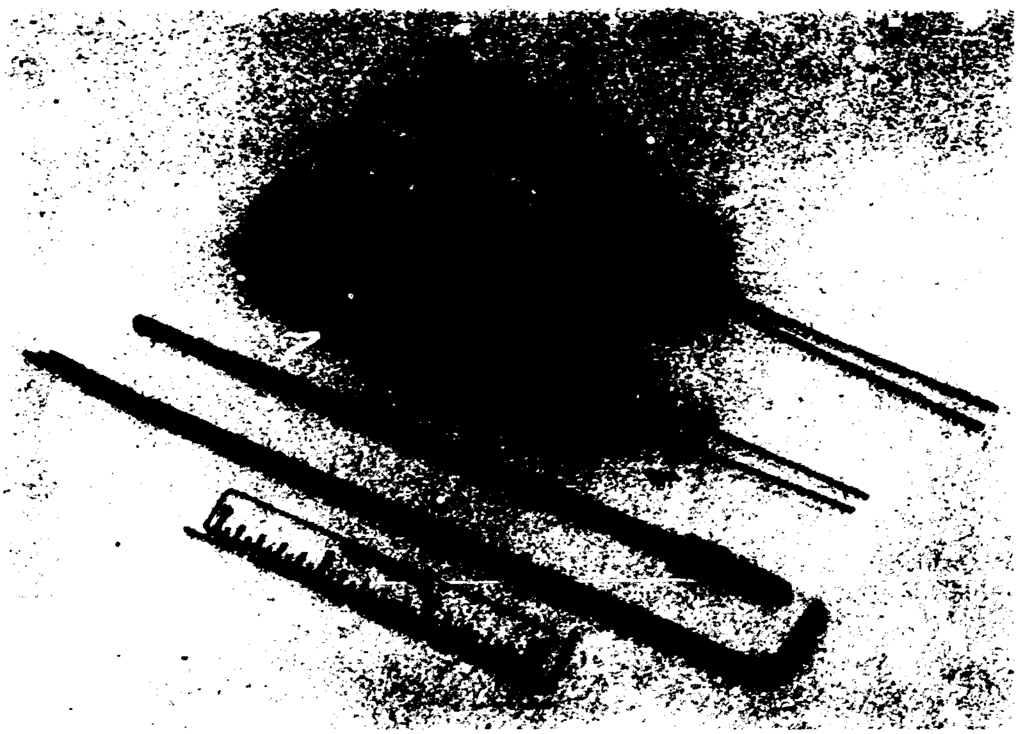


Fig. 3.7-4. Seven-port Pitot probe for measuring fluid flow.

materials processing. Since this study began in June 1988, initial measurements have been made on noise in laser beams, and methods have been examined for discriminating between thermal noise and system noise using analog signal correlation techniques.

Acknowledgments

Participants in the work reported here who are not I&C Division members include W. W. Engle, Jr., of the Engineering Physics and Mathematics Division, D. C. Watkin of ORNL Engineering, and W. B. Reese and J. A. Thie, consultants.

3.8 FEMA ENGINEERING SUPPORT PROGRAM

M. E. Buchanan

The Federal Emergency Management Agency maintains the Radiological Instrumentation Test Facility (RITF) to assist in managing instrumentation for local, state, and federal FEMA programs. Because equipment and manpower available at the facility are inadequate to meet its needs, the agency depends on other organizations for support. A program in existence within I&C for some 27 years provides research, engineering, and technical support to FEMA for development, production, and maintenance of radiological instruments. Another program, the Electromagnetic Pulse Protection (EMP) Program, began

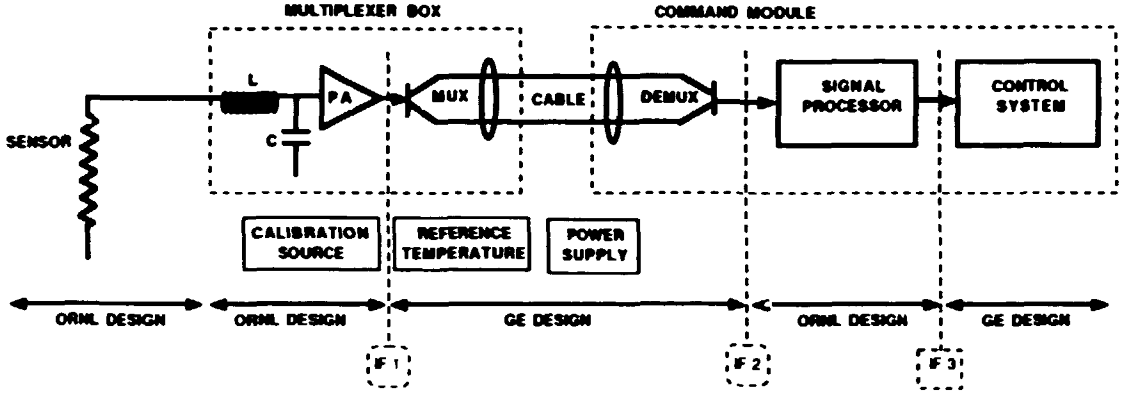


Fig. 3.7-5. Block diagram of the SP-100 diverse temperature measuring system (DTMS).

in 1986 with the goal of providing EMP protection to selected FEMA National Radio System (FNARS) facilities.

3.8.1 RADIATION DETECTOR DEVELOPMENT

The Detector R&D Subsection of the Advanced Measurements Group is responsible for a major portion of radiation detection development for FEMA. FEMA has requested that I&C develop a low-cost gamma dose rate meter for use in shelters.

3.8.1.1 Extended-Range, Low-Cost Dose Rate Meter

This dose meter development provides a radiation detection system that has a useful dynamic range from background to 500 R/h. The intended application is for small, battery-powered personal radiation dose rate meters for use by the public in emergency shelters. Unlike instruments that use complex microcomputers and expensive detection schemes, this instrument uses low-cost, high-quality, off-the-shelf microchip technology. The development is amenable to mass production.

3.8.1.2 Wide-Range Meteor Burst Gamma Monitoring System

A wide-range meteor burst gamma monitoring system (WRMB-1) was developed to continuously track ambient radiation levels through a network of unmanned remote stations. The system consists of (1) a Si PIN diode detector and preamplifier assembly capable of measuring gamma radiation levels from 10^{-4} R/h to 104 R/h and (2) data acquisition and processing hardware responsible for powering the system, processing and storing the data, and controlling transfer of the data to a commercially available communication board that controls the actual link with a master station via meteor burst communications.

3.8.1.3 Detector Design Optimization Program

A fission counter performance simulation program was converted for use on a personal computer to allow for interactive parametric sensitivity studies and design optimization of fission counter performance at very high count rates. The program was rewritten also to model the charge-sensitive preamplifiers used in Si PIN diode radiation detectors, such as the WRMB-1 mentioned above, to allow studies of the relationships between dose rate and air equivalence in PIN diode systems using extended-range counting circuitry. This is a particularly important study since there is no readily available source of monochromatic radiation over the energy range from 80 keV to 3 MeV and over the dose rate range from 0 to 104 R/h.

3.8.1.4 VSVI Dose Rate Meter

A new, very simple, very inexpensive gamma or X-ray meter was conceived and developed. In its simplest form it consists of a sensor (air ion chamber, PIN photodiode, or photoconductor with small CsI crystal), one integrated circuit, a few passive components, and a lithium battery for a total component cost of ~$10. This meter provides an LED output that blinks with a frequency that is an exponential function of the radiation field strength. A patent disclosure has been filed on this development. "Bells and whistles" added to the above item produce a very inexpensive air ion chamber-based instrument that features the blinking LED, an acoustical chirper, and an LCD counter with reset for accurate determination of dose rate. Total component cost with all of these options remains below $50, even in prototype quantities.

3.8.2 ROLLA DOSIMETER R&D FACILITY

This group provides engineering support to the FEMA dosimeter R&D facility at Rolla, North Dakota. A low-cost, molded plastic dosimeter that uses a carbon fiber for the electrometer is being developed for emergency shelter applications. Originally this was an RITF project, and the Rolla facility is continuing the effort using techniques and procedures similar to those needed by industry to produce this device in large quantities.

3.8.2.1 Pilot Production Facility Workstation Development

A workstation was designed and built using an IBM PC XT computer to support FEMA's Rolla Pilot Production Facility. Software, written to work in conjunction with the workstation, leads the operator through a series of measurements on the partially assembled dosimeter. Based on these measurements, the workstation then calculates and instructs the operator to install one of three scale lengths that will give the best accuracy. Based on the selected scale, the program then predicts the dosimeter's accuracy. If this accuracy is within the specified accuracy range, a 20-digit bar code label is printed and attached to the dosimeter. The label can then be scanned at a later date to read all important parameters affecting the dosimeter's accuracy. This process will be of great help in detecting manufacturing and design problems and reducing operator assembly errors, and it may eliminate the need for accuracy tests. Eliminating accuracy tests would save considerable time, eliminate the need for an expensive radiation source, and eliminate administrative costs associated with source licensing film badges.

3.8.2.2 Dosimeter Ionization Chamber Volume Computer Program

A computer program was written that will calculate a dosimeter's ionization chamber volume. The program is useful in evaluating various "what if" conditions. Ionization chambers are sealed at ambient pressure, and their volume must be known. The internal shape of an ionization chamber is such that accurate calculation of its volume using a conventional calculator is tedious and time-consuming.

3.8.2.3 Dosimeter Optics Computer Program

A computer program was written to represent FEMA dosimeter optics. The model, based on thick lens equations for accuracy, is very useful when specifying dimensional tolerances for components that normally affect optical quality—such as lens radii of curvature, thickness, material, and component spacing. The program can be used to make design changes and study "what if" conditions quickly, eliminating time-consuming and error-prone methods associated with traditional hand-held calculators.

3.8.2.4 Dosimeter Chargers

A new type of piezoelectric dosimeter charger was conceived and developed that produces seven different ergonomic variations (see Fig. 3.5-1). The new chargers are functionally equivalent to earlier devices but cost only about 10% as much (a reduction that will save the government at least $700M if the design is selected and the estimated 7 million units are produced and deployed). A patent disclosure has been filed on this development.

3.8.3 ELECTROMAGNETIC PULSE PROTECTION PROGRAM

The purpose of the Electromagnetic Pulse Protection Program is to develop engineering design packages to protect FNARS facilities against the effects of high-altitude electromagnetic pulses. To maintain the FEMA hf radio network as a viable entity subsequent to a nuclear attack on the continental United States, FNARS facilities must be protected against the effects of EMP that are likely to be created in a nuclear attack situation. Two engineering design packages have been developed, one for the FEMA Regional Center in Thomasville, Georgia, and another for the Kentucky State Emergency Operational Center in Frankfort.

Acknowledgments

Participants in the work reported here include several RSS staff members and two members of the Research Instruments Section.

3.9 ACOUSTIC INSTRUMENTATION RESEARCH AND DEVELOPMENT PROGRAM

W. H. Sides, Jr.

Oak Ridge National Laboratory is providing assistance to the David W. Taylor Research Center, formerly the David W. Taylor Naval Ship Research and Development Center, under an interagency agreement. DTRC is the U.S. Navy's principal research, development, test, and evaluation center for naval vehicles. DTRC's main laboratories are at Carderock and Annapolis, Maryland.

Two areas of primary interest to DTRC are ship and submarine silencing and structural methods to design and test high-strength hulls and components. ORNL provides assistance to DTRC in design and development of R&D instrumentation systems and test facilities for these key areas. A principal R&D method for DTRC is use of experimental models of proposed submarine designs, including models of components and complete submarines. Most models are built to large scale and are highly instrumented with onboard computer-based data acquisition systems and other instrumentation.

Energy Systems provides assistance to DTRC under a subprogram within the ORNL Space and Defense Technology (SDT) Program. That subprogram is the Acoustic Instrumentation Research and Development Program. Currently, the AIRD Program Manager also is the Associate Director of SDT. Any Energy Systems organization may be called upon to provide expertise and facilities in support of DTRC. Current AIRD projects are being performed by ORNL, Central Engineering, the ORGDP Fabrication and Plant Services Division, and the Y-12 Fabrication and Product Engineering divisions.

Two I&C Division projects for AIRD–development of two data acquisition systems–have been completed. Four other projects are in progress: noise analysis methods development, wake flow measurement, and two large data acquisition systems. These projects are being performed by three I&C Reactor Systems Section groups–Special Assignments, Process Instrument Development, and Surveillance and Diagnostic Methods–and by the MACES Real-Time Computer Systems Group.

3.10 PUBLICATIONS AND PRESENTATIONS

D. C. Agouridis, "New Solution of the Problem of EMP Coupling on Cables Over Ground of Finite Conductivity," *IEEE Trans. Nucl. Sci.* NS-33(6), 1686 (1986).

D. C. Agouridis, *Excitation of Transmission Lines by Distributed Sources*, ORNL/TM-10376, May 1987.

D. C. Agouridis, "EMP Coupling to Shielded Cables," 24th Annual Conference on Nuclear and Space Radiation in Electronics, Snowmass Village, Colo., July 28-31, 1987.

D. C. Agouridis, "Thermal Noise of Linear Passive Multiports," Proc. 9th International Conference on Noise in Physical Systems, University of Montreal, May 25-29, 1987; *Proceedings*, 554 (1987).

D. C. Agouridis, "Thermal Noise of Transmission Lines: A Generalized Solution," *1987 IEEE Trans. Instrum. Meas.* **1M-36**(1), 132 (March 1987).

D. C. Agouridis, "EMP Simulators and Public Safety: An Analysis," 1988 IEEE Conference on Nuclear and Space Radiation Effects, Portland, Oreg., July 11-15, 1988.

D. C. Agouridis, "EM Coupling on Shielded Cables Revisited," Sixth Biennial Conference, 1988 Nuclear EMP Meeting, Menlo Park, Calif., May 16-20, 1988, to be published in *App. Comput. Electromagn. Soc. J. Newsl.*

D. C. Agouridis and C. E. Easterly, "EMP Simulators and Public Safety: An Analysis," The Bioelectromagnetic Society 10th Annual Meeting, Stamford, Conn., June 1988; also submitted to *Bioelectromag.*

J. L. Anderson, R. L. Anderson, E. W. Hagen, T. C. Morelock, T. L. Huang, and L. E. Phillips, "Post Implementation Review of Inadequate Core Cooling Instrumentation," IEEE 1988 Nuclear Science Symposium, Orlando, Fla., November 9-11, 1988; proceedings to be published.

J. M. Bailey, B. R. Upadhyaya, and R. E. Battle, *Optimum Control Techniques for Nuclear Power Plants*, ORNL/TM-10372, October 1987.

S. J. Ball, "Control of Two-Phase Evaporation Flows," in *Measurement and Control in Water Desalination*, N. Lior, ed., Elsevier Science Publishers, Amsterdam, October 1986.

S. J. Ball, "Advanced Control Test Operation (ACTO) Facility," 1987 Eastern Simulation Conference, Orlando, Fla., April 6-9, 1987; *Tools for the Simulation Profession*, Robert Hawkins and Keith Klukis, eds., SCS Society for Computer Simulation, 117-120 (1987).

S. J. Ball, R. E. Battle, E. W. Hagen, J-P. Renier, O. L. Smith, R. S. Stone, L. L. Joyner, and A. F. McBride, *An Assessment of the Safety Implications of Control of the Calvert Cliffs-1 Nuclear Plant*, vol. 2, NRC Report NUREG/CR-4265, ORNL/TM-9640, July 1986.

R. E. Battle and G. K. Corbett, "Remote Control System for a 2-MW Research Reactor," IEEE Industry Applications Society, 23rd Annual Meeting, Pittsburgh, Pa., October 2-6, 1988, proceedings to be published.

R. E. Battle and G. K. Corbett, "Digital, Remote Control System for a 2-MW Research Reactor," IEEE Nuclear Science Symposium, Orlando, Fla., November 9-11, 1988; proceedings to be published.

R. C. Berkan, W. C. Jordan, R. L. Macklin, C. March-Leuba, A. W. Renshaw, and D. Ugolini, "Preliminary Design Concept for Axial Xenon Oscillation Modeling and Control," Student Design Entry, American Nuclear Society 1986 Design Competition, The University of Tennessee, Knoxville.

R. C. Berkan and B. R. Upadhyaya, "Dynamic Modeling of the EBR-II for Simulation and Control," *Trans. Am. Nucl. Soc.* 54, 253-55 (June 1987); also UTNE/BRU88-1, August 1988.

R. C. Berkan, B. R. Upadhyaya, and R. A. Kisner, "Control Strategy Developments Applied to the EBR-II Steam Generator System," Am. Nucl. Soc. 1988 Annual Meeting, San Diego, California, June 12-16, 1988; *Trans. Am. Nucl. Soc.* 56, 381-82 (1988).

E. D. Blakeman and J. March-Leuba, "Stability of Subcritical Modes in Boiling Water Reactors," *Trans. Am. Nucl. Soc.* 56, 565-67 (1988).

C. R. Brittain, P. J. Otaduy, L. A. Rovere, and R. B. Perez, "A New Approach to Hierarchical Decomposition of Large Scale Systems," 3rd IEEE International Symposium on Intelligent Control. Arlington, Va., August 22-24, 1988.

M. E. Buchanan and N. E. Clapp, Jr., "Technology of Agroacoustic Data Collection, Analysis and Interpretation," Agroacoustics Symposium, Jackson, Miss., April 26-27, 1988.

M. E. Buchanan and H. T. Kerr, "Acoustical Techniques in Beekeeping," Cherokee Audubon Society, Etowah, Tenn., September 15, 1987.

M. E. Buchanan, H. T. Kerr, and K. H. Valentine, "Advanced Acoustical Techniques in Beekeeping," Advanced Technology Session, 1st Annual Meeting, Beekeepers of Tennessee Association, Knoxville, Tenn., May 13-14, 1988.

D. G. Cacuci, R. B. Perez, and J. March-Leuba, "Limit Cycles and Bifurcations in Nuclear Systems, *Trans. Am. Nucl. Soc.* 53, 239 (1986).

M. M. Chiles, J. T. Mihalczo, and E. D. Blakeman, "High-Efficiency Scintillation Detector for Thermal and High-Energy Neutrons and Gamma Radiation," IEEE Nuclear Science Symposium, San Francisco, Calif., October 21-23, 1987; *IEEE Trans. Nucl. Sci.* 35(1), 110-11 (February 1988).

N. E. Clapp, Jr., "Discussion of Noise Analysis Techniques," presented at Department of Electrical Engineering, Tennessee Technological University, Cookeville, Tenn., October 13, 1987.

N. E. Clapp, Jr., "Data Acquisition and Signal Analysis," USDA/ORNL Meeting on Potential Collaboration BARC-East, Beltsville, Md., September 28, 1988.

N. E. Clapp, Jr., and B. Damiano, "Computer Simulation of a Motor Pump Unit to Aid in Interpreting Vibration Data," IEEE Conference and Exhibit, Southeastcon '88, Knoxville, Tenn., April 10-13, 1988; *Proceedings*, 244-47 (1988).

N. E. Clapp, Jr., A. W. Renshaw, and C. E. Snyder, "A Menu-Driven Knowledge Retrieval System Accessing ASCII Data," Conference on User-Oriented Content-Based Text and Image Handling, Massachusetts Institute of Technology, Cambridge, Mass., March 21-24, 1988, *Proc. 1988 Recherche d'Informations Assistes par Ordinateuer.*

B. Damiano and J. A. Thie, "Noise Data Management Using Commercially Available Data Base Software," American Nuclear Society/European Nuclear Society 1988 International Conference, Washington, D.C., October 3-November 3, 1988.

J. B. Davidson, "Electronic Vision: Applications in Physics, Chemistry, and Biology," ORNL Summer Seminar Series, August 18, 1987.

D. D. Fa[illegible]r, "Micro-Transmitter for Tracking Honeybees," 1st Annual Meeting, Beekeepers of Tennessee Association, Oak Ridge, Tenn., May 13-14, 1988.

Z. Frei and B. R. Upadhyaya, *Empirical Modeling of Steady-State Behavior of Linear and Nonlinear Systems with Application to Signal Validation*, DOE/NE/37459-11, August 1987.

D. N. Fry, *Summary of the Fourth Conference on United States Utility Experience in Reactor Noise Analysis, Hartford, Conn., May 12-14, 1987.*

D. N. Fry, "Summary of the Fourth Conference on United States Utility Experience in Reactor Noise Analysis," SMORN-V, Munich, October 12-16, 1987; *Prog. Nucl. Energy*, Pergamon Press, 1988.

D. N. Fry, F. J. Sweeney, and B. Damiano, "Degradation Monitoring of Reactor Internals," NPAR Program Managers' Technical Review Meeting, Oak Ridge, Tenn., February 25-26, 1987.

O. Glockler and B. R. Upadhyaya, "Reactor Noise Diagnostics Based on Multivariate Autoregressive Modeling," 4th Conference on Utility Experience in Reactor Noise Analysis, Rocky Hill, Conn., May 1987.

O. Glockler and B. R. Upadhyaya, "Application of Multivariate Signal Analysis Algorithms to Reactor Diagnostics," *Trans. Am. Nucl. Soc.*, 54, 364-65 (June 1987).

O. Glockler, B. R. Upadhyaya, and T. W. Kerlin, *Signal Validation Algorithms for Consistency Checking and Sequential Probability Ratio Testing of Redundant Measurements*, DOE/NE/37459-6, July 1987.

O. Glockler, V. M. Morgenstern, and B. R. Upadhyaya, "Signal Validation Using Simultaneous Consistency Checking of Multivariate Measurements," *Trans. Am. Nucl. Soc.* (October/November 1988).

O. Glockler, G. Por, J. Valko, and B. R. Upadhyaya, "Monitoring and Diagnostics of Pressurized Water Reactor Power Plants Using Process Instrumentation," IMEKO XI Conference, Houston, Tex., October 1988.

J. M. Googe, R. A. Hess, P. D. Ewing, and D. C. Agouridis, *Task 2: Examination of Specifications and Standards Relating to the Susceptibility of Medical Electronic Devices to Transient Electrical Overstress*, ORNL/TM-10769, April 1988.

R. M. Harrington, "Containment Venting as a Mitigation Technique for BWR MARK I Plant ATWS," U.S. Nuclear Regulatory Commission 14th Water Reactor Safety Research Information Meeting, Gaithersburg, Md., October 27-31, 1986; *Proceedings*. pp. 7-3 through 7-5, NUREG/CP-0081, October 1986; also *Nucl. Eng. Design* 108, 55-69 (1988).

R. M. Harrington and C. A. Flanagan, *Advanced Neutron Source (ANS) Regulatory Requirements and Safety-Related Considerations: August 1988 (Draft)*, ORNL/TM-10949.

H. M. Hashemian, J. A. Thie, and B. R. Upadhyaya, "Reactor Sensor Surveillance Using Noise Analysis," *Proceedings, Topical Meeting on Reactor Physics and Safety* 2, 1074-87 (1986), NUREG/CP-0080.

H. M. Hashemian, J. A. Thie, B. R. Upadhyaya, and K. E. Holbert, "Sensor Response Time Monitoring Using Noise Analysis," SMORN-V, Munich; *Prog. Nucl. Energy*, Pergamon Press, 1988; also *Overview of SMORN-V*, Munich, 1988.

H. M. Hashemian, J. A. Thie, and B. R. Upadhyaya, "Reactor Sensor Surveillance Using Noise Analysis," *Nucl. Sci. Eng.* 98, 96-102 (1988).

R. A. Jenkins and T. M. Gayle, "Human Smoking Dosimeter for Behavioral Studies," Interagency Forum on Smoking and Health, Washington, D.C., March 10, 1987.

E. J. Kennedy and T. N. Blalock, Development of a Radiation Hardened 600 Watt Switchmode Power Converter, TR-EE/EL-20, The University of Tennessee, Knoxville, August 1988.

T. W. Kerlin, B. R. Upadhyaya, et al., "A Parallel-Signal-Processing Approach to Signal Validation," *Trans. Am. Nucl. Soc.* 55, 430-31 (1987).

M. K. Kopp, K. H. Valentine, J. A. Williams, and R. H. Bamberger, "New Method of Gamma Dose-Rate Measurement Using Energy-Sensitive Counters," IEEE 1986 Nuclear Science Symposium, Washington, D.C., October 29-31, 1986; *IEEE Trans. Nucl. Sci.* NF34(1), 616-18 (February 1987).

R. C. Kryter, "Assessment of Nonintrusive Methods for Monitoring the Operational Readiness of Solenoid-Operated Valves," 16th Water Reactor Safety Information Meeting, National Institute of Standards and Technology, Gaithersburg, Md., October 24-27, 1988.

R. C. Kryter and H. D. Haynes, "Motor Current Signature Analysis for Determining Operational Readiness of Motor-Operated Valves (MOVs)," 4th Conference on Utility Experience in Reactor Noise Analysis, Hartford, Conn., May 12-14, 1987.

R. C. Kryter, L. E. Klobe, and S. P. Hendrix, compilers, *An Overview of SMORN V--Munich, 5th Symposium on Reactor Noise, October 12-16, 1987*, O.C.D.E. Nuclear Energy Agency, Paris, March 11, 1988.

R. L. Macklin, R. B. Perez, G. De Saussure, and R. W. Ingle, "High Resolution Measurement of the 238U Neutron Capture Yield for Incident Neutron Energies Between 1 and 100 keV," *Trans. Am. Nucl. Soc.* 54 (1987).

C. March-Leuba and J. March-Leuba, "Separation of Spatial Effects in Frequency-Domain Subcriticality Measurements," *Ann Nucl. Energy* 15(7), 347-56 (1988).

C. March-Leuba, J. March-Leuba, and F. C. Difilippo, "Interpretation of Subcriticality Measurements with Strong Spatial Effects," *Trans. Am. Nucl. Soc.* 54 (1987).

C. March-Leuba, J. March-Leuba, and R. B. Perez, "Optimal Filtering, Parameter Tracking and Control of Nonlinear Nuclear Reactors," 1988 International Reactor Physics Conference, Jackson Hole, Wyo., September 18-21, 1988.

J. March-Leuba, *Review of Dresden 3 Single Loop Operation Stability Tests*, ORNL/NRC/LTR-87/04, April 1987.

J. March-Leuba, *NRC Software Submittal Package: RTSTAB and OFTSTAB*, ORNL/NRC/LTR-87/05, July 1987.

J. March-Leuba, *Stability Calculations for the Grand Gulf-1 and Susquehanna-2 Boiling Water Reactors*, ORNL/NRC/LTR-87/08, September 1987.

J. March-Leuba, "ARSISO: A Linear Approximation of an ARMA Model," IEEE International Conference on Acoustics, Speech and Signal Processing, New York, April 11-14, 1988.

J. March-Leuba, "Nonlinear Dynamics and Chaos in Boiling Water Reactors," NATO Advanced Workshop on Nonlinear and Stochastic Phenomena in Nuclear Systems Conference, Valencia, Spain, May 22-27, 1988; *Proceedings*.

J. March-Leuba and E. D. Blakeman, "A Study of Out-of-Phase Power Instabilities in Boiling Water Reactors," 1988 International Reactor Physics Conference, Jackson Hole, Wyo., September 18-21, 1988.

J. March-Leuba and D. N. Fry, *Grand Gulf-1 and Susquehanna-2 Stability Tests*, ORNL/NRC/LTR-87/01, April 1987.

J. March-Leuba and D. N. Fry, "Stability Tests in the Grand Gulf Unit 1 Boiling Water Reactor," *Trans. Am. Nucl. Soc.* 55, 603-04 (1987).

J. March-Leuba and W. T. King, "Development of a Real-Time Stability Measurement System for Boiling Water Reactors," *Trans. Am. Nucl. Soc.* 54, 670-71 (1987).

J. March-Leuba and W. T. King, "A Real-Time BWR Stability Measurement System," 5th Specialists' Meeting on Reactor Noise, Munich, October 12-16, 1987; *Prog. Nucl. Energy*, Pergamon Press, 1988.

J. March-Leuba and C. March-Leuba, "A Transient Reactivity Monitor Based on Optimal Control Theory," IEEE Nuclear Science Symposium, Orlando, Fla., November 9-11, 1988.

G. Mathai and B. R. Upadhyaya, "Data Classification and Prediction for Fault Monitoring and Diagnostics," U.T. Measurement and Control Engineering Center Report, MCEC/NE/BRU87-2, September 1987.

J. T. Mihalczo, "Evaluation of the ^{252}Cf-Source-Driven Neutron Noise Analysis Method for Measurement of LWR Fuel Storage Casks," *Trans. Am. Nucl. Soc.* 55, 402 (1987).

J. T. Mihalczo, "Development of Portable Subcriticality Measurement System for Spent Fuels Shipping and Storage Casks," Burnup Credit Workshop, Washington, D.C., February 23-24, 1988.

J. T. Mihalczo, "The ^{252}Cf Noise Analysis Method for In-Plant Criticality Safety," *Trans. Am. Nucl. Soc.* 56, 334 (1988).

J. T. Mihalczo, E. D. Blakeman, and G. E. Ragan, "Cf-Source-Driven Neutron Noise Measurements for Three Interacting Tanks of Uranyl Nitrate Solution," *Trans. Am. Nucl. Soc.* 54, 208 (1987).

J. T. Mihalczo, E. D. Blakeman, and G. E. Ragan, "Subcritical Interaction Experiments with Four Safe Storage Bottles Containing Aqueous Uranyl Nitrate," International Seminar on Nuclear Criticality Safety, Tokyo, October 17-23, 1987, *Proceedings*, 410 (1987).

J. T. Mihalczo, E. D. Blakeman, and G. E. Ragan, "^{252}Cf-Source-Driven Noise Analysis Measurements for Six Interacting Safe Bottles of Aqueous Uranyl Nitrate," American Nuclear Society, Washington, D.C., October 30-November 3, 1988.

J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, and E. B. Johnson, "Dynamic Subcriticality Measurements Using the Cf Neutron Noise Method," Knolls Atomic Power Laboratory, Schenectady, N.Y., September 16, 1986; also Seminar at Nagoya University, Japan, October 26, 1987.

J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, E. B. Johnson, and H. Seino, "Dynamic Subcriticality Measurements Using the ^{252}Cf-Source-Driven Neutron Noise Method," *Trans. Am. Nucl. Soc.* 54, 207 (1987).

J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, R. C. Kryter, R. C. Robinson, H. Seino, T. Matsumoto, and H. Yamana, "^{252}Cf-Source-Driven Neutron Noise Measurements of Subcriticality for a Slab Tank Containing Aqueous Pu-U Nitrate," International Seminar on Nuclear Criticality Safety, Tokyo, October 17-23, 1987; *Proceedings*, 401 (1987).

J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, R. C. Kryter, and H. Seino, ^{252}Cf-Source-Driven Neutron Noise Measurements of Subcriticality for an Annular Tank of Aqueous Pu-U Nitrate Solution," *Trans. Am. Nucl. Soc.* 55, 387 (1987).

J. T. Mihalczo, W. T. King, and E. D. Blakeman, "Subcriticality Measurements for Coupled Uranium Metal Cylinders Using the ^{252}Cf-Source-Driven Neutron Noise Analysis Method," *Nucl. Sci. Eng.* 95, 11-13 (1987).

J. T. Mihalczo, E. D. Blakeman, W. T. King, and R. C. Kryter, *Performance Evaluation of a Measurement System for the ^{252}Cf-Source Driven Neutron Noise Analysis Determination of Subcriticality*, ORNL/TM-10145, February 1988.

J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, R. C. Kryter, H. Seino, and R. C. Robinson, *^{252}Cf-Source-Driven Neutron Noise Measurements of Subcriticality for a Slab Tank of Aqueous Pu-U Nitrate*, ORNL/TM-10139, March 1988.

J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, R. C. Kryter, H. Seino, and R. C. Robinson, *^{252}Cf-Source-Driven Neutron Noise Measurements of Subcriticality for an Annular Tank Containing Aqueous Pu-U Nitrate*, ORNL/TM-10138, August 1988.

J. T. Mihalczo and G. T. Ragan, "A Portable Measurement System for Subcriticality Measurements by the Cf-Source-Driven Neutron Noise Analysis Method," *Proc. IEEE 1987 Nuclear Science Symposium, San Francisco, California, October 21-23, 1987.*

J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, and E. B. Johnson, *Dynamic Subcriticality Measurements Using the ^{252}Cf-Source-Driven Noise Analysis Method*, ORNL/TM-10122, June 1988.

J. T. Mihalczo and E. D. Blakeman, "A Study of Out-of-Phase Power Instabilities in Boiling Water Reactors," 1988 International Reactor Physics Conference, Jackson Hole, Wyo., September 18-21, 1988.

J. W. Minrick, J. D. Harris, P. N. Austin, J. W. Cletcher, and E. W. Hagen, *Precursors to Potential Severe Core Damage Accidents: 1985; A Status Report*, NUREG/CR-4674 (ORNL/NOAC-232), vols. 1 and 2, December 1986.

J. W. Minrick, J. D. Harris, P. N. Austin, J. W. Cletcher, and E. W. Hagen, *Precursors to Potential Severe Core Damage Accidents: 1984; A Status Report*, NUREG/CR-4674 (ORNL/NOAC-232), vols. 3 and 4, May 1987.

J. A. Mullens, "ESTATE: An Expert Nuclear Plant Status Monitor and Display," Society for Computer Oriented Simulation MultiConference, San Diego, Calif., February 3-5, 1988.

