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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Instrumentation and Controls Division Progress Report for the Period July 1, 1982 to July 1, 1984

Volume 1

MASTER

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FOR THE UNITED STATES

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Instrumentation and Controls Division Progress Report for the Period July 1, 1982 to July 1, 1984

Volume I

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INSTRUMENTATION AND CONTROLS DIVISION

OVERVIEW

R. G. Eads

The ORNL Instrumentation and Controls Division performs basic instrumentation and controls research, development and design engineering, specialized instrument fabrication and production, and maintenance services for instruments, electronics, and computers. The I&C Division is one of the largest R&D organizations of its type, 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 enhance the Laboratory's expertise and capabilities in this rapidly expanding, innovative area of technology.

The primary mission of the Instrumentation and Controls Division is to support the programs and projects of the Oak Ridge National Laboratory by applying its expertise and capabilities as required to complement the efforts of others in performing basic research and mission-oriented technology development. The contribution of I&C may be a few hours of maintenance service, the fabrication of a special instrument or instrumentation system, the performance of a research and development task in the I&C facilities, or the assignment of from one to many I&C engineers and scientists to a multidisciplinary team working in a specific research area or development project in an ORNL program or division. 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. During FY 1984 the level of the R&D support engineering effort was $9.3 million, and the level of maintenance effort was $5.8 million. In this progress report, the I&C Division's R&D support engineering and maintenance work are described in overviews of the engineering sections and the maintenance functions, as well as in specific articles on work in progress and abstracts of published work. A complete list of tasks performed is not provided in order to avoid excessive detail.

The second role of the I&C Division is the performance of basic and applied instrumentation research and development tasks which are in support of ORNL programs and which are of sufficient scope that the I&C effort constitutes a separate program element with direct funding and management responsibility within the Division. The principal funding agencies for such programs are the U.S. Department of Energy, the U.S. Nuclear Regulatory Commission, the Federal Emergency Management Agency, the Department of Defense (U.S. Navy), and the Electric Power Research Institute. During FY 1984 the level of effort in this area was $13.7 million. As might be expected, the scope of the I&C work in this category is comprehensive and suitable for publication. Essentially all major R&D efforts of the Division are represented in this report, either by summaries or abstracts of published reports, articles, and meeting papers, or as summaries of work not yet published.

Figure 1 illustrates the levels of effort in research and development, R&D support engineering, and maintenance during the past five years, and Table 1 contains the dollar amounts expended in each area during the same period. Projections are included for FY 1985 and are subject to increase or decrease. In this reporting period, I&C has experienced continued growth in funding of both R&D and R&D support engineering efforts. The size of the I&C staff has remained quite stable since 1978, except for a modest peak in the interval 1980 through 1982 (see Fig. 2).

Demand for the capabilities of I&C in both the Y-12 Plant and the Oak Ridge Gaseous Diffusion Plant has continued to grow, with I&C involvement in the ORGDP AVLIS Program growing most notably. The future direction of nuclear fuel enrichment R&D in the United States is being reevaluated, with the potential for growth or decline depending on the enrichment option selected by DOE. Support for Y-12 Plant projects has grown modestly, and that trend is expected to continue for the next two years.

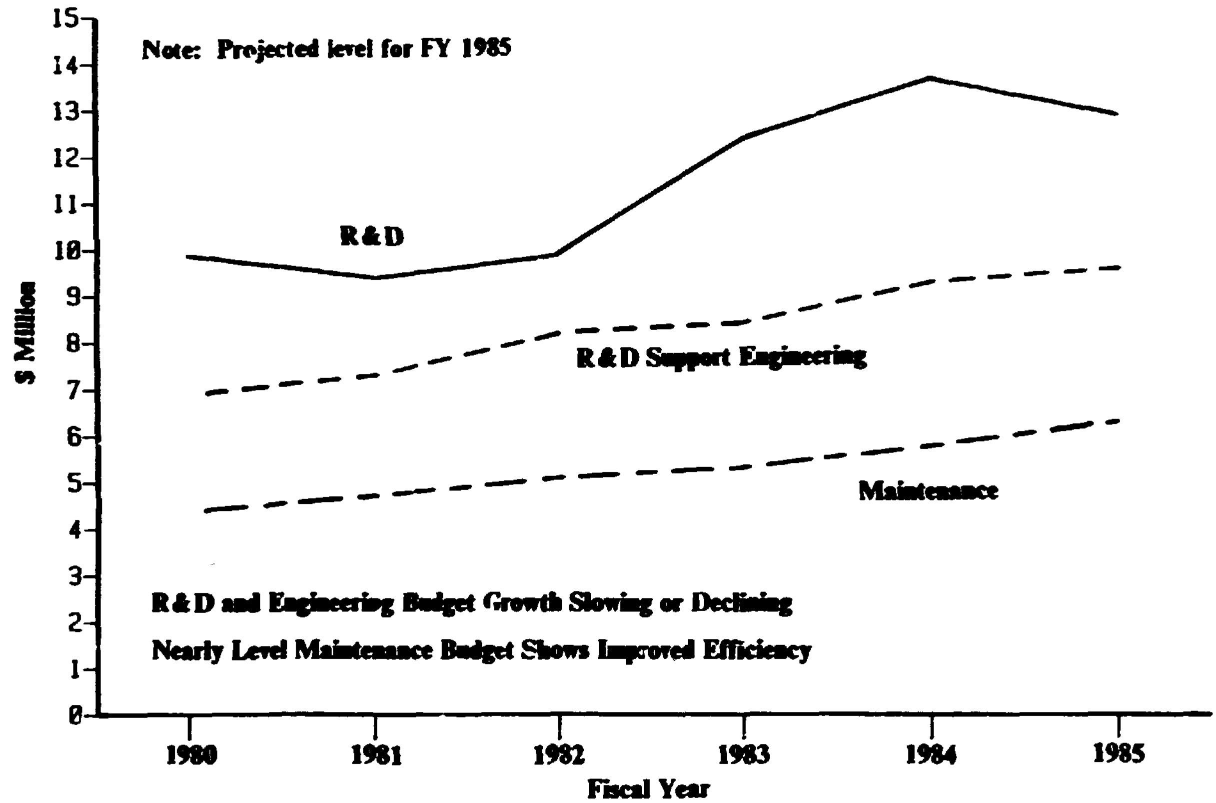

Fig. 1. Level of R&D support engineering effort, maintenance effort, and R&D effort in the ORNL Instrumentation and Controls Division.

Table 1. Level of I&C Division effort in dollars FY 1980 through FY 1985

Fiscal year	R&D support engineering ($)	Maintenance ($)	R&D ($)
1980	6,905,000	4,380,000	9,929,000
1981	7,318,000	4,673,000	9,411,000
1982	8,185,000	5,103,000	9,926,000
1983	8,359,000	5,322,000	12,372,000
1984	9,334,000	5,816,000	13,700,000
1985*	9,643,000	6,264,000	12,912,000

*Projected.

The most notable challenge facing the I&C Division in the upcoming two years is the funding uncertainty in certain key areas. This uncertainty is reflected in the projected funding decline in the R&D effort. In the current NRC programs, we are experiencing the natural completion of many programs that resulted from the Three Mile Island accident. A further decline in NRC research funding in the future is clearly indicated. The future of the nuclear power option for the United States is also uncertain, although several studies are under way to develop a nuclear power strategy for the future. At present there is considerable encouragement for I&C in these studies, yet it may be a number of years before a new direction is clearly

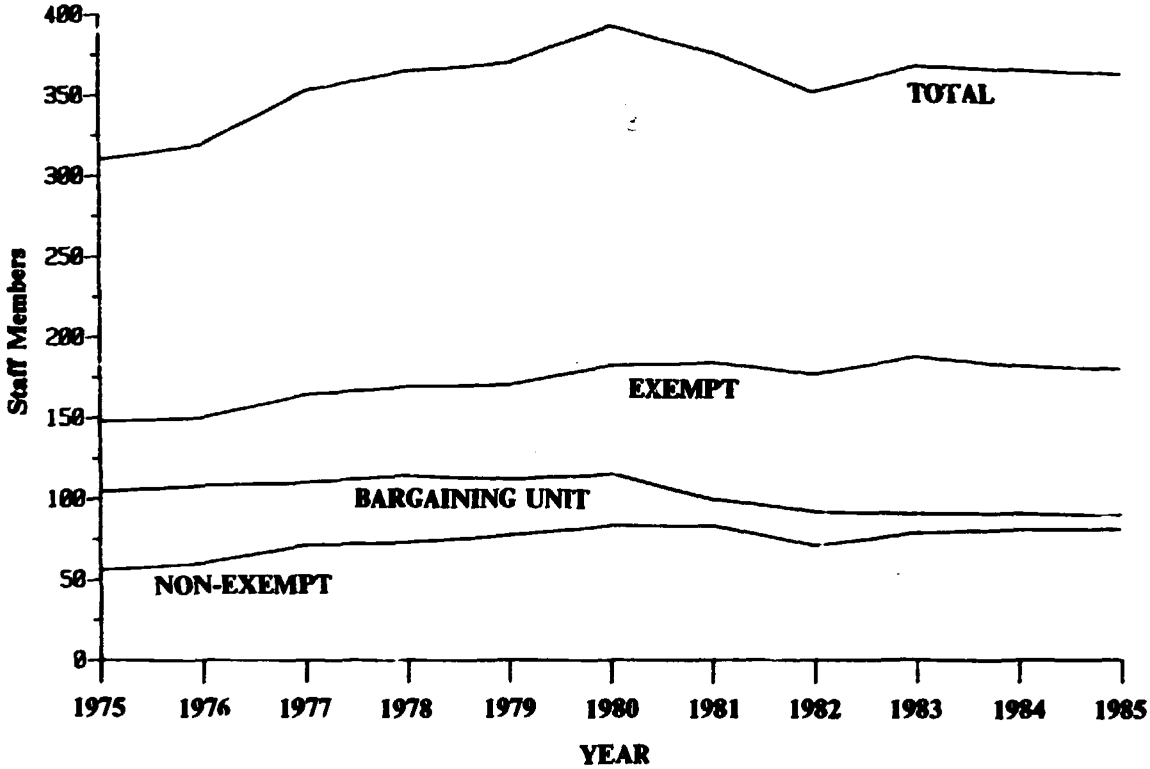

Fig. 2. Number of staff members in the ORNL Instrumentation and Controls Division, 1975–1985.

established. The Oak Ridge National Laboratory is referred to as a multiprogram laboratory, meaning that it supports many DOE programs rather than just one or a few. Correspondingly, the I&C Division is very diverse and does not depend on funding from just one or a few programs; for that reason, I&C continues to be involved in ongoing programs while at the same time has the ability to respond quickly to new activities.

During the past two years the I&C Division has continued to seek recognition through patents and I·R 100 Awards for achievements in hardware and sometimes software development. It is recognized that these awards complement the role of publications as indicators of the performance of the Division staff. Table 2 lists the patent applications filed and patents assigned during the reporting period, while Table 3 lists the I·R 100 nominations submitted by ORNL on behalf of the I&C Division and indicates awards received. The sizable number of patents and award nominations, along with the publication record represented in this report, demonstrates that the I&C Division has been very productive during this reporting interval.

Table 2. Patent applications filed and patents issued July 1, 1982 through July 1, 1984

CNID No.	Name	Description	Patent No. and date
		Patents issued	
4092	A. L. Case J. B. Davidson	Electronic Method for Autofluorography of Macromolecules on Two-D Matrices	4,389,670 June 21, 1983
4035	K. H. Valentine M. K. Kopp	Neutron Detection Apparatus	4,390,786 June 28, 1983
4014	D. C. Agouridis	Photovoltaic Radiation Detector Element	4,394,676 July 19, 1983
4052	M. K. Kopp K. H. Valentine	Neutron Flux Profile Monitor for Use in a Fission Reactor	4,404,164 September 13, 1983
4017	R. J. Fox	Radiation Dosimeter	4,415,237 November 15, 1983
4097	F. W. Manning	Pocket Radiation Dosimeter-Dosimeter	4,430,569 February 7, 1984
4116	D. R. Miller V. R. Brantley*	Device and Method for Measuring the Coefficient of Performance of a Heat Pump	4,432,232 February 21, 1984
4223	S. C. Rogers	Tunable Damper for an Acoustic Waveguide	4,452,334 June 5, 1984
4113	F. W. Manning	Portable Battery-Free Charger for Radiation Dosimeters	4,449,049 May 15, 1984
		Patent applications filed	
4[illegible]5	R. J. Fox	Optical Fiber Distributed Line Peak Temperature (SN 403,278)†	July 1982
4196	W. R. Hamel	A Cantilever Coriolis Mass Flowmeter (SN 433,299)	October 1982
4223	S. C. Rogers	Ultrasonic Probe Dampener (SN 435,797)	October 1982
4224	D. R. McNeilly	Inexpensive Wide-Range Lock-in Amplifier (SN 447,728)	December 1982
4235	R. A. Maples	Pistol-Grip Dosimeter Charger (SN 460,502)	January 1983
4295	K. R. Carr	Magnetically Coupled Rotational Viscometer (SN 501,313)	June 1983
4355	W. B. Dress, Jr.	Biasing and Fast Degaussing Circuit for Magnetic Materials (SN 539,011)	October 1983
4363	D. R. McNeilly	Noise Isolation in High-Speed Circuits (SN 566,760)	December 1983
4301	B. S. Weil‡ G. R. Wetherington, Jr.	Beam Focusing Indicator for a Laser Cutting System (SN 450,305)	December 1982

*Engineering Technology Division.
†Serial number of patent application (not a patent number).
‡Fuel Recycle Division.

Table 3. I-R 100 Awards
1983–1984

Winners

Model M-2 Control System (1984)
- P. E. Satterlee
- H. L. Martin
- J. N. Herndon

Ultrasonic Pulsed Neutron Time-of-Flight Spectrometer (1984)
- H. A. Mook[*]
- G. K. Schulze

Nominations

ORNL RAMPS: Remote Analyzer for Multicomponent Process Streams
- D. D. McCue
- D. T. Bostick[†]
- R. E. Harper
- M. L. Bauer
- R. D. Seals[‡]
- J. E. Strain[†]

ORNL Wireless In-Core Flux Monitor
- T. V. Blalock
- R. M. Carroll
- M. M. Chiles
- J. T. DeLorenzo
- E. J. Kennedy
- J. M. Rochelle[**]
- K. H. Valentine

ORNL Peak Temperature Measurement System
- R. J. Fox

ORNL-Dosimeter Charger
- F. W. Manning
- H. N. Wilson
- R. A. Maples

ORNL Ultrahigh-Sensitivity Fission Counter
- G. W. Allin
- J. G. Carter
- M. M. Chiles
- W. T. Clay
- G. C. Cuerrant
- J. A. Harter
- C. E. Fowler
- M. K. Kopp
- K. H. Valentine
- L. G. Christophorou[††]

ORNL Digital Control System for a Teleoperated Servomanipulator
- P. E. Satterlee
- H. L. Martin
- J. N. Herndon[‡‡]

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[*] Solid State Division.
[†] Analytical Chemistry Division.
[‡] Y-12 Plant Development Division.
[**] The University of Tennessee, Knoxville.
[††] Health and Safety Research Division.
[‡‡] Fuel Recycle Division.

Section 1

RESEARCH INSTRUMENTS

1.0. Overview

1.1. U.S. Navy RADIAC Development Program

1.2. Accelerator Support

1.3. Engineering Support for ORNL Fusion Energy Division

1.4. Instrument and Detector Development

1.5. Computer Systems

1.6. Security

1.7. Environmental Monitoring

1.8. FEMA Engineering Support

1.9. Facility and System Engineering Support

1. RESEARCH INSTRUMENTS

1.0 SECTION OVERVIEW

H. R. Brashear

The Research Instrument Section (RIS)* performs research, development, design, fabrication, and systems implementation of measurement instruments and instrumentation systems dealing primarily with nuclear research and applied health physics. The primary mission of the section is to support the programs and projects of ORNL, national fusion and fission energy programs, and national defense. Section activities range from generic research on sensors and measurement techniques through development, design, fabrication, and testing of state-of-the-art instruments not commercially available; and application of complete data collection systems, data reduction, and experimental control in research and engineering environments.

ACCOMPLISHMENT HIGHLIGHTS

- Applied research on two different plastic semiconductor materials has resulted in the development of an alpha particle detector, in both current mode and pulse mode, and a Schottky-barrier diode. These early results point to the possible fabrication of more complex active electronic devices. (See 1.1.5)
- During this reporting period, this section won an I·R 100 Award jointly with the ORNL Solid State Division for development of an ultrasonically pulsed neutron spectrometer (reported in the previous progress report.[1])
- The ORNL Physics Division, with significant participation by this section, has become a world leader in the development of detectors for heavy ion physics. (See 1.2.1, 1.2.2, 1.2.6, 1.2.7, 1.2.8, and 1.2.9.)
- Development efforts in the I&C Reactor Systems Section culminated in the design and fabrication of two ultrahigh-sensitivity fission chambers, one for fast neutrons and one for thermal neutrons. These instruments have a sensitivity of 45 counts/(s·nv), which is approximately 40 times that of the best previous fission chamber. (See 3.1.7, 1.4.2.)
- This section developed a wireless in-core neutron flux monitor with ultrasonic signal transmission that demonstrates (1) the use of solid-state electronics operating at 230°C in the presence of neutron and gamma fluxes within the damage range of most solid-state devices, (2) the operation of a fission counter with 10-V bias, and (3) ultrasonic data transmission in a liquid at 230°C. (See 1.4.6.)
- The development of "smart" (microprocessor) battery-operated portable instruments enhances measurement capabilities while making the instruments simpler to use. (See 1.1.0 and 1.4.1.)
- Security system developments in badge readers, including a stand-alone reader with bubble memory, have improved control of personnel in secure areas. (See 1.5.2, 1.6.1, and 1.6.4.)
- A broadband midsplit cable television trunk system for high-speed data transmission and video is now in operation at the ORNL X-10 and Y-12 sites. (See 1.9.7 and 2.5.2.)
- Development of improved beam current monitors for ORELA has facilitated investigation of accelerator beam characteristics and modeling of their behavior. (See 1.2.10 and 1.2.11.)

FUTURE TRENDS

The present trend toward de-emphasizing nuclear-based technology development is expected to continue as a result of diminishing DOE funding of ORNL programs. Likewise, increasing funding from other

1. F. R. Mynatt, ORNL-5931/V1, December 1982, p. 84.
*The acronym list at the end of this report may be folded out for reference.

federal agencies, principally the Department of Defense (DOD), is expected to continue. The net result of these trends is to broaden the development base of this section and increase the technology development of the staff while maintaining a nationally needed core of experts in radiation instrumentation development.

Sensor developments are expected to continue in both areas with increased emphasis on sensor development in the areas of analytical and environmental monitoring. Applied research in sensor and active device development based on an emerging class of plastic semiconductor materials is expected to continue.

Automatic testing equipment (ATE) development utilizing expert systems–based programming is expected to increase and be applicable to both military hardware and the more complex instrumentation within ORNL. Microprocessor-based "smart" instrument development, both fixed and portable, is expected to continue with (1) multiple functions incorporated, (2) more versatile information displays, and (3) the added feature of communication with other measurement instruments or computers. The application of general-purpose personal computers in the research laboratory is expected to continue. It will supplant some of the smaller minicomputer systems and will require more in-house custom interfacing and software development. The quest for custom monolithic circuit development capability to reduce costs, increase reliability, and improve instrumentation capability will also continue.

SECTION ORGANIZATION

The RIS technical staff includes electronics and electrical engineers, physicists, chemical engineers, mechanical engineers, engineering technologists, drafting technicians, and designers. Administratively, the section is organized into seven groups with two staff members on special assignment. Functionally, teams are organized from these groups and the other sections or other ORNL divisions as a matrix to obtain the proper mix of expertise required for a particular project. Activities of the groups are described below.

Accelerator Physics Group

This group of experienced scientists and engineers supports projects using the various ORNL particle accelerators operated by the ORNL Physics Division and Engineering Physics and Mathematics Division. The facilities supported are

- Holifield Heavy Ion Research Facility (HHIRF)
- Oak Ridge Isochronous Cyclotron (ORIC)
- Oak Ridge Electron Linear Accelerator (ORELA)
- Magnetic Fusion Energy Accelerator (a 300-kV Cockroft Walton generator).

Heavily oriented toward nuclear physics, this group is responsible for the hardware and software interface between the HHIRF and its control and monitoring computers; for operations and systems development at ORELA; for the design, development, and fabrication of all state-of-the-art particle detectors and electronics used with ORIC, HHIRF, and ORELA; and for the design and setup of all experiments at ORELA with special emphasis on the data acquisition systems between the experiments and the data processing computers.

Computer Systems Group

This group provides hardware and software design and field support of minicomputer- and microcomputer-based research instrumentation systems utilizing a wide range of digital and analog hardware from many different manufacturers. Custom circuit design and software development is applied in CAMAC-based nuclear spectrometry, time-of-flight data acquisition, nuclear pulse height spectrometry, experiment control interfaces, and precise positioning using stepper motors. Computer systems have been custom tailored for environmental monitoring, nuclear waste monitoring, and the Emergency Response Center. Distributed systems have been developed for security management including microprocessor-controlled badge readers, remote distribution of laser videodisc data and pictures, and remote sensor monitoring of personnel and vehicles. Special projects range from nuclear reactor fuel plate inspection to battery-operated, low-power field environmental data acquisition instrumentation. In addition, support is provided to the ORNL Fusion Energy Division in microwave instrumentation and high-voltage/high-current power supply designs and specifications.

Electronic Systems Development Group

This group develops, designs, and analyzes electronic circuits and systems for a broad spectrum of applications. Its staff has special expertise in the areas of low-power analog and digital circuit design, radiation-hardened and high-temperature electronics, power electronics design, remote signal transmission, and analog and digital signal processing. These capabilities are applied in discrete, hybrid, and monolithic construction technologies. Areas of activities include instrumentation development for applied health physics, metrology, environmental monitoring, analytical chemistry, particle physics, automatic testing, and low-power portable instruments (with and without microcomputers). Additional areas of design include power controllers, robotics application, high-energy capacitor discharge experiments, and fission chamber data transmission in liquid metal.

Mechanical Development Group

This group specializes in one-of-a-kind mechanical developments and designs in support of other groups and divisions within ORNL. These designs include details of sensor components, pressure vessels, vacuum systems, flywheel testing, positioners, and special instrument packaging. This group becomes part of the design team when special fabrication techniques, material compatibility, adhesive systems, dimensional stability, or tooling design are required to produce intricate parts. Examples of projects include a die to form intricately shaped fission chamber electrodes, a high-resolution, high-capacity load cell balance, and a remote-positioning optics system for transmitting strain data from a rotating specimen in a vacuum chamber.

Product Design and Drafting Group

This group supports a wide variety of R&D projects at ORNL, the Y-12 Plant, and ORGDP. These activities include printed circuit designs, instrument packaging designs, mechanical and electrical drafting, metalphoto panel layout, photography associated with product fabrication, chemical milling, documentation of products, and coordination of product fabrication to produce a complete package for the user. Computer-aided design is used extensively to produce high-quality products at minimum time and expense.

Sensor Systems Group

This group provides sensor research, development, design, and fabrication primarily, but not exclusively, in the nuclear radiation field. Detector designs include the traditional gas, scintillation, and solid-state types that require attributes not commercially available (commercial detectors are always specified where applicable). 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 health physics survey instruments. Research on plastic materials which exhibit semiconducting properties continues, as does research on alternate analytical techniques to measure long half-life radioisotopes before transmutation. This group also consults with a variety of customers requesting expertise on radiation shielding calculations and radiation effects on materials and electronics.

Special Electronics Group

This group provides radio frequency engineering including broadband cable systems for high-speed data, video, and security communications; systems engineering including microcomputer programming and interface designs; instrument development; and field engineering in nuclear spectroscopy and environmental monitoring. The expertise of this group also includes applied engineering in the areas of electromagnetic pulse (EMP) susceptibility and mitigation for commercial radio broadcast stations and measurements of electromagnetic interference (EMI) from digital processing equipment.

1.1.0 OVERVIEW

W. L. Bryan

The I&C Division supplies radiation detection and measurement expertise to the U.S. Navy for use in its Radiation Detection, Indication, and Computation (RADIAC) development program. This program includes preliminary systems studies for detectors and complete instruments and advanced instrument development. In addition, the I&C Division assists the Navy with current RADIAC instrument inventory-related projects.

System studies on advanced detector and instrument systems involve literature surveys in current state-of-the-art approaches, analysis of candidate capabilities and limitations, cost-benefit summaries, recommendations, and project proposals.

Based on the Navy's evaluation of an advanced detector systems study, several potential detector concepts are pursued independently by I&C investigators. In this development phase, measured capabilities are compared to results of the theoretical analysis contained in the detector systems study. After research on several potential detectors is complete, production costs and cost-benefit figures are determined for each option.

Following the selection of a detector, advanced development on the chosen instrument or measurement system begins. Such a project may develop bench-scale subsystems and advanced prototypes. The final system must be evaluated by the Navy before production requirements are established and Navy procurement of the system begins. The time period from the instrument systems study to actual Navy procurement may be as much as six to eight years.

In addition to these development activities, the I&C Division develops standards for the RADIAC program which ensure reliable, compatible RADIAC instruments and systems with low life-cycle costs. I&C Division also evaluates the reliability of the current instruments in RADIAC inventory, and redesigns and retrofits equipment as necessary.

1.1.1 SYSTEMS STUDY FOR AN ADVANCED TRITIUM DETECTOR

G. A. Colman

(Abstract of thesis for the Master of Science Degree, The University of Tennessee, Knoxville, June 1984)

This thesis describes a thorough and comprehensive systems study on the development of an advanced tritium-in-air monitor. Three technologies were investigated for possible use in a state-of-the-art tritium detector system: double-resonance laser-induced fluorescence spectroscopy, direct beta detection using a CaF_2(Eu)/bismuth germanate phoswich structure, and indirect beta detection using a closed-loop liquid scintillation system.

The concept of each of these technologies is discussed in this thesis. Various detector systems are proposed, and the numerous components making up each system are selected based on performance and cost. Calculations of sensitivity and estimated purchase price are included in the analysis of each proposed system. Each is also evaluated in terms of its time constant, portability, movability, ability to distinguish between the elemental (HT) and oxide (HTO) forms of tritium in air, and the ability to reject false signals from external alpha-, beta-, and gamma-emitting radionuclides.

This thesis is intended to be used as an aid in the selection of a conceptual system to be developed as an advanced tritium-in-air monitor; therefore, development costs and probabilities of successful implementation are given for each proposed system. It is concluded that two systems, a laser-induced fluorescence detector and a CaF_2(Eu)/bismuth germanate detector, should be considered for further development, and a development scenario is recommended.

1.1.2 BETA DETECTION SYSTEMS STUDY

G. A. Colman

A systems study was undertaken at ORNL for the development of a state-of-the-art beta detection system for the U.S. Navy. The current technology was first surveyed by comparing existing detection techniques. Following that, the various technologies were assessed in terms of their potential application under the criteria established for the conceptual system. Although three different systems were considered initially– based on G-M tubes, Si surface-barrier detectors, and solid scintillation detectors—the Si surface-barrier system was rejected because of its high cost. The study was therefore directed toward the conceptual development of two detector-based systems, G-M tubes and solid scintillation detectors.

Each detector-based system was analyzed for sensitivity to gamma background, and various techniques were explored in order to reduce this sensitivity. It was determined that lead shielding would be adequate for the G-M tube-based system, but that a phoswich structure with an additional guard detector would be required for the solid scintillation detector system. Whether lead shielding is required for the solid scintillation system depends on the background exposure level at the detector site.

The G-M tube systems would be used when isotope identification is not required. If, on the other hand, it is decided that isotope identification is necessary, it is recommended that the solid scintillation systems be employed.

This work was carried out within the framework of a conventional systems study, broken down into three main phases—concept, selection, and analysis. The synthesis phase normally included in a systems study was not included here. It is anticipated that this phase will occur later based on a favorable evaluation of the proposed systems.