L. C. Oakes, "Oak Ridge National Laboratory," *Nucl. Plasma Sci. Newsl.* 3, 12-15 (September 1987).

L. C. Oakes and R. L. Shepard, "Johnson Noise Thermometer for High-Radiation and High-Temperature Environments," 5th Symposium on Space Nuclear Power Systems, Albuquerque, N. M., January 11-14, 1988; *Trans. Symp. Space Nucl. Power Sys.*, CONF-880122-Summaries, 515-19 (1988).

P. J. Otaduy, "Promises in Intelligent Plant Control Systems," ANS Topical Meeting on Artificial Intelligence in the Nuclear Industry, Snowbird, Utah, August 30-September 2, 1987; to be published in *Artificial Intelligence and Innovative Computer Applications in the Nuclear Industry*, Plenum Press.

E. E. Purvis, III, J. Marchaterre, B. W. Spencer, J. F. Carew, J. G. Guppy, G. J. Van Tuyle, S. J. Ball, R. M. Harrington, L. C. Oakes, L. R. Dodd, and J. P. McNeece, *Report of the U.S. Department of Energy's Team Analyses of the Chernobyl-4 Atomic Energy Station Accident Sequence*, DOE/NE-0076, November 1986.

A. L. Qualls, R. E. Uhrig, and B. R. Upadhyaya, "Development of an Expert System for Signal Validation," DOE/NE/37959-17, July 1988; also *Trans. Am. Nucl. Soc.* (October/November 1988).

J-P. A. Renier and O. L. Smith, *A RETRAN Model of the Calvert Cliffs-1 Pressurized Water Reactor for Assessing the Safety Implications of Control Systems*, NUREG/CR-4758, ORNL/TM-10236, March 1987.

A. W. Renshaw, "Soviet Designed Pressurized Water Reactors," American Nuclear Society North/North Central Regional Student Conference, University of Maryland, College Park, March 18-19, 1988.

A. W. Renshaw, R. G. Upton, and J. A. McEvers, *A Methodology for Software Development for Real-Time Process Control as Applied to Automated Evaporator Startup*, ORNL/TM-9618, July 1988.

M. J. Roberts, "Cable Parameter Estimation Based on Impedance Measurements at One End," *Rev. Sci. Instrum.* 58(4), 681-86 (April 1987).

M. J. Roberts, "Comparison Between 2-Wire and 3-Wire Models for Shielded, Twisted-Pair Cables Used in Johnson Noise Thermometry," *Rev. Sci. Instrum.* 59, 298-303 (February 1988).

J. T. Robinson, D. Ebeling-Koning, and N. E. Todreas, "Void Distribution in Bubbly Flow Through Yawed Rod Arrays, *Int. J. Multiphase Flow* (in press).

J. T. Robinson and R. A. Kisner, "An Intelligent Dynamic Simulation Environment: An Object-Oriented Approach," *Third International Symposium on Intelligent Control*, Arlington, Va., August 24-26, 1988.

J. T. Robinson and P. J. Otaduy, "An Expert System for Alarm Diagnosis and Filtering," ANS Topical Meeting, Snowbird, Utah, August 31-September 2, 1987; *Artificial Intelligence and Other Innovative Computer Applications in the Nuclear Industry*, D. Majumdar, ed., 127-134, Plenum Press, New York.

J. T. Robinson and P. J. Otaduy, "An Object-Oriented Programming Package for Power Plants," Society for Computer Oriented Simulation Multiconference, San Diego, Calif., February 2-5, 1988; in *Artificial Intelligence and Simulation: The Diversity of Applications*, Troy Henson, ed., 55-58 (1988).

J. T. Robinson and P. J. Otaduy, "An Application of Object-Oriented Programming to Process Simulation," Symposium on Demonstrations of Artificial Intelligence in Chemical Engineering, National Meeting of the American Institute of Chemical Engineers, Denver, Colo., August 22-25, 1988.

L. A. Rovere, P. J. Otaduy, C. R. Brittain, and R. B. Perez, "Hierarchical Control of a Nuclear Reactor Using Uncertain Dynamics Techniques, 3rd IEEE International Symposium on Intelligent Control, Arlington, Va., August 22-24, 1988.

D. L. Selby, R. M. Harrington, F. J. Peretz et al., *ORNL Contributions to the Advanced Neutron Source (ANS) Project for October 1986-March 1987*, ORNL/TM-10579, November 1987.

D. J. Shieh and B. R. Upadhyaya, "Stochastic Estimation Approach for the Evaluation of Thermal-Hydraulic Parameters in Pressurized Water Reactors, *Nucl. Tech.* **73**, 19-29 (April 1986).

D. J. Shieh and B. R. Upadhyaya, "Application of the Extended Kalman Filtering for the Estimation of Core Coolant Flow Rate in Pressurized Water Reactors," 6th Power Plant Dynamics, Control and Testing Symposium, Knoxville; *Proceedings*, 1, 28.01-28.14 (1986).

D. J. Shieh, B. R. Upadhyaya, and F. J. Sweeney, "Application of Noise Analysis Technique for Monitoring the Moderator Temperature Coefficient of Reactivity in Pressurized Water Reactors," *Nucl. Sci. Eng.* **95**(1), 14-21 (1987).

R. L. Shepard, "Gee Whiz–Another ASTM Standard," Guest Editorial, *ASTM Stand. News* **16**(5), 4-5 (May 1988).

R. L. Shepard, T. V. Blalock, M. J. Roberts, and J. A. Harter, *In Situ Calibration of Resistance Temperature Detectors in Nuclear Plants Using Johnson Noise Thermometry*, EPRI NP-5537, February 1987.

C. M. Smith and R. C. Gonzalez, *Automated Long-Term Surveillance of a Commercial Nuclear Plant*, NUREG/CR-4577, ORNL/TM-10015, September 1987.

C. M. Smith and R. C. Gonzalez, "Automated Long-Term Surveillance of a Commercial Nuclear Power Plant," *IEEE Trans. Nucl. Sci.* **35**(1), 966-81 (February 1988).

O. L. Smith, *Dynamic Behavior and Control Requirements of an Atmospheric Fluidized-Bed Coal Combustion Power Plant: A Conceptual Study*, ORNL/TM-9821, June 1987.

O. L. Smith, "The Safety Implications of Control Systems Program at ORNL," Topical Meeting on Anticipated and Abnormal Transients in Nuclear Power Plants, April 12-15, 1987, Atlanta; *Proceedings*, 1, II-11 through II-18 (June 1987).

O. L. Smith, "Methodology for Coupling the Air and Ground Modules in the State-of-the-Art Contingency Analysis Code," Operations Research Society of America and The Institute of Management Science National Meeting, St. Louis, October 25-28, 1987.

R. S. Stone, A. F. McBride, and E. W. Hagen, *Generic Extensions of the Plant-Specific Findings of the Safety Implications of Control Systems (SICS) ORNL Program*, ORNL/NRC/LTR-86/19, March 1987.

F. J. Sweeney, *Utility Guideline for Reactor Noise Analysis*, EPRI NP-4970, February 1987.

F. J. Sweeney and D. N. Fry, "Thermal Shield Support Degradation in Pressurized Water Reactors," 1986 ASME PVP Conference, Symposium on Special Topics of Structural Vibration, Chicago, Ill., July 20-24, 1986; *1986 Am. Soc. Mech. Eng. PVP* **104**, 59-66 (1986).

R. E. Uhrig, "Artificial Intelligence and Training of Nuclear Reactor Personnel," International OECD-CSNI Specialist Meeting on Training of Nuclear Reactor Personnel, Orlando, Fla., April 21-24, 1987; *Proceedings*, NUREG/CP-0089, CSNI Report No. 138, 225-37, 1987.

R. E. Uhrig, Panel Discussion, Annual Meeting of Operations Research Society of America, New Orleans, La., May 4-6, 1987.

R. E. Uhrig, EPRI Seminar "Expert Systems Applications in Power Plants," Panel Discussion, Boston, May 27-29, 1987.

R. E. Uhrig, "Use of Expert Systems in Nuclear Power Plants," 1987 Summer National Meeting of the American Institute of Chemical Engineers, Minneapolis, Minn., August 16-19, 1987.

R. E. Uhrig, "Applications of Artificial Intelligence in the U.S. Nuclear Industry," ANS Topical Meeting on Artificial Intelligence and Other Innovative Computer Applications in the Nuclear Industry, Snowbird, Utah, August 31-September 2, 1987; *Proceedings*, 11-19, Plenum Press (1988).

R. E. Uhrig, "Artificial Intelligence and Computer Programming," Workshop of the Computer Programmers Group of the Environmental Division of TVA, Gatlinburg, Tenn., September 11, 1987.

R. E. Uhrig, "Opportunities for Automation and Control of the Next Generation of Nuclear Power Plants," National Science Foundation Workshop on Research Needs of the Next Generation Nuclear Power Technology, Idaho Falls, Idaho, October 5-7, 1987.

R. E. Uhrig, "Use of Probabilistic Risk Assessment in Expert System Usage for Nuclear Power Plant Safety," IEEE Symposium on Nuclear Power Systems, San Francisco, California, October 21-23, 1987; *Proceedings*.

R. E. Uhrig, "Use of Artificial Intelligence to Enhance the Safety of Nuclear Power Plants," 16th Water Reactor Safety Information Meeting, National Institute of Standards and Technology, Gaithersburg, Md., October 24-27, 1988.

R. E. Uhrig, "NRC Study of NASA's Review of the Space Shuttle Risk and Hazards," 1987 Annual Meeting of the Society for Risk Analysis, Houston, Tex., November 2-3, 1987.

R. E. Uhrig, "Use of Probabilistic Risk Assessment (PRA) in Expert Systems to Advise Nuclear Plant Operators and Managers," Conference on Application of Artificial Intelligence, Orlando, Fla., April 4-6, 1988; *Appl. Artif. Intelligence VI*, SPIE 937, 210-15 (1988).

R. E. Uhrig, "Nuclear Utilities Put Artificial Intelligence to Work," *Power Mag.*, June 1988.

R. E. Uhrig, "Artificial Intelligence and Expert Systems," DOE/ANL Training Course on the Potential Safety Impact of New and Emerging Technologies on the Operation of DOE Nuclear Facilities, Idaho Falls, Idaho, August 29-September 1, 1988.

R. E. Uhrig, "Neural Networks and Neural Computing," DOE/ANL Training Course on "The Potential Safety Impact of New and Emerging Technologies on the Operation of DOE Nuclear Facilities," Idaho Falls, Idaho, August 29-September 1, 1988.

B. R. Upadhyaya, "Sensor Fault Monitoring and Process Diagnostics," American Physical Society, New Orleans, La., March 1988; *Bull. Am. Phys. Soc.* 33(3), 462 (1988).

B. R. Upadhyaya, "Combined Dynamic Data Analysis and Process Variable Prediction Approach for System Fault Detection," IEEE International Conference on Acoustics, Speech and Signal Processing, Dallas, Tex., April 1987.

B. R. Upadhyaya et al., "Signal Validation in Nuclear Power Plants," DOE/NE/37959-1, May 1987.

B. R. Upadhyaya et al., "Development of an Integrated Signal Validation System in Nuclear Power Plants," DOE/NE/37459-12, September 1987.

B. R. Upadhyaya et al., "An Integrated Approach for Signal Validation in Nuclear Power Plants," ANS Topical Meeting on Artificial Intelligence and Other Innovative Computer Applications in the Nuclear Industry, Snowbird, Utah, August 31-September 2, 1987; *Proceedings*, 167-174 (1988).

B. R. Upadhyaya et al., "An Integrated Architecture for Signal Validation in Nuclear Power Plant," *Proc. 3rd IEEE International Symposium on Intelligent Control*, Arlington, Va., August 1988.

B. R. Upadhyaya et al., "Development and Testing of an Integrated Signal Validation System for Nuclear Power Plants," DOE/NE/37959-24, September 1988.

B. R. Upadhyaya and R. C. Berkan, "Dynamic Modeling of the EBR-II for Simulation and Control," UTNE-BRU-86-02, November 1986.

B. R. Upadhyaya, R. C. Caglar, and O. Glockler, "Results of Alcoa Hot Line Facility Data Analysis," Measurement and Control Engineering Center Report no. MCEC/NE/BRU87-3, September 1987.

B. R. Upadhyaya and K. E. Holbert, "Computation of Data-Driven Models with Application to Power Plant Signal Validation," 1988 ANS/ENS International Conference, Washington, D.C., October 1988.

B. R. Upadhyaya, G. Mathai, and J. D. Green, "Data Clustering and Prediction for Fault Detection and Diagnostics," American Control Conference, Atlanta, June 1988.

B. R. Upadhyaya, D. J. Shieh, F. J. Sweeney, and O. Glockler, "Analysis of In-Core Dynamics in Pressurized Water Reactors with Application to Parameter Monitoring," SMORN-V, 5th Symposium on Reactor Noise, Munich, West Germany, October 12-16, 1987; *Prog. Nucl. Energy*, Pergamon Press, 1988.

B. R. Upadhyaya, F. P. Wolvaardt, and O. Glockler, "An Integrated Approach for Signal Validation in Dynamic Systems," SMORN-V, 5th Symposium on Reactor Noise, Munich, Germany, October 12-16, 1987; *Prog. Nucl. Energy*, Pergamon Press, 1988.

B. R. Upadhyaya, F. P. Wolvaardt, and O. Glockler, "An Integrated Approach for Sensor Failure Detection in Dynamic Processes," U.T. Measurement and Control Engineering Center Report No. NE-MCEC-BRU-87-01, March 1987.

B. R. Upadhyaya, F. P. Wolvaardt, and O. Glockler, "An Integrated Approach for Signal Validation in Process Control," IMEKO XI Conference, Houston, Tex., October 1988.

K. H. Valentine, K. G. Falter, R. L. Shepard, and W. B. Reese, "Development of a 10-Decade Single-Mode Reactor Flux Monitoring System," Specialists' Meeting on Instrumentation and Reactor Core Assessment, Cadarache, France, June 7-10, 1988.

K. H. Valentine, M. K. Kopp, J. A. Williams, and D. D. Falter, "The Approach to Air-Equivalent Dose-Rate Measurements Using Silicon Pin Diode Radiation Detectors," DOD RADIAC Working Group Meeting, Naval Ocean Systems Center, San Diego, Calif., January 21-22, 1987.

K. H. Valentine, M. K. Kopp, and J. A. Williams, "Feedback Threshold Control Extends Pulse Rate Measurements into the Pileup Region," *IEEE Trans. Nucl. Sci.* **NF 34**(1), 78-81 (February 1987).

K. H. Valentine, J. A. Williams, R. L. Shepard, D. D. Falter, and C. A. Hahs, "Development of a High-Temperature High-Sensitivity Fission Counter for Liquid Metal Reactor In-Vessel Flux Monitoring," Specialists' Meeting on Instrumentation and Reactor Core Assessment, Cadarache, France, June 7-10, 1988.

J. D. White, *Advanced Controls Program Plan for Advanced Reactors: FY 1988-1992*, DOE/OR-894, August 1988.

J. D. White and D. B. Trauger, "ORNL R&D on Advanced Small and Medium Power Reactors: Selected Topics," 16th Water Reactor Safety Information Meeting, National Institute of Standards and Technology, Gaithersburg, Md., October 24-27, 1988.

T. L. Wilson, Jr., D. H. Cook, and A. Sozer, "Small Break LOCA Analysis of the ORNL High Flux Isotope Reactor," EPRI Conference on Power Plant Simulators and Modeling, Charlotte, N.C., June 15-17, 1988.

4. TELEROBOTIC SYSTEMS

OVERVIEW

W. R. Hamel

The Telerobotic Systems Section (TSS) was formed in May 1987 to reflect the increasing I&C focus in the areas of teleoperation and robotics research and development. While continuing to emphasize expertise in manipulator and servocontrol development, the Section is also improving its capabilities in the area of sensors for robotic applications. To provide a stronger theoretical basis for TSS research and development activities, analytical capabilities are also being improved. Since the Section's formation, a number of staff transfers from within the Oak Ridge complex as well as new additions have furthered the development of these capabilities.

During this reporting period, the Telerobotic Systems Section has continued to support development of teleoperation systems for the ORNL Consolidated Fuel Reprocessing Program (CFRP) as well as basic research in autonomous robotics for the Center for Engineering Systems Advanced Research (CESAR). In association with CFRP, the TSS has played key roles in commercialization of the advanced servomanipulator and in cooperative programs with the French and Japanese. In CESAR, the Section has contributed significantly through the development of testbeds for basic research in mobile robotics (HERMIES IIB) and control of manipulators with redundant degrees of freedom (CESARm). The Section has been a major contributor in development of a telerobotic research for the U.S. Army Human Engineering Laboratory (HEL) Soldier-Robot Interface Project (SRIP). From concept to hardware and software implementation, the Section has led development of the Laboratory Telerobotic Manipulator (LTM), a next-generation space manipulator which is nearing completion and demonstration for the NASA Langley Research Center. In this report TSS programs and projects have been grouped as energy-related, space-related, and defense-related.

The Remote Systems Engineering Section of the Central Engineering Organization has been an integral part of the robotics research and development team working in close collaboration with the Telerobotic Systems Section. This group has been responsible for the detailed mechanical engineering design on a number of TSS projects including the NASA LTM and CESARm.

The Telerobotic Systems Section is organized into three groups: Telerobotic Sensors and Electronics, Telerobotic Systems and Controls, and Telerobotic Systems Analysis. These functional groups provide the fundamental technical specialties associated with telerobotics research and development. The mission of each group and highlights of recent activities are described.

TELEROBOTIC SENSORS AND ELECTRONICS

W. W. Manges
G. A. Armstrong S. M. Killough
M. A. Dinkins D. H. Thompson*
R. L. Glassell

The Telerobotic Sensors and Electronics Group (TSE) is responsible for research, development, and deployment of the hardware and software necessary to convert real-world sensed data into a form that can be used for control of robots and manipulators. In addition to traditional sensors such as position encoders and resolvers, this group also assists with video, audio, ultrasonic, and range sensors from simple potentiometers to a sophisticated laser range camera that returns an image representing both reflectance and range data. Computer hardware and software development to make sensor data available to controllers, as well as the human interaction necessary to effectively control robotic systems, also falls within the expertise of this group. The tightly coupled VME-based 68020 supermicrocomputer systems developed by TSE yield performance commensurate with system requirements. TSE works extensively with the Telerobotics Systems Analysis (TSA) Group on development and implementation of control algorithms and with the Telerobotic Systems and Controls (TSC) Group on integration of robotic systems.

Support activities include (1) work for the National Aeronautics and Space Administration (NASA), (2) development in the Center for Engineering Systems Advanced Research (CESAR) Laboratory, (3) deployment of the Soldier Robot Interface Project (SRIP) robotic vehicle research testbed, and (4) activity in the Man-Robot Symbiosis research project. Because of its experience and expertise in high-speed supermicrocomputer systems, TSE is also involved in the Bureau of Engraving and Printing stamp-examining project.

TELEROBOTIC SYSTEMS AND CONTROL

J. N. Herndon
G. K. Corbett J. B. Mitchell
F. W. DePicro M. W. Noakes
R. R. Feezell† J. C. Rowe
D. H. Gray‡

The Telerobotic Systems and Control Group (TSC) has primary responsibility for management and execution of design, fabrication, and integration of large-scale telerobotic systems including mechanical design and fabrication management, electromechanical and digital control system hardware design and fabrication, and complex system-level application software development. Overall Section work is primarily of a large-project nature, and this group provides support to almost all TSS projects. TSC has lead responsibility to develop the telerobotic control system for advanced nuclear fuel reprocessing under the ORNL

*ORNL Engineering.
†Midwest Technical, Inc.
‡ORNL Engineering.

Consolidated Fuel Reprocessing Program (CFRP); to design, fabricate, and demonstrate advanced telerobotic manipulator systems for space applications under the Laboratory Telerobotic Manipulator (LTM) Program; and to design, fabricate, and demonstrate advanced control station configurations for U.S. Army teleoperated vehicles under the Interim Remote Command Center of the Technology Enhancement of Autonomous Machines Project (TEAM). Key accomplishments during the past 2 years include (1) completion of design, fabrication, and assembly of the LTM, which is nearing initial operation; and (2) formal completion of the final features of the Advanced Integrated Maintenance System (AIMS), including advanced servomanipulator (ASM) robotic operation and wireless signal transmission.

A key technical effort of this group has been to move toward more conventional operating system-based control implementation with emphasis on more standard programming languages to improve our ability to interface with other robotic research institutions. OS-9 and VxWorks are two operating systems being used. TSC is moving rapidly to primary use of C as the programming language of choice for application software while retaining its demonstrated FORTH capabilities for key low-level software that requires rapid development and tight interaction with hardware.

TELEROBOTIC SYSTEMS ANALYSIS

S. M. Babcock

J. Anderson*	J. F. Jansen
W. J. Book†	R. L. Kress
H. M. Costello	J. Lenoir**
R. V. Dubey‡	R. Magness**
J. A. Euler‡	R. C. Muller
J. Huang**	B. S. Richardson

The Telerobotic Systems Analysis Group (TSA) performs mathematical modeling and control system analysis in support of basic and applied telerobotics research and development in the Telerobotic Systems Section. The TSA Group is engaged in mathematical modeling, simulation, control algorithm development, and experimental verification associated with telerobotic systems. As a part of this function, TSA members have been responsible for development and maintenance of capabilities in the area of three-dimensional solid modeling, which is used primarily in conceptual design efforts, and for development of general-purpose robotic simulation software.

While the group's focus is toward analysis, TSA members also function as lead engineers for specific projects and perform tasks involving data acquisition system development and digital controls system integration. During the past year, two Ph.D. employees have been added to the full-time staff of the TSA.

*Tennessee Technological University.
†Georgia Institute of Technology.
‡The University of Tennessee, Knoxville.
**Graduate student, The University of Tennessee, Knoxville.

Major accomplishments during the past 2 years include

1. completion of a unique, 7 degree-of-freedom (DOF) manipulator (CESARm), development of a solid model of the manipulator, and implementation of control algorithms for robotic and teleoperator control including real-time redundancy resolution by gradient optimization for the CESARm;
2. application of these algorithms to the NASA LTM;
3. development of joint level-control algorithms, including an adaptive controller, for robotic operation and bilateral force-reflecting teleoperation for a new manipulator system using traction drives and differential pitch/yaw (P/Y) joints (NASA-LTM);
4. project management and system integration for development of a remotely piloted vehicle for military research and development;
5. development of a control concept for stabilizing TV cameras mounted on off-road military vehicles;
6. development of a digital speed-control system for military vehicles; and
7. development of a data acquisition system for helicopter simulator sickness studies.

While TSA members worked on nearly all TSS projects in various capacities, the most significant participation was in conjunction with CESAR, the NASA LTM Project, the HEL SRIP, the U.S. Marine Corps (USMC) GATERS Project, and the Navy Simulator Sickness Project.

Past efforts in telerobotic control of manipulators with redundant degrees of freedom will provide a basis for future work in the area of bilateral, force-reflection algorithms for teleoperators having dissimilar masters and slaves. Development of an adaptive joint control algorithm for teleoperators will lead to still further research and applications. Future activities of this group will also encompass vision research including that recently initiated on low-data-rate viewing for remotely piloted vehicles. Other proposed research includes telerobotic systems with significant time delays.

4.1 ENERGY-RELATED ACTIVITIES

4.1.1 ADVANCED TELEOPERATIONS FOR NUCLEAR FUEL REPROCESSING: CONSOLIDATED FUEL REPROCESSING PROGRAM

4.1.1.1 Completion of AIMS Work Including Integration of Advanced Servomanipulator, Facility, and All Menu-Driven Man-Machine Interface Systems

The ASM is a prototypic, remotely maintainable, force-reflecting master/slave teleoperator (Fig. 4.1-1) developed for remote maintenance and handling studies within CFRP at ORNL. The goal of CFRP has been to advance the technology of in-cell systems planned for future nuclear fuel cycle facilities. The ASM, as part of the Advanced Integrated Maintenance System, has become an integral part of CFRP. Recent AIMS work has been the fine tuning and expansion of software and documentation to meet the changing needs of operations. During this time, the ASM has been used extensively for training and experimentation in remote operations (Fig. 4.1-2).

To provide the highest level of software integrity, both system and application software are stored on two 20-Mbyte hard disks on the system, each partitioned into two sides. One side contains the proven operating software used for operations-oriented testing and provides a backup in case of hard disk failure; the other contains various experimental software packages. Both experimental and operations software are backed up onto floppy disks. Additionally, one of the operations sides is write-protected to prevent inadvertent changes from corrupting proven software. Experimental software that has been tested and proven useful can be moved into the operations drives by authorized personnel. Any one of the four sides can boot and run AIMS. During operation, any drive on either hard disk is available for software editing and development from the terminals. Rather than dedicating the whole system to one experiment for long periods of time, system operation allows several experiments to develop simultaneously and to run alternately within a few minutes of one another.

4.1.1.2 AIMS Experimental Work

The ASM has provided a development tool for examining the needs and constraints necessary for hot cell teleoperation. The features and flexibility of AIMS controls architecture allow R&D modifications to be made easily while retaining the integrity of operations software. Several significant experiments have been completed.

ASM Teach/Playback Robotics. Teach/playback robotics has been implemented on AIMS in such a way that it may be used in conjunction with teleoperation. Using master arms to teach the ASM slave, command position data are collected and stored on floppy disks. To play back a routine, the contents can be uploaded to the hard disk, which is capable of transferring the control data to the slave arms over the local area network in real time. Up to 16 different routines may be loaded onto the hard disk at a time. A selection menu determines which recorded task is tied to the ROBOTICS playback pad on the manipulator menu. An operations task is then brought to a certain point through teleoperation. If needed, ASM teleoperation can alternate with robotics, and the task can continue.

ORNL Photo 2779-86

Fig. 4.1-1. The Advanced Servomanipulator (ASM).

Operations testing on the usefulness of robotics on the ASM has yet to be completed, but several significant possibilities have emerged. The simplest application would be to provide "zero stance" for the arms, a mode that is useful for many maintenance and calibration tasks and one that provides a starting point for other robotic routines. Another advantage would be the ability to change tools by allowing the robot to reach around to a transporter-mounted tool box and automatically select tools for various remote maintenance functions. Actual tasks could be supplemented by making gross motions of the arms via teleoperation and then making selective motions, such as ratcheting a wrench, via robotics.

Operator/Manipulator Frequency Response Tests. Minimum servomanipulator frequency response requirements have been of concern and contention for a long time. To allow the ASM to function similarly to manipulators of slower response times, a single-pole filter has been added to the master/slave mode between master command data and slave motion. Also added is a velocity limit module that measures slave arm velocity, and passes all velocities that are under the limit but regulates the motor drive signal to clip velocities that are over the limit. Terminal selections from a table of parameters permit combinations

ORNL Photo 1306-86

Fig. 4.1-2. View of the AIMS high bay.

of cutoff frequency and velocity limiting. Various remote maintenance and specially constructed tasks have been completed that test operator performance for particular manipulator characteristics. Performance data will be published after analysis.

Time Delay Teleoperation Experimental Capabilities. In order to investigate possible maintenance scenarios for space-based (e.g., SDI Program) teleoperation, a simulated time-delayed teleoperation mode has been developed. Because the goal in this case has been to review operations, not controls, this mode does not insert delay into the master/slave loop. Rather, one arm operates as a master/slave with no delay, functioning as if it were on a ground-based mockup. The other slave arm is driven robotically and delayed a prespecified amount to simulate a remote space location. This operations scenario requires a ground-based mockup for each vehicle that requires maintenance.

4.1.1.3 ASM Commercialization

TSS has participated in a significant effort by the ORNL Fuel Recycle Division to commercialize the ASM. Technology transfer has included control software listings and hardware schematics as well as mechanical patents and all mechanical drawings. REMOTEC, the company awarded the technology, is examining the design for commercial applications.

4.1.1.4 Sampler Vehicle Development

The I&C Division has worked with the Mechanical Design Group of ORNL Engineering to develop a new-generation remote automated sampling vehicle (Fig. 4.1-3) for CFRP. Developed in collaboration with the Power Reactor and Nuclear Fuel Development Corporation of Japan, the vehicle is currently in Japan for testing. The control system, which consists of the onboard controller, operator control station, sample station interface, and signal transmission system, commands all the information and instructions for performing remote process sample initiation and retrieval. Under operator guidance, the control system is capable of simultaneously initiating sample flow in any or all active sample stations, directing the vehicle to retrieve sample bottles from selected stations, and keeping the operator informed about current system status. In the automatic control mode, the operator enters a short command string specifying stations from which samples are to be collected. The system then carries out steps to collect and replace the sample bottles. In the manual mode, the operator can single-step any sampler operation. The system can also provide a printout of the daily command log of the vehicle and a history of sample bottles handled during a selected period.

The onboard sampler controller presented an interesting design problem because all electronics must fit inside a shielded 15-cm (6-in.) cube. The hardware consists of an 80C88 microprocessor on a C-44 bus board supported by 16 Kbytes of ROM and 16 Kbytes of RAM. Support boards include an A/D converter board, RS-232 serial board, relay driver board, and station ID decode board. Vehicle control software is programmed in polyFORTH and resides entirely in 16-Kbyte ROM. Software updates and parameter tables may be downloaded from the operator control station through the serial link, allowing changes to be made without burning new ROMs.

The operator control station employs an IBM PC AT-compatible NCR as the system controller. Using a color touchscreen (see Fig. 4.1-4), operators can communicate with the sampler vehicle, operate sample station solenoid control valves, read bottle ID labels with a bar code reader, and store and/or print out bottle records. Engineering personnel can communicate with the vehicle software directly through keyboard input. In order to use commercial packages for menu graphics, the operator control station software is written in compiled C. Operator control station and vehicle control software communicate by command strings passed over the serial link.

Since the vehicle must travel extensively along a track in a stainless steel-lined process cell, serial communications are handled via two-way radio and lossy coaxial cable. The vehicle uses a short antenna mounted under the vehicle to couple to a lossy coaxial line that runs the length of the track. A home station recharges vehicle batteries, reads bottle bar codes, and provides a hardwired backup serial link between vehicle and operator.

4.1.2 CESAR: BASIC RESEARCH IN ROBOTICS AND INTELLIGENT SYSTEMS

The Center for Engineering Systems Advanced Research at ORNL was established by the DOE Office of Basic Energy Sciences in 1983 as a national center for long-range, multidisciplinary research and development in machine intelligence and advanced control theory. Initial research emphasis was on autonomous remote operations, with specific

ORNL Photo 3824-88

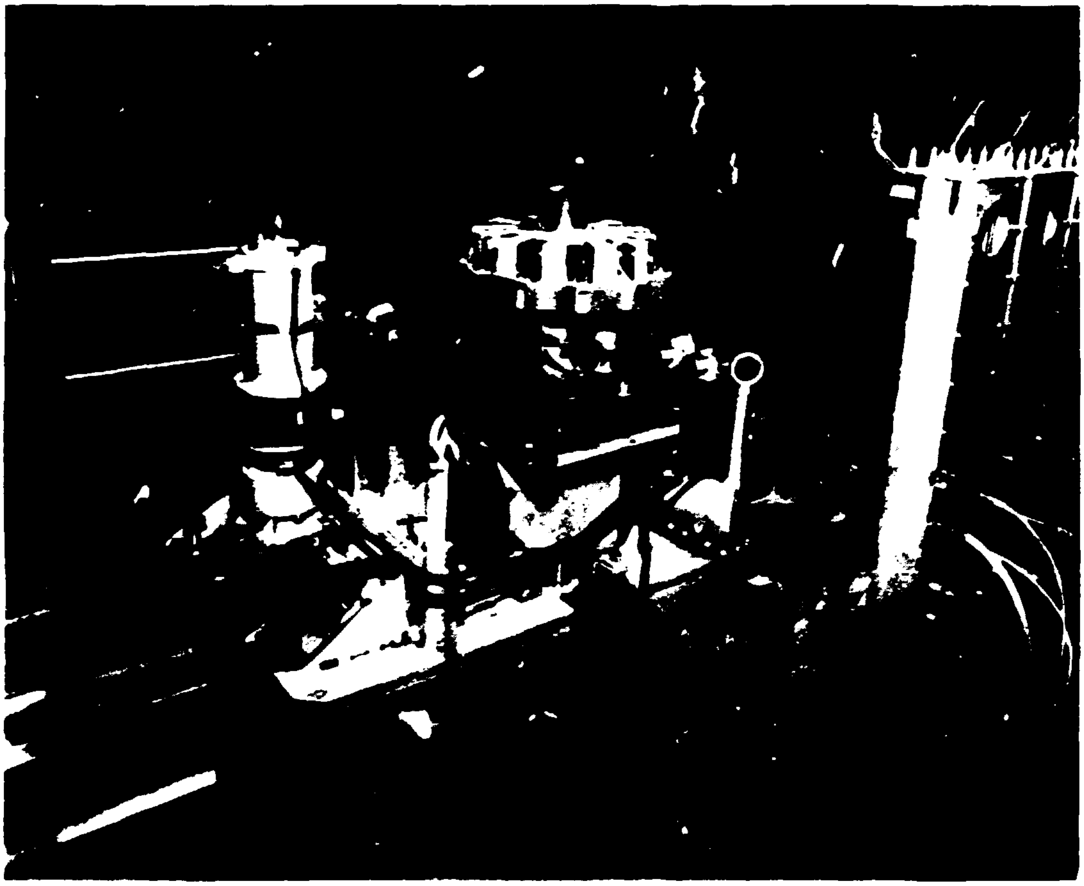


Fig. 4.1-3. Sampler vehicle on track.

applications in unstructured, hazardous environments. TSS participation in CESAR has focused on (1) mobile robot development for machine intelligence experiments and (2) manipulator development for robot dynamics and controls. These areas of research are being integrated in the development of the HERMIES III robot.

4.1.2.1 HERMIES IIB

Mobile robotics R&D activity at the CESAR Laboratory includes culmination of the upgrade from HERMIES II to HERMIES IIB as well as the beginning of deployment of HERMIES III.

Upgrades to HERMIES IIB allow total onboard computer capability for navigation, vision, mobility, and manipulation. Figure 4.1-5 illustrates the HERMIES IIB controls; the robot itself is shown in Fig. 4.1-6. Vision-guided manipulation that allows HERMIES to push buttons on the panel illustrates the capability of the robot.

4.1.2.2 CESARm: 7-Degree-of-Freedom Research Manipulator

Development of CESARm has continued. CESARm provides a test bed for advanced manipulator design and control methodologies suitable for mobile applications in unstructured environments. Having 7 degrees of freedom, CESARm is one of three known

ORNL Photo 3867-88

Fig. 4.1-4. Operator control station.

redundant, all-revolute joint manipulators. This feature is demonstrated in Fig. 4.1-7, in which three arm configurations are shown for the same hand position and orientation. Redundancy is a significant quality for manipulators in unstructured environments. While the workspace of an assembly line robot can be controlled, manipulators in unstructured environments must be reconfigurable to avoid obstacles.

An effort is under way to develop a verified analytical model of CESARm. As part of this effort, a complete computer aided-design solid model of the manipulator has been developed, resulting in mass, center of gravity, and inertia tensor data for CESARm links. A test stand was used to identify inertia for elements with insufficient design data. A mathematical model of CESARm being developed to allow forward dynamics simulation and inverse dynamics calculations is unique in that the four-bar linkage, which drives the elbow joint and counterbalance, and compliant cable drive trains to the wrist pitch, yaw, and roll are being considered. In a separate effort, capability for automating manipulator dynamic model development utilizing MACSYMA has been initiated.

In a study of multivariable control algorithms for the cable-driven, P/Y differential wrist, three controller design techniques were compared: (1) pole placement through full-state feedback, (2) pole placement with proportional-plus-integral compensation, and (3) linear quadratic regulator designed for asymptotic modal properties.

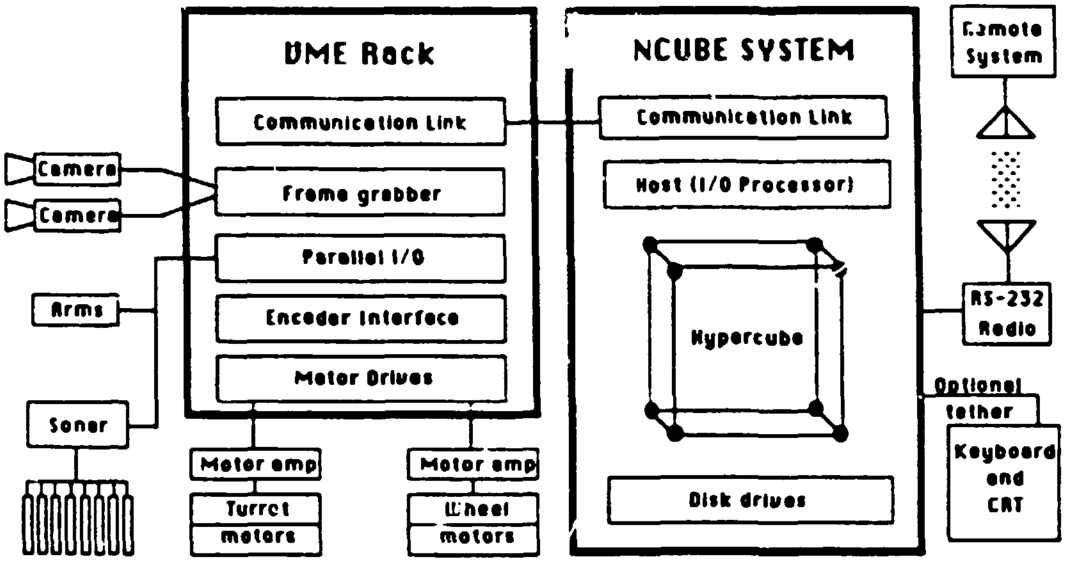


Fig. 4.1-5. Block diagram of HERMIES IIB.

A computationally efficient kinematic optimal control scheme developed for 7-DOF robots with spherical wrists uses the gradient projection optimization method in the framework of resolved motion rate control and does not require calculation of the pseudo-inverse of the Jacobian. An efficient formulation for determining joint velocities for given Cartesian components of linear and angular end-effector velocities is obtained; thus, this control scheme is well suited for real-time implementation, which is essential if the end-effector trajectory is continuously modified based on sensory feedback. This scheme was implemented on a Motorola 68020 VME bus-based controller of CESARm, and various performance criteria have been used to demonstrate its effectiveness. Figure 4.1-8 compares the results of a least-norm velocity solution with a solution optimized for obstacle avoidance. The obstacle chosen was the manipulator support post. Figure 4.1-9 compares the results of a least-norm velocity solution with a solution optimized for joint limit avoidance. In the optimized solution, the elbow limit is avoided and the hand continues to rise as commanded. Singularity avoidance has also been investigated, and an approach to limit the amount of self-motion (reconfiguration without end-effector motion) based on joint velocity bounds has been developed.

4.1.2.3 HERMIES III

The next-generation robot for CESAR is being built for initial deployment in February 1989. The cardboard and plywood model of HERMIES III shown in Fig. 4.1-10 illustrates how the 7-DOF manipulator will be mounted to the mobility platform. HERMIES III will be the first mobile 7-DOF manipulator in the world. The diagram in Fig. 4.1-11 shows the computer capability planned for this robot. Anticipated onboard computer capacity far exceeds any known mobile platform. Experiments planned include combining mobility and manipulation to allow integrated operations in a human-scale environment.

ORNL Photo 7734-87

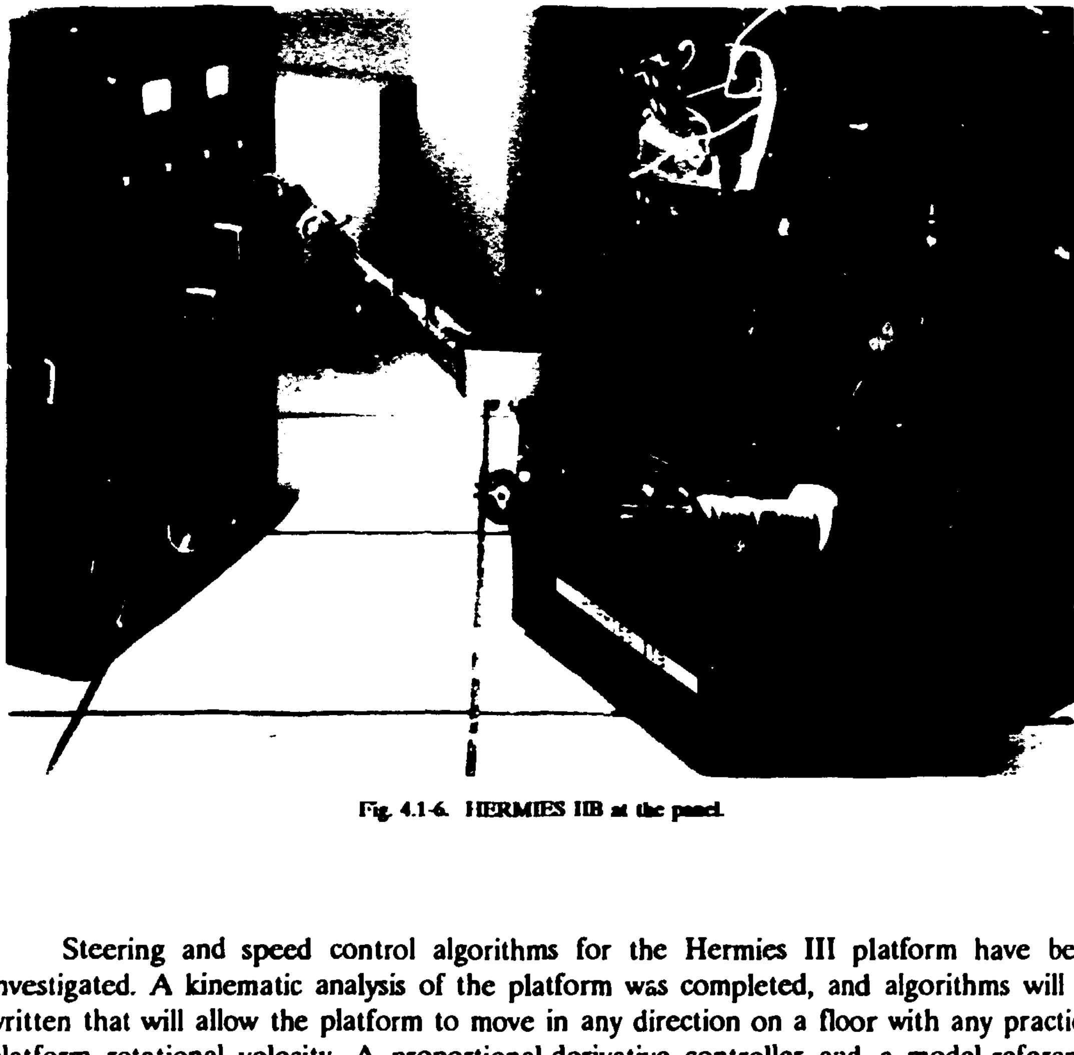


Fig. 4.1-6. HERMIES IIB at the panel.

Steering and speed control algorithms for the Hermies III platform have been investigated. A kinematic analysis of the platform was completed, and algorithms will be written that will allow the platform to move in any direction on a floor with any practical platform rotational velocity. A proportional-derivative controller and a model-reference adaptive controller were designed and analyzed. A dead-reckoning algorithm was developed that will permit the platform to compute its absolute position from a reference point.

4.1.3 MAN-ROBOT SYMBIOSIS

The man-robot symbiosis project begun in 1986 is supported by the ORNL Exploratory Fund. This project seeks to improve interaction between a human and a robot, not simply by improving the human interface or providing robotic capability for repetitive tasks, but by achieving a "symbiotic" relationship. The activities of the human and the robot are monitored by an intelligent program to ascertain the dynamic performance capabilities of both. By breaking jobs into known subtasks, these performance characteristics can be used in assigning tasks to the more appropriate partner, robot or human. TSS, which is leading manager of this project, has made contributions in data structure definition and

ORNL Photo 6767-86

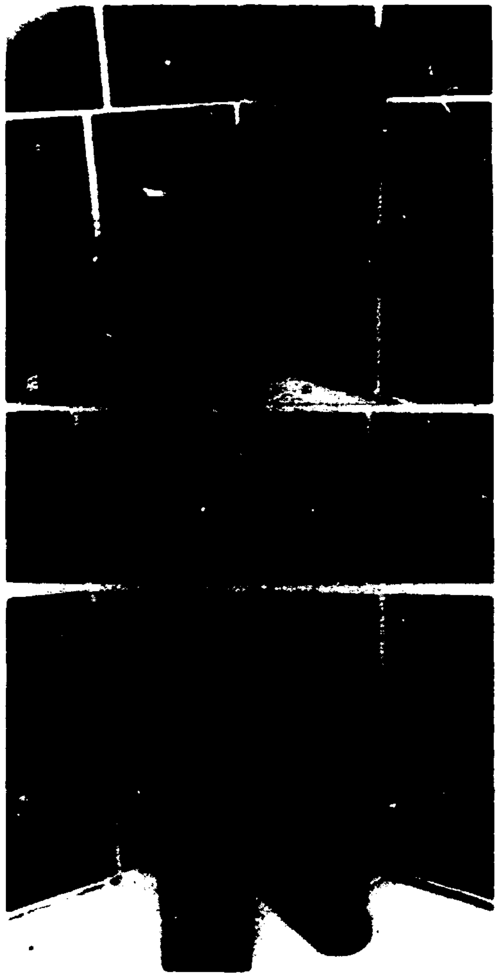


Fig. 4.1-7. Three configurations of CESARm.

communication mechanism hardware and software as well as sensors, computers, and system integration. By working with members of EP&M and FRD, the team has successfully demonstrated dynamic task allocation and sensor-based object recognition via trainable neural networks. The coming year will see integration of the basic capability demonstrated this year and the addition of an automated monitor and presenter/interpreter. Figures 4.1-12 and 4.1-13 illustrate the overall software block diagram and the hardware and low-level software interconnections.

As a part of the man-robot symbiosis project, telerobotic control of CESARm using a nonforce-reflecting master controller (Fig. 4.1-14) has been demonstrated. The kinematic control algorithm described above is used in conjunction with forward kinematics calculations for the master controller to provide unilateral position control of the CESARm end effector. A gradient projection algorithm operating in real time allows optimization of a performance criterion for resolution of the redundancy of the slave. Position scaling and indexing between master and slave are included.

ORNL Photo 11118 88

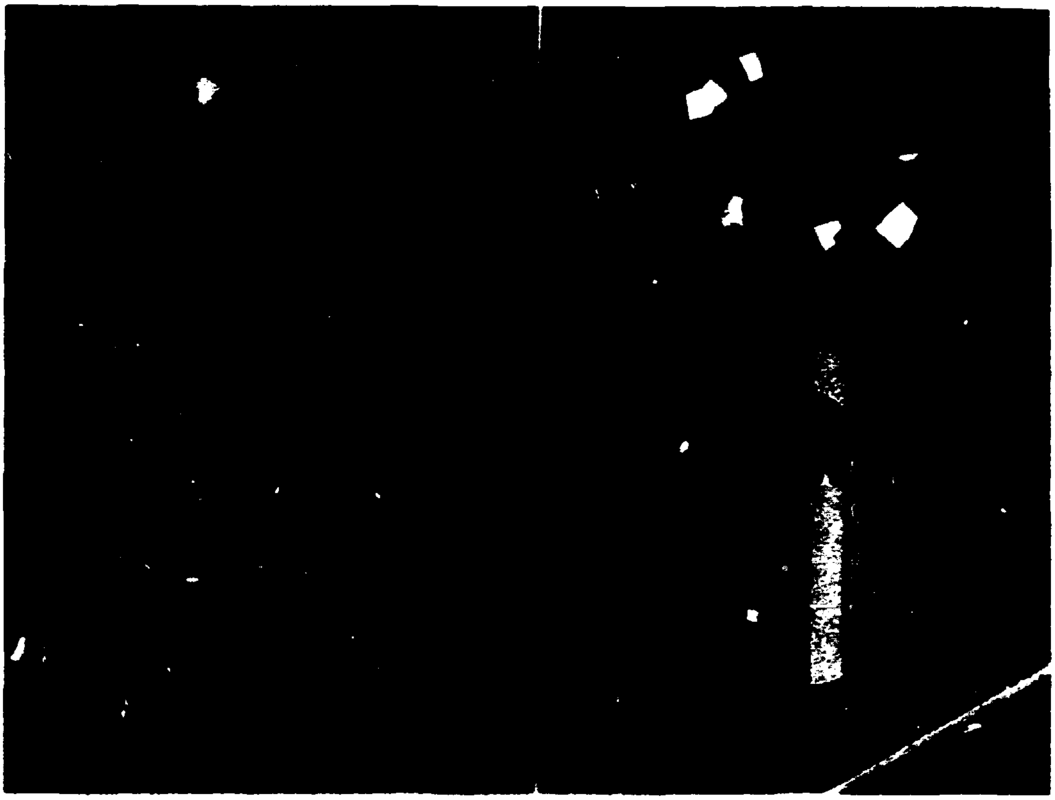


Fig. 4.1-8. Obstacle avoidance-CAD model comparison.

4.1.4 NUCLEAR ENERGY UNIVERSITY PROGRAM IN ROBOTICS FOR ADVANCED REACTORS

4.1.4.1 Integrated Experiments

Research sponsored by DOE at four U.S. universities is being coordinated through the Robotics and Intelligent Systems Program (RISP). Integration activity for this program includes software and hardware from the Universities of Tennessee, Texas, Michigan, and Florida, brought together at the CESAR Laboratory to illustrate navigation, manipulation, and path planning. This project required the interconnection of VME-based computers, NCUBE hypercube computers, and a VAX/VMS-based computer.

4.1.4.2 Conceptual Design of Wrist-End Effector for Articulated Manipulator-Transporter System

The conceptual design of a wrist/end effector compatible with the articulated manipulator-transporter system (ATMS) under development by the University of Florida and Odetics is being performed by TSS and ORNL Engineering. Several possible wrist/end-effector concepts have been investigated: (1) a pitch/yaw/roll wrist with parallel jaw end effector, (2) pairs of 6- and 7-DOF arms, and (3) a pitch/yaw/roll wrist with multifinger end

ORNL Photo 11119-88

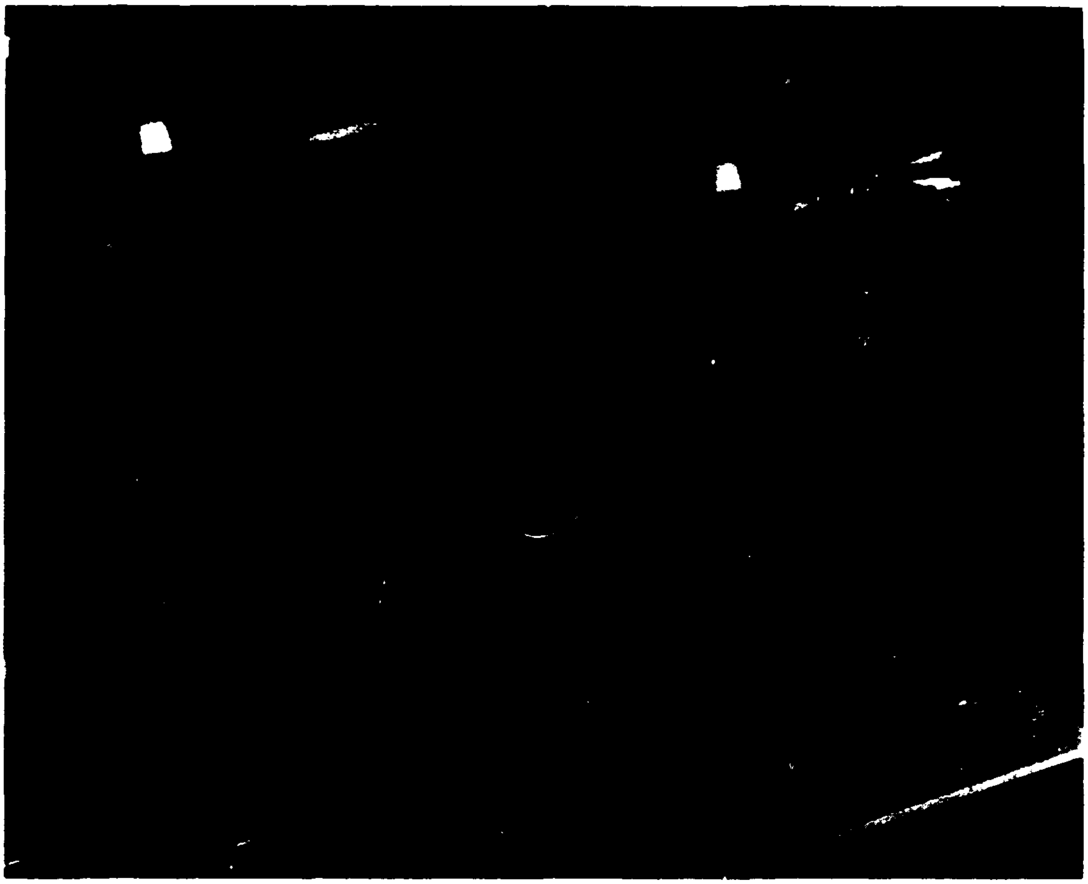


Fig. 4.1-9. Joint limit avoidance-CAD model comparison.

effector. Figure 4.1-15 depicts one example of ATMS with a pair of manipulators. CATIA 3D-CAD conceptual solid models have been used to compare the volumetric reach of each of the three end-effector options and to illustrate typical tasks. Using the CATIA 3D-CAD model of the ATMS with the pitch/yaw/roll end effector and a model of an impact wrench, operations to change tools and unbolt a large flange have been generated. A preliminary concept for a three-fingered hand (Fig. 4.1-16) has been developed, and several grasp configurations have been depicted using a CATIA solid model.

4.1.5 TELEROBOTICS FOR FUSION REACTOR OPERATIONS AND MAINTENANCE

TSS work with the fusion energy community dates back to 1984 when we upgraded the SM-229 master/slave manipulators with digital controls for the Princeton Plasma Physics Laboratory (PPPL). The planned operation of the Tokamak Fusion Test Reactor (TFTR) in deuterium-tritium (D-T) mode in 1990 will require upgrading the control system for use in that facility. Experience gained from ASM, CESARm, and NASA control systems enables us to effectively meet TFTR requirements within cost and schedule constraints.

A facility being designed for Princeton, the Compact Ignition Tokamak (CIT), requires much more R&D activity from TSS. This entirely new facility is being designed to ease requirements for remote maintenance.

ORNL Photo 1153-88

Fig. 4.1-10. HERMIES III model.

4.1.5.1 Tokamak Fusion Test Reactor External Manipulator

The TFTR manipulator controls upgrade includes designing for reliability. Single-point failure modes have been evaluated and eliminated where economically feasible. Our work takes into account a migration path to allow some simple robotic capability and to improve the human interface. Working with Engineering and Fusion Energy Division (FED), by summer 1990 we expect to have the new control system installed on the existing manipulator and integrated into a pedestal-mounted system.

4.1.5.2 Compact Ignition Tokamak Project

The CIT will be deployed in 1992 to permit new fusion energy experiments at PPPL. Remote handling design will be based on experience in control room design, mobile manipulation, and telerobotic manipulator controls development. Multiple slave manipulators, integrated control of a mobile manipulator, and provision for collision avoidance capabilities dictate an extensive preliminary design phase. TSS has provided PPPL with evaluation data on existing manipulator systems and assisted in detailing preliminary requirements for the human interface and mobile manipulator.

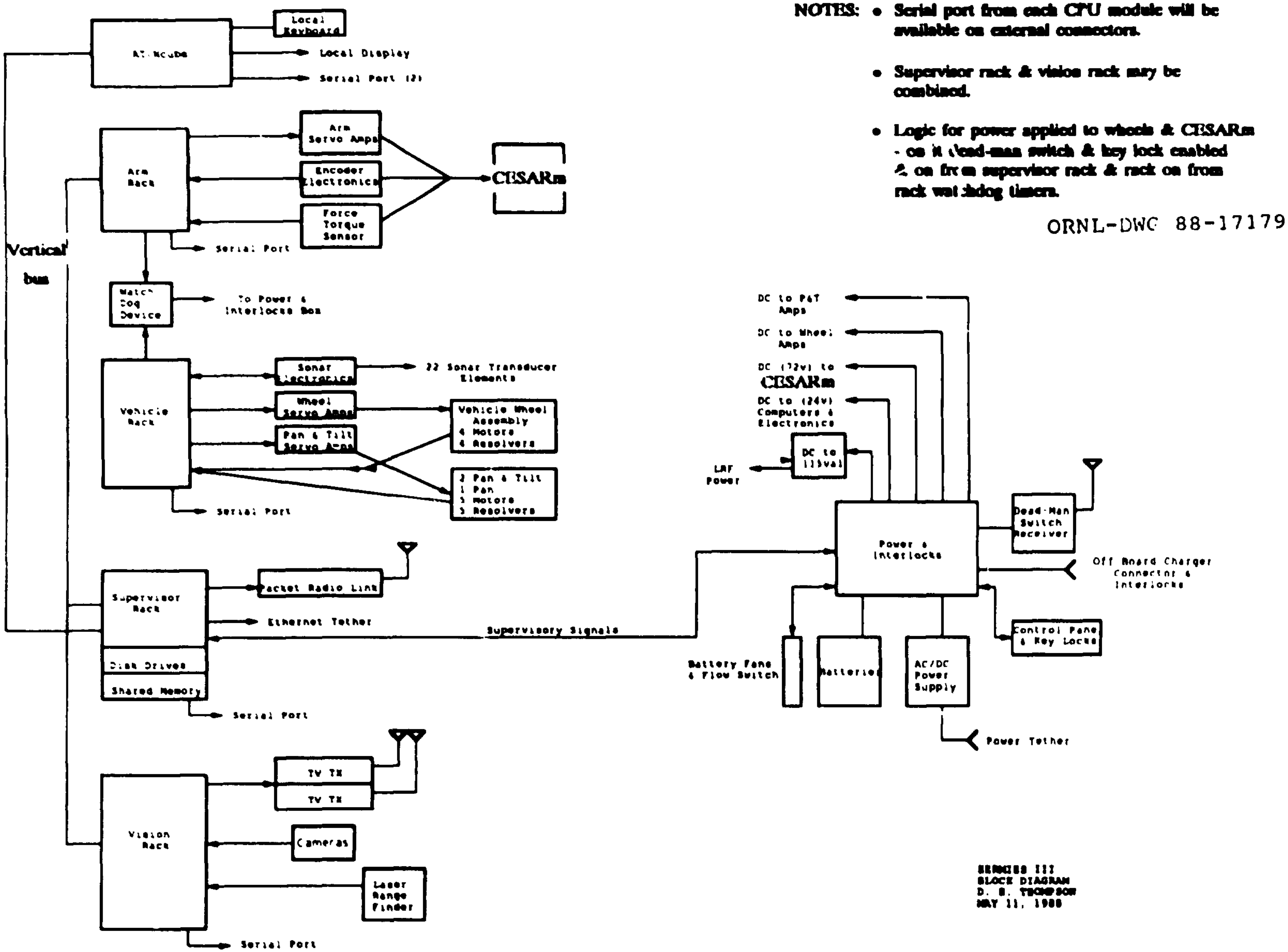


Fig. 4.1-11. HERMIES III computers and interconnections.

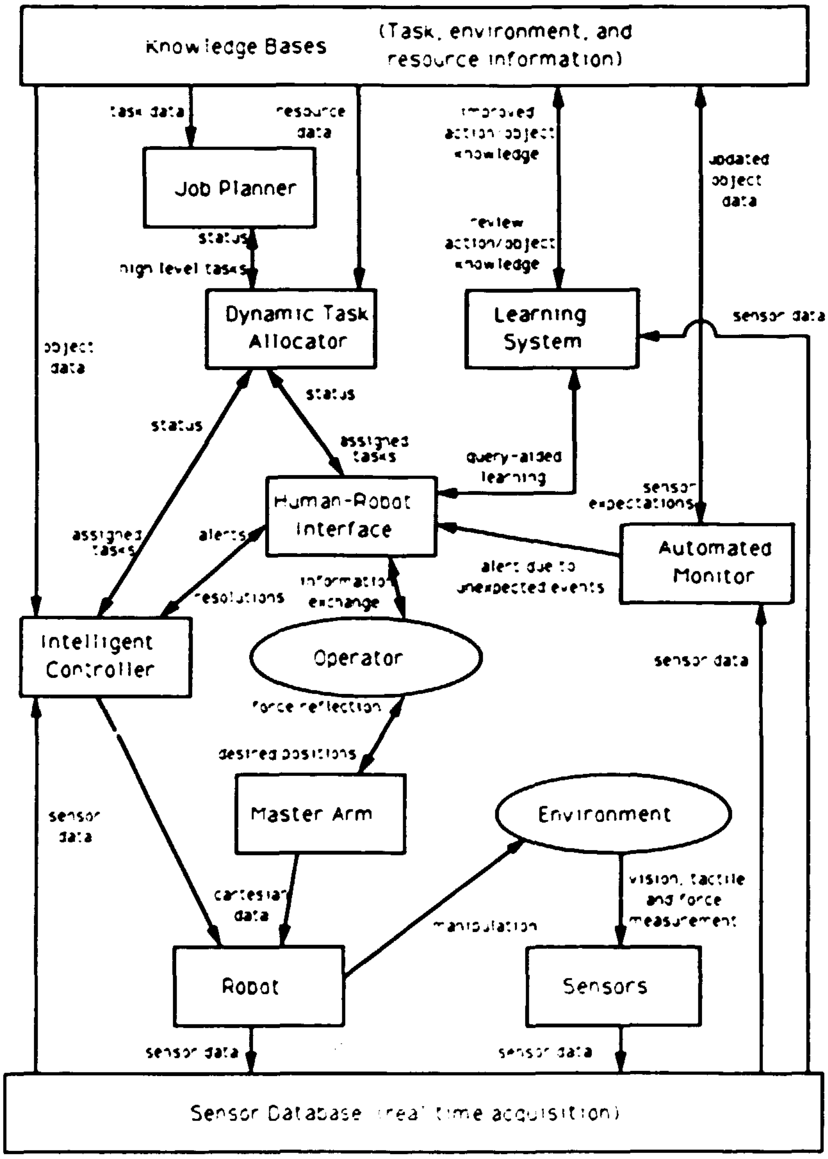


Fig. 4.1-12. Block diagram of overall software for Man-Robot Symbiosis Project.

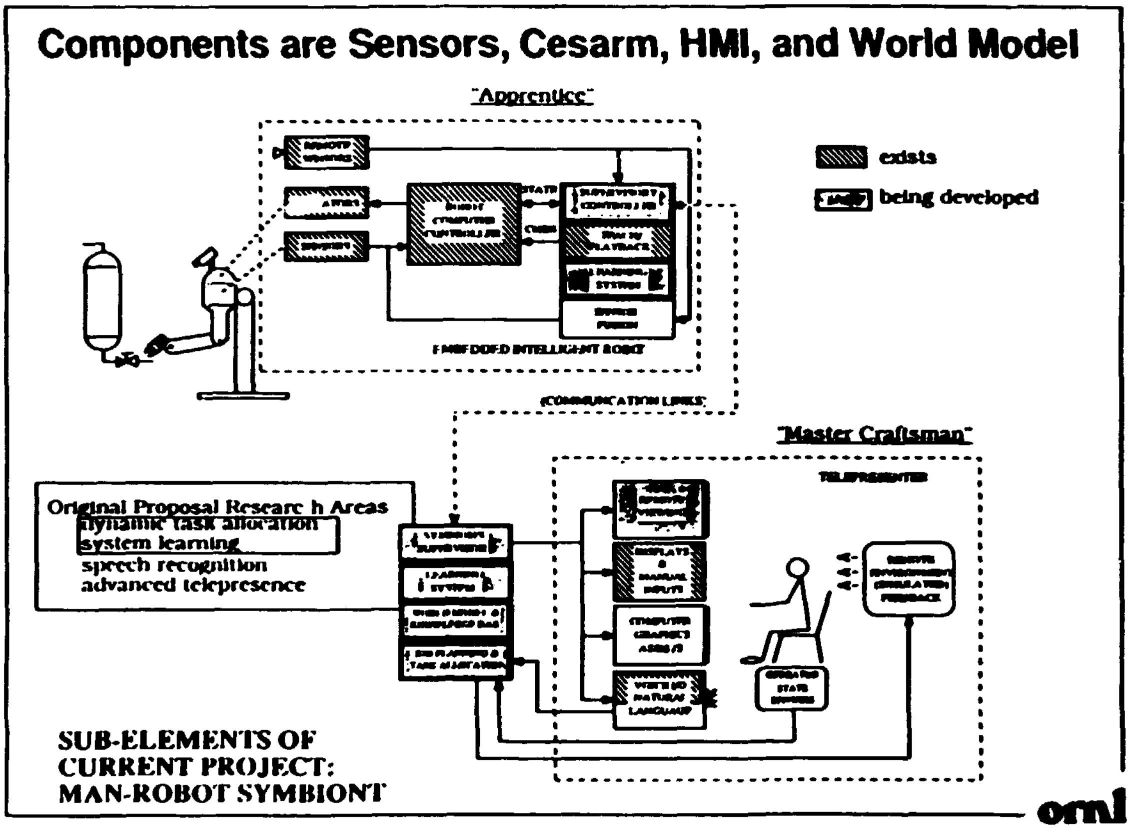


Fig. 4.1-13. Diagram of hardware/software interconnections between sensors, CESARm, HMI, and world model.

4.2 SPACE-RELATED ACTIVITIES: LABORATORY TELEROBOTIC MANIPULATOR PROJECT

The LTM project is developing telerobotic manipulator prototype hardware that has space application as its primary design focus but which will have ground laboratory operation as its initial use. This program, in progress for 19 months, is sponsored by the Automation Technology Branch of the NASA Langley Research Center.

4.2.1 MECHANICAL FEATURES

The original LTM concept (shown in Fig. 4.2-1), was developed at ORNL during a conceptual study on dexterous manipulation needs for the U.S. space program.[*] The concept is based on the desire to merge the best features of existing teleoperator manipulator systems with the best features of programmable robotic systems. The aim is to provide a highly dexterous teleoperated system with flexibility for evolution into robotic operations as

*H. L. Martin, et al., *Recommendations for the Next Generation Space Telerobot System*, ORNL/TM-9951, March 1986.

ORNL Photo 7732-87

Fig. 4.1-14. Kraft Telerobotics, Inc., nonforce-reflecting master controller.

the NASA programs grow. The mechanical design incorporates a strong emphasis on modularity. As shown in Fig. 4.2-2, manipulator arms, both kinematic replica masters and slaves, are composed of three modular pitch/yaw (P/Y) modules with an output roll and end effector. Traction drives provide for backlash-free power transmission in the differential mechanisms of the P/Y joints and require little lubrication, both key concerns for electromechanical servomechanisms for space.