1.1.3 ADVANCED SOLID-STATE RADIATION DETECTOR FOR ALPHA PARTICLE DETECTION

M. L. Bauer G. A. Colman

An effort which was undertaken in FY 1983 is continu. on the development of active electronic devices using plastic semiconductors. Plastics are being investigated for use as alpha detectors. The work thus far has concentrated on the development of two plastic semiconductors, poly-para-phenylene and poly-diacetylene, as candidates for alpha detectors because of their potential use in low-cost, rugged detectors that could be manufactured using this class of material.

These materials have special properties in that their conductivity falls between that of a metal and that of an insulator. Further, their conductivities can generally be varied over a wide range by introducing controlled concentrations of impurities (doping). The two materials examined in this work have the additional property of being stable in atmospheric conditions, a fact not true of some other plastic semiconductors being developed for other purposes.

Two devices were successfully constructed during this reporting period. A Schottky-barrier diode was fabricated from antimony pentachloride doped poly-para-phenylene using thin crystals, and a radioconductive alpha detector was fabricated from poly-diaceltylene.

Poly-para-phenylene was manufactured by two techniques. One produced a powder which, according to published literature, had chains averaging 9 to 11 monomer units in length, while the other method used thin films of crystalline p-terphenyl, doped and polymerized by using antimony pentachloride. Only the units made from the p-terphenyl successfully showed useful semiconducting properties.

Poly-diacetylene was manufactured from 2,4 hexadiyne, 1,6 diol and toluene sulfonyl chloride by the method of G. Wegner.[1] These pink crystals were then polymerized by heating. This process forms an intrinsic conductor of high re[illegible] with radioconducting properties; its resistance changed reversibly under irradiation, and pulses could be collected from biased sensors.

Future efforts will be aimed at the fabrication of reproducible devices with optimal geometric configurations and devices with enhanced detection properties. With the success of this work, efforts may branch into other areas of active sensors such as ChemFETs, and into the fabrication of active devices such as transistors, from these materials.

1. G. Wegner, *Die Makromol. Chemie* **145**, 85–91 (1971).

1.1.4 DEVELOPMENT REPORT: A RADIAC SYSTEM FOR MEASURING AQUEOUS TRITIUM CONCENTRATION BY THE LIQUID SCINTILLATION METHOD

G. A. Colman J. T. DeLorenzo
G. W. Allin J. E. Phelps

(Abstract of ORNL/TM-9290, October 1984)

This report describes the design, assembly, and testing of a room temperature bench-scale liquid scintillation system for aqueous tritium measurement. With this system urine or water samples with tritium concentrations of 1 to 5 microCuries per liter can be measured within 20% uncertainty in a typical counting time of 40 s to 3 min, depending on the background count rate, activity level, and degree of quench. Concentrations above 5 μCi/L can be measured within 10% uncertainty in a typical counting time of less than 3 min. In water samples, tritium concentrations as low as 0.1 μCi/L can be measured within 20% uncertainty in a typical counting time of 30 min, and within 30% uncertainty in less than 10 min. These operating parameters may be modified if necessary. For instance, changing the minimum measurable activity from 1 μCi/L to as little as 0.1 μCi/L can be accomplished by a simple change in the operating program.

The microprocessor incorporated into this system collects, processes, and transmits data and also interacts with the operator, which minimizes the work load and thereby reduces the chance of operator-induced error. Very little training is required: the operator simply follows basic instructions on the display.

A novel photomultiplier tube balance circuit was developed especially for use with this system. It maximizes counting efficiency and also eliminates the need for stocking matched pairs of photomultiplier tubes.

The design of the signal processing system is based on the use of a fast coincidence gate. This eliminates the need for refrigerating the scintillator or storing it in the dark. The design of the system also allows the degree of quench for a particular sample to be determined without the use of a radioactive gamma source. Gamma sources are used to determine quench in many commercial liquid scintillation counters.

1.1.5 ARCADES: AUTOMATIC RADIAC CALIBRATION AND DIAGNOSTIC EQUIPMENT SYSTEM

M. S. Emery J. E. Phelps

The U.S. Navy has many RADIAC radiation detection systems that require extensive time and money to maintain. Because new designs are becoming more and more complex, the time needed to troubleshoot and maintain these systems is increasing. The Navy would like an automatic system that could speed up the maintenance process. By automating most of the service procedures for RADIAC meters, the time involved, and, consequently, the cost of service should be sharply reduced.

To do this work, an IEEE-488 programmable test system was assembled from off-the-shelf components. The system controller is a Fluke 1722A instrument controller, and test instruments include a Hewlett-Packard 1738A digital multimeter and 8116A function generator, a Tektronix 7D20 digitizer and oscilloscope, and a Keithley 705 scanner. Peripheral equipment consists of an extra floppy disk drive and a printer, and future plans call for the use of a signature analyzer.

The ARCADES will monitor strategic bias voltages and internal RADIAC waveforms to provide an initial Go/No-Go test. If the unit passes this initial test, the system will proceed to an automated calibration procedure. If the unit fails initial Go/No-Go tests, failed instrument subsystems will be identified through either fully automatic diagnostics or computer-assisted interactive troubleshooting. With microprocessor RADIAC designs, nonvolatile electronic calibration will be implemented. ARCADES will assist the operator during troubleshooting essentially as an "online manual."

All ARCADES hardware except the signature analyzer has been procured. Design standards for new RADIAC meters are being drafted to ensure compatibility with ARCADES, and some simple software has been written to test the retrofit of the Navy's AN/PDR-45E RADIAC meter.

1.1.6 U.S. NAVY INSTRUMENTS

1.1.6.1 ADVANCED AUTO-RANGING HAND-HELD RADIAC DEVICE

G. T. Alley W. L. Bryan

In the ongoing development of the hand-held beta-gamma survey instrument, which is the basic tool of U.S. Navy health physicist, the following innovative features have been incorporated to reduce the calibration and other maintenance costs and lay the groundwork for establishing an entire family of survey RADIACs with common electronics and functionality. The SKF443-R2 RADIAC (ref. 1), which is a microprocessor-based instrument that uses a liquid crystal display to present the data in linear analog format over five decades, was used as the starting point of this development.

Calibration and maintenance costs of these types of Navy instruments exceed the capital cost of the instruments by at least a factor of two during the lifetime of the instrument. The Navy uses open-source calibration ranges in which the dose rate is principally the inverse-square of the distance between the source and detector. Although this open-source range is accurate and, even more important, uniform between ranges, it is labor intensive due to the calibration method used and the instrument design.

Since the SKF443-R2 is a microcomputer-based RADIAC, the addition of nonvolatile memory to store calibration coefficients requires little circuit change. Then by adding a serial interface, the calibration coefficients can be changed in real time on the calibration range.

The addition of computer-controlled positioning of the RADIAC on the range and real-time determination of calibration coefficients for the required dose rate (a minimum of ten calibration positions for this instrument—two on each range) reduces the range time required during calibration by an estimated 80%. In practice, the computer controlling positioning of the detector on the range also calculates the new coefficients for each range, transmits and programs the coefficients into the nonvolatile memory, determines whether the response of the detector and the electronics are within tolerance, and automatically inserts the calibration data into the database, and prepares a report of the calibration.

1. H. N. Hill, ORNL-5758, pp. 199–202.

1.1.6.2 SUPPORT OF EXISTING INSTRUMENTS FOR THE U.S. NAVY

J. E. Phelps W. L. Bryan
G. W. Allin R. E. Cooper

At the request of the U.S. Navy, a circuit design has been developed for retrofit of the Navy's Model PDR-45E RADIAC Meter in order to improve reliability and repairability over the earlier design. The RADIAC meter itself uses a pulsed G-M tube and operates in three ranges—5 R/h, 50 R/h, and 500 R/h (F.S.). The new circuit design is more easily calibrated, features much greater MTBF, is resistant to probe short circuits and damage caused by probe removal with power on. The retrofit design features a smaller and more flexible and reliable probe. The new circuit design fits the existing instrument and may simply be plugged in to replace the old design. The new design alleviates all of the failure modes of the old design and, through improved circuit implementation, provides a significantly more reliable replacement than the original AN/PDR-45E electronics while retaining full functional compatibility.

An interface between the U.S. Navy CP-1112 TLD reader instrument and an RS-232 equipped computer system has been implemented. This interface reduces errors resulting from incorrect instrument readings and manual data entry while it greatly speeds TLD reading and logging operations.

The interface is designed around an RCA CDP 18S600 single-board computer. The computer has an RCA BASIC III interpreter kernel installed so that the operating program is written in BASIC III and software can be easily modified for future system improvements. The system is housed in an RCA four-card industrial chassis with an internal 117-V ac power supply. Connections to the TLD reader and the RS-232 device are provided on the front panel.

1.2 Accelerator Support

1.2.0 OVERVIEW

The Accelerator Physics Group provides experienced scientists and engineers for the support of the various particle accelerators operated by the ORNL Physics and Engineering Physics and Mathematics divisions. This operational support extends to the Holifield Heavy Ion Research Facility (HHIRF); the Oak Ridge Isochronous Cyclotron (ORIC); the Oak Ridge Electron Linear Accelerator (ORELA); and the 300-kV Cockroft-Walton deuteron linear accelerator used with the Magnetic Fusion Energy (MFE) shield and blanket test program. The expertise of this group has contributed greatly to the success of the accelerator programs. Heavily oriented toward nuclear physics, they are responsible for the hardware and software interface between the HHIRF and its control and monitoring computers, for operation and system development on ORELA, for the design, development, and fabrication of all particle detectors used with ORIC and ORELA, and for the design and setup of all experiments at ORELA, with great emphasis on the data acquisition systems between the experiments and the data-processing computers.

1.2.1 MULTIPARAMETER FOCAL PLANE DETECTOR SYSTEM FOR THE BROAD-RANGE SPECTROMETER

T. P. Sjoreen[*]

R. L. Auble[†] E. E. Gross[†]
F. E. Bertrand[†] D. C. Hensley[†]
J. L. Blankenship M. V. Hynes[‡]
J. L. C. Ford, Jr.[†] D. Schull[**]

The good resolution, higher energy heavy ion beams from the HHIRF tandem and coupled accelerators offer new possibilities for charged particle spectroscopy with heavy ions. However, full exploitation of these capabilities requires magnetic spectrometers with advanced focal plane detector systems. The energies available, particularly from the coupled accelerators (up to 25 MeV/amu) together with the dispersion of the present ORNL spectrometers, demand a focal plane counter with a position resolution of at least a few tenths of a millimeter. The heart of the new system, which has been installed in the BRS, is a vertical drift chamber (VDC) having an intrinsic position resolution of about 0.1 mm and able to measure the angle of the particle trajectory at the focal plane to within about 10 mrad. This counter covers about 40 cm of the focal plane corresponding to ~120 MeV in excitation energy for an incident 400-MeV beam. Following is a detailed description of the design and performance of this counter.

An adequate focal plane system must also identify the type of particle detected at the focal plane. In the most general case at least four parameters must be measured since the energy, mass number, atomic number, and charge state (E, A, Z, q) of the heavy ion must be determined. The position-sensitive detector (the vertical drift chamber) provides one measured parameter, namely $B\rho$ (B = magnetic field, and ρ = radius of curvature in the field B).

The other necessary parameters to completely determine the identity of the detected nuclei are obtained by three additional counters:

Start detector. A 2.5 cm × 2.5 cm parallel plate avalanche detector near the exit of the scattering chamber provides one of the fast timing signals used to measure the flight time of reaction products through the spectrometer. The detector consists of 1.5-μm mylar gas windows and ~100-$\mu g/cm^2$ electrodes (total thickness ~600 $\mu g/cm^2$) and did not affect the resolution of particles detected at the focal plane in tests with 400-MeV ^{16}O ions.

Stop detector. A second timing signal is obtained from a 40-cm-long parallel plate avalanche detector mounted directly on the back of the vertical drift chamber. This counter furnishes the event signal used to initiate the analysis of an event in the multidetector system, the timing signal with which to measure the electron drift times in the vertical drift chamber, and the second timing signal necessary to determine the time-of-flight (TOF) through the spectrometer. Comparison of the count rates in this detector with those in the ionization chamber discussed below indicate a detector efficiency of essentially 100% for 400-MeV ^{16}O ions when using 7 torr of isobutane and a bias of 600 V.

Ionization chamber. The final detector in the system following the avalanche and vertical drift chambers is a large 40-cm-deep ionization chamber with a 40-cm-long entrance window. A segmented anode structure makes it possible to measure the energy loss (ΔE) and total energy (E) of the particles with $\leq 2\%$ and $\leq 1\%$ resolution respectively.

By measuring TOF, ΔE, and E in addition to the $B\rho$ value, the parameters of detected nuclei can be completely determined. In addition, by measuring the trajectory angle at the focal plane it is possible to determine the angle at which the particle entered the spectrometer. Thus, structured angular distributions can be measured across the spectrometer entrance window so that the full solid angle of the spectrometer can be utilized without loss of angular resolution. Furthermore, measurements of the electron drift times in the ionization chamber yield a constant monitor of the position and vertical height of the beam spot at the target. Thus, one can avoid vertical beam shifts which may reduce the effective solid angle. Figure 1.2-1 is a photograph showing the ionization chamber, the vertical drift chamber and the second parallel plate avalanche counter.

ORNL-PHOTO 4670-83

Fig. 1.2-1. Three counters used at the focal plane of the BRS.