4.2.2 CONTROL SYSTEM FEATURES

The LTM control system is based on a combination of off-the-shelf VME bus electronics and custom electronics embedded within the manipulator arm. As shown in Fig. 4.2-3, all arm sensor data are acquired via onboard data acquisition boards and communicated through the arm to the VME bus racks over optic fiber serial links. Onboard joint processor logic and power boards are custom units designed and fabricated at ORNL. The manipulator arm wiring is reduced significantly and can be routed internally. The LTM VME bus-based racks use Motorola 68020-based single-board computers for control. Arm control algorithm loops are closed within these racks, and the amplifier output drives are directly wired through the arm to the respective dc servomotors.

ORNL Photo 11124-88

Fig. 4.1-15. CATIA drawing of ATMS with two arms.

4.2.3 STATUS AND POTENTIAL FUTURE ACTIVITIES

The LTM system is nearing initial operation. After performance testing, efforts will begin for interfacing the LTM to force-reflecting hand controllers, as described in Sect. 4.4. The LTM system will be shipped to Langley Research Center in early 1989.

4.2.4 SYSTEM TECHNOLOGY SUPPORT FOR LTM

A master-slave control algorithm with bilateral force reflection and a proportional-integral (PI) robotic control algorithm were developed and implemented for a traction-drive-differential P/Y joint using drive train torque, motor velocity, and output position feedback. The PI loop was integrated into a teach/playback program to demonstrate robotic action. Master-slave operation with force reflection was demonstrated using proportional position control loops for each of two test stands. Experimental results showed that the control loops exhibit satisfactory robotic and master-slave performance with sufficient (and adjustable) arm stiffness. Also, a counterbalance routine was successfully implemented to electronically support the end effector and its actuator for both robotic and master/slave modes of operation.

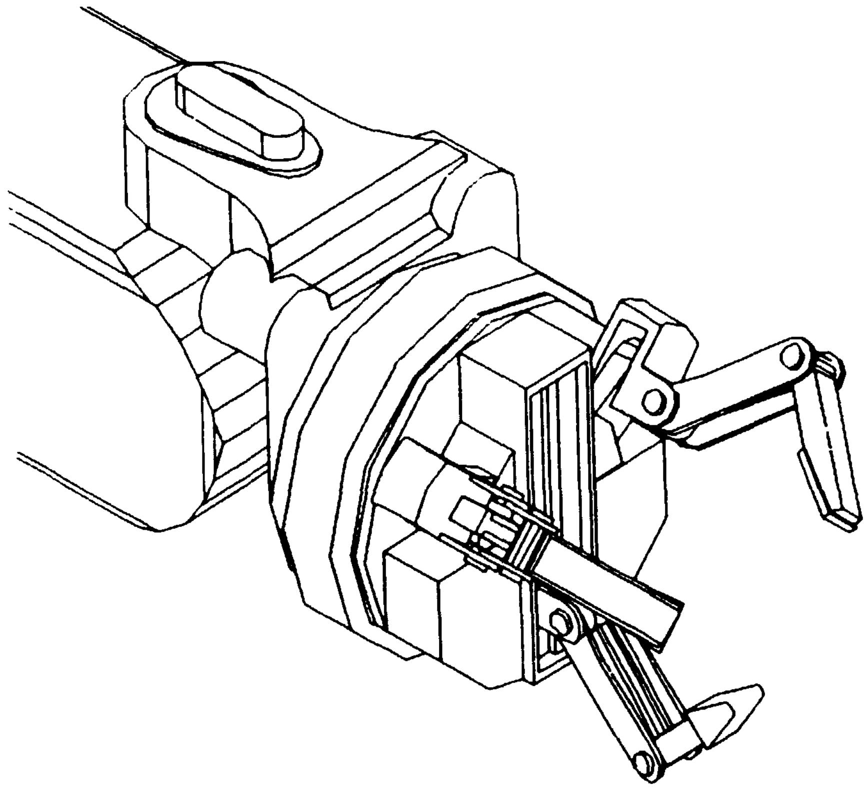


Fig. 4.1-16. CATIA drawing of P/Y-roll wrist with multifinger end effector.

In addition, a model reference adaptive controller (MRAC) has been implemented on the NASA test stand. The MRAC design concept is to synthesize a control signal and/or change various control gains, in real time, to force the manipulator to behave as specified by a reference model. To guarantee global stability, this MRAC design was based on Popov's hyperstability criteria in conjunction with the positive real theorem. Because of the algorithm's insensitivity to payload variations and parameter uncertainty, major objectives were to improve manipulator performance and significantly reduce the time required for controller tuning.

Two analytical studies were performed in support of the LTM design effort. In the first, the manipulator was modeled as a series of rigid links coupled by compliant joints to determine fundamental vibrational modes. These data are significant in that the bandwidth of manipulator control systems is usually limited to ~50% of the fundamental vibration frequency. A design objective was to assure a control bandwidth suitably matched to human operators. In the second study, the singular configurations of the LTM were identified by studying the rank of Jacobian. One advantage of 7-DOF manipulators such as the LTM is that singular configurations can be avoided using self-motion of the manipulator without restricting manipulator workspace.

In a separate effort, a kinematic control algorithm for Cartesian position control of manipulators with redundant degrees of freedom (demonstrated initially on CESARm and described in Sect. 4.1.2.2) has been applied to the LTM and implemented on both an Apple Macintosh II and a VME bus Motorola 68020 system. The LTM implementation includes performance indices appropriate for LTM joint limit avoidance and singularity avoidance,

ORNL Photo 9924-85

Fig. 4.2-1. Laboratory telerobotic manipulator (LTM).

software structures compatible with LTM control software, and a graphic display for previewing robotic trajectories. Testing will follow completion of LTM assembly.

4.3 DEFENSE-RELATED ACTIVITIES

4.3.1 SRIP MOBILE TELEROBOTICS TEST BED

ORNL is systems integrator for the Soldier Robot Interface Project. SRIP is a project of the U.S. Army Human Engineering Laboratory for development of a general-purpose robotics and teleoperations research test bed to study potential applications of telerobotic technology to battlefield operations, with an emphasis on soldier-machine interface (SMI) issues. Army interest is based on the desire to utilize technology to affect such factors as manpower amplification (e.g., increasing personnel effectiveness) and soldier risk exposure (e.g., survivability) in warfare environments. Two areas for potential telerobotic applications are battlefield logistics and combat support.

ORNL Photo 2640-88

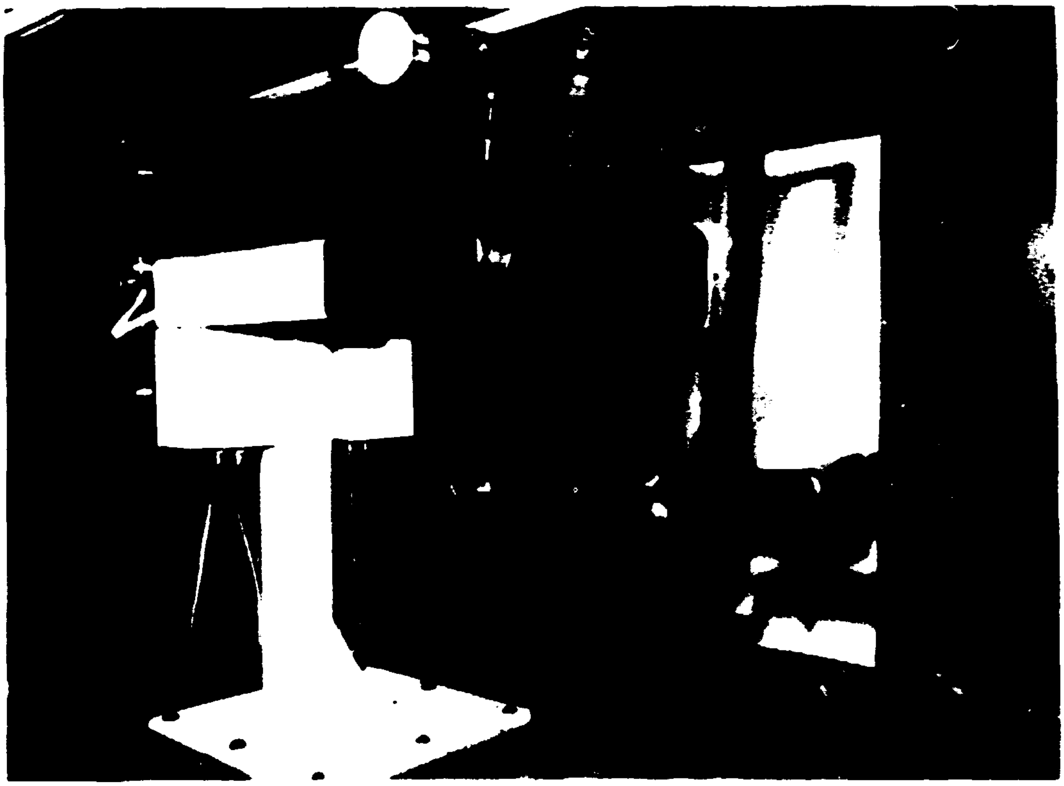


Fig. 4.2-2. Traction drive P/Y joint.

4.3.1.1 System Description

SRIP is composed of a mobile vehicle linked to a mobile SMI station via high-speed data communications (see Fig. 4.3-1.) A distributed digital control system controls the vehicle and various subsystems. The vehicle is a mobile platform with a remote viewing system, an onboard VME bus computer, a communications system, a power conversion system, and various sensors. It is designed to support a 3-DOF, 1350-kg (300-lb) capacity platform manipulator which mates with a separate 3-DOF wrist, both to be added in 1989.

The mobile platform is a modified Chikusui eight-wheeled skid-steered utility vehicle. All that remains of the original vehicle are the engine, wheels, and chain housings for the wheels. The frame was rebuilt and the engine (a 16-hp Mitsubishi diesel) remounted to lower vehicle profile and accommodate the manipulator mounting. A dual hydrostatic transmission and power conversion system have also been added, as have fenders for mounting vehicle electronics enclosures. Changes in the original vehicle were performed at the U.S. Army Tooele Depot. A fiberglass cover will be placed over the electrical enclosures and engine compartment for weather protection. The vehicle weighs a little less than 18,140 kg (4000 lb) and is capable of speeds of 13 to 16 kph (8 to 10 mph) on smooth surfaces.

The platform manipulator will provide a 136-kg (300-lb) lift capacity (1.2:1 lift-to-weight ratio), an 2.6-m (8-ft) reach, and horizontal and vertical tip speeds in excess

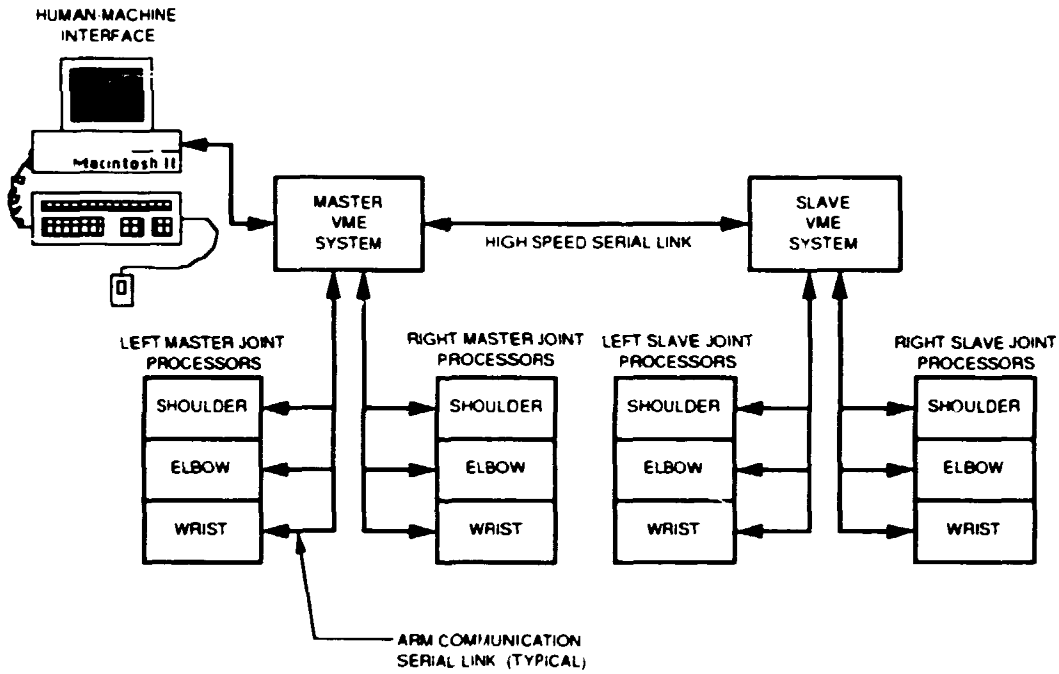


Fig. 4.2-3. Diagram of the LTM control system.

of 1.3 and 0.6 m/s (50 and 24 in./s) respectively. The manipulator will have 3 degrees of freedom. The ranges of motion for the shoulder roll, shoulder pitch, and elbow pitch are ±360, >180, and 180 degrees respectively. The cross section of the manipulator is 16.25 cm^2 (6.5 in.^{2}), and the drive linkages are in the arm housings. There will be both an electrical and a mechanical interface between the arm and the wrist.

The spherical wrist will provide high capacity in a relatively small package. While weighing only 34 kg (75 lb), it will be capable of lifting 102 kg (225 lb). Integral drives will provide 3 degrees of freedom. The pitch and yaw, driven through a differential, will have ±113 and ±90 degrees of motion, respectively, and wrist roll will be continuous. Joint speeds will be 1.13 m/s (44 in./s) at a 0.31-m (12-in.) radius for both the pitch and yaw and 20 rpm for the roll. Feedback will be provided by resolvers at the joints and on the motors, and plans are to attach a force-torque sensor to the wrist. The sensor has an integral microslip ring to accommodate wiring through the wrist roll joint.

4.3.1.2 Control Architecture

The control system uses three processors, two at the SMI and one onboard. A VME 32-bit bus with a Motorola 68020 CPU is used for both onboard and base station systems, and an OS-9 operating system is used for both VME systems. A Macintosh II, used as the SMI processor, is connected to the base station processor through an RS-232 link. The Macintosh II provides a graphics interface for digital command input and graphical representation of key system parameters. Figure 4.3.2 shows the main driving menu. Additional pull-down menus are available.

ORNL Photo 4351-88

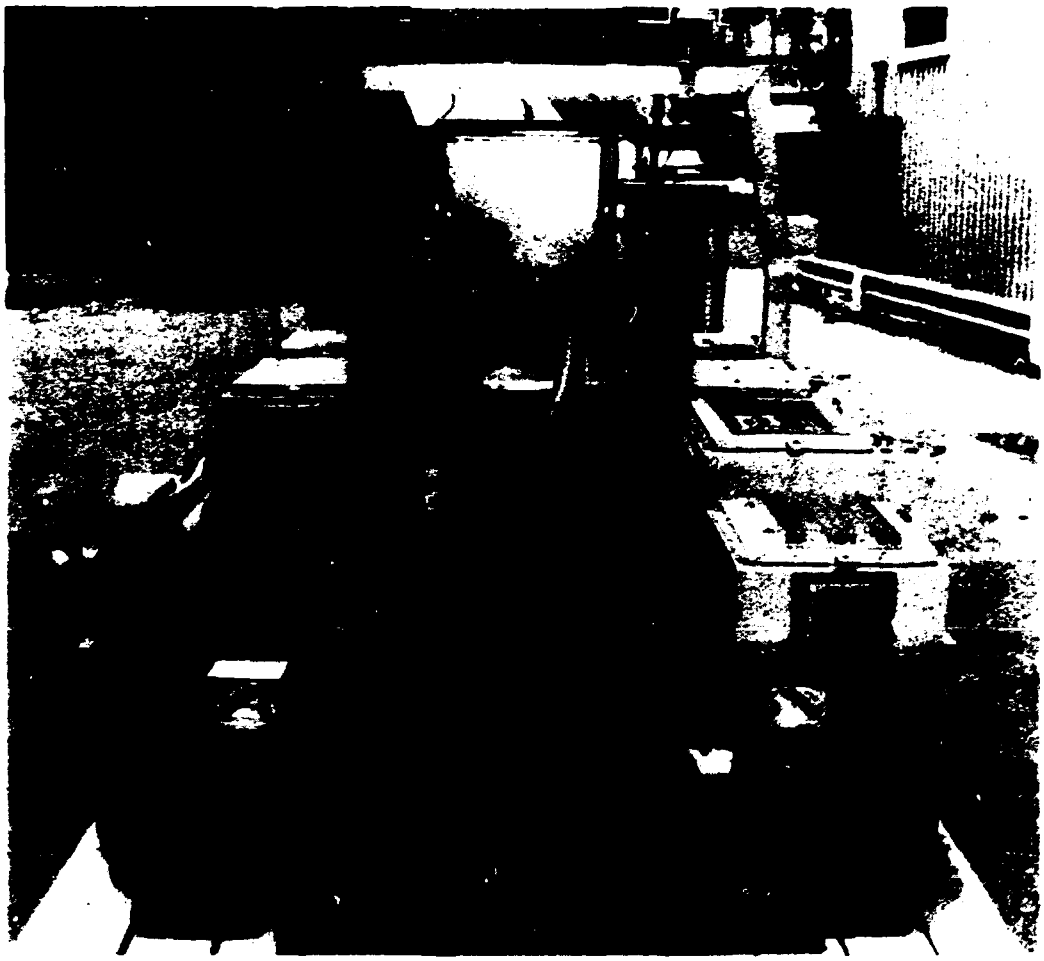


Fig. 4.3-1. Vehicle for Soldier-Robot Interface Project (SRIP).

Software for SRIP on both the Macintosh II and VME systems has been written in C, which permits use of much of the same code on all three processors. Software, centered around a series of data bases containing system and command status information, has been designed to be easily expanded to accommodate growth. Communication between base station and onboard processors is currently accomplished utilizing an RS-232 link over a wavelength multiplexed fiber optic link. This link has two video and two digital channels on a single fiber. A cable payout and retrieval mechanism is mounted on the back of the vehicle to handle dispersement and retrieval of the 500 m (1640 ft) of cable.

4.3.2 LOW-RATE SPEED CONTROLLER FOR LVS AND TANK FLAIL VEHICLES

In support of the Tooele Army Depot, a computer-based speed control was developed for maintaining very slow constant speeds of U.S. Army flail-type minesweeping vehicles. Two prototype minesweeping vehicles are AARDVARK flailing units installed on an M-60 tank and on an MK14 LVS truck. The tank and truck are outfitted with actuators and servosystems for joystick operation of throttle, brake, and steering. The computer system, which can control either the truck or the tank about an operating point of 1.6 kph (1 mph),

ORNL Photo 4352-88

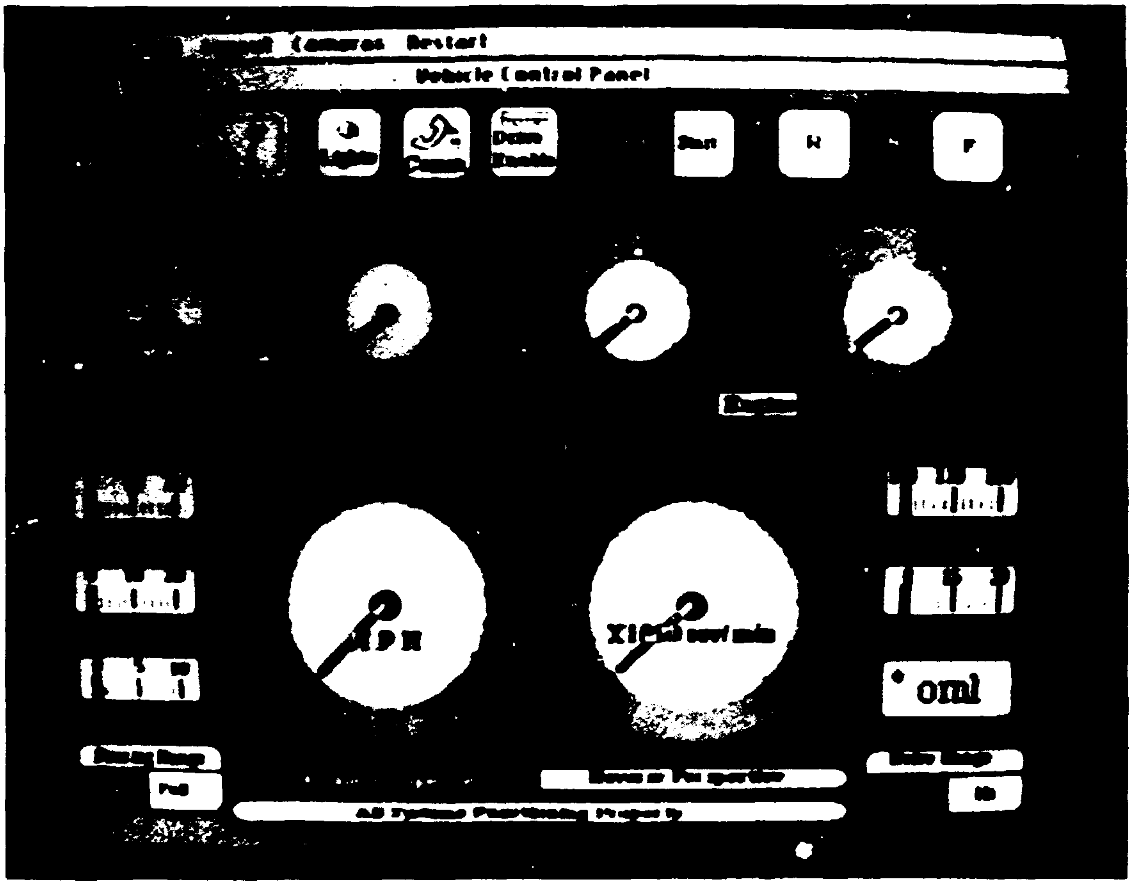


Fig. 4.3-2. SRIP processor environmental model with menus.

has a total operating range of 8 kph (5 mph). The control unit features an on-off mode in which the computer allows the operator to take manual control at any time but resumes control when the operator releases the joystick.

The computer system is designed and packaged for a harsh environment, for portability and quick installation, and for easy operation. The speed control system is based on a VME diskless computer; the VME rack contains 68020 CPU, memory, ADC, and DAC cards. Speed is measured with a radar gun mounted at the rear of the flail vehicle; this signal is fed to a frequency-to-voltage converter and then to the computer for control. The computer uses the OS-9 operating system, and all programing is in C language.

A basic PID algorithm was implemented for the lower range of speed control, which is less than the 2.4 kph (1.5 mph) idle speed of truck and tank. A proportional control was implemented for rates above the idle speed. Both brake and throttle are controlled on the LVS truck; however, only the throttle is used for the tank controller. In the below-idle mode on the tank, the brake is set to a fixed value, while in the above-idle mode the brake is released. The computer will automatically select either the tank or the truck program.

The vehicles were tested over a variety of terrains: on a flat field, on gradual uphill and downhill grades, into and out of deep ditches, and over a bumpy field. The above-idle speed control mode performed admirably for both tank and truck, holding the desired speed to within 0.4 kph (0.25 mph). Overall, the slow mode control responded well to very large disturbances such as pulling out of a hole or climbing out of a ditch. The controller also performed responsively to the bumpy field; however, the tank lacked the necessary braking for speed control while rolling into a ditch. Although the long delay times and highly nonlinear nature of both actuator-controlled vehicles restricted system speed response, the tank and truck exhibited desirable speed control for minesweeping purposes.

4.3.3 SEMIAUTONOMOUS COMBAT ROBOTICS: ARMY TEAM PROJECT

The U.S. Army Human Engineering Laboratory (HEL) is investigating various roles for robotics in future military missions. The Technology Base Enhancement for Autonomous Machines (TEAM) Program will assess opportunities for increased survivability by virtue of multiple combat vehicle robotics (CVR) systems. Combined remote control and autonomous vehicle operations are being studied as means of increasing the near-term value and practicality of CVRs. Specific TSS activities in support of this program are in low data-rate driving, remote command center development, and program management. In addition, TEAM support is used in applying the SRIP mobile robot to TEAM-related experiments in low data-rate driving.

4.3.4 REMOTE VEHICLE DRIVING: USMC GROUND-AIR TELEROBOTICS SYSTEMS PROGRAM

The Telerobotic Systems Section, in participation with the USMC Ground-Air Telerobotics Systems (GATERS) Program, completed a study in camera stabilization for a remotely controlled combat vehicle. The stabilization technique developed uses accelerometer feedback from the camera to actively attenuate disturbances viewed on the remote display, which result from the vibration and bounding of the remote vehicle. The accelerometer feedback approach is less expensive than currently used gyro-based units and requires minimal additions to the existing USMC teleoperated vehicle (TOV). This investigation focused on stabilization of a Sony charge-coupled device (CCD) camera for a single degree of freedom (the tilt angle) using disturbance-accommodating accelerometer feedback.

A model of the high-mobility multipurpose wheeled vehicle (HMMWV) was simulated to understand the mechanisms and magnitudes of the motion this vehicle transmits to the camera system. The two degrees of freedom modeled were vertical displacement and angular rotation about the vehicle body center of mass. The two-dimensional analysis comprised vehicle and axle inertias coupled with suspension springs and dashpots, as well as ground effects due to tire spring rates. The vehicle simulation exhibited a 4-Hz response to a terrain described by 10-cm (4-in.) bumps 1 m (~3 ft) apart.

A control scheme was developed to track large-scale motion of the vehicle and position commands from the remote operator while attenuating the higher frequency disturbances of the camera. The basic approach was to feed back the accelerometer signal from the camera, which contained both the high- and low-frequency oscillations of the disturbance, to a position control loop. By conditioning the accelerometer signal such that the low-frequency signal was filtered and the high-frequency signal was passed, inverted, and summed to the position command, the tilt motor received a drive signal to track low frequencies and negate the high frequencies, or camera jitter. This algorithm was simulated (using the TOV simulation as the disturbance input) and resulted in almost perfect tracking of the gross vehicle motion and tilt commands while attenuating camera jitter by 75%.

A test stand was designed and fabricated to demonstrate the feasibility of the accelerometer feedback approach to camera stabilization. A Sony CCD camera and tilt motor assembly were mounted to the shaft of a second dc motor secured to a base plate. The dc motor was used to represent the angular rotation of the TOV-transmitted motion to the camera tilt assembly. A rotary accelerometer was mounted in line with the camera tilt axis, a 10-bit encoder was mounted to the tilt motor shaft, and the stabilization control algorithm was implemented in C language on a VME computer. A joystick was incorporated into the system to act as the tilt command from the remote operator. The test results exhibited a reasonable tracking ability of the tilt command and low-frequency vehicle motion. A slight delay in tracking resulted from imprecise balancing of the camera assembly rotary inertia. The high-frequency response of the system successfully eliminated 90% of the camera jitter. A VHS video camera documented the comparison between uncompensated and compensated displays of the camera viewing a picture of a landscape.

Conclusions from the ORNL camera stabilization study, and recommendations to the Marine Corps, are that camera stabilization using accelerometer feedback is a viable approach for improving teleoperation and merits further research, and that the described camera control system could be implemented on the TOV to track motion of <1 Hz while attenuating disturbances in the 1- to 10-Hz range. Higher frequency disturbances (greater than 20 Hz) that result from engine and structural vibration can be effectively reduced with passive damping types of suspension.

4.4 NEW ACTIVITIES

4.4.1 COMPACT MASTER CONTROLLER CONCEPTS FOR NASA LTM

Force-reflecting hand controllers that can operate within spatial constraints will be required for space applications. Key requirements are dexterous control in restricted spaces, minimization of power requirements, and ability to be stowed when not in use. TSS is working with NASA Langley Research Center to investigate these issues.

An activity presently being initiated is to purchase and interface a commercially available six-axis force-reflecting hand controller with the seven-axis LTM slave arms. In turn, they must be capable of interfacing with other controllers such as six-axis joysticks. The objective is to provide a common testing environment (the LTM slave arms) for "flyoffs" of the various possible controller options for space manipulators.

4.4.2 AIR FORCE ROBOTIC TELEPRESENCE PROGRAM: CONTROL OF REDUNDANT MANIPULATORS WITH DISSIMILAR NONREDUNDANT MASTERS

A new telerobotics research project has been initiated for the Armstrong Aerospace Medical Research Laboratory (AAMRL) at Wright-Patterson Air Force Base. Its primary objective is to develop and analyze bilateral force-reflecting control methodologies for teleoperator systems with kinematically dissimilar masters and slaves. A secondary objective is to develop software to implement the control techniques on AAMRL robotic manipulators.

Research will be done in three phases. In Phase I, several bilateral control techniques will be investigated to develop novel control schemes and determine their relative strengths in actual dissimilar master/slave operations. Also, a commercial force-reflecting master controller will be procured and integrated into the CESARm control system (see Sects. 4.1.2 and 4.1.3). In Phase II, several performance criteria will be consio -ed for optimization through computer-generated solutions and direct human input, with the objective of maximizing performance benefits of kinematically redundant slaves. In Phase III, ORNL will adapt or, if necessary, develop AAMRL-compatible software for demonstration of control schemes and for follow-on work.

4.4.3 BUREAU OF ENGRAVING AND PRINTING PROGRAM: SYSTEM ARCHITECTURES FOR HIGH-SPEED WEB INSPECTION

Using sophisticated system-level software to integrate data from specialized sensors optimized for collecting data on particular classes of flaws, TSS is working with other I&C sections as well as with ORNL Engineering and University of Tennessee faculty to help develop a system for the Bureau of Engraving and Printing to help it control product quality. TSS involvement includes high-speed, tightly coupled VME systems and precision control of servomechanisms. Deliverables over the next 2 to 3 years include hardware, software, and concepts.

4.5 PUBLICATIONS AND PRESENTATIONS

G. O. Allgood, F. R. Gibson, D. H. Gray, and W. W. Manges, "The Implementation of a Hierarchical Control Strategy in the Development of the AVLIS Thermal Control Subsystem," 1988 International Symposium on Communications and Controls, Baton Rouge, La., October 19-21, 1988.

G. O. Allgood, F. R. Gibson, and W. W. Manges, "Development of an Optimal Control Strategy for the Startup and Outgassing of Material Handling Demonstration Module," 1988 International Symposium on Communications and Controls, Baton Rouge, La., October 19-21, 1988.

W. H. Andrews, Jr., G. A. Armstrong, and T. L. Bowers, *Railroad-Highway Grade Crossing Signal Visibility Improv ment Project Final Report*, vol. I; *Data and Hardware Details*, vol. II; *User's Guide*, vol. III; ORNL Reports FHWA/RD-86/186, 187, and 188, October 1986.

S. M. Babcock, R. V. Dubey, J. A. Euler, R. L. Glassell, R. L. Kress, W. R. Hamel, and M. S. Jaster, "Telerobotic Control of the Seven-Degree-of-Freedom Cesar Manipulator," NATO Advanced Research Workshop on Robots with Redundance: Design, Sensing, and Control, Salo, Lago di Garda, Italy, June 27-July 1, 1988; *Proceedings* (to be published).

S. M. Babcock, W. R. Hamel, and S. M. Killough, "Advanced Manipulation for Autonomous Mobile Robots," International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, Washington, March 29-April 2, 1987; *Proceedings*, 290-97 (1987).

R. E. Battle and G. K. Corbett, "Remote Control System for a 2-MW Research Reactor," IEEE Industry Applications Society, 23rd Annual Meeting, Pittsburgh, Pa., October 2-6, 1988, proceedings to be published.

R. E. Battle and G. K. Corbett, "Digital, Remote Control System for a 2-MW Research Reactor," IEEE Nuclear Science Symposium, Orlando, Fla., November 9-11, 1988; proceedings to be published.

T. W. Burgess, J. N. Herndon, S. L. Schrock, and C. H. Nowlin, *Summary Report of CFRP Experiences with Signal Transmission Techniques for Remote Applications*, ORNL/TM-10599, February 1988.

B. L. Burks, D. L. Barnett, J. P. Jones, and S. M. Killough, "A Demonstration of Autonomous Navigation and Machine Vision Using The Hermies-IIB Robot," 1987 Southeastern Regional Media Leadership Council Conference on Microcomputers and Artificial Intelligence in Communication Technologies, The University of Tennessee, Chattanooga, October 29-31, 1987.

B. L. Burks, D. L. Barnett, S. M. Killough, R. C. Mann, and F. G. Pin, "Dealing with Unanticipated Events in Autonomous Navigation," 26th IEEE Conference on Decision and Control, Los Angeles, December 9-11, 1987; *Proceedings*, 3, 1808-15 (1987).

B. L. Burks, G. deSaussure, C. R. Weisbin, J. P. Jones, and W. R. Hamel, "Autonomous Navigation, Exploration, and Recognition," *IEEE Expert*, 18-27 (Winter 1987).

G. K. Corbett, M. W. Noakes, and C. T. Kring, "Integration of Robotics and Teleoperation for the Advanced Servomanipulator," 2nd International Symposium on Robotics and Manufacturing Research, Education and Applications, Albuquerque, N.M., November 16-18, 1988.

H. M. Costello and S. M. Babcock, "Experimental Two-Degrees-of-Freedom Joint," 1987 Goddard Conference on Space Applications of Artificial Intelligence and Robotics, Greenbelt, Md., May 13-14, 1987.

J. V. **Draper**, E. Sundstrom, and J. N. **Herndon**, "Joint Motion Clusters in Servomanipulator Operation," Human Factors Society 30th Annual Meeting, Dayton, Ohio, September 30-October 5, 1986.

R. V. Dubey, J. A. Euler, and S. M. Babcock, "An Efficient Gradient Projection Optimization Scheme for a Seven-Degree-of-Freedom Redundant Robot with Spherical Wrist," 1988 International Conference on Robotics and Automation, Philadelphia, April 24-29, 1988; *Proceedings*, 1, 28-36 (1988).

R. V. Dubey, J. A. Euler, and S. M. Babcock, "Optimization of Performance Criteria with Bounded Joint Velocities for Robots with One Degree of Redundancy," USA-Japan Symposium on Flexible Automation, Minneapolis, July 18-20, 1988; *Crossing Bridges: Advances in Flexible Automation and Robotics*, vol. 1, Book No. 10271A, 115-122 (1988).

R. V. Dubey, J. A. Euler, S. M. Babcock, and J. N. Herndon, "Laboratory Telerobotic Manipulator Prototype Singularity Analysis, ORNL/TM-10633.

R. V. Dubey, J. A. Euler, S. M. Babcock, and R. L. Glassell, "Real Time Implementation of a Kinematic Optimization Scheme for Seven-Degree-of-Freedom Redundant Robots with Spherical Wrists," American Control Conference, Atlanta, June 15-17, 1988; *IEEE J. Robotics Autom.*, 1376-78 (1988).

J. A. Euler, R. V. Dubey, and S. M. Babcock, "Self-Motion Determination Based on Joint Velocity Bounds for Redundant Robots," 2nd International Symposium on Robotics and Manufacturing Research Education and Applications, Albuquerque, N.M., November 16-18, 1988.

J. A. Euler, R. V. Dubey, S. M. Babcock, and W. R. Hamel, "A Comparison of Two Real-Time Control Schemes for Redundant Robots with Bounded Joint Velocities," IEEE International Conference on Robotics and Automation, Scottsdale, Ariz., May 14-19, 1989.

M. J. Feldman, N. R. Grant, and J. N. Herndon, "Remote Maintenance for Waste Handling: Application of Servomanipulators to a New Generation of Hot Cells,: presented at the American Nuclear Society Topical Meeting on Waste Management and Decontamination and Decommissioning, Niagara Falls, New York, September 14-18, 1986.

M. G. Forest-Barlach and S. M. Babcock, "Inverse Dynamics Position Control of a Compliant Manipulator," IEEE J. Robotics and Automation, RA-3(1), 75-83 (1987).

W. R. Hamel, "Manipulator Technology: The Critical Element of Usefule Autonomous 'Working' Machines," Intelligent Autonomous Systems, An International Conference, Amsterdam, December 8-11, 1986.

W. R. Hamel, "Experiments in Autonomous Robotics," 5th Symposium on Energy Engineering Sciences, Argonne National Laboratory, Argonne, Ill., June 17-19, 1987; *Experiment Research in Autonomous Robotics*, CONF-8706187, 123-30 (1987).

W. R. Hamel and S. M. Babcock, "Manipulator Technology: The Critical Element of Useful Autonomous 'Working' Machines," Intelligent Autonomous Systems Conference, Amsterdam, December 8-11, 1986.

W. R. Hamel and F. G. Pin, "The Man-Robot Symbiosis Project," WATTec 88, Knoxville, Tenn., February 16-19, 1988.

W. R. Hamel, B. S. Richardson, and S. M. Kilough, "Evaluating Telerobotics for Battlefield Support Operations," International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, Wash., March 29-April 2, 1987; *Proceedings*, 284 (1987).

J. N. Herndon, "Genesis of the Advanced Servomanipulator," France CEA/USDOE-ORNL Specialists' Meeting on Remote Technology, Marseilles, France, February 19-24, 1987.

J. N. Herndon, "Robotics Technology for Hazardous Environments," Lecture at Webb School, Knoxville, Tenn., February 1, 1988.

J. N. Herndon, "Telerobotics for Human Dexterity in Hostile Environments," WATTec 88, Knoxville, Tenn., February 18, 1988.

J. N. Herndon and W. R. Hamel, "Telerobotic Technology for Nuclear and Space Applications," AIAA/NASA/USAF Symposium on Automation, Robotics, and Advanced Computing for the National Space Program, Arlington, Va., March 9-11, 1987.

J. N. Herndon and W. R. Hamel, "Robotic Systems for NASA Ground-Based Research," *Int. J. Robotics Auton. Sys.* 4(1), 19-25 (March 1988).

J. N. Herndon, W. R. Hamel, and D. P. Kuban, "Traction-Drive Telerobot for Space Manipulation," 1987 IEEE International Conference on Robotics and Automation, Raleigh, North Carolina, March 30-April 3, 1987; *Proceedings*, 450-55 (1987).

J. N. Herndon, W. R. Hamel, and A. J. Meintel, "Robotic Systems for NASA Ground-Based Research," *Robotics*, 4(1), 19-25 (1988).

J. N. Herndon, C. T. Kring, M. J. Feldman, D. P. Kuban, H. L. Martin, J. C. Rowe, and W. R. Hamel, "Advanced Remote Handling Developments for High Radiation Applications," Robots 86 Conference, Robotics International of SME, Chicago, April 20-25, 1986; *Proceedings, Robotics International of SME*, 5.53-5.65 (1986).

J. N. Herndon, C. T. Kring, and J. C. Rowe, "Advanced Remote Handling for Future Applications: The Advanced Integrated Maintenance System," International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, Wash., March 29-April 2, 1987; *Proceedings*, 622-29 (1987).

R. L. Kress, "Adaptive Model-Following Control For Hyperthermia Treatment Systems," Dissertation presented for the Doctor of Philosophy Degree, University of Arizona, Tucson, May 1988.

C. T. Kring, J. N. Herndon, and J. C. Rowe, "Advanced Remote Handling for Future Nuclear Applications: The Advanced Integrated Maintenance System," at WATTec 87, Knoxville, Tenn., February 17-20, 1987.

D. P. Kuban and W. R. Hamel, "Application of a Traction-Drive Seven-Degrees-of-Freedom Telerobot to Space Manipulation," American Astronautical Society 10th Annual Guidance and Control Conference, Keystone, Colo., January 31-February 4, 1987; *Guidance and Control* 63, 381-97 (1987).

D. P. Kuban, J. N. Herndon, D. M. Williams, J. C. Rowe, S. D. Zimmerman, H. M. Costello, and S. M. Babcock, "NASA/Industry Briefing on the Laboratory Telerobotic Manipulator (LTM)." Oak Ridge, Tenn., May 19, 1987.

D. P. Kuban, M. W. Noakes, and E. C. Bradley, "The Advanced Servomanipulator System: Development Status and Preliminary Test Results," International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, Wash., March 29-April 2, 1987; *Proceedings*, 638-44 (1987).

W. W. Manges, G. O. Allgood, and D. H. Thompson, "Mapping a Hierarchical Control Strategy onto a Distributed System Architecture," 1988 International Symposium on Communications and Controls, Baton Rouge, La., October 19-21, 1988.

R. C. Mann, W. R. Hamel, and C. R. Weisbin, "The Development of an Intelligent Nuclear Maintenance Robot," 1988 IEEE International Conference on Robotics and Automation, Philadelphia, April 24-29, 1988; *Proceedings*, 1, 621-23 (1988).

R. C. Muller, G. O. Allgood, and B. Van Hoy, "Prototype Data Acquisition and Analysis System for Navy Operational Flight Simulators," 1988 Meeting of the American Institute of Aeronautics and Astronautics Simulation Technology Conference, Atlanta, September 7-9, 1988.

M. W. Noakes, "Robotics," Presentation at Eagleton Middle School, Maryville, Tenn., January 16, 1987.

M. W. Noakes, "Robotics and the Space Station," Fairview Elementary School, Maryville, Tenn., April 20, 1988.

M. W. Noakes, G. K. Corbett, and C. T. Kring, "A Controls Architecture that Supports Servomanipulator Development," American Nuclear Society 3rd Topical Meeting on Robotics and Remote Systems, Charleston, S.C., March 13-16, 1989.

B. S. Richardson, G. A. Armstrong, and W. W. Manges, "Telerobotic Vehicle for Evaluating Remote Battlefield Support Operations," 2nd International Symposium on Robotics Manufacturing Research, Education and Applications, Albuquerque, N.M., November 16-18, 1988.

J. C. Rowe, R. F. Spille, and S. D. Zimmerman, "Integrated Digital Control and Man-Machine Interface for Complex Remote Handling Systems," International Topical Meeting on Remote Systems and Robotics in Hostile Environments, Pasco, Wash., March 29-April 2, 1987; *Proceedings*, 645-53 (1987).

C. R. Weisbin, J. Barhen, and W. R. Hamel, "Research and Development Program Plan for the Center for Engineering Systems Advanced Research (CESAR)," ORNL/TM-10232 (January 1987).

5. MAINTENANCE MANAGEMENT DEPARTMENT

OVERVIEW

D. R. Miller

The Maintenance Management Department (MMD) has continued its traditional role of providing services and products to the four I&C Division engineering sections as well as to other ORNL divisions. The annual budget of the Department is currently ~$7M. Activities performed include maintenance and fabrication involving 50,000 or more instruments having a total value in excess of $65M. The staff of the Department consists of 20 management and staff personnel, 29 technical support personnel, and 98 instrument technicians.

Strengthening MMD support of environmental monitoring and nuclear facility instrumentation has been the major new activity during the past 2 years. In particular, this has consisted of developing and publishing a comprehensive instrument calibration plan,[*] writing and issuing more than 40 detailed instrument calibration procedures, developing and presenting a short course for technicians addressing calibration of process instruments, completing a revision of the I&C Division operating safety requirements plan,[†] conducting special training for all personnel on quality assurance and NQA-1 subjects, making significant revisions in the MMD work management software program (MAJIC) to more fully meet the requirements of the ORNL Research Reactors Division, and upgrading the tools and work space directly involved in support of environmental monitoring and nuclear facility instrumentation.

In addition, MMD has assumed responsibility for management of all ORNL electronic equipment maintenance contracts and has pioneered a fixed-price arrangement for certain in-house computer support services.

The Department also initiated and completed two new support facilities. A greatly enlarged and centralized printed circuit fabrication facility was completed and made operational, and a unique multimedia, wide-range flow calibration facility was designed, constructed, and made operational.

5.1 ENVIRONMENTAL AND PROCESS INSTRUMENTATION

J. D. Blanton

Group maintenance activities include analytical chemical instrumentation, pulse height analyzers, test equipment, process instrumentation, environmental and radiation monitoring equipment, and other diverse research instrumentation.

This group is composed of one general supervisor, five supervisors, and 12 engineering technologists who direct and assist 47 instrument technicians located in 16 shops.

---

[*] *Instrument Calibration Plan of the Maintenance Management Department*, ORNL/TM-10990, February 1988.
[†] *Maintenance Management Department Operational Safety Requirements Program*, ORNL/TM-10846, June 1988.

This reporting period has seen a continuation of the addition and upgrade of equipment and introduction of new technology in many areas, which has required additional personnel training. State-of-the-art gaseous and liquid effluent radiation and water quality monitors are among the major improvements realized with completion of Phase I of the ORNL Environmental Monitoring System Upgrade. This new equipment monitors air quality for ORNL as well as the entire Oak Ridge area. A total of 21 stations monitor and report to a central data concentrator. Maintenance Management Department personnel are assisting in developing specifications and procedures to maintain operations and system reliability.

The calibration plan for MMD has been written as part of our continuing improvement of maintenance activities. This document prescribes the methods and procedures for management of the MMD calibration program. Additional calibration procedures will be written as the need arises.

A revised Maintenance Management Department Operational Safety Requirements Program has been issued. This document provides a surveillance plan for nonreactor nuclear facility operating requirements.

5.1.1 ORNL X-RAY EQUIPMENT SAFETY UPGRADE (J. D. Blanton, R. P. Effler, Jr.)

In 1983, a project was initiated to upgrade the personnel safety features of ORNL analytical and radiographic X-ray generating devices. In order to establish applicable standards and to investigate and grant requests for deviations from those standards whose intent is satisfactorily met by other methods, the ORNL X-Ray Safety Standards Review Committee was appointed on May 27, 1987. This committee, which reports to the Director of the Environmental Compliance and Health Protection Division, consists of representatives from the Metals and Ceramics, Environmental Compliance and Health Protection, and I&C divisions. Thus far the committee has established hardware and procedural safety standards based on those of the NBS (ANSI) and on Sect. 2.8 of the ORNL Health Physics Radiation Protection Manual. These standards are used by a committee member to survey each X-ray device to determine its level of compliance and then convey recommendations and deviation requests to the committee.

Upon this project's inception it became apparent that certain new electronic circuitry would be required to bring some ORNL X-ray generating equipment into compliance with the new standards. Some of this equipment is used in a unique research environment in which implementation of traditional safety circuitry would prove unfeasible or prohibitively expensive. The new circuitry requirements consist primarily of new annunciator failure interlock systems for ac and dc, continuous, and pulsating warning systems. Existing circuitry was used wherever feasible as part of these new electronic safety systems. Appropriate new circuitry that meets these requirements has been designed in MMD and approved for ORNL use by the Review Committee. Installation of numerous examples of these new circuit systems has taken place, and several more are under way or planned.

The I&C MMD has been requested to perform most of the actual X-ray equipment hardware upgrade work, and that task is well under way. Upgrade work has been completed for X-ray machinery used by the Solid State Radioisotopes and Analytical Chemistry divisions, and is in progress for machinery used by the Metals and Ceramics, Environmental Sciences, and Chemistry divisions and the ORNL Quality Department. The entire upgrade project will be essentially completed by August 1988.

5.1.2 PROCESS INSTRUMENT MAINTENANCE (R. A. Vines, B. M. Anderson, J. W. McNeillie, G. R. Sullivan)

The Process Instrument Maintenance Group includes the main shop in Building 3500, and three satellite shops in Buildings 2519, 3005, and 3606. The group is staffed by a supervisor, 3 engineering technologists, and 10 instrument technicians and is primarily responsible for providing process instrument systems maintenance, calibration, and fabrication throughout ORNL.

The main shop provides field maintenance and calibration of all customer instruments as required; calibration of secondary field standards; fabrication and test of thermocouples; inspection and calibration of new instruments; and design, fabrication, and installation of control loops and associated electronics. The Panel/Leak Detector Shop in Building 3005 is responsible for leak detector and vacuum system maintenance repair and calibration and process control panel and instrument rack fabrication. One technician in Building 3606 provides special electronics support for I&C engineering, and one technician in Building 2519 is responsible for maintenance and calibration of all steam plant, waste water treatment plant, and laboratory water supply system instrumentation.

5.1.3 ENVIRONMENTAL AND RADIATION MONITORING MAINTENANCE (B. L. Carpenter, N. A. Langley, B. R. Heidel, K. W. Buckles)

This group includes a supervisor, 3 engineering technologists, and 12 instrument technicians who provide maintenance and other support for portable radiation survey, fixed-station, and other monitoring equipment for the ORNL Environmental Compliance and Health Protection Division and the Gaseous and Liquid Waste Disposal Section of the ORNL Operations Division.

In addition to servicing all ORNL portable radiation survey instrumentation, two technicians also service portable units for the Radiological Survey Activities (RASA) Group of the ORNL Health and Safety Research Division as well as all portable radiation survey instruments at ORGDP. A service group of six technicians has maintenance responsibility for stationary radiation monitoring instrumentation; fallout; and local, perimeter, and remote air monitoring systems as well as all facility radiation and contamination alarm systems and other similar alarm systems. In addition to normal maintenance and routine system checks, this group provided support in the shakedown and successful operation of a new perimeter air monitoring system, a water-quality monitoring system, and new stack monitoring systems. Upgrading of other monitoring equipment continues. One technologist and four technicians provide service to the Gaseous and Liquid Waste Disposal Section including normal routine maintenance and systems checks. The group also provided support in the shakedown and successful operation of newly installed process waste monitoring equipment and supported upgrade and modification of the Waste Operations Control Center.

5.1.4 SPECIAL ELECTRONICS MAINTENANCE (A. J. Millet, K. L. Allison, R. P. Effler)

One supervisor, two engineering technologists, and seven instrument technicians staff the Special Electronics Maintenance Shop. To provide efficient maintenance support, the shop is divided into three sections.

The Analyzer Maintenance Section, staffed by two instrument technicians, provides maintenance support on pulse-height analyzer systems, liquid scintillation counting equipment, phototypesetting equipment, and miscellaneous nuclear instruments located throughout ORNL.

The Test Equipment and Oscilloscope Calibration Section provides maintenance as well as calibration on test equipment and oscilloscopes. This section is staffed by two instrument technicians and one engineering technologist. Equipment calibrated by this section is traceable to NBS. A portable computer-controlled oscilloscope calibrator makes possible field calibration of oscilloscopes, resulting in reduced labor costs, reduced downtime, and less chance of equipment damage during handling. Upgrade of calibration equipment in this area has resulted in a more efficient operation.

The Field Support Section, staffed by three instrument technicians, provides field support for the Solid State and Environmental Sciences divisions as well as the ORNL Quality Department in Building 2000. Field shops are located in Buildings 3001, 2000, and 1505.

5.1.5 4500 AREA MAINTENANCE (T. E. Chambers, B. C. Davis, J. L. Lane, E. R. Tapp)

This group consists of a supervisor, 3 engineering technologists, and 13 instrument technicians. The group provides support for Buildings 1505, 2011, 2026, 4500N, 4500S, 4508, 4515, 5500, 5505, and 5507, which house the following ORNL divisions: Chemistry, Physics, Chemical Technology, Analytical Chemistry, Metals and Ceramics, Health, Health and Safety Research, and Environmental Sciences. To provide efficient maintenance support, this group mans six shops located near each respective research area. The shops are combined administratively to reduce costs by sharing personnel, expertise, test equipment, and materials.

The shop in Building 4500S/B52 is staffed by one technologist and four instrument technicians and provides maintenance, calibration, and design support for the ORNL Metals and Ceramics Division. The primary function of this shop is to maintain creep test machines, which must operate at controlled temperatures for long periods of time. One of the projects presently being carried out is the design and installation of a computer interface system for test stands. Another project is the upgrade of outmoded temperature control systems to state-of-the-art control systems throughout the Creep Test Facility.

The shop in Building 4500S/S248 has two technologists and four instrument technicians. This shop provides maintenance and calibration support of chemical analysis instrumentation used by the Chemistry and Analytical Chemistry divisions and in the Walker Branch and Melton Branch Watershed projects for the Environmental Sciences Division. A project currently under way is installation and checkout of subsurface weir instrumentation.

The shop in Building 4515 is manned by one instrument technician, who is helping install state-of-the-art instrumentation. This building is a new user facility at ORNL.

Three one-man shops provide instrument support for the Health, Metals and Ceramics, and Health and Safety Research divisions.

5.1.6 EXPERIMENTAL LIQUID SCINTILLATION SPECTROMETER (J. D. Blanton, R. P. Effler, Jr.)

Liquid scintillation spectrometry is a technique of radioactive sample analysis most frequently used to determine the levels of beta particle-emitting radioisotopes contained in large numbers of liquid samples from a high-volume production process. The radioisotopes ^{14}C, ^{3}He (tritium), and ^{32}P lend themselves most readily to this type of spectroscopic analysis, and most of the readily available liquid scintillation spectroscopy equipment is designed for this specific capability. A researcher in the ORNL Chemistry Division, however, required a liquid scintillation spectroscopy system for analysis of samples containing isotopes that emit beta particles energy levels significantly different from these. It was also considered desirable for the equipment to be readily adaptable to analysis of samples containing isotopes that can be analyzed by their alpha particle energy spectra.

A used liquid scintillation spectrometer was obtained, and its framework and photodetection systems were used as the basis for a specialized system specifically designed for this unique application. A new fast coincidence circuit, a special multichannel analyzer interface, and a new sample changer interface were designed and assembled. The remainder of the new circuitry was assembled from NIM standard modules modified and adapted for the system.

Radioisotopes with a broad range of beta and alpha emission can be identified and quantified with this system. Analysis setup is greatly facilitated by the multichannel analyzer interface, which allows continuous visual inspection of that portion of the sample's radioenergy spectrum that is admitted into either of the system's two counting channels. This eliminates the considerable guesswork usually required for adjustment of channel energy discriminators. A printer was interfaced to the system to automatically produce a hard copy of each sample analysis.

This system provides a cost-effective instrument with capabilities that otherwise could have been obtained only by a large expenditure of capital funds.

5.2 COMMUNICATION AND DATA INSTRUMENTATION

C. W. Kunselman

This group is composed of a general supervisor, 5 supervisors, and 2 engineers who, with the assistance of 15 engineering technologists, direct and assist the activities of 51 instrument technicians in 11 shops. The activities of this group include maintenance of computers, data terminals and data communication equipment, reactor instrumentation, two-way radio communication equipment, video equipment (including broadband and CATV systems), and security systems. The group has a facility that fabricates instruments, printed circuit boards, and photometal for plaques. The group also manages small instrument projects and provides on-site support for ORNL Engineering.

The new printed circuit facility was brought on-line in May 1988 and is now operational. The new facility houses printed circuit, photometal, and drilling operations in one area and will make possible additional services such as silk screening, different plating for circuit boards, and color photometal.

The greatest area of growth during this reporting period has been in automated data processing (ADP) equipment quantity and service. Installation of local area networks

(LANs) has increased very rapidly and has required increased attention to that work area. A special shop has been established with a staff of two plus one engineer for ADP and LAN customer support. This group will assist, advise, and support customer needs as required. An engineering technologist from this group is assisting the Fusion Energy Design Center in software, PC networks, equipment selection, and personnel training in system use.

New areas of activity for this group include the following:

1. in-house VAX maintenance,
2. customer interface with vendor regarding PC equipment still under warranty,
3. broadband certification,
4. local area networks, and
5. writing new instrument procedures.

One of the continuing goals of this group is to minimize equipment downtime and operating expense by providing training and keeping replacement parts on site.

5.2.1 PC MAINTENANCE AND TERMINAL SHOP (C. W. Tompkins, W. A. Bratten, S. H. Dykes, B. J. Langford, V. F. McClain, T. E. Stanford)

This shop consists of 1 supervisor, 5 engineering technologists, and 11 technicians responsible for maintenance, installation, and upgrading of personal computers and associated equipment, data terminals, remote job entry stations, and supporting C&TD communication and plotting equipment.

The PC population has grown to ~3,000 plus associated peripherals representing numerous manufacturers. Two engineering technologists and six technicians are responsible for maintenance, installation, and upgrading of this equipment.

Data terminals and associated equipment are slowly declining in number. At present there are ~2,000 terminals representing forty-eight manufacturers. One engineering technologist and two technicians are responsible for maintenance, installation, and upgrading of this equipment.

One engineering technologist and two technicians are assigned to support C&TD communication systems, plotting equipment, and local area networks.

One engineering technologist and one technician are assigned to support the ORNL Engineering Physics and Mathematics Division by maintaining the remote job entry station and all computer-associated equipment in the division.

Exchanges or necessary repair parts and technical assistance are obtained from local dealers when possible. In recent years, PC retrofit and upgrade activity has become a substantial part of the work of this shop.

5.2.2 COMPUTER MAINTENANCE (R. P. Rosenbaum, K. H. Pate, D. W. Valentine)

This 11-member service group is responsible for maintenance on mini- and midsize computer systems, Ethernet communication networks, and Hewlett-Packard equipment at ORNL. The approximately 325 computer systems supported range in size from desktop HPs to the DEC VAX 11/785, along with related peripheral equipment such as disk drives, printers, plotters, magnetic tapes, and data collection equipment. The Ethernet communication network is now undergoing rapid expansion to include the entire ORNL complex.

Strong emphasis is placed on training, maintaining adequate spare parts, exercising rigorous preventive maintenance, and ensuring factory backup service through service contracts. Innovation and vendor support permit this group to perform required services in a timely and cost-effective manner.

5.3 COMMUNICATION AND SECURITY MAINTENANCE

H. C. Ford
G. D. Inman
C. A. Smith

The 12 persons in this group are responsible for maintaining site-wide two-way radios, the security CATV network and other security alarm systems and badge readers, the broadband data system, building sound systems, and video equipment. They also provide audiovisual support for meetings at ORNL.

The accomplishments of this group during this reporting period include training four technicians to repair and maintain the broadband system, training one additional technician to repair the security alarm system, scheduling noise leakage tests on the broadband system (required by the FCC), and level testing pilot carriers through the MAJIC system for the broadband data system.

A new communication analyzer was purchased this year, doubling the maintenance and calibration capacity of the radio shop.

The security CATV has been updated, black and white cameras have been replaced with color cameras, and some new TV monitors have been installed. Also, the test equipment inventory for the CATV and broadband systems has been expanded with the addition of a Wavetek 1882 spectrum analyzer. This device will improve troubleshooting time on noise and other maintenance problems of the cable systems.

The satellite receiver station was updated by this group to allow ORNL to receive both "C" band and "K" band satellite programs, which can be retransmitted to all Oak Ridge facilities via the broadband system.

The dual security alarm system was made operational, and security panels were reworked to ensure easier operation and access for the operators. This upgrade was commended by DOE inspection teams.

Preventive maintenance and checkout procedures for the security maintenance system have been rewritten to cover changes in the system. This system is still expanding with installation of additional alarm points and changes in badge reader requirements.

5.4 ELECTRONIC FABRICATION

C. R. Cinnamon
R. S. Thomas
K. E. Wright

This 13-member group builds instrument prototypes, makes major instrument modifications, and produces electronic instruments. Technicians working with the I&C Division engineering staff construct prototypes and fabricate instruments for I&C engineering groups and other ORNL research staff members. Printed circuit boards, produced in small quantities in the group PC Board Facility from drawings generated by the Product Development Drafting and Group, are used in prototypes and in small production jobs. Photometal work for panels, decals, plaques, and nameplates is also performed in this facility.

Significant accomplishments during this reporting period include fabrication of instruments for the USRADS Project in Colorado and for health physics survey and reactor instruments.

Major improvements include bringing the new printed circuit facility on-line, producing printed circuit boards, and implementing a record system to track fabrication and photometal projects.

Four technicians were enrolled in the Digital Logic and Solid-State Fundamentals training courses.

5.5 REACTOR SYSTEMS MAINTENANCE AND ENGINEERING SUPPORT

C. G. Allen
A. J. Beal
H. L. Haga
M. T. Hurst

This group of 14 persons maintains all ORNL operating reactors and provides support for ORNL facilities and engineering projects.

Reactor systems maintenance, which includes only technicians certified for reactor control work, provides maintenance services to all reactors at ORNL. This group provided maintenance assistance for several significant design changes to the control and safety-related systems at the HFIR facility. Previously established maintenance programs have continued.

Maintenance personnel continued to gain more experience with the systems and to increase their diagnostic ability when faced with equipment malfunctions or abnormal conditions. Increased proficiency, redundant instruments, and interchangeability of modules have enabled the technicians to perform all routine plant maintenance on-line while the reactors are operating. Preventive maintenance capability was also improved so that through careful scheduling less than 10% of the programmed maintenance work will require the reactor to be shut down.

Extensive preparation, changes, and instrument calibrations were required to install two new experiments in the HFIR for the ORNL Metals and Ceramics Division. In addition, the experiments in operation at the BSR facility were maintained.

5.5.1 ENGINEERING SUPPORT (C. G. Allen, A. J. Beal, M. T. Hurst)

This group coordinates field installation of engineering projects for ORNL Engineering. Based on approved drawings delivered by ORNL Engineering, I&C maintenance procures and/or provides parts and material; submits cost estimates; ensures proper assignment of work to respective crafts; and coordinates, fabricates, calibrates, installs, and checks out systems in a timely and orderly manner. The scope of such projects requires close coordination of I&C and ORNL Plant and Equipment Division services. Upon completion of each project, a fully functioning system is delivered to the operating organization. During the past 2 years this group has been involved in several large-scale improvement projects. A nonradiological waste water treatment project (NRWTP) for the Operations Division included installation of two distributed control systems accommodating ~340 field process signals. Coupled with the NRWTP was an upgrade of process waste monitoring (PWMS) methods and installation of a liquid waste metals monitor at the HFIR-TURF and TRU facilities.

MMD engineering assistance was provided by the I&C MACES staff to design, fabricate, install, and test a new flow stand calibration system for the I&C Division.

Another large project was design, fabrication, installation, and testing of a data acquisition/control system and signal instrument upgrade for the design basis accident (DBA) process control system at Building 2026.

5.5.2 6000/7600 AREA MAINTENANCE (R. H. Brown)

This group is composed of one supervisor and six instrument technicians. Four instrument technicians provide service in support of work primarily related to the 25-MV Tandem and ORIC accelerators at the Holifield Heavy Ion Research Facility. This includes service of machines as well as support to research personnel, from ORNL and all over the world.

Two instrument technicians provide service in support of work primarily related to the Oak Ridge Electron Linear Accelerator and research personnel.

5.6 MMD TRAINING PROGRAMS

J. D. Blanton
C. T. Stansberry
R. P. Effler, Jr.

The exponential increase in the technological data available to designers of instrumentation and control systems requires that a continuous and intensive training program be an integral component of an effective maintenance organization. The MMD maintains a training program covering subjects ranging from the fundamentals of technical theory to the practical application of theory to the specifics of a particular instrument or system. Safety topics such as cardiopulmonary resuscitation and first aid are also taught because they are considered essential to the well-being of all Laboratory employees.

Training courses take the form of in-house lecture classes, video tape classes (MMD maintains a library containing more than four hundred tapes), outside seminars, and satellite transmitted training sessions. These media are used to cover such diverse topics as the fundamentals of digital logic, operational safety requirements, reactor access training, laboratory emergency response center, microprocessors, and a broad range of on-the-job and off-the-job safety concerns.

The MMD training program is of necessity dynamic. Its content and format are constantly reviewed and updated to reflect the changing scientific and technological environment of ORNL. All MMD courses are available to any Laboratory employee who has a need for the subject material presented. Employee training records are kept in a data base on the I&C VAX computer system, and this information is available to those to whom it is essential (e.g., maintenance supervisors). Adequate, high-quality training is an indispensable tool to a research facility such as ORNL.

5.7 RESTART OF THE ORNL HIGH FLUX ISOTOPE REACTOR

D. R. Miller

The Maintenance Management Department of the Instrumentation and Controls Division has a significant commitment to provide maintenance support for all ORNL research reactors. In the past 2 years this support has been undergoing change and upgrade in response to new DOE regulations and recommendations relating to reactor operation. Following the shutdown of the ORNL High Flux Isotope Reactor ordered by DOE, the MMD solicited guidance from several experts and then formulated a strategy for increasing its capability and expanding and improving its management systems.

One of the first goals set was that of beginning a multiyear program aimed at becoming the leading maintenance organization among all DOE contractors in instrument calibration. The Department initiated this process with a significant lead due to the excellent synergism between the engineering and maintenance segments of the I&C Division. A MMD Calibration Committee was formed to gather data about the state of the art in metrology and about our local calibration systems. Following this, the committee recommended that a definitive calibration plan be written which would address the diverse needs of a multiprogram laboratory such as ORNL. Such a document was issued which describes the plan developed. The document, ORNL/TM-10990, prescribes the methods and procedures for management of the MMD calibration program.

A companion goal suggested by the Calibration Committee was to develop detailed individual instrument calibration procedures. These procedures would be in a uniform format and would apply to ORNL reactors as well as to other ORNL nuclear facilities. A special meeting was called in March 1988 to discuss this project with the I&C technical staff. Several MMD staff members were assigned responsibility for drafting segments of the total package. By July 1988, drafts of more than 40 calibration procedures were delivered for editorial review. They were then copied in a format specific to the ORNL Research Reactors Division and issued for use at the HFIR.

The second element of overall MMD reactor support improvement was to substantially strengthen management systems, of which the key system was determined to be the MMD work and equipment information management system. This set of software packages, identified as the Maintenance Acccountabilty, Jobs, and Inventory Control (MAJIC) system and its associated operating procedures, was examined to identify weaknesses in light of current DOE and Research Reactors Division requirements. It was determined that significant improvements in the preventive maintenance recall procedure, the calibration standard identification system, and storage of specific calibration data were needed. By the end of this reporting period all of the planned improvements were being implemented in software, and operating procedures were in preparation.

The third major element of the reactor support upgrade was the MMD instrument technician training program. In many ways this was the most challenging of the three projects. Department personnel participated in the Seventh Symposium on Training of Nuclear Facility Personnel in April 1987, the 1988 DOE National Maintenance Managers' Conference, and numerous regional nuclear facility conferences in 1987 and 1988. In addition, in 1988 MMD personnel visited a training center operated by a commercial power utility and studied its program and practices. The Department concluded that the extensive effort required makes preparation of a revised, comprehensive training plan a long-range goal. For the near term, MMD elected to revise and reissue the existing in-house training plan based on ANSI 3.1 guidance and to begin job-specific training at once. A team of expert instructors was assembled using many of the original HFIR design team members and staff specialists in such areas as troubleshooting solid state devices, emergency systems in the HFIR, and procedures for approval to perform work at the HFIR. All of this training, given to all I&C personnel regularly assigned or identified as backup personnel for HFIR support, is recorded on videotape for future use.

5.8 PUBLICATIONS

5.8.1 INSTRUMENT CALIBRATION PLAN OF THE MAINTENANCE MANAGEMENT DEPARTMENT

Report ORNL/TM-10990 documents the methods and procedures for management of the I&C Division Maintenance Management Department Calibration Program as required by ORNL Quality Assurance Procedures and by the I&C Maintenance Management Plan (ORNL/TM-10136).

The primary function of the MMD Calibration Program is to ensure the measurement integrity of any instrument used in inspection or testing to provide quantitative data concerning end items, systems, or subsystems.