Although this counter system has become operational only recently, it already has been used in a number of experiments. Results (described elsewhere in this report) from a ^{28}Si (^{11}B, ^{10}B) experiment at 93 MeV using the direct tandem beam, and from a ^{28}Si (^{18}O, ^{18}F) measurement at 348 MeV using the coupled accelerators, are shown in Figs. 1.2-2 and 1.2-3 respectively. These two figures

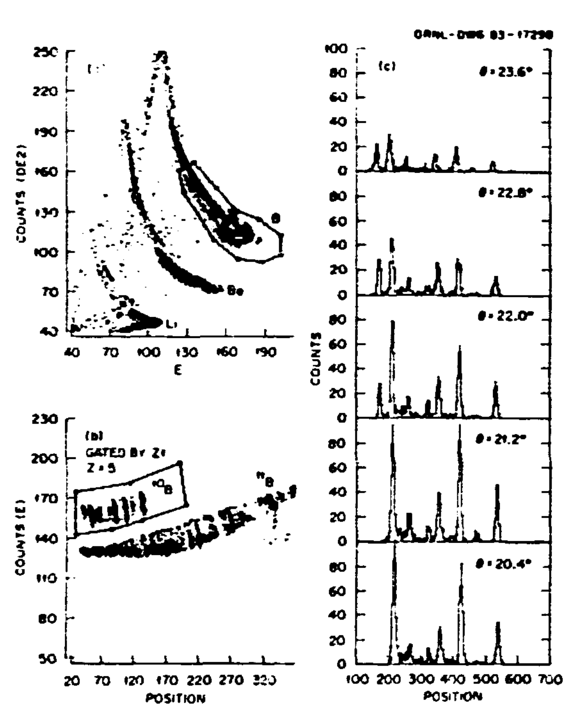

Fig. 1.2-2. Spectra from a study of spin-orbit effects in the ^{28}Si(^{11}B, ^{10}B) ^{29}Si reaction at 93-MeV bombarding energy.

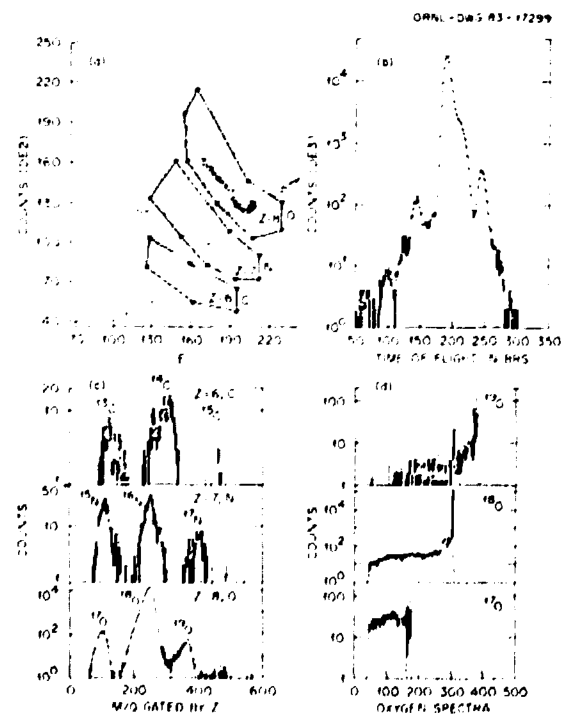

Fig. 1.2-3. Spectra from the study of single charge exchange with heavy ions using the (^{18}O, ^{18}F) reaction at 348-MeV bombarding energy.

illustrate the power of the focal plane system as a tool for investigating direct reactions with heavy ions.

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‡Los Alamos National Laboratory.
**Visiting Scientist, GSI, Darmstadt, Federal Republic of Germany.

1.2.2 THE VERTICAL DRIFT CHAMBER AS A HIGH-RESOLUTION FOCAL PLANE DETECTOR FOR HEAVY IONS

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J. L. Blankenship **D. C. Hensley†**
R. L. Auble† **D. Schull‡**
F. E. Bertrand† **M. V. Hynes****

[Abstract of *Nucl. Instrum. Methods Phys. Res.* **224**, 421–31 (1984); also ORNL-6004, 148–50 (1984)]

A vertical drift chamber in the focal plane of a magnetic spectrometer has been tested with ^{12}C (129 MeV), ^{14}N (176 MeV), and ^{16}O (140 MeV) ions. An experimental position resolution of ≤0.5 mm was measured, corresponding to an intrinsic detector resolution of about 0.1 mm (fwhm). The angle of the ion trajectory with respect to the focal plane was measured to within ~10 mrad, which corresponds to an intrinsic detector resolution of about 7 mrad. The angle measuring capability of the counter permits the measurement of angular distributions across the spectrometer opening and the correction of the counter data for magnet aberrations. Details of the electronics and gas handling systems and the detector performance with heavy ions are presented.

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1.2.3 DESIGN AND PERFORMANCE OF A VERTICAL DRIFT CHAMBER FOR HEAVY ION APPLICATIONS

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J. L. C. Ford, Jr.† **J. L. Blankenship**
T. P. Sjoreen† **F. E. Bertrand†**

[Abstract in *Nucl. Instrum. Methods Phys. Res.* **224**, 89–96 (1984)]

A vertical drift chamber has been specifically designed and constructed as a focal plane detector for heavy ion applications. Tests were performed with ^{12}C(129 MeV, ^{14}N(176 MeV), and ^{16}O(140 MeV) ions and a magnetic spectrometer. The operating characteristics at 50, 100, and 200 torr were investigated using isobutane as the counter gas. The intrinsic precision of the drift cells determined to be about 75 μm at 200 torr with isobutane. This value is indicative of an intrinsic detector resolution of 0.1 mm (FWHM) in track position and 7 mrad (FWHM) in track angle, for angles between 30 and 44°. Slightly larger values were measured at the lower pressures. Measurements of the electron drift times, the wire identification resolution, and the counter efficiency were made from multiple sweeps of the elastic peak across the counter by ramping the magnetic field of the spectrometer. Details of the detector design, operation, and performance are presented.

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1.2.4 FAST PULSE ELECTRONICS

J. L. Blankenship

A fast pulse amplifier (Q-5921) was designed to provide the gain and fast rise time needed for use with parallel plate avalanche detectors (PPAD), multiwire proportional detectors, and thin silicon detectors in timing applications. The circuit design is similar to that of Stelzer[1] but utilizes hybrid microcircuit components mounted on a conventional printed circuit board. Up to eight amplifier channels are incorporated in a single-width NIM. Each amplifier can be assembled as either inverting or noninverting, so that a single NIM can accept signals from the anode, cathodes, and/or sense wire planes of a PPAD.

Each amplifier channel has an input impedance of 50 Ω and has diode overload protection. Amplifier gain is 200, and the unipolar output pulse has a rise time of 1 ns, a decay time of 40 ns, and an amplitude of 0 to −5 V across 50 Ω. Amplifier noise is <10 μV rms referred to the input. Coaxial cable lengths are matched to within ±3 mm between channels, and crosstalk between channels is less than −60 dB.

A subnanosecond rise time pulse generator (Q-5927) was designed for development and testing of the fast-timing-pulse amplifiers used with microchannel plate and parallel plate avalanche detectors. The fastest pulse generator commercially available is BNC Model BI-2, which has a 3-ns rise time. The response of an amplifier to a positive step function can be obtained with the 7S12 sampling oscilloscope module by Tektronix using the S-52 pulse generator head and the S-4 sampling head. However, the response of an amplifier that requires a negative-input pulse or a narrow pulse cannot be obtained with the sampling oscilloscope pulser.

The Q-5927 fast pulse generator has both positive and negative output pulses available, with rise times of ~150 ps, pulse width adjustable from 3 to 30 ns, and an amplitude of ~0.25 V. Pulse repetition rate is variable from 100 Hz to 10^5 Hz. A trigger pulse is available in advance of the test pulse, with time advances variable from 0 to 80 ns. The short delays are useful for real-time oscilloscope displays, and the 80-ns delay is matched to the Tektronix 7S12 pretrigger requirement. This pretrigger eliminates the use of an 80-ns delay line in the signal path, which would degrade the pulse rise time. The pulse generator design is based on ECL logic and the Tektronix (part No. 152-0177-22) tunnel diode.

1. H. Stelzer, *Nucl. Instrum. Methods* 133, 409 (1976).

1.2.5 POSITION-SENSITIVE PARALLEL PLATE AVALANCHE COUNTER DEVELOPMENT

R. L. Auble*
I. Y. Lee* J. L. Blankenship

In an earlier report,[1] a parallel plate avalanche counter (PPAC) was described that has position sensitivity in one direction. At that time, two counters oriented at 90° to each other were required to obtain both x and y coordinates. The additional electrodes introduced by such stacking limit the detectable energy-mass range of the particles. These detectors have now been modified to provide both x and y position information from a single detector volume.

The overall construction is similar to that previously used, except that the anode has been divided into 0.25-cm-wide strips. The new counter is shown schematically in Fig. 1.2-4. The anode and cathode are made of 1.5-μm-thick mylar, with a thin (~50 μg/cm²) vapor-deposited coating of aluminum or gold. To form the anode, the metal coating was deposited through a wire grid consisting of 0.025-cm-diam wires spaced 0.25 cm apart. The sense wires are 20-μm-diam gold-coated tungsten spaced 0.2 cm apart. The various planes are separated by 1.6 mm. Delay line "chips," each having ten 2-ns delay lines,[2] are used to encode each sense wire or anode strip. The sense wire and anode signals are amplified and then analyzed in a time-to-digital converter.

The cathode is connected to ground via the 50-Ω input of the amplifier, and this signal is used to provide fast timing and pulse height information. Typical operating pressures have been 600 to 1300 Pa of isobutane with anode voltages in the range of 500 to 600 V. Breakdown, at a pressure of

ORNL-DWG 83-17425

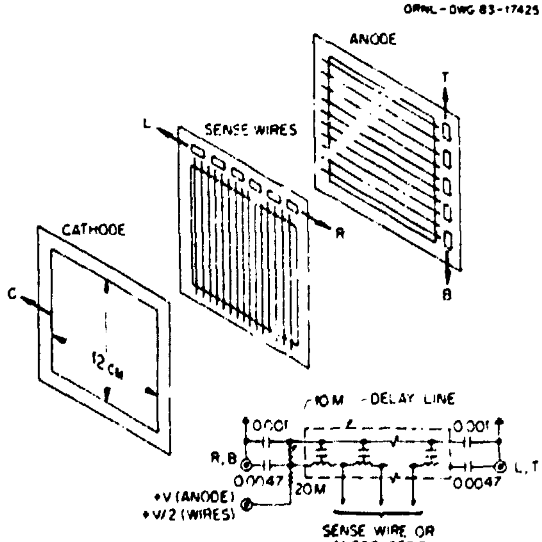

Fig. 1.2-4. Schematic drawing of the x-y position sensitive parallel plate avalanche counter.

7 torr, occurs at approximately 650 V and care must be exercised to avoid sparking that can cause removal of the metal coating on the cathode.

The detectors have been tested with 5.8-MeV alpha particles and with ^{252}Cf fission fragments with good results: no "cross-talk" has been observed between signals from the different planes; the position resolution is equal to or better than the sense wire or anode strip spacing; the timing resolution using the cathode signal is better than 0.5 ns; and the amplitude of the cathode signal provides a reasonable ΔE measurement. These detectors have been used in a study of the focusing properties of the velocity filter using elastically scattered 100 MeV ^{197}Au and will be used in a study of the fission decay of the giant quadrupole resonance in heavy nuclei.

*Physics Division.

1. H. N. Hill, ORNL-5787, November 1981, pp. 145–47.
2. Rhombus Industries Inc., Model TZB12-5.

1.2.6 DEVELOPMENT OF MULTIWIRE PROPORTIONAL DETECTORS FOR FISSION MEASUREMENTS

J. L. Blankenship   F. E. Obenshain*

Two multiwire proportional detectors were designed to measure fission products following heavy ion fusion. One design has a sensitive area of 2 × 2 cm² and provides a fast timing pulse, typically the start signal. The other design has an 8 × 10 cm² working area and provides both a fast timing signal and 2-d position information.

The 2 × 2 cm² detector shown in Fig. 1.2-5 has four polypropylene foils of ~50 μg/cm² each in the beam path. Two foils are windows, and the other two are cathodes coated with 20 μg/cm² aluminum. The anode plane consists of 20-μm-diam tungsten (6% gold coated) wires spaced 1 mm on center. Typical operating conditions are 1.5 torr pressure of isobutane and 400 V on the anode. The output pulses have a rise time of ~2 ns and pulse widths (FWHM) of 3 to 4 ns.

Timing performance was evaluated by accumulating the time-of-flight distribution (TOF) of fission fragments from ^{252}Cf for a 2.1-cm flight path. A thin, over-biased silicon surface barrier detector provided the stop pulse. Precision measurements by Schmitt et al.[1] demonstrate an intrinsic width

ORNL-PHOTO 5439-83

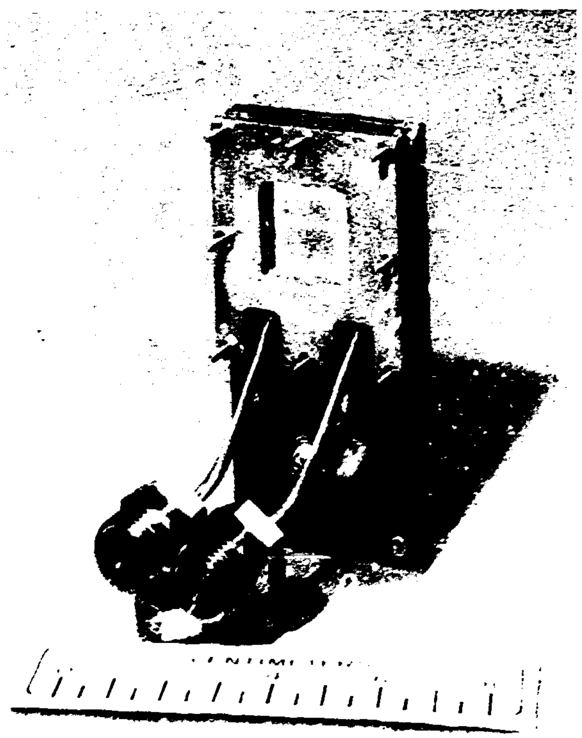

Fig. 1.2-5. The 2 × 2 cm² multiwire proportional counter for fast timing.

of 167 ps for the lighter fragment group. The 2 × 2 cm² detector timing distribution was 400 ps FWHM. If the silicon detector is assumed to contribute 100 ps, then 2 × 2 cm² detector timing performance was 349 ps FWHM.