The MMD Calibration Program covers measurement standards and equipment, technical personnel, plant-wide work centers, measurement equipment users, calibration data, and integrated planning. These elements are combined in a structured program to ensure the reliability and accuracy of systems, subsystems, and equipment by verifying that equipment used to make measurements or quality judgments conforms to established technical requirements.

5.8.2 MAINTENANCE MANAGEMENT DEPARTMENT OPERATIONAL SAFETY REQUIREMENTS PROGRAM

Report ORNL/TM-10846 describes the requirements, procedures, and responsibilities of the I&C Maintenance Management Department for instrument maintenance in ORNL nonreactor nuclear facilities having designated operational safety requirements. This report outlines applicable DOE, Martin Marietta Energy Systems, Inc., and ORNL procedures.

The objective of this document is to present a surveillance plan for nonreactor nuclear facility safety hardware, thereby fulfilling the requirements of the responsible ORNL operating division. Scheduled maintenance and surveillance plans for components or systems as required by ORNL operating safety requirements are also addressed.

5.8.3 INSTRUMENTATION AND CONTROLS DIVISION MAINTENANCE MANAGEMENT PLAN

The 1988 revision of the Maintenance Management Plan (ORNL/TM-10136, Rev. 2) includes new sections covering the long-range work plan and cross-cut* budget required by DOE. The management plan is an outline of the various structured activities performed by the I&C Maintenance Management Department. In addition, all currently applicable DOE guidelines and requirements are described.

MMD policies and procedures described in the management plan are intended to comply with Energy Systems, DOE, and ORNL directives. Particular subjects covered include safety, quality assurance, emergency preparedness, and support of nuclear facilities.

5.9 LIST OF PUBLICATIONS

J. D. Blanton, "Instrument Calibration Plan of the Maintenance Management Department," ORNL/TM-10990.

J. D. Blanton and A. J. Millet, "Maintenance Management Department Operational Safety Requirements Program," ORNL/TM-10846, June 1988.

M. A. Broders and D. R. Miller, *Energy and Cost Savings Analysis of Wood Burning Boiler Plant*, Fort Stewart, Ga., Validation of ECIP Project No. 193, ORNL/CON-219, August 1987.

D. R. Miller, "DOE National Meeting Technical Program Survey of DOE Contractor Maintenance Information Systems," National Department of Energy Maintenance Managers Conference, New Orleans, La., March 28-31, 1988.

D. R. Miller, *Instrumentation and Controls Division Maintenance Management Plan*, ORNL/TM-10136 (Revised), July 1988.

C. T. Stansberry, *ORNL Nuclear Reactor Qualification and Training Requirements for I&C Division Maintenance Personnel*, ORNL/TM-10131, April 1987.

*"Cross-cut" is a term used by DOE in reference to maintenance support of real property and related property at ORNL.

APPENDIX

SUPPLEMENTARY 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.

Advisory Committee - 1988

J. B. Ball, Physics Division, Oak Ridge National Laboratory, Post Office Box X, Oak Ridge, TN 37831

Peter F. McCrea, Vice President and Director of Corporate Research, The Foxboro Company, Foxboro, MA 02035

Division Consultants

R. K. Adams
J. D. Allen
J. Anderson
W. Appleton
D. W. Bouldin
T. L. Bowers
R. P. Broadwater
R. V. Bubey
D. Brzakovic
C. L. Carnal
W. H. Casson
J. P. Cook
R. W. Courtney
E. P. Epler
J. A. Euler
J. T. Farmer
R. R. Feezell
M. B. Herskovitz
C. S. Hollander
S. K. Hussain
T. W. Kerlin
B. Lieberman
B. I. Leinart
J. Lewin
J. L. Lovvorn
F. W. Manning
J. H. Marable
C. D. Martin
H. D. Miller
E. C. Muly, Jr.
W. P. Murray
D. F. Newport
W. W. Parkinson
R. B. Perez
W. B. Reese
J. M. Rochelle
R. W. Rochelle
E. R. Rohrer
G. V. S. Raju
R. F. Saxe
M. A. Schultz
D. L. Senn
G. E. Shafer
G. V. Smith
J. D. Stanley
J. A. Thie
R. W. Tucker, Sr.
P. R. Upadhyaya
C. H. Weaver
D. K. Wehe
S. J. Wertheimer
H. N. Wilson
M. K. Wu

United States-Taiwan AIT/CCNNA Program for Nuclear Cooperation

Shian-Shing Shyu	Institute of Nuclear Energy Research
Wei-Min Chia	Institute of Nuclear Energy Research
Wei-Chu Yu	Institute of Nuclear Energy Research
Hwai-Pwu Chou	National Tsing Hwa University

Graduate Students

D. J. Auslander
R. C. Berkan
A. R. Bugos
M. L. Granger
J. G. Horner
S. K. Hussain
R. B. Magness
M. N. Natour
B. S. Schwartz

Coop Students

J. D. Belcher
R. F. K. Bliss
C. E. Burton
W. R. Clem
M. A. Hannah
F. B. Hedspeth, Jr.
C. A. Hendrich
C. D. Hopper
D. L. Houser
L. P. Hull
M. R. Kedl
E. M. King
T. J. Preston
M. D. Smith
B. K. Swail
T. E. Talley, Jr.
M. E. Wyman

SEMINARS PRESENTED OR SPONSORED BY INSTRUMENTATION AND CONTROLS DIVISION STAFF

During this reporting period the Instrumentation and Controls Division presented or sponsored the seminars listed to inform I&C staff and other interested members of the local scientific community about topics of general interest in areas of instrumentation and controls.

Use of Artificial Intelligence in Science and Engineering, *Robert E. Uhrig, ORNL and The University of Tennessee, Knoxville;* Oak Ridge Section, IEEE, March 9, 1987.

Non-Concurrent Error Detection in Mixed Devices, *Marc L. Simpson, University of Virginia, Charlottesville*; June 4, 1987.

Adaptive Model-Following Control for Hyperthermia Treatment Systems, *R. L. Kress, University of Arizona, Tucson;* July 16, 1987.

Comparison of Robotic Positional Control Strategies, *John F. Jansen, Virginia Polytechnic Institute and State University, Blacksburg;* July 28, 1987.

Robot Control for Tomorrow–Neural Networks, *William B. Dress, ORNL*; Robotics International, September 8, 1987.

Control of Uncertain Nonlinear Systems with Application to Electric Machinery and Robotic Manipulators, *David G. Taylor, Electrical Engineering Department, University of Illinois Urbana;* September 10, 1987.

Power Communication Skills for Women, *Hattie Hill-Stokes, Career Track Seminars*; November 2-3, 1987.

TELEROBOTICS RESEARCH SEMINAR, November 19, 1987: **Overview,** *W. R. Hamel, Moderator*; **Advanced Teleoperators for Fuel Reprocessing,** *M. W. Noakes*; **The Future in Space Manipulation,** *J. N. Herndon*; **Stabilization of Teleoperated Mobile Vehicle Viewing,** *H. M. Costello*; **Control of Manipulators with Redundant Kinematics,** *S. M. Babcock.*

Your Research Can Benefit From Recent Advances in and Cost-Effectiveness of VLSI Chips, *Don Bouldin, Electrical Computing Engineering Department, The University of Tennessee, Knoxville;* December 7, 1987.

An Overview of Fiber Optics, *Dr. Don Gilbert, Tennessee Technological University, Cookeville;* December 10, 1987.

Use of Neutron Noise Techniques to Estimate Reactor Power, *Ricardo M. Waldman, Atomic Energy Commission of Argentina, Buenos Aires;* December 18, 1987.

A Parallel Computing Architecture for Artificial Intelligence--Expert Systems Processing, *P. L. Butler, ORNL*; East Tennessee/Oak Ridge IEEE Computer Society, January 11, 1988.

Capability of Laser Scattering Diagnostics for Nonintrusive Measurements, *Dr. Homer Powell, Tennessee Technological University, Cookeville;* February 23, 1988.

ARTIFICIAL INTELLIGENCE RESEARCH COLLOQUIUM, March 8, 1988: **A Darwinian Approach to Artificial Neural Systems,** *W. B. Dress*; **Applications of Artificial Intelligence in the U.S. Nuclear Industry,** *R. E. Uhrig*; **A Parallel Machine for Running Expert Systems in Real Time,** *P. L. Butler*; **Promises in Intelligent Plant Control Systems;** *P. J. Otaduy.*

Concurrent Error Detection in Programmable Logic Arrays, *Larry Wurtz, Auburn University, Ala.;* March 22, 1988.

Microrobotics, Microcutting, and Systems Integration, *Steve Charles, Vitreoretinal Surgeon, Memphis;* March 28, 1988.

Modeling and Control of Wheeled Mobile Pobots, *Patrick F. Muir, Carnegie Mellon University;* April 14, 1988.

Instrumentation for Nondestructive Testing to Determine Internal Quality of Fruit, Stewart V. Bowers III, Clemson University; July 15, 1988.

The $400 million Alcoa Plant Upgrade, *John R. Burke and Ken Main,* Aluminum Company of America; July 28, 1988.

Career Development Strategies for Women, Satellite Videoconference, Coastline Community College; August 19, 1988.

TECHNOLOGY TRANSFER

The rights to manufacture and market the Instrumentation and Cont ols Division developments described here have been transferred to private industry through the Martin Marietta Energy Systems Technology Transfer Program.

Africanized Bee Detector

The Acoustical Peak Identification System (APIS) is a field portable device that identifies subspecies of honeybees. In particular, it can distinguish between flying Africanized and European honeybee subspecies by means of the different sounds produced by their wingbeats. The frequencies of the characteristic peaks in the acoustical signature of flying honeybees differ for each of these subspecies. APIS employs sensitive tone decoders to locate those peaks, and a simple visual readout indicates to the user which type of honeybee is present.

Signal-Conditioning Electronics Package for MCSA

Motor current signature analysis (MCSA) is a powerful monitoring technology that provides a nonintrusive means of detecting changes in process conditions or the presence of mechanical abnormalities "downstream" from a primary mover. Although developed specifically for determining the effects of service wear on motor-operated valves used in nuclear power plants, MCSA is applicable to a broad range of electric-motor-driven equipment.

Ultrasonic Range and Data System (USRADS)

The ultrasonic range and data system was developed to correlate a radiological surveyor's location with radiation data collected by a portable survey instrument. Special computer algorithms distinguish between valid signal paths and error or echo signal paths from houses, trees, or utility buildings. This system was developed for use as a data collection and tracking system for radiological surveys performed in an urban environment as part of the DOE Uranium Mill Tailings Remedial Action Program.

The following developments have been made available for licensing to private industry through the Martin Marietta Energy Systems Technology Transfer Program.

OPSNET: A Parallel Architecture for Expert Systems

OPSNET is a new computer architecture for high-speed execution of expert system software. Sixty-four microprocessors controlled by a host microcomputer execute rule-based code at speeds that compare favorably with superminicomputer speeds.

Real-Ops: Real-time Expert System for Control

Real-Ops is a real-time expert system language for engineering applications. It extends and enhances Carnegie-Mellon's OPS5 language to include real-time, multitasking, asynchronous control applications.

Remote Sensor and Cable Identifier

The remote sensor and cable identifier (RSCI) system automatically identifies the sensor and cables that are connected to each input channel of a data acquisition system (DAS). The passive identifier modules attach to sensors or cable connectors and operate in a manner transparent to the DAS. The system is a powerful quality assurance tool for large, complex, heavily instrumented experiments and installations.

INSTRUMENTATION AND CONTROLS DIVISION PATENT APPLICATIONS FILED AND PATENTS ISSUED JULY 1, 1986 THROUGH JULY 1, 1988

ESID No.	Name	Description	Patent No. and date
		Patents Issued	
4507	H. L. Martin S. M. Killough	Electromechanical Actuator for the Tongs of a Servomanipulator	4,608,526 August 26, 1986
4409	W. B. Jatko D. R. McNeilly L. H. Thacker	Precision Linear Ramp Function Generator	4,611,176 September 9, 1986
CNID 4512	Richard J. Fox	Fiber-Type Dosimeter with Improved Illuminator	4,697,084 September 29, 1987
CNID 4501	R. S. Ramsey* R. A. Todd	Pulsed Helium Ionization Detection System	4,705,947 November 10, 1987
60-X	R. S. Ramsey* R. A. Todd	Closed-Loop Pulsed Helium Ionization Detector	4,705,948 November 10, 1987
		Patent Applications Filed	
79-X	M. K. Kopp	Method of Radiation Dose-rate measurement with energy-sensitive counters	December 20, 1986
233-X	M. M. Chiles J. T. Mihalczo E. D. Blakeman	High Efficiency Scintillation Detector for Thermal and Fast Neutrons and Gamma Radiation	February 27, 1987
158-X	H. R. Brashear M. S. Blair J. F. Phelps M. L. Bauer C. H. Nowlin	Ultrasonic Ranging and Data Telemetry System	March 23, 1987
142-X	W. F. Johnson C. A. Burtis†	Rotor & Disk System for Automated Processing of a Whole Blood Sample into Multiple, Microliter Aliquots of Plasma	April 8, 1987
39-X	P. L. Butler J. D. Allen, Jr.	Parallel Machine Architecture for Production Rule Systems	June 9, 1987
234-X	W. F. Johnson C. A. Burtis W. A. Walker	Rotor for Processing Liquids Using Movable Capillary Tubes	July 17, 1987
165-X	S. P. Baker R. L. Dural	Transmission of Low Frequency Analog Signals over AC Power Lines	July 30, 1987

*Analytical Chemistry Division.
†Chemical Technology Division.

Patent Applications Filed (continued)

238-X	R. M. Carroll	In-Situ Restoration of Platinum Resistance Thermometer Calibration	October 23, 1987
304-X	H. T. Kerr M. E. Buchanan K. H. Valentine	Field-Portable Africanized Bee Detectors	March 3, 1988
265-X	J. E. Phelps	Packet Personal Radiation Monitor	March 31, 1988
285-X	T. M. Gayle B. C. Davis	Sensor for the Detection of Liquids on Floors and Other Surfaces	July 27, 1988*

*Statutory Invention Registration filed.

SCIENTIFIC AND PROFESSIONAL ACTIVITIES, ACHIEVEMENTS, AND AWARDS

July 1, 1986 - July 1, 1988

D. C. Agouridis

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

C. G. Allen

Senior Member, Instrument Society of America
Member, I&C Safety Committee
Member, MMD MAJIC Committee

G. T. Alley

Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member, Tau Beta Pi
Registered Professional Engineer

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
Invited Paper: "Motion Sickness Symptoms and Postural Changes Following Flights in Motion-Based Flight Simulators," G. O. Allgood, R. S. Kennedy, B. W. Van Hoy, M. G. Lilienthal, The 4th International Meeting on Low Frequency Noise and Vibration, Humanisthuset, Sweden, June 1987
Invited Paper: "Etiological Significance of Equipment Features and Pilot History in Simulator Sickness," G. O. Allgood, R. S. Kennedy, K. S. Berbaum, N. E. Lane, M. G. Lilienthal, AGARD Conference, Brussels, September 1987,
Invited Paper: "Enhanced Utility of War Games Through AI - From Basic Constructs To Synthetic Intelligence," G. O. Allgood, D. S. Hartley, Joint National Meeting of the Operations Research Society of America and The Institute For Management Science (ORSA/TIMS), St. Louis, October 25-28, 1987
Invited Paper: "Very Low Frequency Vibration in a Motion Base Helicopter Simulator Compared to the Simulated Platform," G. O. Allgood, R. S. Kennedy, K. S. Berbaum, B. W. Van Hoy, Acoustical Society of America, Honolulu, November 14-18, 1988

Invited Paper: "Basic Constructs for a Weapons Platform/Weapons Suite Mapping Onto Mission Profiles - A Classifier For JTLS ATO Expert System," G. O. Allgood, L. C. Williams, Office of Joint Chiefs of Staff Military Aides Planning Conference, Hurlburt Field, Ft. Walton Beach, Florida, November 16, 1988

A. H. **Anderson, Jr.**

Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member, Tau Beta Pi
Registered Professional Engineer

R. L. **Anderson**

IR-100 Award, *Remote Sensor and Cable Identifier*, 1987
Member, American Physical Society
Member, American Society for Computing Machinery
Member, American Vacuum Society
Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society
Member, Instrument Society of America
Member, Optical Society of America
Member, Society of Photo-Optical Instrumentation Engineers
Member, Sigma Xi
Metric Coordinator, Instrumentation and Controls Division

W. H. **Andrews, Jr.**

Senior Member, Instrument Society of America
Member, Computer Security Institute
Member, IEEE Computer Society
Member, Eta Kappa Nu
Invited Presentation: "Hardware for Improved Crossing Signal Visibility," National Transportation Research Board Annual Meeting, Washington, D. C., January 1987

G. A. **Armstrong**

Member, Instrument Society of America
Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member, Omicron Delta Kappa
Member, Phi Kappa Phi
Member, Tau Beta Pi

S. M. Babcock

Member, American Association for Artificial Intelligence
Member, American Society of Mechanical Engineers
Member, Robotics International; President, Knoxville Chapter
Invited Paper: "Telerobotic Control of the Seven-Degree-of-Freedom CESAR Manipulator," S. M. Babcock, R. V. Dubey, J. A. Euler, R. L. Glassell, R. L. Kress, W. R. Hamel, NATO Advanced Research Workshop on Robots with Redundancy: Design, Sensing, and Control, Salo, Lago di Garda, Italy, June 27-July 1, 1988
Invited Paper: "Self-Motion Determination Based on Joint Velocity Bounds for Redundant Robots," J. A. Euler, R. V. Dubey, S. M. Babcock, Second International Symposium, Robotics and Manufacturing Research, Education and Applications, Albuquerque, New Mexico, November 16-18, 1988
Invited Paper: "A Comparison of Two Real-Time Control Schemes for Redundant Robots with Bounded Joint Velocities," J. A. Euler, R. V. Dubey, S. M. Babcock, W. R. Hamel, IEEE International Conference on Robotics and Automation, Scottsdale, Arizona, May 14-19, 1989

S. P. Baker

Senior Member, Instrument Society of America
Registered Professional Engineer

S.J. Ball

Member, Society for Computer Simulation
Member, Sigma Xi
Chairman, ORNL Reactor Operations Review Committee
Invited Publication: "Control of Two-Phase Evaporation Flows," in *Measurement and Control in Water Desalination*, ed., N. Lior, Elsevier Science Publishers, Amsterdam, October 1986

T. R. Barclay

Registered Professional Engineer

D. D. Bates

Member, Martin Marietta Energy Systems Inventor's Forum
Member, Fusion Energy Division Committee on Major Electrical Equipment Review
Member, Fusion Energy Division Committee to Review LCTF Coil Protection System
Member, Fusion Energy Division Major Electrical Review Committee
Member, Fusion Energy Division Safety Review Committee for ISX-B Gyrotron Power System

R. E. Battle

Member, Institute of Electrical and Electronics Engineers; Newsletter Editor, Oak Ridge Section; Member, Working Group 4.3, Station Blackout
Registered Professional Engineer

M. L. Bauer

Member, American Vacuum Society; Member, Executive Committee, Tennessee Valley Chapter

Member, Society of Photo-Optical Instrumentation Engineers

Invited Paper: "Improved Capabilities for Area Environmental Monitoring at Oak Ridge National Laboratory," A. C. Morris, Jr., M. L. Bauer, R. E. Pudelek, IEEE Nuclear Science Symposium, Washington, D.C., October 27-November 1

D. W. Bible

Invited Paper: "Radiation-Hardened Television Camera Development," D. W. Bible, A. C. Morris, Jr., E. J. Kennedy, S. F. Smith, France/USDOE Meeting on Remote Systems Technology, Oak Ridge, May 5-9, 1986

E. D. Blakeman

Invited Paper: "^{252}Cf-Source-Driven Neutron Noise Measurements of Subcriticality for a Slab Tank Containing Aqueous Pu-U Nitrate," J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, R. C. Kryter, R. C. Robinson, H. Seino, T. Matsumoto, H. Yamana, International Seminar on Nuclear Criticality Safety, October 19-23, 1987, Tokyo

Invited Paper: "Subcritical Interaction Experiments with Four Safe Storage Bottles Containing Aqueous Uranyl Nitrate," J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, International Seminar on Nuclear Criticality Safety, October 19-23, 1987, Tokyo

A. V. Blalock

Member, Eta Kappa Nu

Member, Tau Beta Pi

T. V. Blalock

Member, Institute of Electrical and Electronics Engineers; Member, Transducers Committee

Haliburton Engineering Professorship, The University of Tennessee

J. L. Blankenship

Senior Member, Institute of Electrical and Electronics Engineers

Member, American Physical Society

J. D. Blanton

Senior Member, Instrument Society of America

Member, Institute of Industrial Engineers

Member, ORNL Health Physics Instrument Committee

R. S. Booth

Fellow, American Nuclear Society

Member, ORNL Wigner Fellowship Selection Committee

C. R. Brittain

Invited Paper: "A New Approach to Hierarchical Decomposition of Large-Scale Systems," C. R. Brittain, P. J. Otaduy, L. A. Rovere, R. B. Perez, 3rd IEEE International Symposium on Intelligent Control, Arlington, Virginia, August 22-24, 1988

E. R. Broadaway

Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society
Member, IEEE Power Engineering Society
Member, Phi Kappa Phi
Member, Tau Beta Pi
Invited Paper: "Monitoring Load Control at the Feeder Level Using High Speed Monitoring Equipment," J. H. Reed, W. R. Nelson, G. R. Wetherington, E. R. Broadaway, Athens Advisory Committee, Athens, Tennessee, September 23, 1987
Invited Paper: "Monitoring Load Control at the Feeder Level Using High-Speed Monitoring Equipment," J. H. Reed, W. R. Nelson, G. R. Wetherington, E. R. Broadaway, Institute of Electrical and Electronic Engineers/Power Engineering Society Winter Meeting, New York, January 31-February 5, 1988

W. L. Bryan

Member, Institute of Electrical and Electronics Engineers

M. E. Buchanan

Member, ETA Kappa Nu
Member, Phi Kappa Phi

P. L. Butler

R&D-100 Award, *OPSNET Parallel Expert System Computer*, 1988
Martin Marietta Energy Systems Inventors Award, May 1987
Member, FORTH Interest Group
Member, Institute of Electrical and Electronics Engineers
Member, Tau Beta Pi
M.S., The University of Tennessee, Knoxville; Thesis: "Design and Implementation of a Parallel Processing Machine for Artificial Intelligence Applications, "December 1987
Invited Paper: "Design and Implementation of a Parallel Computer for Expert System Applications," P. L. Butler, J. D. Allen, Jr., D. W. Bouldin, Applications of Artificial Intelligence VI, Sponsored by SPIE and IEEE, Orlando, April 6, 1988
Invited Paper: "Parallel Architecture for OPS5," P. L. Butler, J. D. Allen, Jr., D. W. Bouldin, Fifteenth Annual International Symposium on Computer Architecture, Honolulu, May 30, 1988

C. L. Carnal

Member, Institute of Electrical and Electronics Engineers
Faculty Advisor and Member, Eta Kappa Nu
Member, Phi Kappa Phi
Member, Tau Beta Pi
Registered Professional Engineer

M. H. Carpenter

Member, American Society for Engineering Management
Member, American Society of Mechanical Engineers
Member, Kappa Mu Epsilon
Member, Pi Tau Sigma
Member, Tau Beta Pi

C. R. Cinnamon

Member, National Institute for Certification in Engineering Technology

N. E. Clapp, Jr.

Senior Member, Instrument Society of America
Member, Phi Eta Sigma
Member, Phi Kappa Phi
Member, EPRI's Instrument Calibration Reduction Program Advisory Committee
Member, ORNL Scientific and Technical Computing User Advisory Committee

D. A. Clayton

Member, Digital Equipment Corporation Users' Society
Member, Institute of Electrical and Electronics Engineers
Member, IEEE Automatic Controls Society
Member, IEEE Computer Society
Member, Eta Kappa Nu

G. K. Corbett

Member, Institute of Electrical and Electronics Engineers; Treasurer, Oak Ridge Section

R. I. Crutcher

Registered Professional Engineer
M.S., The University of Tennessee, Knoxville; Thesis: "Analysis of a Data Isolation Technique for a Broadband Local Area Network," June 1988
Invited paper: "A Mixed-Modem Solution for Sensitive Data Segregation on a Broadband Network," R. I. Crutcher, P. D. Ewing, Eleventh DOE Computer Security Group Conference, Kansas City, Missouri, May 4, 1988
Invited paper: "A Mixed-Modem Approach to Data Isolation on a Broadband Local Area Network," R. I. Crutcher, P. D. Ewing, IEEE Southeastcon '88, Knoxville, April 11, 1988

B. Damiano

Member, American Nuclear Society
Member, American Society of Mechanical Engineers
Member, Tau Beta Pi
Registered Professional Engineer

J. B. Davidson

Member, Sigma Xi
Member, Martin Marietta Energy Systems Inventors Forum Board of Directors
Invited Presentation: "Electronic Vision: Applications in Physics, Chemistry and Biology," ORNL Summer Seminar Series, August 18, 1987

F. W. DePiero

M.S., Michigan State University, June 1987

K. W. Drescher

(I&C) Electronic Design and Integrated Fabrication Committee

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
Adjunct Professor, The University of Tennessee, Knoxville
Judge, International Science Fair, Knoxville, 1988
Invited Paper: "Alternative Knowledge Acquisition: Developing a Pulse-Coded Neural Network," Long Island University Computer Technology Symposium, Brookeville, New York, January 23, 1987
Invited Paper: "High Performance Neural Networks," 1987 Rochester FORTH Conference on Applications of Real-Time Artificial Intelligence, University of Rochester, Rochester, New York, June 12, 1987
Invited Paper: "Applications of Concurrent Neuromorphic Algorithms for Autonomous Robots," W. B. Dress, J. Barhen, C. C. Jorgensen, NATO Advanced Research Workshop On Neural Computers, Dusseldorf, West Germany, September 28-October 2, 1987; in *Neural Computers*, NATO ASI Series F, Vol. 41, Springer-Verlay, New York
Invited Paper: "A Darwinian Approach to Artificial Neural Systems," W. B. Dress, J. R. Knisley, IEEE Systems, Man, and Cybernetics Annual Conference, Washington, D. C., October 22, 1987
Invited Seminar: "Two Biological Metaphors for Synthetic Neural Systems," ISA/IEEE Joint Meeting, Knoxville, March 3, 1988
Invited Presentation: "Comment on Breakdown of the Bicameral Mind," American Philosophical Association, Cincinnati, April 29, 1988

Invited Presentation: "Electronic Life and Synthetic Intelligent Systems," 1988 Military Computing Conference, Anaheim, May 4, 1988
Invited Presentation: "Two Biological Metaphors for Synthetic Neural Systems," 17th ASIS Mid Year Meeting, Ann Arbor, Michigan, May 17, 1988
Invited participant: Santa Fe Complex Systems Summer School, Sante Fe, New Mexico, June-July 1988
Invited Presentation: "Real-Time Neural Nets," Real Time Computing Conference, Anaheim, November 17, 1988
Invited article: "Electronic Life and Synthetic Neural Systems," *Advances in Mathematics and Computers in Medicine* (in press)
Keynote Address: "Real-Time Engineering Applications of Artificial Intelligence," 1987 IEEE-Rochester Section Joint Seminar Series, Rochester Institute of Technology, Rochester, New York, February 26, 1987
Plenary Address: "Synthetic Intelligence or Biology and Computers," 1988 IEEE Southeastcon, Knoxville, April 11, 1988
ORNL Speakers Bureau: "Artificial Intelligence: Past, Present, and Future," Independent Computer Consultants Association, Nashville, May 2, 1987
ORNL Speakers Bureau: "Artificial Intelligence and Autonomous Robots," Roane State Vocational Technical Center, Harriman, Tennessee, April 25, 1988
ORNL Speakers Bureau: "Two Biological Metaphors for Synthetic Intelligent Systems," Roane State Vocational School, Technical Writing Class, Harriman and Knoxville, Tennessee, May 20, 1988
ORNL Speakers Bureau: "Intelligent Machines." National Mu Alpha Theta Convention, Knoxville, August 3, 1988
ORNL Speakers Bureau: "Electronic Life," Y-12 Computing and Telecommunications Division Seminar, Oak Ridge, Tennessee, October 25, 1988
ORAU Traveling Lecture: "Two Biological Metaphors for Synthetic Intelligent Systems," Special EE and Biomedical Seminar Series, University of North Carolina, Chapel Hill, November 19, 1987
ORAU Traveling Lecture: "Artificial Intelligence or Synthetic Intelligence?" University of Tennessee, Chattanooga, March 24, 1988
ORAU Traveling Lecture: "Synthetic Intelligence or Biology and Computers," Western Kentucky University Physics and Astronomy Seminar, Bowling Green, Kentucky, April 18, 1988
ORAU Traveling Lecture: "Electronic Life," Virginia Commonwealth University, College of Medicine, Richmond, Virginia, October 13, 1988; Auburn University, Auburn, Alabama, November 10, 1988
ORAU Traveling Lecture: "Real-Time Neural Nets," Auburn University, Auburn, Alabama, November 10, 1988

B. G. **Eads**

Senior Member, Instrument Society of America
Member, Institute of Electrical and Electronics Engineers
Member, Tau Beta Pi
Member, AVID Advisory Committee
Member, Computer Security R&D Steering Group
Member, Task Group on Global Environmental Studies

R. P. Effler

Member, ORNL X-Ray Safety Standards Review Committee

M. S. Emery

Member, Institute of Electrical and Electronics Engineers

P. D. Ewing

Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member, Kappa Mu Epsilon
Member, Southeastern Consortium for Minorities in Engineering Advisory Board
M.S., The University of Tennessee, Knoxville; Thesis: "Gain and Electric Field Radiation Pattern Approximations for the E-Plane Horn Antenna," June 1988
Invited Paper: "A Mixed-Modem Solution for Sensitive Data Segregation on a Broadband Network," R. I. Crutcher, P. D. Ewing, Eleventh DOE Computer Security Group Conference, Kansas City, Missouri, May 4, 1988
Invited Paper: "A Mixed-Modem Approach to Data Isolation on a Broadband Local Area Network," R. I. Crutcher, P. D. Ewing, IEEE Southeastcon '88, Knoxville, April 11, 1988

R. J. Fox

Member, Institute of Electrical and Electronics Engineers
U.S. Patent No. 4,697,084: *Fiber-Type Dosimeter with Improved Illuminator*, September 29, 1987

D. N. Fry

Member, American Nuclear Society
Member, Tau Beta Pi
Session Chairman: Symposium on Reactor Noise (SMORN V), Munich, West Germany, October 12-16, 1987
U.S. Representative, Program Committee, Specialists' Meeting on Instrumentation and Reactor Core Assessment, Cadarache, France, June 7-10, 1988

T. M. Gayle

Member, Air Pollution Control Association
Member, American Chemical Society
Registered Professional Engineer
Invited paper: "Human Smoking Dosimeter for Behavioral Studies," R. A. Jenkins, T. M. Gayle, Interagency Forum on Smoking and Health, Washington, D.C., March 10, 1987

F. R. Gibson

Member, Instrument Society of America

J. T. Glassell

Member, Tau Beta Pi

R. L. Glassell

Member, Institute of Electrical and Electronics Engineers
Invited Paper: "Telerobotic Control of the Seven-Degree-of-Freedom CESAR Manipulator," S. M. Babcock, R. V. Dubey, J. A. Euler, R. L. Glassell, R. L. Kress, W. R. Hamel, NATO Advanced Research Workshop on Robots with Redundancy: Design, Sensing, and Control, Salo, Lago di Garda, Italy, June 27-July 1, 1988

S. S. Gould

Senior Member, Instrument Society of America
Member, SME/CASA MAP/TOP Users Society
Honorary Member, Delta Kappa Omicron
Member, Fusion Energy Division Advisory Review Committee, IFSMTF Data System Upgrade Path
Member, Y-12 Plant Manufacturing Automation Committee

E. W. Hagen

Fellow, Instrument Society of America
Member, Institute of Electrical and Electronics Engineers; Nuclear Power Engineering Committee, Subcommittee 7, Human Factors
Member, International Electrotechnical Commission Subcommittee 45A, Reactor Instrumentation
Member, Eta Kappa Nu
Member, Tau Beta Pi
Registered Professional Engineer
Editor, Control and Instrumentation, *Nuclear Safety*

C. A. Hahs

Member, ASME Operations, Applications, and Components Committee (Pressure Vessel and Piping Division, Valves)
Member, National Society of Professional Engineers
Member, Oak Ridge Mobile Steam Society
Member, Tennessee Society of Professional Engineers
Registered Professional Engineer, Missouri

W. R. Hamel

Martin Marietta Energy Systems Technical Achievement Award, 1987
Tennessee Society of Professional Engineers Outstanding Achievement Award, Advanced Integrated Maintenance System (AIMS), February 1987
Senior Member, Institute of Electrical and Electronics Engineers
Member, American Society of Mechanical Engineers; Member, Oak Ridge Section College Affairs Committee
Member, Robotics International; Chairman, Subchapter 5157
Member, Phi Kappa Phi
Member, Sigma Xi
Member, Tau Beta Pi