Breskin[2] has achieved a timing spread of 200 ps FWHM for a similar detector under comparable operating conditions but using 27 MeV ^{16}O particles.

The 8 × 10 cm² detector shown in Fig. 1.2-6 has the same construction materials (windows, cathodes, anode wires) as the 2 × 2 cm² except that the cathodes have segmented, 3-mm-wide stripes of aluminum, each of which is connected to a tap on a set of lumped-element delay-line chips to provide position encoding. The delay-line chips are tested to obtain tap-to-tap delay and are sorted into sets with closely matching properties and minimum spread in delays per tap. The orientation of the stripes on the two cathodes is orthogonal to provide x-y coordinate readout. The timing signal is taken

ORNL-PHOTO 5440-83

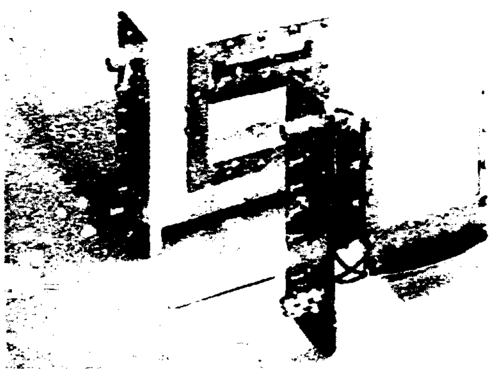

Fig. 1.2-6. The 8 × 10 cm² position-sensitive, multiwire proportional detector.

from the anode and has a rise time of ~3 ns (10 %) and a pulse width of 12 ns FWHM. Timing resolution was evaluated from the ^{252}Cf fission fragments TOF over a 6-cm flight path. The timing distribution was 830 ps FWHM, and an intrinisic Schmitt.[1] The start pulse was furnished by a 2 × 2 cm² detector, which has an estimated timing width of 349 ps. Thus, the intrinsic timing performance of the 8 × 10 cm² detector was 591 ps FWHM. Typical gas pressures are 2 to 4 torr of isobutane and bias voltages are 420 to 480 V. Position resolution is limited by the discrete width of the aluminum stripes, and position linearity is determined by the uniformity of delay increments between taps.

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*Physics Division.

1. H. W. Schmitt et al., *Phys. Rev.* **137**, B837 (1965).
2. A. Breskin, R. Chechik, and N. Zwang, *IEEE Trans. Nucl. Sci.* **NS27**, 133 (1980).

1.2.7 LARGE IONIZATION DETECTORS FOR HEAVY ION REACTIONS

J. L. Blankenship
F. E. Obenshain* **A. H. Snell**[†]

The time-of-flight facility is instrumented with a start detector, a position-sensitive stop detector, and an 80-cm-deep ion chamber to obtain E and ΔE. The stop detector and ion chamber window assemblies have been replaced with new designs enabling easy replacement or repair to the stop detector. The new window design provides a more uniform electric field and a better measurement of ΔE beginning with the first anode segment.

The original PPAD provided good timing performance but did not provide for x- and y-coordinate readout. The new stop detector is an 8 × 10 cm² multiwire proportional detector (MWPD) with position encoding from the striped cathodes and is identical in design to the detector described previously[1] for use in fission measurements. This design requires an additional window of 50 μg/cm² in the particle path but prevents gas contamination of the stop detector by gas leaking or diffusing from the ion chamber. Small freon leaks from the ion chamber caused several PPAD failures in the original design. An adapter and housing for the MWPD was also designed to connect the flight tube to the front flange of the ion chamber. A rectangular mounting flange on the side of the housing receives the MWPD and enables its easy replacement.

The ion chamber entrance window now projects into the region between the cathode and the Frisch grid and has a graded electric field which ensures proper charge collection from all particle entrance points.

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*Physics Division.
[†]Consultant.

1. H. N. Hill, ORNL-5787, November 1981, p. 145.

1.2.8 A GAS-HANDLING SYSTEM FOR HEAVY ION DETECTORS

J. L. Blankenship **C. A. Reed***

A high-stability, pressure-regulated, variable-flow gas-handling system has been developed for general use with gas-filled heavy ion detectors. This design features a graphic front panel which illustrates the function of each valve and control. The vacuum manifold is 1.9 cm in diameter and is connected to the gas-handling system by three valves, which enable the pumpout of the system by section.

The absolute gas pressure is measured by a capacitance manometer made by MKS Instruments, Inc., and is displayed on a 4.5-digit readout; the pressure setpoint is adjusted by a ten-turn potentiometer in conjunction with a three-position decade switch on the pressure controller. Pressure transducers with full-scale ranges from 10 to 10,000 torr are interchangeable; therefore, the gas-handling system can accommodate, for example, a PPAD operating at 1.5 torr for one experiment and an ion chamber operating at 1000 torr for another. The gas flow rate is controlled by the manual setting of a sensitive needle valve; therefore, a large range of flow rates can be achieved, including a static gas-filled system.

*Guest assignee from Oak Ridge Associated Universities.

1.2.9 A 4-π CHARGED PARTICLE DETECTOR

R. W. Ingle J. K. Dickens*

A detector to study the neutron-induced charged-particle reactions from various materials is being designed and fabricated for testing at ORELA by the Engineering Physics and Mathematics Division Fusion Data Group.

This detector, utilizing 4-π detection geometry, uses thallium-activated cesium iodide scintillation crystals as the particle detectors. Recoil particles (protons and alphas) produced by the interaction of neutrons from the ORELA pulsed-neutrons source and the thin foils are detected by cesium-iodide crystals.

Two 2-in.-diam by 4-mm-thick CsI crystals are coupled edgewise to separate photomultiplier (PM) tubes by 4-mm-thick lucite light pipes. The center of the crystals is 3 in. from the face of the PM tube. Each crystal and light pipe assembly is covered with thin (.25-mil) aluminized mylar for optical separation and light collection. The two crystals are mounted together in sandwich fashion, with the sample oils to be studied (polyethylene or aluminum) mounted between them. Dow Corning optical cement is used to attach the crystals to the light pipe and the light pipe to the PM tube. The two-crystal assembly is mounted perpendicular to the beam neutrons at ORELA.

Beam neutrons pass through the first crystal, interact with the sample to produce recoil protons or alphas in the forward direction, and are then detected by the second crystal. Events recorded in the first crystal are recorded as beam-generated background, which is subtracted from events recorded in the second crystal.

Cesium iodide has many favorable properties for a detector of this type. The decay time of the scintillations produced in the crystal is a function of particle type and, to a lesser degree, energy. For example, the decay time constant for a 5-MeV proton is approximately 425 ns and for a 5-MeV alpha about 550 ns. For a 661-keV gamma ray, the decay time is approximately 700 ns. Pulse shape discrimination is therefore used to separate the particle types from gamma ray background, which permits a lower energy range of particle recoil to be studied. In this case, we can separate recoils from beam neutrons of energy down to 500 keV. Cesium iodide is nonhydroscopic, which permits multiple detectors such as this to be assembled easily without the complexity of elaborate vacuum systems. The major advantage for these very low count rate experiments is to have 4-π geometry, thus obtaining sufficient data in a reasonable time period to determine reaction cross sections. However, detailed angular distributions of reaction particles cannot be deduced from the expected data.

*Engineering Physics and Mathematics Division.

1.2.10 SYSTEM DEVELOPMENTS AND IMPROVEMENTS FOR ORELA

T. A. Lewis

ORELA was designed to produce short, intense neutron pulses for the measurement of neutron cross sections for time-of-flight techniques.[1,2] ORELA is normally operated about 3500 h each year, and significant effort is invested in improving the reliability, ease of operation, and beam performance of the accelerator. To maximize the number of neutrons in an ORELA burst of given duration, a technique of prebunching the electron beam from the gun before it enters the accelerator has been investigated.

In the past year, final tests of the prebunching system were performed. Experimental data on the current as a function of time at the end of the prebuncher (the input of the accelerator) were obtained for a variety of initial electron beam and prebuncher conditions.

To calculate the expected prebuncher beam, sufficient data to characterize the electron beam from the gun and the potential differences applied to the prebuncher structure were also obtained and used in the ballistic model[3] previously developed at

ORELA. These calculated and experimental data were in substantial agreement and significant prebunching was obtained. The report of this investigation[4] was presented at the Southeastern Section Meeting of the American Physical Society, October 24–27, 1984.

Further tests revealed some disagreement between calculated and measured beam transmission factors for the accelerator structure located "downstream" of the prebuncher. To further investigate these differences, the prebuncher was removed and tests were conducted on the downstream structure using a simplified configuration of the injection system. Preliminary results from these tests suggest the possibility that the accelerator is more sensitive to incoming electron energy and to incoming beam emittance than predicted by the original ballistic models. These tests will continue with the goal of developing adequate models to predict actual beam behavior in the accelerator and beam transport systems.

A new system of beam monitors and an independent scheme for calibration of the average beam power on the target were the major advances in diagnostic capabilities. Magnetic field quality was improved by straightening and increasing the solenoid field along the beam center line, especially in the critical area of the low-energy electron injector. Another improvement to the electron injector was accomplished by the installation of a hard tube gun modulator, which allows easier pulse width control and reduces the number and magnitude of undesirable secondary pulses from the electron gun.

Construction has begun on the Electron Beam Injector Laboratory (EBIL). This second-floor extension of Building 6010 will provide about 2400 ft^2 of additional space for improved electron gun production, test, and storage facilities. Space will also be available for characterization of an entire injection system to be compared with the improved beam models now being developed.

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1.2.11 NEW ORELA BEAM MONITORS AND MONITORING SYSTEMS

G. K. Schulze   J. W. T. Dabbs*

ORELA, which serves as a source of pulsed high-energy neutrons, has been in operation for more than a decade. During this period several types of monitors have been used for determining the pulsed electron beam parameters. It is particularly essential to know the pulse rise time, the width at the half-maximum value, and the peak amplitude and shape in order to facilitate adjustment of the operation. However, only multiturn, toroidal type monitors have been used routinely and only at the electron gun and accelerator output. Because of heavy emphasis on developmental work on an electron prebuncher, there was a great need to develop improved monitors to obtain information on beam transmission.

The essential beam parameters to be measured are a peak amplitude of up to 50 A and pulse widths from 4 to 50 ns FWHM, with rise times of 2 ns or less. The maximum pulse repetition rate is 1000 Hz. The monitors are required to operate in axial fields of up to 3 kilogauss.

A new monitor and monitoring system developed and installed at ORELA meets these needs. Basically, the monitor design is a one-turn, toroidal-shaped inductive loop having a square cross section surrounding a ferrite center. A narrow resistive ring centered between pressure contact electrode areas at the inner and outer radii on a thin ceramic substrate comprises one face of the toroidal box. Also located on the ceramic substrate are four 50-Ω resistors used for series matching of the signal, developed across the resistive ring, to four output ports. These outputs divide the ring into quadrants.

Because of the unique properties of ferrite materials as a function of frequency and the particular combination of design choices, the monitor output signals provide the required beam parameter and centering information. When summed, the four signals represent the beam envelope with reasonable accuracy, regardless of beam position. The difference between signals taken from diametrically opposite quadrants yields beam-centering information.

In this application the sum and difference signals are derived from the four monitor output signals by a combination of three resistive networks. These three signals are connected to low-transmission loss cables, along with the outputs of the other monitors in the system, by bridging amplifiers. These are controlled by switched dc levels sent from the operator's console.

Beam current monitors of various designs described previously appear to function in a similar fashion. This design differs in several ways from the previous art: (1) it incorporates only one distributed single-turn inductive pickup rather than four independent loops; (2) it effectively utilizes a uniformly distributed shunt resistance fabricated on a thin ceramic substrate by thick-film techniques, which facilitates duplication and contributes to the superior high-frequency response; (3) the frequency-dependent properties of the core and the mechanical design permit the extraction of centering information from the high-frequency components and the shape and magnitude from all components of the pulse spectrum; (4) the mechanical design allows controlled limited bending of the thin MACOR® ceramic substrate similar to that of a belleville washer, which permits ease of assembly and clamping of the entire unit using only a simple threaded clamping ring and spanner wrench; and (5) the use of many thin ferrite washers and separators allows high inductance to be retained in high magnetic fields.

*Engineering Physics and Mathematics Division.

1.2.12 UPGRADE OF THE HEAVY ION FACILITY BEAM DEFLECTOR AND BUNCHERS

J. M. Rochelle N. F. Ziegler*
R. I. Crutcher R. M. Beckers†

Electronics and instrumentation engineering services support the redesign of the HHIRF 1f and 2f buncher resonators and the addition of a beam chopper resonator. Theoretical and experimental studies are aimed at minimizing the power required to generate a 5-kV peak at 4 to 15 MHz for the 1f resonator and a 3-kV peak at 8 to 30 MHz for the 2f resonator.

Both resonators are high-Q L-C tank circuits with inductive coupling to match a 50-Ω transmission line. Present plans call for the use of two interchangeable coils (one 4- to 8-MHz and one 8- to 15-MHz) to cover the required 1f tuning range without excessive losses. Also, the 8- to 15-MHz coil will be usable in the 2f resonator if needed.

The chopper resonator is expected to be a center-tapped tank circuit providing balanced 2-phase voltages of 4 kV peak-to-peak at 500 kHz and 2 MHz.

Assistance is also being provided for the design of amplitude and phase detectors, phase shifters, and other associated circuits.

*Physics Division.
†ORNL Engineering.

1.2.13 NEUTRON FILTERS FOR PRODUCING MONOENERGETIC NEUTRON BEAMS

J. A. Harvey*
N. W. Hill J. R. Harvey†

[Abstract of *Nucl. Data for Sci. and Technol.*, 856–58 (1983)]

Neutron transmission measurements have been made on high-purity, highly-enriched samples of ^{58}Ni (99.9%), ^{60}Ni (99.7%), ^{64}Zn (97.9%) and ^{184}W (94.5%) to measure their neutron "windows" and to assess their potential usefulness for producing monoenergetic beams of intermediate energies from a reactor. Transmission measurements on the Los Alamos Sc filter (44.26 cm Sc and 1.0 cm Ti) have been made to determine the characteristics of the transmitted neutron beam and to measure the total cross section of Sc at the 2.0 keV minimum. When corrected for the Ti and impurities, a value of 0.35 ± 0.03 b was obtained for this minimum.

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1.2.14 SOLID STATE EFFECTS ON THERMAL NEUTRON CROSS SECTIONS AND ON LOW ENERGY RESONANCES

J. A. Harvey* N. W. Hill
H. A. Mook† O. Shahal‡

[Abstract of *Nucl. Data for Sci. and Technol.*, 961–64, (1983)]

The neutron total cross sections of several single crystals (Si, Cu, sapphite), several polycrystalline samples (Cu, Fe, Be, C, Bi, Ta), and a fine powder copper sample have been measured from 0.002 to 5 eV. The Cu powder and polycrystalline Fe, Be and C data exhibit the expected abrupt changes in cross section. The cross section of the single crystal of Si is smooth with only small broad fluctuations.

The data on two "single" Cu crystals, the sapphite crystal, cast Bi, and rolled samples of Ta and Cu have many narrow peaks $\sim 10^{-3}$ eV wide. High resolution (0.3%) transmission measurements were made on the 1.057-eV resonance in ^{240}Pu and the 0.433-eV resonance in ^{180}Ta, both at room and low temperatures to study the effects of crystal binding. Although the changes in Doppler broadening with temperature were apparent, no asymmetries due to a recoilless contribution were observed.

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1.2.15 ^{238}U SELF-INDICATION RATIO MEASUREMENTS IN THE RESONANCE REGION

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J. L. Munoz-Cobos† R. B. Perez‡
G. de Saussure‡ J. H. Todd

(Abstract of paper presented at Meeting on Advances in Reactor Physics and Core Thermal Hydraulics, Kiamesha Lake, New York, September 22–24, 1982)

An accurate knowledge of the ^{238}U resonance parameters and of the ^{238}U (n,γ) cross section in the resolved resonance region is required for the calculation of several parameters in both thermal and fast reactors.

Others have demonstrated the usefulness of self-indication ratio measurements to test the adequacy of resonance parameters. The purpose of this paper is to compare a set of self-indication ratio measurements, performed over a wide range of ^{238}U sample thicknesses, with a calculation based on the ENDF/B-V evaluated data over the resolved resonance region.

It is hoped that these measurements, together with similar previous self-indication data, will provide a useful integral test for differential cross section adjustment and validation procedures for the ENDF/B files.

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1.2.16 AFTERPULSES AT SEVERAL μS FOR AN RCA-8854 MULTIPLIER

C. H. Johnson* J. A. Harvey†
N. W. Hill D. J. Horen*

[Abstract in *Bull. Am. Phys. Soc.* **28**(7), 992 (September 1983)]

At the ORELA time-of-flight facility we have extended the energy for neutron detection down to 5 keV for liquid or plastic scintillators by accepting pulses corresponding to a few photoelectrons. At such low levels there is a background of afterpulses which occur in the photomultiplier, a 5-in. RCA-8854 PMT, several microseconds after the earlier detection of a neutron or γ-ray. To study these we placed a hydrogenous filter in the flight path to remove essentially all neutrons and leave only the narrow initial γ-ray burst and its afterpulses. The time spectrum of the afterpulses (after the 1.1 μs clock dead time) shows sharp peaks at 1.15, 2.15, 2.4, 2.9, 5.65, and 6.3 μs and much broader peaks at 4.5, 7.5, and 14 μs. For the γ-ray burst, which includes γ-ray energies mainly below 1.5 MeV, there is a 14% probability that a detector event will have an afterpulse later than 1.1 μs. The probability increases with initial pulse height. Presently we are investigating the use of two photomutipliers in coincidence for minimizing this background.

*Physics Division.
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1.2.17 APPLICATION OF NEW TECHNIQUES TO ORELA NEUTRON TRANSMISSION MEASUREMENTS AND THEIR UNCERTAINTY ANALYSIS: THE CASE OF NATURAL NICKEL FROM 2 keV TO 20 MeV

D. C. Larson*
N. M. Larson† N. W. Hill
J. A. Harvey* C. H. Johnson‡

(Abstract of ORNL/TM-8203, ENDF-333, October 1983)

The neutron transmission through a 2.54-cm sample of natural nickel has been measured for neutron energies between 2 keV and 20 MeV. The ORELA Facility was used to provide the neutrons which were detected at the 200-m flight path by a

NE110 proton recoil detector. A selective gating system was utilized to minimize background effects due to large light-level events which produce phototube afterpulsing and long decay-constant light emission in the detector. A detailed discussion of the development of this system is given.

Known background sources are described, and the methods used to correct for these backgrounds are presented. An in-depth uncertainty analysis is given for this measurement, with explicit formulas derived for each effect contributing to the cross-section uncertainty. Parameter uncertainties and correlations among the parameters describing the backgrounds, deadtime, and other sources of uncertainty are given. To obtain a covariance matrix for this measurement, the final cross-section results are binned into 15 energy groups, and a covariance matrix is provided for this 15-group set. We find that the largest contributions to the cross-section uncertainty are due to sample properties, beam monitors (used to normalize sample-in and sample-out counts), and ORELA power variations during the run which affect the deadtime correction. Overall uncertainties in the cross section for this measurement are on the order of 2%. The resulting cross sections are compared with the ENDF/B-V file for nickel; many resonances not presently in the file are observed, and energy-scale differences are noted.

*Engineering Physics and Mathematics Division.
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‡Physics Division.

1.2.18 A COUPLED-CHANNELS ANALYSIS OF ELASTIC AND INELASTIC SCATTERING OF ^{18}O FROM ^{28}Si

B. L. Burks et al.*† J. L. Blankenship

[Abstract in *Bull. Am. Phys. Soc.*, 29(7), 1026, (1984)]

Differential cross sections have been measured in 0.33° steps over the center of mass angular range 3.1 to 20.9° for three states populated by bombardment of a ^{28}Si target with a 351.7 MeV ^{18}O beam. A collective one-phonon vibrational model is being used to perform a coupled channels analysis of the elastic scattering data and inelastic scattering to 2^+ states at 1.779 MeV in ^{28}Si and 1.982 MeV in ^{18}O. Deformation parameters will be extracted from the coupled channels analysis and compared to those obtained from light ion scattering experiments.

*Physics Division.
†Because of the large number of coauthors, only the principal author and coauthors from the Instrumentation and Controls Division are listed here. See Publication for a complete listing of authors.

1.2.19 MEASUREMENTS OF THE NEUTRON TRANSMISSION AND CAPTURE CROSS SECTIONS IN ^{204}Pb

D. J. Horen* J. A. Harvey†
R. L. Macklin† N. W. Hill

[Abstract of *Phys. Rev. C* 29(6), 2126–34 (June 1984)]

High- resolution neutron transmission measurements have been performed on ^{204}Pb in the energy interval E = 0.4\n105 keV. The transmission data were analyzed using a multilevel R-matrix code to deduce resonance parameters. Previously obtained neutron capture data were reanalyzed in the interval 2.6\n86 keV. Values of $G\Gamma_n\Gamma_\gamma/\Gamma$ were determined from the capture data. For those resonances where Γ_n could be determined from the transmission data, the capture data were analyzed to extract Γ_γ. Our results yield an average capture for a steller temperature kT = 30 keV of 89.5 ± 4.5 mb. The s-wave level density for ^{205}Pb corresponding to the neutron energy range investigated (i.e., E~105 keV) relative to that for ^{207}Pb (which has about the same neutron separation energy) is greater by about a factor of 10. The average s-wave strength function in this energy region is determined as $S_0 = 0.93 \times 10^{-4}$. This is an order of magnitude greater than that for a similar energy region in ^{206}Pb + n where a doorway is observed at E~500 keV. However, the strength function in the initial E = 0\n100 keV in ^{204}Pb + n is almost identical to the average value of that for ^{206}Pb + n when the averaging interval for the latter is taken as $E_n \simeq$ \n1000 keV (i.e., over the doorway state). This suggests that the s-wave doorway state observed in the higher mass lead isotopes is completely mixed with "background" states in ^{205}Pb, and most likely no intermediate structure will be observed in the s-wave strength function for the ^{204}Pb + n reaction.

*Physics Division.
†Engineering Physics and Mathematics Division.

1.2.20 1982 SNEAP REPORT ON THE OAK RIDGE 25-MV TANDEM ACCELERATOR

N. F. Ziegler*

E. G. Richardson* D. M. Galbraith*
J. E. Mann* J. A. Biggerstaff*
R. C. Juras J. A. Benjamin*
C. M. Jones* G. D. Alton*

(Abstract of paper presented at Symposium of Northeastern Accelerator Personnel, Seattle, October 6–8, 1982)

During this reporting period, the contractor for construction of the 25-MV Tandem Accelerator, National Electrostatics Corp., corrected a number of problems that arose during the first six months of operation. The contract with NEC was closed on June 4, 1982, and for the remainder of the year the accelerator was operated by the ORNL Physics Division for the facility research program. This paper discusses several aspects of accelerator operation.

*Physics Divison.

1.2.21 ADDITIONAL PROJECTS

Drift Chamber Design. Design of a 1.2-m × 1.2-m drift chamber was completed for the construction of nine drift chambers to be built as a joint effort of ORNL and the University of Tennessee Physics Department. These chambers are to be used in the E636 experiment at Fermilab by a consortium which includes ORNL and UT. The chambers are to be used to determine the downstream trajectories of particles exiting a 30-in. bubble chamber. *(G. W. Allin, H. R. Brashear, M. L. Bauer, W. L. Bryan, H. O. Hohn,* R. E. Cooper, J. C. Turner)*

Software Modifications to the Control System of the HHIRF Tandem Accelerator. The control system for the HHIRF Tandem Accelerator was expanded because of the installation of a new beam line. The software was modified to handle additional accelerator and injector parameters as well as all parameters of the beam line. Other improvements were made in the control system operating software. These improvements included numerous small changes which improved the ease of maintenance and of future expansions. The good quality of the original software along with the modifications to it make the operation of this software nearly routine. *(R. C. Juras)*

*Physics Division.

1.3 Engineering Support for ORNL Fusion Energy Division

1.3.0 OVERVIEW

Several I&C Division engineers are assigned to the ORNL Fusion Energy Division to provide instrumentation support. This instrumentation performs a wide variety of tasks centered on developing high-voltage and high-current power supplies, custom experiment data acquisition and control, microwave power measurement and control instrumentation, laser firing and shutter control, and special data-collection needs. The following articles describe a sampling of the variety of engineering support provided.

1.3.1 LOSS-OF-COOLANT DETECTOR

R. E. Wintenberg

An instrument was designed to detect the loss-of-coolant flow in 1 of 12 passages in any of 24 magnets. Twenty-four flow sensors were used in the design, such that the loss of one coolant channel would result in a flow signal change of 1/12 (about 8%). Because pressure changes in the water supply cause flow changes greater than this amount, a "galloping" setpoint was required.

The approach taken was to average all 24 flow signals and to compare each signal with the average. As illustrated in the block diagram (Fig. 1.3-1), the flowmeters are of the paddle-wheel type with an electrically isolated magnetic pickup coil. The source impedance is relatively low, and the signal is carried to the instrument on a shielded twisted pair of wires.

The paddle-wheel flowmeter output, roughly a sinewave, is applied to a bridge rectifier that is direct-current biased into conduction. The bias signal provides compensation at low flow rates where the signal amplitude is small. The full-wave rectifi-

ORNL-DWG 84-18132

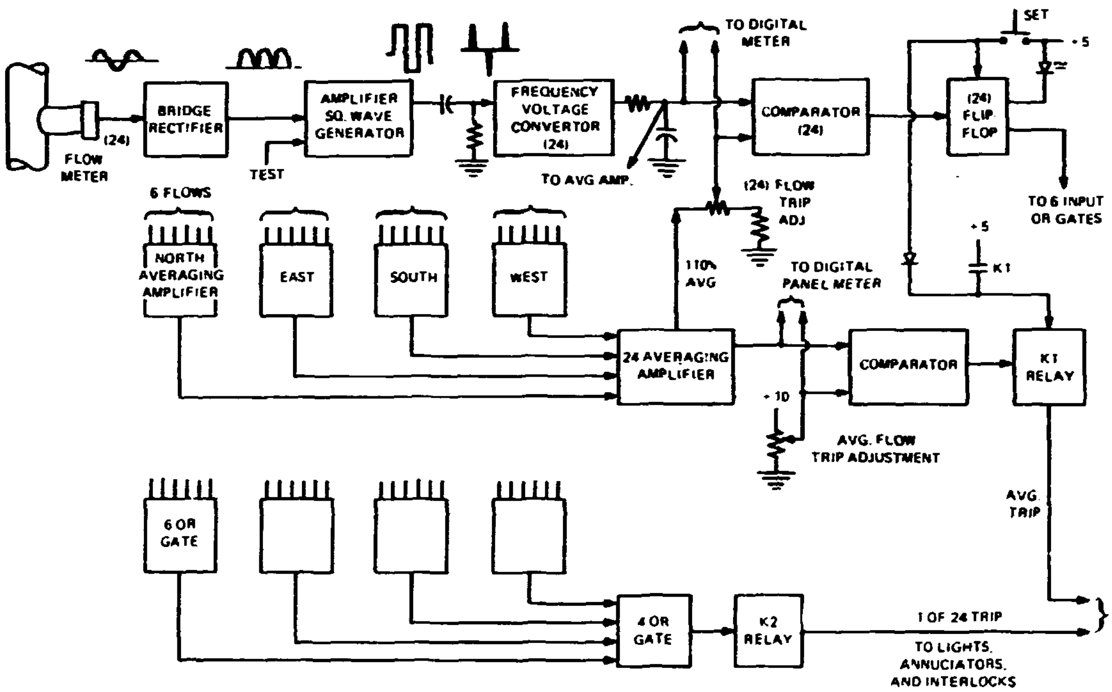

Fig. 1.3-1. Block diagram of hose break detector.

cation doubles the frequency, allowing a shorter filtering time constant at the top of the frequency-to-voltage converter. The amplifier/square wave generator shapes the signal for RC differentiation into the frequency-to-voltage converter.