DOE Technology Exchange Representative in Remote Systems Technology to United Kingdom, Japan, and West Germany
Member, Advisory Review Committee, NASA Langley Research Center Robotics and Intelligent Machines Programs
Robotics Technical Advisor to U.S. Army Human Engineering Laboratory and the Defense Advanced Research Projects Agency
Member, DOD Joint Directors of Laboratories, Joint Technology Panel for Robotics, Subpanel on Explosive Ordnance Disposal
Member, Army Science Board Advisory Committee
Member, National Science Foundation Research Team on Grant Awarded to Rensselaer Polytechnic Institute for Research Support of a Technology Assessment of Mobile Robots in Western Europe
Chairman, ORNL Robotics and Automation Council (1986)
Member, ORNL Technology Evaluation Committee
Technical Reviewer, *ASME Journal of Dynamics, Systems, and Controls*
Technical Reviewer, *Nuclear Engineering Technology*
Technical Reviewer, Addison-Wesley Series on Robotics
Technical Reviewer, DOE Small Business Innovative Research Program
Technical Reviewer, ORNL Exploratory Studies Program
Chairman, 1988 Man-Machine Symbiotic Systems Workshop, Oak Ridge Associated Universities, December 5-6, 1988
Invited Paper: "Telerobotic Control of the Seven-Degree-of-Freedom CESAR Manipulator," S. M. Babcock, R. V. Dubey, J. A. Euler, R. L. Glassell, R. L. Kress, W. R. Hamel, NATO Advanced Research Workshop on Robots with Redundancy: Design, Sensing, and Control, Salo, Lago di Garda, Italy, June 27-July 1, 1988
Invited Paper: "A Comparison of Two Real-time Control Schemes for Redundant Robots with Bounded Joint Velocities," J. A. Euler, R. V. Dubey, S. M. Babcock, W. R. Hamel, IEEE International Conference on Robotics and Automation, Scottsdale, Arizona, May 14-19, 1989

J. E. **Hardy**

Member, American Society of Mechanical Engineers
Member, Instrument Society of America
Registered Professional Engineer
Invited Paper: "Advanced Instrumentation for PWR Reflood Studies - An International Cooperative Effort," WATTec '88, Knoxville, February 1988

R. M. **Harrington**

Member, American Nuclear Society
Member, ORNL Reactor Operations Review Committee

J. N. Herndon

Martin Marietta Energy Systems Technical Achievement Award, 1987
Tennessee Society of Professional Engineers Outstanding Achievement Award, Advanced Integrated Maintenance System (AIMS), February 1987
Member, American Nuclear Society; Member, National Executive Committee, Remote Systems Technology Division
Member, American Society of Mechanical Engineers
Member, Robotics International; Chairman, Subchapter 5157
Member, Pi Tau Sigma
Member, Tau Beta Pi
DOE Technology Exchange Representative in Remote Systems Technology to France, Japan, and West Germany
Technical Reviewer, *Nuclear Engineering Technology*
Technical Reviewer, DOE Small Business Innovative Research Program
Invited Speaker: "Remote Handling Technology Development at Oak Ridge National Laboratory," Astronaut Science Colloquium, Johnson Space Center, March 1, 1988.
Invited Article: "Robotic System for NASA Ground-Based Research," *International Journal of Robotics and Autonomous Systems*, March 1988

P. G. Herndon

Member, Instrument Society of America
Member, Three-Plant Standards Committee

R. A. Hess

Member, IEEE Electromagnetic Compatibility Society

J. S. Hicks

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

M. S. Hileman

Member, Instrument Society of America

N. W. Hill

Member, Institute of Electrical and Electronics Engineers
Member, U.S. NIM-CAMAC Committee
Member, Review Committee, *Nuclear Instruments and Methods*, North Holland, Amsterdam

B. S. Hoffheins

Invited Publication: "Intelligent Thick-Film Gas Sensor," B. S. Hoffheins, R. J. Lauf, M. W. Siegel, *Journal of the International Society for Hybrid Microelectronics - Europe*, September 1987

Invited Presentation: "Intelligent Thick Film Gas Sensor," The Fifth Annual Texas Regional Symposium, Dallas, April 11-12, 1988

Invited Presentation: "Gas Sensor Arrays for Olfactory Analysis: Issues and Opportunities," B. S. Hoffheins, R. J. Lauf, Third International Conference and Exposition of Machine Perception Technology, Chicago, September 13-15, 1988

J. H. Holladay

Senior Member, Instrument Society of America

Member, American Society for Testing and Materials; Member, Committee E-20, Temperature Measurement

Member, Eta Kappa Nu

Member, Tau Beta Pi

ORNL Standards Coordinator for Instrumentation and Controls Division

J. L. Horton

Senior Member, Instrument Society of America

Member, Institute of Electrical and Electronics Engineers

Registered Professional Engineer

M. A. Hunt

Member, Institute of Electrical and Electronics Engineers

Member, Society of Photo-Optical Instrumentation Engineers

J. O. Hylton

Member, Instrument Society of America

Member, Sigma Xi

R. W. Ingle

Member, Eta Kappa Nu

Member, Tau Beta Pi

Member, Phi Kappa Phi

Registered Professional Engineer

Chairman, ORNL Stores Stock Advisory Committee

J. F. Jansen

Member, Institute of Electrical and Electronics Engineers

Registered Professional Engineer, North Carolina

J. M. Jansen, Jr.

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

IR-100 Award, *Remote Sensor and Cable Identifier*, 1987
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
U.S. Patent No. 4,737,657, *Remote Sensor Identifier*, W. B. Jatko, D. R. McNeilly, April 12, 1988
Invited Paper: "Computer Vision Applied to Workspace Intrusion Detection Systems," WATTec, Knoxville, February 1987

E. B. Johnson

Fellow, American Nuclear Society; Member, Publications Steering Committee; Member, ANS Standards Committee; Member and Secretary, Standards Subcommittee 8, Fissionable Materials Outside Reactors; Member, Standards Subcommittee 1, Performance of Critical Experiments
Member and Secretary, American National Standards Committee N16, Nuclear Criticality Safety
Member, American Physical Society
Member, New York Academy of Sciences
Member, Sigma Xi
Member, NRC Atomic Safety and Licensing Board Panel
Member, ORNL Reactor Operations Review Committee

W. F. Johnson

U.S. Patent No. 4,740,472, *Rotor and Disk System for Automated Processing of Whole Blood Sample for Analysis in a Centrifugal Fast Analyzer*, C. A. Burtis, W. F. Johnson, W. A. Walker, 1988
Invited Paper: "Development of a Simple Automated Rotor for Processing and Aliquoting a Single Whole Blood Specimen into Multiple Aliquots of Plasma," C. A. Burtis, W. F. Johnson, W. A. Walker, Oak Ridge Conference on Advanced Analytical Techniques for the Clinical Laboratory, San Antonio, April 9-10, 1987

R. C. Juras

Member, Institute of Electrical and Electronics Engineers

E. J. Kennedy

Invited paper: "Radiation-Hardened Television Camera Development," D. W. Bible, A. C. Morris, Jr., E. J. Kennedy, S. F. Smith, France/USDOE Meeting on Remote Systems Technology, Oak Ridge, May 5-9, 1986
Invited Paper: "Radiation Hardening of In-Cell Electronics," S. F. Smith, E. J. Kennedy, France/USDOE Meeting on Remote Systems Technology, Marseilles, France, February 19-24, 1987

S. M. Killough

Member, Institute of Electrical and Electronics Engineers

R. A. Kisner

Registered Professional Engineer

Member, Babcock & Wilcox Owners Group Advanced Central System Task Force Advisory Panel

Member, ORAU Traveling Lecture Program

Cochairman, 39th International Science and Engineering Fair, Engineering Judging, Knoxville, May 1988

Invited Paper: "An Intelligent Dynamic Simulation Environment: An Object-Oriented Approach," J. T. Robinson, R. A. Kisner, Third International Symposium on Intelligent Control, Arlington, Virginia, August 24-26, 1988

M. K. Kopp

Member, Institute of Electrical and Electronics Engineers

Member, Sigma Xi

Registered Professional Engineer

R. L. Kress

Member, American Society of Mechanical Engineers

Member, Institute of Electrical and Electronics Engineers

Ph.D., University of Arizona; Dissertation: "Adaptive Model-Following Control for Hyperthermia Treatment Systems," May 1988

Invited Paper: "Telerobotic Control of the Seven-Degree-of-Freedom CESAR Manipulator," S. M. Babcock, R. V. Dubey, J. A. Euler, R. L. Glassell, R. L. Kress, W. R. Hamel, NATO Advanced Research Workshop on Robots with Redundancy: Design, Sensing, and Control, Salo, Lago di Garda, Italy, June 27-July 1, 1988

R. C. Kryter

Member, American Nuclear Society

Member, ASME Standard-Preparation Subgroup on LWR Loose-Part Monitoring and Diagnostics

Member, Phi Beta Kappa

Member, Sigma Pi Sigma

Invited Paper: "^{252}Cf-Source-Driven Neutron Noise Measurements of Subcriticality for a Slab Tank Containing Aqueous Pu-U Nitrate," J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, R. C. Kryter, R. C. Robinson, H. Seino, T. Matsumoto, H. Yamana, International Seminar on Nuclear Criticality Safety, October 19-23, 1987, Tokyo

C. W. Kunselman

Senior Member, Instrument Society of America

Member, Institute of Certification of Engineering Technicians

T. A. Lewis

Member, Institute of Electrical and Electronics Engineers
Member, Accelerators and Radiation Sources Review Committee

R. F. Lind

Member, American Society of Mechanical Engineers
Registered Professional Engineer
Patent Application Filed: *Process For Forming Foil Strain Gages in Place*, June 1988

J. M. Madison

Member, Tau Beta Pi

W. W. Manges

Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society; Vice Chairman, Oak Ridge Section
Registered Professional Engineer

J. March-Leuba

Martin Marietta Energy Systems Author of the Year Award, 1986
Martin Marietta Energy Systems Jefferson Cup Award, 1986
Member, American Nuclear Society; Member, Thermohydraulics Division Program Committee

L. C. Maxey

Member, Institute of Electrical and Electronics Engineers
Member, Instrument Society of America
Member, Eta Kappa Nu
Member, Tau Beta Pi
Member, Phi Kappa Phi

D. W. McDonald

Senior Member, Instrument Society of America
Member, Institute of Electrical and Electronics Engineers
Member, IEEE Automatic Controls Society
Member, IEEE Computer Society
Member, Eta Kappa Nu

S. A. McElhaney

Member, American Physical Society
Member, Sigma Pi Sigma
Invited Paper: "Dual Scintillator with Pulse Shaping Electronics as a Wide-Energy Range Neutron Detector," M. M. Chiles, S. A. McElhaney, R. A. Todd, Health Physics Society 22nd Midyear Meeting on Instrumentation, San Antonio, December 4-8, 1988

J. A. McEvers

Member, Institute of Electrical and Electronics Engineers
Member, IEEE Automatic Controls Society
Member, IEEE Computer Society
Member, Society of Manufacturing Engineers
M.S., The University of Tennessee, Knoxville; Thesis: "Design of a Controlled Temperature Flue Gas Corrosion Probe," August 1988

D. E. McMillan

Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society
Registered Professional Engineer

M. J. Meigs

Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu

J. T. Mihalczo

Member, American Nuclear Society; Member, Executive Committee, Nuclear Criticality Safety Divison
Invited Paper: "^{252}Cf-Source-Driven Neutron Noise Measurements of Subcriticality for a Slab Tank Containing Aqueous Pu-U Nitrate," J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, R. C. Kryter, R. C. Robinson, H. Seino, T. Matsumoto, H. Yamana, International Seminar on Nuclear Criticality Safety, October 19-23, 1987, Tokyo
Invited Paper: "Subcritical Interaction Experiments with Four Safe Storage Bottles Containing Aqueous Uranyl Nitrate," J. T. Mihalczo, E. D. Blakeman, G. E. Ragan, International Seminar on Nuclear Criticality Safety, October 19-23, 1987, Tokyo

D. R. Miller

Senior Member, Instrument Society of America; President, Local Section
Member, American Institute of Plant Engineers; President, Local Chapter
Member, Energy Systems Nonexempt Review Committee
Member, ORNL Radioactive Operations Committee
Member, I&C Division Long-Range Planning Committee
Member, I&C Division Management Support Team for Females
Technical Chairman, National DOE Maintenance Managers Conference, New Orleans, March 1988

G. N. Miller

IR-100 Award, *Remote Sensor and Cable Identifier*, 1987
Member, Institute of Electrical and Electronics Engineers
Member, Instrument Society of America; Director, Test Measurement Division; Associate Director, Aerospace Industries Division; Vice President, Local Section
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, 33rd ISA International Instrumentation Symposium, Las Vegas, 1987
Invited Paper: "Sensor Selection for Measurement and Control," Sensors Expo, Chicago, September 13-15, 1988

J. A. Moore

M.S., The University of Tennessee, Knoxville; Thesis: "Electronic Implementation of a Closed-Loop Gas-Flow Control System," December 1986

M. R. Moore

Member, Institute of Electrical and Electronics Engineers

R. L. Moore

Member, Institute of Electrical and Electronics Engineers
Member, Instrument Society of America
Member, ORNL Reactor Experiment Review Committee

A. C. Morris, Jr.

Member, Institute of Electrical and Electronics Engineers
Registered Professional Engineer
Invited paper: "Radiation-Hardened Television Camera Development," D. W. Bible, A. C. Morris, Jr., E. J. Kennedy, S. F. Smith, France/USDOE Meeting on Remote Systems Technology, Oak Ridge, May 5-9, 1986
Invited paper: "Improved Capabilities for Area Environmental Monitoring at Oak Ridge National Laboratory," A. C. Morris, Jr., M. L. Bauer, R. E. Pudelek, IEEE Nuclear Science Symposium, Washington, D.C., October 27-November 1

C. A. Mossman

IR-100 Award, *Remote Sensor and Cable Identifier*, 1987
Member, Instrument Society of America

J. A. Mullens

Member, ORNL Scientific and Technical Computing Technical Advisory Committee

R. C. Muller

Member, Digital Equipment Corporation Users' Society

T. N. Muncy
Member I&C Division Troublebuster 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. W. Noakes
Member, Robotics International; Chairman-Elect, Local Chapter
Invited Paper: "A Controls Architecture that Supports Servomanipulator Development," ANS Conference, Charleston, South Carolina, March 1989

C. H. Nowlin
Member, Institute of Electrical and Electronics Engineers

L. C. Oakes
ORNL Corporate Fellow
Life Fellow, IEEE; Member, National Fellows Committee; Member, Administrative Committee of the Nuclear and Plasma Science Society; Liaison to the Power Electronics Council; Member, Administrative Committee of the Power Electronics Council; Member, Education Committee; Member, Reactor Instrumentation Technical Committee
Member, American Nuclear Society
Member, ORNL Challenges In Science Seminar Committee
Member, ORNL Distinguished Scientist Selection Committee

V. K. Pare
Member, American Nuclear Society
Member, American Physical Society
Member, Institute of Electrical and Electronics Engineers

D. G. Prater
Member, Association of Information Systems Professionals
Member, American National Standards Institute
Member, American Society for Quality Control
Member, Institute of Certification of Engineering Technicians

J. A. Ray
Member, Institute of Electrical and Electronics Engineers
Member, ORNL Electrical Safety Committee

C. J. Remenyik
Member, American Association of University Professors
Member, Sigma Xi
Invited Paper: "Presence and Absence of a Water Film Between Moving Air Bubbles and a Plate," 3rd International Colloquium on Drops and Bubbles, Monterey, California, September 1988

A. W. Renshaw

Member, American Nuclear Society
Member, American Women in Science
Member, Instrument Society of America

C. W. Ricker

Member, American Nuclear Society
Member, American Physical Society
Member, Phi Beta Kappa
Member, Sigma Pi Sigma
Member, Sigma Xi
U.S. Member representing ORNL on the American Institute In Taiwan/ Coordination Council For North American Affairs Joint Standing Committee on Civil Nuclear Cooperation

E.M. Robinson

Member, Health Physics Society
Member, American Society of Safety Engineers

J. T. Robinson

Invited paper: "An Intelligent Dynamic Simulation Environment: An Object-Oriented Approach," J. T. Robinson, R. A. Kisner Third International Symposium on Intelligent Control, Arlington, Virginia, August 24-26, 1988.
Invited Paper: "An Application of Object-Oriented Programming to Process Simulation," J. T. Robinson, P. J. Otaduy, Symposium on Demonstrations of Artificial Intelligence in Chemical Engineering, National Meeting of the American Institute of Chemical Engineers, Denver, Colorado, August 22-25, 1988

R. B. Rochelle

Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Engineer-In-Training License

J. C. Rowe

Tennessee Society of Professional Engineers Outstanding Achievement Award, Advanced Integrated Maintenance System (AIMS), February 1987
Member, Tau Beta Pi

F. R. Ruppel

Senior Member, Instrument Society of America; Secretary, Oak Ridge Section
Member, American Institute of Chemical Engineers, Computing and Systems Technology Division
M.S., The University of Tennessee, Knoxville; Thesis: "Development of a Smart Temperature Measurement System Based on a Self-Calibrating Thermocouple," December 1988

G. K. Schulze

Member, Eta Kappa Nu
Member, Phi Eta Sigma
Member, U.S. NIM-CAMAC Committee

R. L. Shepard

Senior Member, Instrument Society of America; Lecturer on Thermometry (Short Courses)
Member, American Society for Testing and Materials; Chairman, Committee E-20, Thermometry
Member, Institute of Electrical and Electronics Engineers; Member, Program Committee
Member, Sigma Xi
Guest Editorial: "Gee Whiz--Another ASTM Standard," *ASTM Standardization News*, May 1988

A. A. Shourbaji

Senior Member, Instrument Society of America

W. H. Sides

Member, American Nuclear Society
Member, Phi Kappa Phi
Member, Tau Beta Pi
Member, Sigma Pi Sigma
Associate Member, Sigma Xi

M. L. Simpson

Member, Institute of Electrical and Electronics Engineers
Ph.D, University of Virginia; Dissertation: "Concurrent and Nonconcurrent Error Detection in Analog to Digital Converters," January 1988
Invited Article: "Optoelectronic-Strain Measurement System for Rotating Disks," *Experimental Mechanics*, March 1987

R. L. Simpson

Member, Digital Equipment Corporation Users' Society

C. A. Smith

Technical Advisor, PIP Committee on Alternative Video Formats

O. L. Smith

Listing in *Who's Who in Frontier Science and Technology*
Listing in *Who's Who in the World*
Member, Sigma Xi
Member, Martin Marietta Energy Systems Inventors' Forum
Invited Paper: "The Safety Implications of Control Systems Program at ORNL," ANS Topical Meeting on Anticipated and Abnormal Transients in Nuclear Power Plants, Atlanta, April 12-15, 1987
Invited Paper: "Methodology for Coupling the Air and Ground Modules in the State-of-the-Art Contingency Analysis Code," Joint National Meeting of the Operations Research Society of America and the Institute of Management Science, St. Louis, October 25-28, 1987

S. F. Smith

Member, Eta Kappa Nu
Member, Tau Beta Pi
Ph.D., The University of Tennessee, Knoxville; Dissertation: "A Study of Universal Modulation Techniques Applied to Satellite Data Collection," June 1987
Invited Paper: "Radiation-Hardened Television Camera Development," D. W. Bible, A. C. Morris, Jr., E. J. Kennedy, S. F. Smith, France/USDOE Meeting on Remote Systems Technology, Oak Ridge, May 5-9 1986
Invited Paper: "Radiation Hardening of In-Cell Electronics," S. F. Smith, E. J. Kennedy, France/USDOE Meeting on Remote Systems Technology, Marseilles, France, February 19-24, 1987
Invited Paper: "AIMS Radiation-Hardened Control System Conceptual Design," France/USDOE Meeting on Remote Systems Technology, Oak Ridge, October 6-7, 1987

C. T. Stansberry

Senior Member, Instrument Society of America
Member, American Society for Training and Development
Member, Iota Lambda Sigma
Member, Maintenance Management Committee - DOE Facilities
Chairman, MAJIC Steering Committee
Member, Martin Marietta Energy Systems Training Committee Subcommittee on Maintenance Training

R. S. Stone

Member, American Nuclear Society
Member, Society for Computer Simulation
Registered Professional Engineer

F. J. Sweeney

Invited Report: "Utility Guidelines for Reactor Noise Analysis," EPRI NP-4970, February 1987

P. A. Tapp

Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society
Member, IEEE Instrumentation and Measurement Society
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, Tennessee and Indiana

L. H. Thacker

Member, Phi Beta Kappa
Member, ORNL Graduate Fellow Selection Panel
Member, ORNL Laser Safety Committee

J. H. Todd

Member, Phi Kappa Phi
Member, Sigma Tau
Member, Engineering Physics and Mathematics Division Safety Committee
Member, Tower Shielding Facility Experiment Review Committee
Registered Professional Engineer

R. A. Todd

Registered Professional Engineer
Ph.D., The University of Tennessee, Knoxville; Dissertation: "Pulsed Helium Ionization Detector Electronics System for Gas Chromatography," March 1988
U.S. Patent No. 4,705,947, *Pulsed Helium Ionization Detection System*, R. A. Todd, R. S. Ramsey, November 10, 1987
U.S. Patent No. 4,705,948, *Closed-Loop Pulsed Helium Ionization Detector*, R. S. Ramsey, R. A. Todd, November 10, 1987
Invited Paper: "Dual Scintillator with Pulse Shaping Electronics as a Wide-Energy Range Neutron Detector," M. M. Chiles S. A. McElhaney, R. A. Todd, Health Physics Society 22nd Midyear Meeting on Instrumentation, San Antonio, December 4-8, 1988

?. W. Tucker, Jr.

Senior Member, Instrument Society of America

B. R. Upadhyaya

The University of Tennessee, Knoxville, College of Engineering Research Development Award, April 1987
The University of Tennessee Outstanding Teacher Award, 1988
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 Physical Society
Member, American Society for Engineering Education
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, *Nuclear Science and Engineering*
Reviewer, *Nuclear Technology*
Reviewer, National Science Foundation
Invited Papers: "Sensor Fault Monitoring and Process Diagnostics," March Meeting of the American Physical Society, New Orleans, 1988
Invited Papers: "Data Clustering and Prediction for Fault Detection and Diagnostics," American Control Conference, Atlanta, June 1988

R. A. Vines

Member, Instrument Society of America

K. A. Wakefield

Member, Association For Computing Machinery
Member, Instrument Society of America

E. E. Waugh

Member, Institute of Electrical and Electronics Engineers

J. C. Wells

Member, Phi Kappa Phi
Member, Tau Beta Pi

G. R. Wetherington

Invited Presentation: "Athens Automation and Control Experiment - The Impact of Load Control on a Feeder," IEEE Power Engineering Society Meeting, Anaheim, September 17, 1986.
Invited Paper: "Monitoring Load Control at the Feeder Level Using High Speed Monitoring Equipment," J. H. Reed, W. R. Nelson, G. R. Wetherington, E. R. Broadaway, Athens Advisory Committee, Athens, Tennessee, September 23, 1987
Invited Paper: "Monitoring Load Control at the Feeder Level Using High-Speed Monitoring Equipment," J. H. Reed, W. R. Nelson, G. R. Wetherington, E. R. Broadaway, Institute of Electrical and Electronic Engineers/Power Engineering Society Winter Meeting, New York, January 31-February 5, 1988

B. R. Whitus

Member, Institute of Electrical and Electronics Engineers
Member, Instrument Society of America
Member, Eta Kappa Nu

R. A. Willems

Member, Eta Kappa Nu
Member, Phi Kappa Phi
Member, Tau Beta Pi

L. C. Williams

Member, Association for Computing Machinery
Member, Society for Industrial and Applied Mathematics
Invited Paper: "Basic Constructs for a Weapons Platform/Weapons Suite Mapping Onto Mission Profiles - A Classifier for JTLS ATO Expert System, G. O. Allgood, L. C. Williams, Office of Joint Chiefs of Staff Military Aides Planning Conference, Ft. Walton Beach, Hurlburt Field, Florida, November 16, 1988

H. N. Wilson

Outstanding Public Service Award from the Federal Emergency Management Agency, April 1987
Member, Institute of Electrical and Electronics Engineers
Member, Eta Kappa Nu
Member, Tau Beta Pi

R. T. Wood

Member, American Nuclear Society
Member, Phi Eta Sigma
Member, Phi Kappa Phi
Member, Tau Beta Pi

K. E. Wright

Member, I&C Division Troublebuster Committee

R. W. Wysor

Member, Gamma Beta Phi
Member, Phi Eta Sigma
Member, Phi Kappi Phi
Member, Pi Tau Sigma
Member, Tau Beta Pi
Engineer in Training License
M.S., The University of Tennessee, Knoxville; Thesis: "Coordinated Control of Relay Feedback Control Systems for Electrical Power Cost Reduction," August 1988

W. L. Zabriskie

Senior Member, Instrument Society of America
Member, Institute of Electrical and Electronics Engineers
Member, IEEE Computer Society
Member, Graphic Arts Technical Foundation
Registered Professional Engineer

W. D. Zuehsow

Member, Institute of Electrical and Electronics Engineers

AUTHOR INDEX

KEYWORD INDEX

NOMENCLATURE

AACE	Athens Automation and Control Experiment
AACETS	Athens Automation and Control Experiment Test System
AAMRL	Armstrong Aerospace Medical Research Laboratory
ACS	advanced control system
ACSL	Advanced continuous simulation language
A/D	analog-to-digital
ADC	analog-to-digital converter
ADP	automated data processing
AEDC	Arnold Engineering Development Center
AGA	acoustic gas analyzer
AI	artificial intelligence
AIMS	Advanced Integrated Maintenance System
AIRD	Acoustic Instrumentation Research and Development
AIRS	Advanced Instrumentation for Reflood Studies
ALMR	advanced liquid metal-cooled reactor
ALWR	advanced light-water reactor
AMFIP	Acoustic Measurements Facilities Improvement Program
ANS	Advanced Neutron Source
ANSDS	automated noise surveillance and diagnostic system
ANSI	American National Standards Institute
APIS	acoustical peak identification system
ARCADES	automatic RADIAC calibration and diagnostic equipment system
ASCF	Army Signature Characterization Facility
ASCII	American Standard Code for Intelligence Interchange
ASIC	application-specific integrated circuit
ASM	advanced servomanipulator
ATD	Applied Technology Division (formerly ETAC)
ATF	Advanced Toroidal Facility
ATMS	articulated manipulator-transporter system
ATV	auxiliary telephone vault
ATWS	anticipated transients without scram
AUB	Athens (TN) Utilities Board
BEP	Bureau of Engraving and Printing
BSR	Bulk Shielding Reactor
BTD	Breakthrough detectors
CAD	computer-aided design
CADAM	computer-aided design and augmented manufacturing
CADD	computer-aided design and drafting
CADRE	computer-assisted detection and report enhancement
CAE	computer-aided engineering
CAM	computer-aided manufacturing
CAMAC	computer-automated measurement and control
CASE	computer-aided software engineering
CATV	cable television
CCTF	Cylindrical Core Test Facility (Japan)
CEA	Commissariat a l'Energie Atomique
CEF	Critical Experiments Facility
CESAR	Center for Engineering Systems Advanced Research
CESARm	CESAR arm
CFRP	Consolidated Fuel Reprocessing Program
CIM	computer-integrated manufacturing
CIMLINC	computer-integrated manufacturing LINC system
CIT	compact ignition tokamak
CMOS	complementary metal-oxide semiconductor
COD	crack opening displacement
CODAS	computer-operated date acquisition system
CPU	central processing unit
CSI	control sequence interface
CVR	combat vehicle robotics

D/A	digital-to-anal
DARPA	Defense Adv
DAS	data acquisiti
DB	dragbody
DBA	design basis a
DCS	distributed co
DEM	Department c
DHI	data handler
DOD	U.S. Departm
DOF	degrees of fre
DOS	U.S. Departm
DTRC	David Taylor
DUT	device under
E^3	electromagnet
EATM	exercise and
ECIP	Energy Conse
ECL	emitter-couple
ECUT	Energy Conse
EDC	Engineering D
EGR	electrographic
EIS	equipment int
EMC	electromagnet
EMI	electromagnet
EMP	electromagnet
EMT	Electromagnet
EPMD	Engineering P
EOD	Explosives Or
EPRI	Electric Powe
EPROM	electronically
ERFU	Environmenta
ESD	electrostatic d
ETAC	Enrichment T
ETC	environmental
EUCFM	Enriched Ura
EURI	Enriched Ura
FCC	Federal Comm
FED	Fusion Energ
FEMA	Federal Emer
FESA	U.S. Army Fa
FFT	fast fourier tr
FID	field interface
FMP	U.S. Navy Fle
FNARS	FEMA Nation
FRACAS	facility radiati
FRG	Federal Repu
FTE	full-time equi
FTP	SDI Fast Tra
GaAs	gallium arseni
GATERS	ground-air tel
GM	Geiger-Muell
HAZWRAP	Hazardous W
HBRR	high bit-rate
HDL	Harry Diamo
HDDR	high-density c
HEL	Human Engin
HERMIES	Hostile Envir
HF	hydrogen sulf
HFIR	High-Flux Iso
HHIRF	Holifield Hea
HIL	heavy ion/ligh
HMI	human/machi

analog
Advanced Research Projects Agency
uisition sy. em
sis accident
d control system
nt of Environment Monitoring
ller and interface
rtment of Defense
f freedom
rtment of State
ptor Research Center
der test

gnetic environmental effects
nd monitoring
Conservation Investment Program
upled logic
Conservation and Utilization Technology Material Program
ng Design Center
phic recorder
t interface systems
gnetic compatibility
gnetic interference
gnetic pulse
gnetic Technology
ng Physics and Mathematics Division
s Ordinance Depot
Power Research Institute
ally programmable read-only memory
ental Restoration and Facilities Upgrade
tic discharge
nt Technology Applications Center
ental test chamber
Uranium Conversion Facility Modification
Uranium Recovery Improvements

Communications Commission
nergy Division
Emergency Management Agency
y Facilities Engineering Support Agency
er transform
face devices
y Fleet Modernization Program
ational Radio System
diation and contamination alarm system
Republic of Germany
quivalent
Track Program

senide
r telerobotics systems
ucer

s Waste Remedial Action Program
ate recorder
mond Laboratories
ity digital recorder
ngineering Laboratory
nvironment Robotic Machine Integrated Experiment Series
sulfide
Isotope Reactor
Heavy Ion Research Facility
flight ion
chine interface

HMMWV	high-mobility multipurpose wheeled vehicle
HPRR	Health Physics Research Reactor
HSST	Heavy Section Steel Technology Program
HTGR	High Temperature Gas-Cooled Reactor
HTHSFC	high-temperature, high-sensitivity fission counter
IAEA	International Atomic Energy Agency
IC	integrated circuit
ICRP	International Commission on Radiological Protection
ICS	integrated control system
IET	integrated equipment test
IGAS	integrated gas analysis and sensing
IGES	International Graphics Exchange System
INS	U.S. Immigration and Naturalization Service
I/O	input/output
IPBB	interplant broadband
IPC	integrated process demonstration
IR	infrared
IVI	interactive video instruction
KWU	Kraftwerk Union
LAN	local area network
LANL	Los Alamos National Laboratory
LERC	Laboratory Emergency Response Center
LMR	liquid metal reactor
LOCA	loss-of-coolant accident
LPR	lithium process restoration
LQG	linear-quadratic-Gaussian
LSV	large-scale vehicle
LTM	laboratory telerobotic manipulator
LTR	loop transfer recovery
MACES	Measurement and Controls Engineering Section
MAJIC	maintenance, accountability, jobs, and inventory control system
MAP	Manufacturing Automation Protocol
MCA	multichannel analyzer
MEL	modular electromagnetic limitator
MFR	U.S. Navy multifunction RADIAC instruments
MHTGR	modular high-temperature gas-cooled reactor
MIPS	million instructions/s
MMD	Maintenance Management Department
MMS	modular modeling system
MNNAS	mult nnel narrow band noise analysis system
MODIL	Manufacturing Operations Development Integration Laboratory
MOSIS	modular survey instrument system
MOTEL	Motorola Intel
MPD	Metal Preparation Division
MRAC	model reference adaptive controller
MRDL	Metrology Research and Development Laboratory
NARDAC	Navy Regional Data Automation Center
NASA	National Aeronautics and Space Administration
NASP	national aerospace plane
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NBS	National Bureau of Standards (now National Institute of Standards and Technology)
NCL	U.S. Navy Calibration Laboratory
NCSASR	National Center for Small-Angle Scattering Research
NIM	nuclear instrument module
NMR	nuclear magnetic resonance
NRR	NRC Office of Nuclear Reactor Regulation
NRWTP	nonradiological waste water treatment project
NSWC	Naval Surface Weapons Center

NUSC	Naval Underwater Systems Center
OCR	optical character recognition
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORIC	Oak Ridge Isochronous Cyclotron
ORR	Oak Ridge Research Reactor
OSHA	Occupational Safety and Health Administration
PAM	perimeter air monitor
PARSAC	programmable advanced RADIAC sound annunciator chip
PBX	Princeton Beta Experiment
PCA	Pool Critical Assembly
PCS	plant control systems
PFM	pulse frequency modulation
PGDP	Portsmouth Gaseous Diffusion Plant
PI	proportional-integral controller
PIC	probe interface chip
PIN	P-intrinsic-N
PLC	programmable logic controller
PMT	photomultiplier tube
PNC	Power Reactor and Nuclear Fuel Development Corporation (Japan)
PNL	Pacific Northwest Laboratory
PPAC	parallel-plate avalanche counter
PPPL	Princeton Plasma Physics Laboratory
PPS	plant protection systems
PRISM	Power Reactor Inherently Safe Module
PROM	programmable read-only memory
PSEI	playback system electronic interface
PWMS	process waste monitoring
PWR	pressurized water reactor
P/Y	pitch/yaw

QA	quality assurance
RADIAC	radiation detectio
RAM	random-access m
RES	NRC Office of N
RETF	Recycle Equipme
rf	radio frequency
RIS	Research Instrum
RISC	reduced instructic
RISP	Robotics and Int
RITF	Radiological Instr
RORC	Reactor Operatin
RRD	Research Reactor
RRSG	Research Reactor
RVDT	rotary variable di
SABL	sequencing and b
SAFR	Sodium Advanced
SAM	security access co
SAW	surface acoustic w
SAXSF	Small-Angle X-ray
SCTF	Slab Core Test F
SDI	Strategic Defense
SICS	Safety implication
SMI	soldier-machine i
SRI	Soldier-Robot Int
SRM	shared resource m
SSAS	sonar signal analy
SSC	superconducting S
TEAM	Technology Base
TEMPEST	study of comprom

ance

iction, indication, and computation
om memory
e of Nuclear Regulatory Research
uipment Test Facility (Japan)
ncy
struments Section
struction set computer
nd Intelligent Systems Program
al Instrumentation Test Facility
perations Review Committee
Reactors Division
Reactor Support Group
able differential transformer

g and batch language
dvanced Fast Reactor
tems control and monitoring system
oustic wave
le X-ray Scattering Facility
Test Facility
Defense Initiative
plications of control systems
chine interface
bot Interface Project
source management
al analysis system
ucting Supercollider

y Base Enhancement for Autonomous Machines
ompromising emanations

TFTR	Toroidal Fusion Test Reactor
TMI	Three Mile Island
TOF	time of flight
TORDAC	torpedo data acquisition system
TOV	teleoperated vehicle
TRU	transuranic
TSCM	technical surveillance counter measures
TSF	Tower Shielding Facility
TSR	Tower Shielding Reactor
TSS	Telerobotic Systems Section
TTL	transistor-transistor logic
TUH	Technical University of Hannover
TURF	Thorium-Uranium Recycle Facility
TVA	Tennessee Valley Authority
UMTRAP	Uranium Mill Tailings Remedial Action Program
UPTF	Upper Plenum Test Facility
URC	universal RADIAC chip
USMC	U.S. Marine Corps
USRADS	Ultrasonic Ranging and Data System
UTSI	The University of Tennessee Space Institute
VLSI	very large scale integration
VSVI	very simple, very inexpensive
WME	working-memory element
WOCC	Waste Operations Control Center
WRMB-1	Wide-range meteor burst gamma monitoring system

INSTRUMENTATION & ...
B. C. EADS, ...
B. M. ...