The filtered direct current output of each of the frequency-to-voltage converters is transmitted (1) to a switched digital panel meter, (2) to a comparator, and (3) to the averaging amplifiers to calculate the 24 average flow rates. Each of the 24 comparators compares its input flow signal with an individually adjusted setpoint derived from the 24 average flow rates. The output of each comparator is used to reset a flip-flop which identifies the tripped channel by lighting an LED and operates a 24-OR logic/relay. The 24 average flow signal is also transmitted to a switched digital panel meter and to a comparator/relay with an adjustable fixed set-point. The setpoint provides a lower-limit alarm on the flow rate that the averaging system would not detect.

The instrument was packaged into Tektronix TM-500 blank modules mounted in a six-wide rack-mounted mainframe. Four single-wide modules were used to house six channels each, and a double-wide module was used to house the common logic, relays, and the digital panel meter. The main-frame had a backplane wiring option that allowed module interconnection and access to the outside world.

This instrument has been constructed and tested but has not been installed as yet. The hose break detector was designed to replace a pressure compensation system which failed to perform satisfactorily because the water viscosity changed drastically with temperature.

1.3.2 ENGINEERING SUPPORT FOR ELMO BUMPY TORUS EXPERIMENT

D. W. Bible

I&C engineers assigned to the Fusion Energy Division ELMO Bumpy Torus experiment provide instrument design and development support relating to plasma diagnostics and microwave power heating systems.

In the area of plasma diagnostics, the neutral beam injection system, a small ion accelerator operating in both the continuous and pulsed mode, is used to investigate various plasma parameters such as confinement time and neutral particle density. During this period, in order to accommodate the ever-changing requirements necessitated by an experimental device such as EBT, several new components were developed for the neutral beam such as a triggered, pulsed ion source deceleration supply of 10 kV at ½ A; a high-voltage clamp for waveshaping of the 20-kV accelerating pulse; a new control and telemetry system using light pipes; and a motor generator and associated controls for powering the ion source focusing magnet.

Additional electrical and mechanical engineering support was provided for the following diagnostic instruments: a junction panel for computer monitoring of individual EBT vacuum conditions, a signal distribution amplifier system, a signal-conditioning amplifier for diagnostic signals, and a miniature ion chamber for use with various diagnostic plasma probes.

In the area of microwave power heating, several instruments or systems were developed to complete the high priority requirement of the operation of a second 28-GHz gyrotron simultaneously with the existing gyrotron. New components included a filament supply and associated control and monitoring components, and additional waveguide arc detectors and electronics. Relocating existing detectors and interfacing various control and operational safety interlock systems of both gyrotrons were necessary for simultaneous or single operation with little interaction and full overload fault protection.

1.3.3 THE EBT-S 28-GHz, 200-kW, CW, MIXED-MODE, QUASI-OPTICAL PLASMA HEATING SYSTEM

T. L. White*
H. D. Kimrey* D. D. Bates
T. S. Bigelow* H. O. Eason*

(Abstract of ORNL/TM-9175, July 1984)

The ELMO Bumpy Torus-Scale (EBT-S) 28-GHz, 200-kW, cw, plasma heating system consists of a gyrotron oscillator, an oversized waveguide two-bend transmission system, and a quasi-optical mixed-mode microwave distribution manifold that feeds microwave power to the 24 plasma loads of the EBT-S fusion experiment. Balancing power to the 24 loads was achieved by adjusting the areas at 24 coupling irises. System performance is easily measured using system calorimetry. The distribution manifold mixed-mode power transmission, reflection, and loss coefficients are 89%, 6%, and 5%, respectively. The overall system efficiency (plasma power/gyrotron power) is 80%, but with some modifications to the distribution manifold we believe the ultimate efficiency can approach 90%. The system reliability is outstanding with a world's record 1×10^5 kW of 28-GHz energy delivered to the EBT-S device with well over 1×10^3 operating hours.

*Fusion Energy Division.

1.3.4 ADDITIONAL PROJECTS

Scanning Interferometer Display Control. This device controls the positioning of two servo-driven mirrors in a microwave interferometer. This instrument also digitizes the "slow" analog data from the interferometer, stores the data, and converts the data back to analog for a flicker-free display (histogram) on an x-y scope display. Digital data and position information are available for computer data storage. The servo-driven mirrors are positioned at each of 15 positions and provide continuous scanning, single scans, and single steps. *(R. E. Wintenberg)*

Temperature Stabilizer. This device was developed to stabilize the temperature of a brass block which mounts ten LEDs in a linear array in the range of 90 to 125°F. The LEDs are used as a pulsed light source in a Thomson Scattering Experiment. The temperature controller uses a thermistor as a temperature sensor, and the block heater consists of a string of resistors mounted in a hole drilled through the block. *(R. E. Wintenberg)*

Phase Lock Loop. This device was designed to measure microwave power delivered to the waveguide of the vacuum pumping ring of the Elmo Bumpy Torus. It was designed to multiply the rotational speed of a turbo-vacuum pump by 60 (the number of blades on the impeller). The resulting signal was to be used to synchronize a microwave detector which monitors microwaves leaking through a screen and scattering from the impeller blades. *(R. E. Wintenberg)*

Photo-Amplifier and Line Driver. Two different sizes of commercial photodiode/amplifiers were packaged with a fast line driver to drive long coaxial cables. Response to a pulsed light source gave a T_R and T_F of 1 μs into a 50-Ω load. The smaller unit was packaged in a Kings KC-99-28 BNC adapter and is approximately 1¼ in. diam by 2 in. long. *(R. E. Wintenberg)*

Fast Turn-off Switch. This development utilizes a relatively new device to solve an old problem. A gate turn-off thyristor is used to cleanly and abruptly interrupt a current flowing in an inductor. In this case, the device used is a Philips E8401 (BTW59) rated at 1.5 kV and 12 A. The gate signal is generated with a mercury-wetted relay and the current turn-off time is less than 1 μs. *(R. E. Wintenberg)*

Isolated Field Current Amplifier. This device was designed and built to isolate 100-mV shunt signals and amplify them to the 10-V level with an accuracy of a few parts in 10,000. Analog Devices instrumentation amplifiers (Model AD524) and isolation amplifiers (Model 289L) were used. Nonlinear positive feedback was used for linearity correction, and thermistors were used for temperature compensation. *(R. E. Wintenberg)*

Piezo Valve Ramp Generator. This device generates a ramp signal to reduce the EBT torus pressure. The ramp driving the demand input of the pressure control servo halts whenever the gas flow valve closes too far. This action assures that the plasma is clean and not overly contaminated by material from the torus walls. The downward ramp is resumed when the servo output is above the lower setpoint, indicating a reasonable gas flow. *(R. E. Wintenberg)*

Generator Control Cabling. This cabling was compiled from an as-built block/cabling diagram of the ELMO Bumpy Torus motor generator control wiring. It was used to prepare drawings integrating an additional four east end generators into a single system for the EBT 9-kA field upgrade. This planned upgrade would have increased field current from 7150 to 9000 A, giving better control of the 28-GHz ECH resonance region. *(R. E. Wintenberg)*

Control Circuits. The control circuits for the EBT 9-kA field were developed to aid Y-12 Electrical and Instrumentation Engineering. Increasing the available generator power for EBT field magnets from 10 to over 20 MW required modifying the controls of the four generators presently used on the west end of Building 9201-2, rebuilding the controls of four generators on the east end, and integrating the bus work and the control panel in the EBT control room to operate all eight generators. The task was ended prior to hardware implementation. *(R. E. Wintenberg)*

Torus Field Correction System. This system was modified by separating the vertical field correction coils (inner and outer) to operate from separate dc supplies. Provisions were made to read the individual currents and to supply compensating signals to the toroidal plasma current integrator. *(R. E. Wintenberg)*

Over Pressure and Rate Alarm. This instrument was designed to operate with a strain gage type pressure sensor from 0 to 300 psig. It consists of a stable, high-gain amplifier; an active differentiator; three comparators; and stable plus-minus reference supplies. This instrument indicates normal pressure between two limits, it alarms on over pressure, and it alarms on an excess rate of pressure rise adjustable from 0 to 1 atm/s. *(R. E. Wintenberg)*

Laser Firing and Shutter Control. This new control was devised to clean up the EBT Thompson Scattering Experiment interlock system. The original had been added to and modified many times. The new system was integrated into one control panel that included controls and interlocks for opening the lead wall window, the egg crate window, the dump shutter, and the uniblitz shutter, and for firing the Quantel laser.

In addition to the developments described above, three dc motor-driven servo systems were designed and built to precisely position collimators and filters for low-energy X rays in an evacuated beam line. The drive units were modified aircraft linear actuators. Position feedback was obtained from 7-in. linear pots having 1 mil resolution. Channel demand was derived from digital signals either from a computer or thumbwheel switches. High-quality operational amplifiers, reference sources, and precision resistors were used in the controller. *(R. E. Wintenberg)*

Varian Vac-Ion Pump Control Unit Modification. A Varian Model 921-0015 vac-ion control unit was modified and will be used to protect the second gyrotron tube on EBT-S. The unit operates to provide a crowbar signal to the gyrotron power supply any time a gas burst from an arc inside the tube exceeds a preset level on the controller. The modification includes a lockout that prevents the power from being turned on until the vacuum in the tube has returned to a safe level such that the controller can be reset. *(D. D. Bates)*

Varian Waveguide Arc Detector Modification. Two Varian Model V-9011 arc detectors were modified to make them compatible with the second gyrotron microwave system on EBT-S. Modifications consisted of adding necessary logic and crowbar driver circuits that would require mandatory testing before operating the tubes and providing crowbar triggers for any arcs that occur in the gyrotron's output waveguide system. *(D. D. Bates)*

Redesign of Interlock System on EBT-S. A major redesign is under way on the equipment and personnel interlock system of EBT-S that will protect all operation modes of the additional power systems. In addition to EBT-S, the interlock system must accommodate the new gyrotron power supply, HV switch, EBT-P test stand, and, in some cases, the simultaneous operation of EBT-S and the EBT-P test stand. *(D. D. Bates)*

Modifications to the Universal Voltronics Gyrotron Power Supply to Reduce Misfiring of the Crowbar System. The heating and cooling distribution for the ignitrons was improved to give a better distribution for the heat rise across the ignitrons, resulting in the elimination of many of the misfires of the crowbar system. Additional improvement was made by identifying and eliminating rivet cold solder joints that connect the double-sided printed circuit boards. The cold solder joints had caused random crowbars to occur in the supply. *(D. D. Bates)*

Digital Readout for Gyrotron ΔT Blocks. A 28-GHz microwave power to the EBT-S plasma is indirectly measured by subtracting all the losses in tube dissipation, waveguide, mode filters, windows, and absorptions from the tube input power. Temperature ΔT blocks measure the various losses and record them on Soltec stripchart recorders.

To facilitate the measurement and power calculations for the many points (>12), a digital readout system is now being designed that will make the operator's task much easier and will aid in the later design of a computer readout. A computer readout system will be a necessity on the multigyrotron system of EBT-P. *(D. D. Bates)*

EBT Gyrotron Power Supply Procedure. A new 1-MV gyrotron power supply is being developed for the Fusion Energy Division. The supply will double the 28-GHz microwave power available for future fusion devices and will also enable development of even higher frequency microwave components.

The supply was developed to its present state by Aydin Inc. of Palo Alto, California; unfortunately, after 18 months' delay, Aydin was incapable of finishing the supply to ORNL specifications, and the contract was terminated at a reduced price agreeable to Aydin and Martin Marietta.

Although most of the large components of the supply are complete, the complex control system requires major redesign. The supply will be finished in the Fusion Energy Division by I&C Division personnel at an estimated cost of $200,000 to $300,000. *(D. D. Bates)*

High-Voltage Switch Acquisition for EBT-S. A switch was developed to switch the EBT-S 28-GHz gryotron power supply between two gyrotron tubes. Since fire regulations prevented the use of an oil-filled switch on the platform above EBT-S, the switch had to operate in air, be insulated to withstand the output of the gyrotron power supply, and be double shielded to conform to the shielding philosophy of the rest of the system.

An 80-kV, 10-A, double-pole, double-throw switch was developed by Universal Voltronics, Inc., to meet ORNL specifications. After acceptance tests on the 8 ft × 8 ft × 4 ft switch at the factory, it was shipped to ORNL for installation.

The switch has been installed on the platform above EBT-S and will be used to switch the beam and gun voltage of the present power supply between Gyrotrons 1 and 2. With the installation of the new Aydin, Inc., Gyrotron supply (which will be used to power No. 2 tube) the HV switch will then switch the existing supply between the new EBT-P test stands of Gyrotron 1 and 2. *(D. D. Bates)*

The Second 28-GHz Gyrotron Tube Socket. Design and installation was completed on the second 28-GHz gyrotron for EBT-S. In addition to doubling the 28-GHz microwave capability to EBT-S, the second gyrotron tube will provide a microwave source to an rf test stand being developed in the Fusion Energy Division. The second socket was completed on schedule and tested with the gyrotron to 212 kW, fulfilling all requirements for the successful completion of the DOE milestone. *(D. D. Bates)*

Technician Training and Certification for Gyrotron Operation in EBT-S. An increased workload of the microwave development group necessitated the training and certification of the EBT-S technicians. The acquisition of a new power system, high-voltage transfer switch, second gyrotron installation, and a test stand for EBT-P (in addition to the demands for normal 28-GHz microwave operation into EBT-S), required specially trained technicians to provide relief in the normal operations of the 28-GHz system.

A 28-GHz system turn-on procedure was written, and one technician was trained and certified to operate the gyrotron to 150 kW. As a backup, another technician has been qualified to operate to 100 kW under normal conditions.

Because improper mode operation can cause extensive damage and downtime, a qualified engineer will continue to operate the system for microwave component development, high-power operations (>150 kW), and for conditioning of new gyrotron tubes. *(D. D. Bates)*

1.4 Instrument and Detector Development

1.4.0 OVERVIEW

A number of instrument systems and detector systems have been developed during this reporting period. Some of these efforts will be reported under other activities (e.g., 1.7, Environmental Monitoring). Work has been carried out in a wide variety of disciplines ranging from exacting mechanical and materials design for the ultrahigh sensitivity fission counter to portable computer systems for field soil moisture measurements to mobile computer and detector systems for the Remedial Action Survey Group of the ORNL Environmental and Occupational Safety Division. Special efforts were made in high-temperature, high radiation field electronics for an in-core flux monitor that would transmit its signal ultrasonically through the liquid sodium in which the sensor sits. The following articles will discuss these and other activities in more detail.