L. C. OAKES, SENIOR TECHNICAL ADVISOR AND CORPORATE FELLOW
MANAGER, POST-CHERNOBYL MODELING & ANALYSIS PROGRAM

RESEARCH INSTRUMENTS
N. P. BRADHEAR, SECTION HEAD
R. J. HENSLEY
S. D. CURD
P. J. TIMMEL

MEASUREMENT & CONTROLS ENGINEERING
C. A. MOSSMAN, SECTION HEAD
M. A. ELLIS
D. S. BROPHY
R. D. LOVELACE
K. S. MAHAN
C. H. STRANDBERG
J. A. WALLER

REACTOR SYSTEMS
D. N. FRY, SECTION HEAD
J. L. DIPPO
R. L. O'MATHICK
K. A. SHARP
D. J. SKLAD (pt)
L. H. SPARKS (pt)

ACCELERATOR PHYSICS
G. K. SCHULZE
J. L. BLANKENSHIP
R. W. HILL
R. W. IBBLE
R. C. JURAS
T. A. LEWIS
M. J. MEIGS
J. M. TODD

ELECTRONIC SYSTEMS DEV
C. H. NOWLIN
D. W. BIBLE
R. I. CRUTCHER (pt)
W. HOLMES
E. J. KENNEDY (UTKpt)
J. A. MOORE
J. W. ROCHELLE (UTKc)
S. F. SMITH
C. W. SOHNS

PRODUCT DEVELOPMENT & DRAFTING
B. P. ADKISSON
K. F. CHAPMAN
R. E. COOPER
M. D. CUTSHAW
M. E. GREENE•
R. L. HANSARD•
D. T. HENSLEY (pt)
S. M. INMAN
R. W. JONES
E. C. KEITH•
R. A. MAPLES
S. A. SHUGART
C. E. STEVENSON
T. R. SUBSCH
J. C. TURNER

PROGRAM MANAGERS
NAVY RADIAC DEV
W. L. BRYAN
IMMIGRATION & NAT. SEC.
E. MADDEN•

COMPUTER SYSTEMS DEV
E. MADDEN
D. D. BATES
B. S. HOFFHEINS
J. M. MADISON
D. E. McMILLAN
C. R. MITCHELL
J. W. REYNOLDS
R. T. ROSEBERRY•
D. E. SMITH
G. W. TURNER
R. I. VANDERMOLEN
R. E. WINTENBERG

MECHANICAL SYSTEMS DEV
G. W. ALLIN
C. A. HAWS

MONOLITHIC SYSTEMS DEV
G. T. ALLEY
M. S. [illegible]
D. F. BOULDIN (UTKc)
C. L. BRITTON
M. S. EMERY
M. N. ERICSON
D. F. NEWPORT (UTKpt)
R. A. TODD
R. A. WILLIAMS

SENSOR SYSTEMS DEV
W. L. BAUER
T. R. BARCLAY
M. M. CHILES
C. E. FOWLER
D. [illegible]
S. A. [illegible]
V. C. MILLER
A. C. MORRIS
J. A. RAMSEY
M. L. SIMPSON
J. R. TARRANT

SPECIAL ASSIGNMENTS
W. L. BRYAN

RESEARCH INSTRUMENT MAINT
C. W. KUNSELMAN•

X-10 PROCESS SYSTEMS DEV AND RESEARCH SUPPORT
O. HYLTON
O. ALLGOOD
A. V. BLALOCK
T. L. BOWERS (c)
R. M. BURNETT
C. L. CARNAL (TTUpt)
J. E. HARDY
J. A. HAWK
J. S. HICKS
M. S. HILEMAN
J. L. HORTON
R. E. HUTCHENS
J. T. HUTTON
W. F. JOHNSON
R. F. LIND
C. W. MARTIN
N. D. McCOLLOUGH
J. A. McEVERS
W. P. MURRAY (c)
C. J. REMENYIK (UTKpt)
D. L. SEHN (c)
A. A. SHOURBAJI (TTUc)
R. B. TUCKER, JR
J. C. WELLS

ADVANCED ARCHITECTURE & COMPUTER SECURITY
W. L. ZABRISKIE
J. O. ALLEN (c)
W. H. ANDREWS
P. L. BUTLER
K. N. CASTLEBERRY
G. N. COFER (c)
J. H. MARABLE (c)
L. C. WILLIAMS (c)

REAL TIME COMP SYSTEMS
J. M. JANSEN, JR
R. R. BENTZ
E. R. BROADAWAY
T. M. BUCKNER
D. A. CLAYTON
J. B. CORDTS
J. T. FARMER• (c)
J. T. GLASSELL
J. A. JEFFERIS•
S. M. ODOM
R. B. ROCHELLE (UTKc)
K. A. SCOTT
R. L. SIMPSON
J. D. STANLEY (c)
R. M. TATE
R. M. TUFT
C. R. WETHERINGTON, JR
R. W. WYSOR
W. D. ZUEHSDOW

Y-12 PROCESS SYSTEMS DEV AND RESEARCH SUPPORT
C. N. MILLER
A. H. ANDERSON, JR
S. P. BAKER
A. H. BOST (c)
N. C. BRADLEY
T. M. CATE
R. M. CHILDS
R. L. DURALL
J. T. FARMER• (c)
F. R. GIBSON
S. S. GOULD
G. W. GREENE
M. E. GREENE•
R. L. HANSARD•
J. M. HEJOLE•
P. G. HERNDON
J. A. JEFFERIS•
E. C. KEITH•
B. I. LEMART (c)
R. L. MOORE
F. R. RUPPEL
P. A. TAPP
R. W. TUCKER, SR (c)
B. R. WHITUS

ELECTROMAGNETIC TECHNOLOGY
R. A. HESS
P. D. EWING
J. M. GOOGE (UTKpt)
J. H. HOLLADAY
D. J. MARSHALL
M. R. MOORE
R. W. ROCHELLE (UTKc)
E. E. WAUGH

INSTRUMENT RESEARCH
D. W. McDONALD
J. L. HILGER (UTKc)
W. A. HUNT
W. B. JATKO
D. D. McCUE
R. N. NODINE
B. C. SUN (c)

MEASUREMENT RESEARCH
R. L. ANDERSON•
M. H. COOPER
W. B. DRESS, JR
J. D. LYONS

SPECIAL ASSIGNMENTS
R. K. ADAMS (c)
M. L. CORBETT (c)
M. B. HERSKOVITZ (c)
C. D. MARTIN (c)
E. R. ROHRER (c)

ADVANCED CONTROL TECHNOLOGIES
R. E. UHRIG•

FACILITIES SUPPORT
K. W. WEST
J. S. ASQUITH
J. A. RAY
J. H. SMITH

SURVEILLANCE AND DIAGNOSTIC METHODS
N. E. CLAPP
B. DAMIANO
J. MARCH-LEUBA
J. A. MULLENS
L. D. PHILLIPS
C. M. SMITH
F. J. SWEENEY
B. R. UPADHYAYA (UTKpt)
R. T. WOOD

PROGRAM MANAGERS
ADVANCED CONTROLS (ACTO)
J. D. WHITE
ADVANCED MEASUREMENT & CONTROL PROGRAMS
R. L. SHEPARD
FEDERAL EMERGENCY MANAGEMENT AGENCY PROGRAMS (FEMA)
M. E. BUCHANAN
ACOUSTICAL INSTRUMENTATION R&D PROGRAMS (AIRD)
W. H. SIDES

SPECIAL ASSIGNMENTS
R. S. BOOTH
J. B. DAVIDSON
R. C. KRYTER

DETECTOR RESEARCH AND DEVELOPMENT
K. H. VALENTINE
O. C. COLE
B. A. DENNING
D. D. FALTER
T. M. GAYLE
L. R. RUTH
J. A. WILLIAMS

ADVANCED MEASUREMENTS
C. W. RICKER
D. C. AGOURIDIS
E. D. BLAKEMAN
T. V. BLALOCK (UTKpt)
R. M. CARROLL
R. J. FOX
E. B. JOHNSON
J. T. MIHALCZO (UTKpt)
V. K. PARE
M. J. ROBERTS (UTKpt)
L. H. THACKER

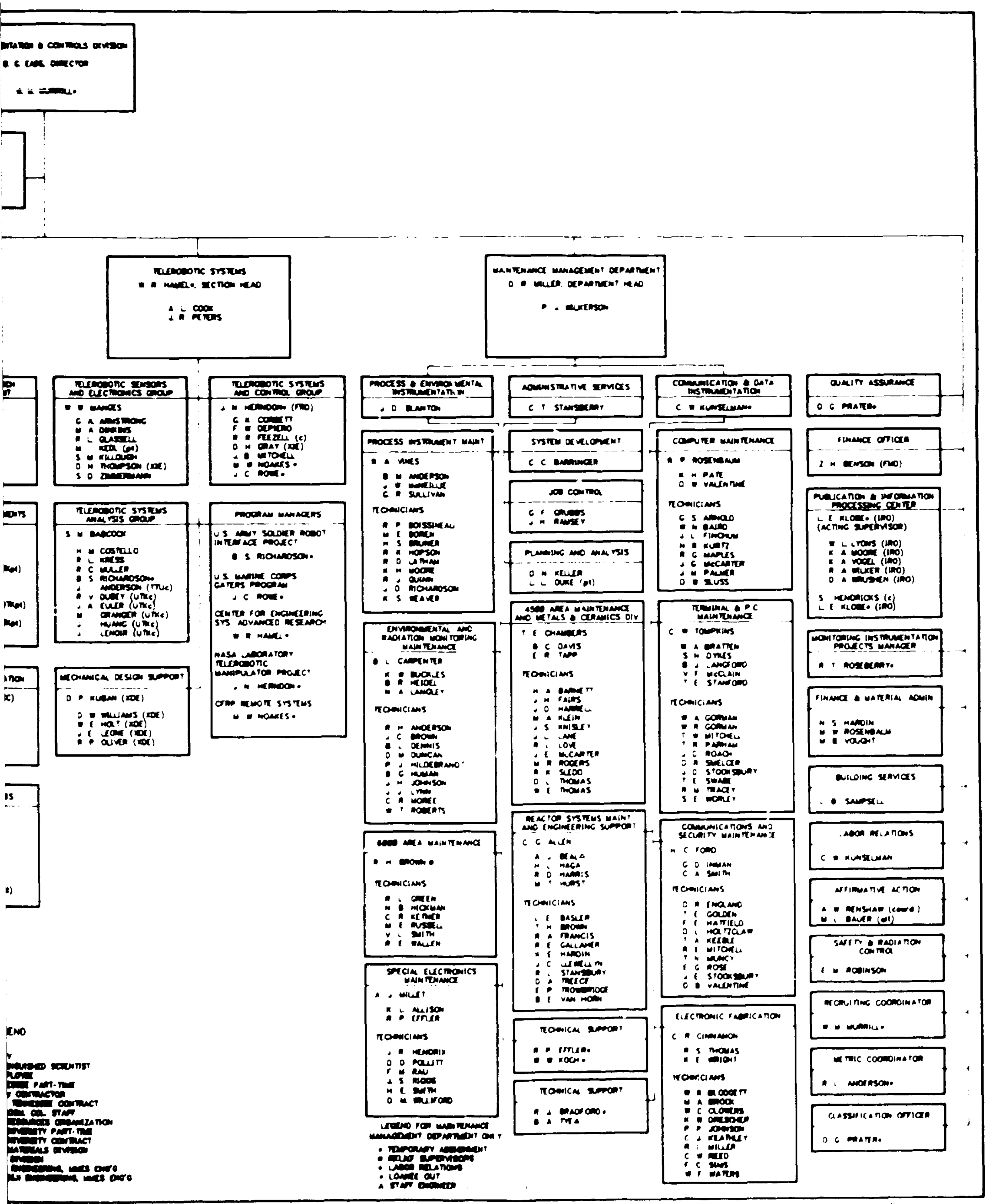
DESIGN AND EVALUATION
J. L. ANDERSON (RSCC)
R. E. BATTLE
E. W. HAGEN
R. A. KISNER
T. C. MORELOCK
T. L. WILSON

DYNAMIC ANALYSIS
S. J. BALL
C. R. BRITTAIN
C. E. FORD
R. M. HARRINGTON
C. E. MURPHY
J. K. MUNRO
A. W. RENSHAW
D. L. SMITH (UTKpt)

LEGEND

•	DUAL CAPACITY
••	UT/ORNL DISTINGUISHED ...
(pt)	PART-TIME EMPLOYEE
(UTKpt)	UNIV. of TENNESSEE PART ...
(c)	CONSULTANT or CONTRACT...
(UTKc)	UNIVERSITY of TENNESSEE ...
(RSCC)	ROANE STATE COM. COL. ...
(IRO)	INFORMATION RESOURCES ...
(TTUpt)	TENN. TECH. UNIVERSITY ...
(TTUc)	TENN. TECH. UNIVERSITY ...
(FMD)	FINANCE AND MATERIALS ...
(FRD)	FUEL RECYCLE DIVISION
(EDE)	EXPERIMENTAL ENGINEERING ...
(IOE)	INSTRUMENTATION ENGINE...

B. A. Eads (signature)
DIVISION DIRECTOR
March 1, 1988

INSTRUMENTATION & CONTROLS DIVISION
E. C. EADS, DIRECTOR
TELEROBOTIC SYSTEMS
W. R. HAMEL•, SECTION HEAD
A. L. COOK
J. R. PETERS
MAINTENANCE MANAGEMENT DEPARTMENT
D. R. MILLER, DEPARTMENT HEAD
TELEROBOTIC SENSORS AND ELECTRONICS GROUP
TELEROBOTIC SYSTEMS AND CONTROL GROUP
TELEROBOTIC SYSTEMS ANALYSIS GROUP
PROGRAM MANAGERS
U.S. ARMY SOLDIER ROBOT INTERFACE PROJECT
U.S. MARINE CORPS GATERS PROGRAM
CENTER FOR ENGINEERING SYS. ADVANCED RESEARCH
NASA LABORATORY TELEROBOTIC MANIPULATOR PROJECT
CFRP REMOTE SYSTEMS
MECHANICAL DESIGN SUPPORT
PROCESS & ENVIRONMENTAL INSTRUMENTATION
ADMINISTRATIVE SERVICES
COMMUNICATION & DATA INSTRUMENTATION
QUALITY ASSURANCE
PROCESS INSTRUMENT MAINT.
SYSTEM DEVELOPMENT
JOB CONTROL
PLANNING AND ANALYSIS
COMPUTER MAINTENANCE
FINANCE OFFICER
PUBLICATION & INFORMATION PROCESSING CENTER
ENVIRONMENTAL AND RADIATION MONITORING MAINTENANCE
4500 AREA MAINTENANCE AND METALS & CERAMICS DIV.
TERMINAL & P.C. MAINTENANCE
MONITORING INSTRUMENTATION PROJECTS MANAGER
FINANCE & MATERIAL ADMIN.
BUILDING SERVICES
REACTOR SYSTEMS MAINT. AND ENGINEERING SUPPORT
COMMUNICATIONS AND SECURITY MAINTENANCE
LABOR RELATIONS
AFFIRMATIVE ACTION
6000 AREA MAINTENANCE
SAFETY & RADIATION CONTROL
SPECIAL ELECTRONICS MAINTENANCE
TECHNICAL SUPPORT
ELECTRONIC FABRICATION
RECRUITING COORDINATOR
METRIC COORDINATOR
TECHNICAL SUPPORT
CLASSIFICATION OFFICER
TECHNICIANS
LEGEND FOR MAINTENANCE MANAGEMENT DEPARTMENT ONLY
• TEMPORARY ASSIGNMENT
• RELIEF SUPERVISORS
• LABOR RELATIONS
• LOANEE OUT
▲ STAFF ENGINEER

ORNL-6524
Distribution Category UC-506
Instruments, Engineering, and Equipment

INTERNAL DISTRIBUTION

1. D. C. Agouridis
2. C. G. Allen
3. G. T. Alley
4. G. O. Allgood
5. G. W. Allin
6. A. H. Anderson, Jr.
7. J. L. Anderson
8. T. D. Anderson
9. W. H. Andrews, Jr.
10. S. P. Baker
11. S. J. Ball
12. R. E. Battle
13. M. L. Bauer
14. A. J. Beal
15. D. W. Bible
16. M. S. Blair
17. J. L. Blankenship
18. J. D. Blanton
19. J. K. Boucher
20. H. R. Brashear
21. E. R. Broadaway
22. R. H. Brown
23. W. L. Bryan
24. P. L. Butler
25. T. E. Chambers
26. K. F. Chapman
27. M. M. Chiles
28. N. E. Clapp, Jr.
29. D. A. Clayton
30. M. H. Cooper, Jr.
31. R. E. Cooper
32. G. K. Corbett
33. J. B. Cordts
34. R. I. Crutcher
35. S. D. Curd
36. J. B. Davidson
37. B. C. Davis
38. F. W. Depiero
39. M. A. Dinkins
40. W. B. Dress, Jr.
41. B. C. Duggins
42. B. G. Eads
43. M. N. Ericson
44. P. D. Ewing
45. D. D. Falter
46. K. G. Falter
47. C. E. Fowler, Jr.
48. D. N. Fry
49. T. M. Gayle
50. F. R. Gibson
51. W. R. Gorman
52. C. A. Grametbauer
53. S. S. Gould
54. W. R. Hamel
55. N. S. Hardin
56. J. E. Hardy
57. J. A. Hawk
58. S. P. Hendrix
59. N. J. Hensley
60. J. N. Herndon
61-63. R. A. Hess
64. J. R. Hightower
65. M. S. Hileman
66. N. W. Hill
67. B. S. Hoffheins
68. L. L. Horton
69. M. A. Hunt
70. J. O. Hylton
71. R. W. Ingle, Jr.
72. J. F. Jansen
73. J. M. Jansen, Jr.
74. W. B. Jatko
75. W. F. Johnson
76. R. W. Jones
77. T. A. Keeble
78. D. N. Keller
79. H. T. Kerr
80. C. R. Kidwell
81. L. E. Klobe
82. W. W. Koch, Jr.
83. E. H. Krieg, Jr.
84. R. C. Kryter
85. D. P. Kuban
86. C. W. Kunselman
87. J. L. Lane
88. R. F. Lind
89. J. J. Lynn, Jr.
90. W. L. Lyons
91. E. Madden
92. F. C. Maienschein
93. W. W. Manges
94. D. J. Marshall
95. L. C. Maxey
96-105. D. W. McDonald
106. S. A. McElhaney
107. J. A. McEvers
108. J. T. Mihalczo
109. D. R. Miller
110. G. N. Miller
111. V. C. Miller
112. T. W. Mitchell
113. K. A. Moore
114. J. A. Moore
115. M. R. Moore
116. O. B. Morgan
117. A. C. Morris, Jr.
118. T. N. Murry
119. W. M. Murrill
120. R. N. Nodine
121. C. H. Nowlin

122. V. K. Paré
123. M. L. Poutsma
124. D. G. Prater
125. J. A. Ray
126. D. E. Reichle
127. A. W. Renshaw
128. J. W. Reynolds
129. B. S. Richardson
130. C. W. Ricker
131. J. D. Roach
132. R. B. Rochelle
133. R. T. Roseberry
134. T. H. Row
135. F. R. Ruppel
136. K. J. Sharp
137. R. B. Shelton
138. R. L. Shepard
139. A. A. Shourbaji
140. W. H. Sides, Jr.
141. D. E. Smith
142. S. F. Smith
143. C. T. Stansberry
144-146. C. N. Strandberg
147. P. A. Tapp
148. R. S. Thomas
149. J. H. Todd
150. R. W. Tucker, Jr.
151. G. W. Turner
152. B. R. Upadhyaya
153. R. I. Vandermolen
154. R. A. Vines
155. K. A. Wakefield
156. R. E. Wallen
157. D. A. Waters
158. E. E. Waugh
159. K. S. Weaver
160. C. R. Weisbin
161. J. C. Wells
162. K. W. West
163. G. R. Wetherington, Jr
164. R. A. Wilker
165. P. J. Wilkerson
166. R. A. Willems
167. L. C. Williams
168. F. W. Young, Jr.
169. W. L. Zabriskie
170. J. B. Ball (Advisor)
171. P. F. McCrea (Advisor)
172-174. Central Research Library
175. ORNL Y-12 Technical Library Document Reference Section
176-177. Laboratory Records Department
178. Laboratory Records - ORNL RC
179. ORNL Patent Section
180. Program Planning and Analysis Office
181-191. I&C Division Publications Office
192. ICC Resource Center

EXTERNAL DISTRIBUTION

U.S. Department of Energy, Oak Ridge, TN 37831

193. Office of Assistant Manager for Energy Research and Development
194. P. J. Gross, Nuclear Research and Development
195. E. E. Hoffman, Nuclear Research and Development
196. R. E. Williams, Engineering

U.S. Department of Energy, Washington, DC 20545

197. N. F. Barr, Office of Health & Environmental Research
198. F. X. Gavigan, Director, Office of Advanced Reactor Programs, NE-53
199. J. D. Griffith, Office of Deputy Assistant Secretary for Reactor Systems Development and Technology, NE-50
200. R. A. Hunter, Director, Office of Facilities Fuel Cycle and Test Programs, NE-55
201. R. G. Lange, LMRS and Breeders Division, Office of Advanced Reactor Programs, NE-532
202. D. J. McGoff, Director, LWR Safety and Technology, NE-42, Office of Reactor Deployment

203. E. E. Purvis, Manager, Innovative Technology, Advanced Technology Development, NE-542
204. R. W. Wood, Office of Health & Environmental Research

U.S. Nuclear Regulatory Commission, Washington, DC 20555

205. G. A. Arlotto, Director, Division of Engineering Technology
206. D. Basdekas, Electrical Engineering Branch, DET
207. R. Bernero, Director, Division of Risk Analysis
208. A. P. D'Zmura, Office of Breeder Reactor Technology Projects, U.S. DOE, Washington, DC 20545
209. W. S. Farmer, Division of Engineering Technology
210. Carl Johnson, Reactor Risk Branch, DRA
211. W. Morris, Chief of Electrical Engineering Branch, DET
212. G. S. Rhee, Office of Nuclear Regulatory Research
213. G. A. Schwenk, Core Performance Branch, DSI

Tennessee Valley Authority

214. D. E. Gray, Tennessee Valley Authority, 1300 Commerce Union Bank Building, Chattanooga, TN 37401
215. E. D. Daugherty, Tennessee Valley Authority, 3N78A Missionary Ridge Place, Chattanooga Office Complex, Chattanooga, TN 37402-2801
216. J. Royce Maner, Tennessee Valley Authority, Chestnut Street Towers II, Room 740, Chattanooga, TN 37401

Electric Power Research Institute
3412 Hillview Avenue, Palo Alto, CA 94303

217. Richard Balchizer, Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94303
218. J. F. O'Brien, Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94303
219. B. K. Sun, Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94303

David Taylor Naval Ship Research and Development Center
Bethesda, Maryland 20084

220. F. S. Archibald, Code 194
221. W. R. Bird, Code 2960
222. R. J. Boswell, Code 1508
223. W. R. Hoover, Code 1930.1
224. G. M. Jebsen, Code 1925
225. W. B. Morgan, Code 15
226. W. G. Niner, Code 1932
227. J. F. O'Donnell, Code 193

228. R. V. Reynolds, Code 1932
229. M. M. Sevik, Code 19
230. W. G. Souders, Code 1508
231. J. R. Spina, Code 1946
232. T. B. Thompson, Code 1933

The University of Tennessee, Knoxville, TN 37916

233. R. K. Adams, Electrical Engineering Department
234. J. A. Euler, Dept. of Mech. and Aero. Eng.
235. R. V. Dubey, Dept. of Mech. and Aero. Eng.
236. R. C. Gonzalez, Department of Electrical Engineering
237. J. M. G oge, Mechanical Engineering Department
238. W. L. Green, Electrical Engineering Department
239. C. Moore, Chem. Met. and Polymer Engineering
240. E. C. Muly, Jr., Director, Measurement and Control Engineering Center
241. T. W. Kerlin, Department of Nuclear Energy
242. R. B. Perez, Department of Nuclear Engineering
243. D. Pitts, Mechanical and Aerospace Engineering
244. G. V. Smith, Mechanical and Aerospace Engineering
245. J. E. Stoneking, Acting Head Engineer, Science and Mechanics
246. Dr. William T. Sayder, Department of Engineering

Naval Air Systems Command Electromagnetic Environmental
Effects Branch, Washington, DC 20361

247. R. V. Carstensen, Code 5161
248. M. E. Davis, Code 5161H
249. D. E. Fellin, Code 5161G
250. R. A. Hammett, Code 5161C
251. A. J. Iacono, Code 5161B
252. E. G. Lockhart, Code 5161F

253. R. W. Albrecht, University of Washington, Department of Nuclear Energy, Seattle, WA 98195
254. Charles Alexander, Head EE Department, Tennessee Technological University, Cookville, TN 38502
255. J. D. Allen (Consultant), 10652 Sandpiper Lane, Knoxville, TN 37922
256. J. F. Andary, Code 710.2, Goddard Space Flight Center, Greenbelt, MD 20771
257. C. J. Borkowski (Consultant), 123 Outer Drive, Oak Ridge, TN 37830
258. T. Braid, Editor of Review of Scientific Instruments, Argonne National Laboratory, Argonne, IL 60439
259. J. Butler, Head, Mechanical Engineering, Naval Explosive Ordnance, Disposal Technology Center, Indian Head, MD 20640
260. J. S. Byrd, E. I. duPont de Nemours and Co., Inc., Savannah River Laboratory, Aiken, SC 29808

261. W. E. Carow, Manager, Oak Ridge Office, Electro-Nucleonics, Inc., Nuclear Operations, 102 Tulsa Road, Oak Ridge, TN 37830
262. D. G. Carroll, General Electric Company, 6835 Via Delora, Box 530954, San Jose, CA 95153-5354
263. L. Conway, Dean, College of Engineering, Chrysler Center, North Campus. University of Michigan, Ann Arbor, MI 48109-2092
264. Louis Costrell, National Bureau of Standards, U.S. Department of Commerce, Washington, DC 20234
265. CMDR M. M. Elkins, Code 8153, Naval Electronics Systems Command, Washington, DC 20360
266. EG&G Ortec, 100 Midland Drive, Oak Ridge, TN 37830
267. E. P. Epler (Consultant), 712 Florida Avenue, Oak Ridge, TN 37830
268. LCDR B. Everett, USN, Assistant for Robotics, Department of the Navy, Naval Sea Systems Command, Washington, DC 20362
269. Harold Falkenberry, P.E., Consulting Engineer, 4561 LaSalle Avenue, Alexandria, VA 22304
270. F. L. Fletcher, Energy Technology Engineering Center, P.O. 1449, Canoga Park, CA 91304
271. F. E. Gelhaus, Program Manager, Nuclear Engineering and Operations Department, 3412 Hillview Ave., Box 10412, Palo Alto, CA 94303
272. R. J. Grill, U.S. Department of Justice, Immigration and Naturalization Service, Rm. 2208, 425 I Street NW, Washington, DC 20536
273. J. M. Grover, Hanford Engineering Development Laboratory, P.O. 1970, Richland, WA 99352
274. J. Hord, Director, Center for Chemical Engineering, National Engineering Laboratory, National Bureau of Standards, 325 Broadway, Boulder, CO 80303
275. Beth Jinkerson, University Programs Division, Oak Ridge Associated Universities, Oak Ridge, TN 37830
276. R. G. Julian, Captain, U.S. Air Force, AAMRL/BBA, Wright-Patterson AFB, OH 45433
277. Dr. Paul L'sowski, Group P-3, MS D449, Los Alamos National Laboratory, Los Alamos, NM 87545
278. R. Mahr, Analytic Disciplines, Inc., 2070 Chain Bridge Road, Suite 400, Vienna, VA 22180
279. C. D. Martin, 102 Moss Road, Oak Ridge, TN 37831
280. A. Meintel, MS 152-D, NASA Langley Research Center, Hampton, VA 23665
281. H. G. McCain, Goddard Space Flight Center, Greenbelt, MD 20771
282. A. O. McCoubrey, Center for Absolute Physical Quantities, U.S. Department of Commerce, National Bureau of Standards, Washington, DC 20234
283. T. P. Mulcahey, Components Technology, Argonne National Laboratory, Argonne, IL 60439
284. Naval Sea Systems Command, Attention: Code CEL-R, Bldg. NC-1, Rm. 4W48, Washington, DC 20362-5101
285. D. W. Nolen, Section Head, Equipment Development Division, Aluminum Company of America, Alcoa Center, PA 15069
286. The Nucleus, Inc., 461 Laboratory Road, Oak Ridge, TN 37830

287. Odetics, T. G. Bartholet, 1380 S. Anaheim Blvd., Anaheim, CA 92805
288. Nancy O'Fallon, Applied Physics Division, Building 315, Argonne NationalLaboratory, Argonne, IL 60439
289. ORAU Technical Library (MERT), P.O. Box 117, Oak Ridge, TN 37830
290. Physics/Optics/Astronomy Library, 374 Bausch and Lomb Buiding, University of Rochester, Rochester, NY 14627
291. J. C. Robinson, Technology for Energy Corporation, 1 Energy Center, Pellissippi Parkway, Knoxville, TN 37922
292. D. A. Rohn, MS 23-2, NASA Lewis Research Center, 21000 Brookpark Road, Cleveland, OH 44135
293. R. L. Rosenfeld, Program Manager, DARPA, 1400 Wilson Blvd., Arlington, VA 22209-2308
294. W. B. Rouse, Search Technology, Inc., 25B Technology Park/Atlanta, Norcross, GA 30092
295. L. Rubin, Massachusetts Institute of Technology, Francis Bitter National Magnet Laboratory, Building NW14-1108B, Cambridge, MA 02139
296. S. J. Rudnick, Electronics Department Head, Argonne National Laboratory, 9800 South Cass Ave., Building 818, Argonne, IL 60439
297. R. F. Saxe (Consultant), Department of Nuclear Engineering, North Carolina State University, Raleigh, NC 27600
298. C. H. Schulman, Manager, Independent Research and Development, Martin Marietta Aerospace, P.O. Box 5837, MP 418, Orlando, FL 32855
299. M. A. Schultz (Consultant), 124 Lakeshore Drive, Apt QS730, N. Palm Beach, FL 33408
300. C. M. Shoemaker, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD 21005
301. C. R. Siebentritt, Jr., PO(DC), Federal Emergency Management Agency, Washington, DC 20301
302. R. J. Soulen, Temperature and Pressure Measurements and Standards, Physics Building, National Bureau of Standards, U.S. Department of Commerce, Washington, DC 20234
303. M. L. Stanley, Idaho National Engineering Laboratory, EG&G, P.O. Box 1625, Idaho Falls, ID 83401
304. Dr. J. A. Thie (Consultant), 12334 Bluff Shore Drive, Knoxville, TN 37922
305. K. H. Valentine, 10401 Roselle St., San Diego, CA 92121
306. J. Vranish, Code 716.3, Goddard Space Flight Center, Greenbelt, MD 20771
307. L. E. Zutovsky, Evaluation Research Corp., 8330 Old Courthouse Road, Vienna, VA 22180

308-438. Given distribution as shown in DOE Category UC-506, Instruments, Engineering, and Equipment