1.4.1 PORTABLE CMOS MICROPROCESSOR-BASED DATA LOGGER FOR SOIL MOISTURE MEASUREMENT

R. A. Willems G. W. Turner

Work was performed for the Environmental Sciences Division to develop a data acquisition system for measuring soil moisture. Knowledge of these conditions is important to hydrologists for determining water movement and waste migration in present and future burial sites.

The moisture content of soils is measured by a tensiometer, a device consisting of a long tube filled with water and having a porous substance at one end and a pressure-measuring device at the other. The tensiometer is buried with the porous end establishing good contact with the ground. As the soil becomes dryer, water escapes through the porous material to produce a vacuum. Alternately, as the soil becomes wet, a positive pressure is registered. Traditionally, these pressures are measured by either a mercury manometer or a vacuum gauge. Recently, however, electrical transducers have been used with good success. These devices are more accurate than the abovementioned items; however, they are also more expensive. As an alternative, several tensiometers can be connected to one pressure transducer by a fluid-scanning switch. This configuration costs much less than one having several individual pressure transducers, and this is the arrangement used in the system described here.

Three major components comprise the data acquisition system. All of these components, with the exception of the data logger, are available commercially.

With recent advances in CMOS technology, intelligent, battery-operated instrumentation is being designed. The instrument developed at ORNL incorporates traditional CMOS circuitry combined with state-of-the-art CMOS microprocessor technology to yield a low-power, high-performance data logger. Control of the instrument is governed by real-time multitasking software, and both the hardware and software are designed to make efficient use of the instrument's battery supply.

The primary purpose of the data logger is unattended periodic sampling of soil moisture. The instrument remains in a low-power mode to conserve its battery supply until a sample is to be taken. When a sample is taken, the instrument leaves its low-power state, waits a short period of time to allow system voltages to stabilize, logs the information, and returns to its original state. This process continues indefinitely until the user terminates the collection process or one of the several components monitored by the software indicates an error in the system.

In addition to periodic sampling, the data logger can be used for initial setup of the field site or for spot checking data obtained from the tensiometers. The instrument allows the user to view data as it is presented to the unit in real time, thus allowing the user to calibrate the system or to isolate faulty equipment.

The unit (Fig. 1.4-1) is housed in an environmentally sealed container and is designed to operate over a wide temperature range. The operator uses a 16-key keypad to enter commands into the unit and a 32-character liquid crystal display to read messages and sensor information. Data obtained from the tensiometers are stored in the instrument's internal memory and written to magnetic tape. Approximately nine days' information can be stored by the unit. In addition, collected data can be examined at the field site, and data can be searched by day, time, channel number, or any combination of the three. The cassette tape produced by the data logger is formatted to keep records independent of each other and to provide a mechanism for qualifying the recorded information.

ORNL-PHOTO 2256-84

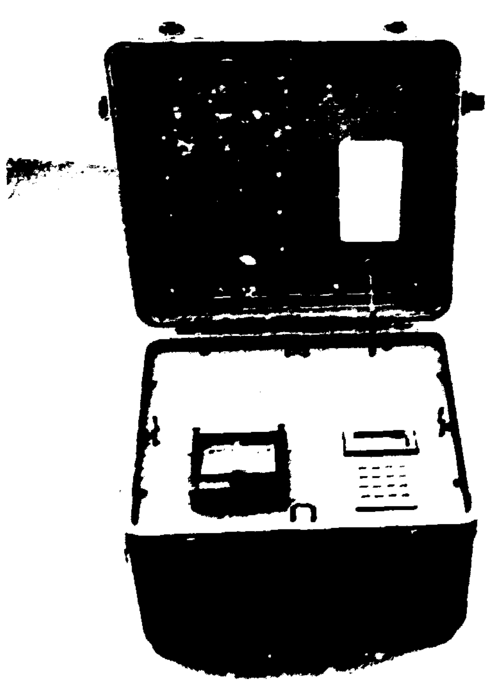

Fig. 1.4-1. Scanivalve data logger developed at ORNL.

1.4.2 ULTRAHIGH-SENSITIVITY FISSION COUNTERS

W. T. Clay

G. W. Allin | C. E. Fowler, Jr.

M. M. Chiles | V. C. Miller

Two slightly different ultrahigh-sensitivity fission counters were developed and fabricated. The first, UHSFC was the development prototype for ex-vessel thermal neutron detection at the Clinch River Breeder Reactor Project (CRBRP).[1] The second, UHSFFC was for fast neutrons in fusion energy experiments.

The UHSFC was developed as a source-range monitor with a thermal neutron sensitivity of ~48 counts/s/nv. It was to be a back-up/replacement for the BF_3 proportional counters at the CRBRP. The UHSFC-2 can be expected to operate longer and with less voltage than BF_3 counters in the hostile environment at the CRBRP, where high gamma fields and high temperatures (5×10^4 R/HV and 180°C, respectively) are expected.

A specialized rubber die was developed to form the required curvature on both the signal and ground electrodes. After the proper profile for both types of electrodes was machined on the 0.5-mm-thick flat plates, they were placed separately onto the die for forming. The formed electrodes were then coated with 2 mg/cm^2 of 97.6% enriched ^{235}U. The total uranium coated area in the counter was 5 m^2. All electrodes had to be reformed after the etching/electroplating process because of changes in the curvature caused by springback.

The UHSFC-2 was assembled by stacking the electrodes around the central support tube into 4 identical sections with 50 electrodes each. All electrodes are parallel to each other with a 1.5-mm gap. This configuration maximizes the ratio of electrode area to sensitive volume. Two of these sections are connected in series by a continuous copper coil to the 29 signal electrodes in each section. This forms one of the two lumped-element 25-Ω inductance capacitance (LC) transmission lines in the UHSFC-2. Low-resistance electrical contacts among the copper inductor, the uranium-coated aluminum electrodes, and the cable end seals were difficult to achieve.

Four high-temperature mineral-insulated (MI) cables with welded end seals were specified and purchased for the UHSFC. Each cable was 13.7 m long and had a characteristic impedance of 23 Ω. The outside sheath on the cable was 4.8-mm-diam 304 stainless steel with a copper inner sleeve. The center conductor was copper, and the dielectric was compacted magnesium oxide. The cable/end seal assembly was specified to have low breakdown-pulse noise and long electrical leakage paths. After a checkout the cables were welded into the counter header.

The four assembled sections were inserted into the 13-cm-OD by 86-cm-long stainless steel cylindrical can, and the header and can were welded to give a helium-leak-tight enclosure for the counting gas: argon + 5% nitrogen at 2 atm absolute.

The other design was the fast fission counter (UHSFFC) for plasma physics diagnostics at ORNL and Princeton University. It is a threshold detector for ~1-MeV fusion neutrons. The fissionable material was highly depleted uranium (99.999% ^{238}U). The four preamplifiers were mounted in an electrostatic housing onto the fission chamber header. With this arrangement, long MI cables were not necessary. However, four each of the 25-Ω transmission stubs were fabricated to couple the signal from the copper inductor on each of the four sections to the preamplifiers. In all other respects the UHSFFC was identical to the UHSFC.

1. K. H. Valentine et al., *IEEE Trans. Nucl. Sci.* NS-30(1), 795 (1983).

1.4.3 CERENKOV DETECTOR FOR MONITORING BURIAL GROUND WATER TABLE

M. M. Chiles
V. C. Miller I. L. Larsen*

The present system for monitoring shallow wells in the vicinity of the ORNL disposal area for ^{90}Sr contamination is by periodic extraction and laboratory analysis of water samples. The main objection to this method is the delay between the time samples are taken and the time the results of the analysis are available. Therefore, a radiation monitor for in situ testing of water samples at the wells is needed.

A Cerenkov detector was designed to use the direct Cerenkov scintillations generated from the high-energy beta particles in the water sample, and a simple proof-of-principle model was assembled and tested. The detector automatically fills with water when submerged and drains when lifted out of the water. A single photomultiplier tube is used in the present model, and, because only small pulses of light are anticipated, a tube having very low, dark noise pulses was selected. However, a few inherent noise pulses still contribute to the background counts of the detector. Some of the undesirable background counts can be rejected by properly setting a pulse height discriminator, but the larger amplitude background pulses have to be compensated for by subtracting the number of background counts from the gross counts after a sample is counted, thus giving the net counts from the beta activity of the sample. A water sample from one of the wells was brought into a laboratory for the proof-of-principle tests and was placed in a liquid scintillation detector to count the beta activity. The data from that sample were used as a reference for the data taken with the Cerenkov detector. Water samples were taken from the well water and diluted by adding distilled water to get samples containing 25, 50, 75, and 100% contaminated water. Figure 1.4-2 shows that the net beta count rate is linear with varying concentrations of well water.

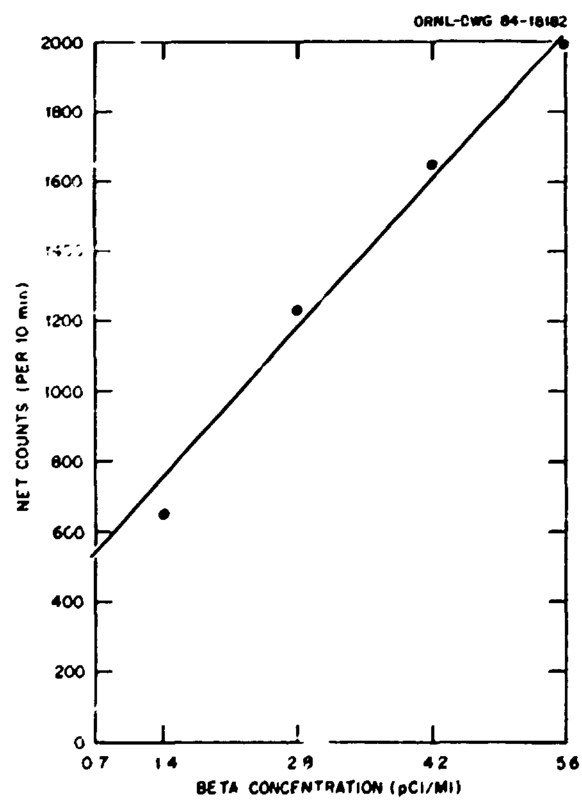

Fig. 1.4-2. Net beta count with varying concentrations of well water.

Preliminary tests indicate that samples with less than maximum permissible concentration (MPC) level allowed for ^{90}Sr in controlled areas (1 × 10^5 μCi/ml) can be detected. However, the sensitivity is approximately four times the lower MPC level allowed for uncontrolled areas.

Tests with the proof-of-principle model proved that high-energy beta particles in the ^{90}Sr decay scheme can be detected in a Cerenkov detector, and an improved model is being designed. The next design will include two low-noise photomultiplier tubes viewing the common water cavity and operated in electronic coincidence in order to eliminate most of the background pulses from the single photomultiplier tube in the previous model. Hence the pulse height discriminator can be operated at a lower level and increase the sensitivity for the lower amplitude beta pulses. This, of course, will increase the net counts per beta activity and improve statistical evaluation of each sample with less counting time.

*Environmental Sciences Division.

1.4.4 INSTRUMENTATION AND CONTROLS SUPPORT FOR REMEDIAL SURVEY GROUP

M. S. Blair
T. R. Barclay B. H. Fulcher

The Instrumentation and Controls Division supports the Remedial Action Survey (RASA) Group of the ORNL Industrial Safety and Applied Health Physics Division at both their main office at ORNL and their satellite operation in Grand Junction, Colorado. This support includes the acquisition of computer hardware and software and the development of custom software packages. The group also develops custom computer interfaces and maintains RASA field instrumentation.

Custom software was developed for the Commodore computer (CBM 8032) and software support was given for IBM PC computers. The software packages developed for the CBM 8032 enabled it to perform data analysis and control a Tracor Northern multichannel analyzer for the Rapid Radium Estimation System. Development of additional software enhanced the database manager for the CBM computer system. Also, I&C helped select and install commercially available software packages for the IBM PC.

Computer hardware support for the RASA Group included selecting and installing various IBM PC circuit boards and accessories. Custom interfaces were designed for the 8032 computer system to enable it to control a multichannel analyzer.

1.4.5 ESTIMATION OF RADIUM CONCENTRATION IN SOIL

M. S. Blair
R. W. Doane* B. A. Berven*

A computer-controlled multichannel analyzer system was developed for the Radiological Survey Activities (RASA) Group of the Health and Safety Research Division to estimate rapidly the concentration of ^{226}Ra in soil samples. The gamma-detection system is controlled by a Commodore Business Machine (CBM) computer system, which operates the counting system and stores sample parameters and raw data on floppy disks so that a permanent record of the data is maintained.

The counting system consists of commercially available NIM electronic modules, the CBM computer system and peripherals, a custom interface board, a multichannel analyzer, and a NaI(Tl) crystal. The NaI(Tl) crystal used in this counting system is a 6- × 9-in. NaI(Tl) crystal with a 3.25-in.-deep by 3.5-in.-diam well to hold the sample for counting. The multichannel analyzer is a Tracor Northern TN 1706, which is connected to the CBM 8032 computer system via a custom interface. The custom interface enables the computer program to control the multichannel analyzer operation.

The software developed for the counting system is a combination of the Commodore BASIC language and machine language subroutines. Machine language subroutines, which are executed from the BASIC program, were written to provide better control over the multichannel analyzer's operation and increase the speed of data transfer between the multichannel analyzer and the computer system. As data are transferred from the multichannel analyzer, a machine language subroutine stores the data in the computer's memory directly as a subscripted variable, thus making it easier for the BASIC program to recall the data for analysis. The BASIC program was written so that the counting system would be user friendly and the operator could select any of its operation modes with a single key-stroke. After the BASIC program has stored the spectral data and sample parameters such as the date, sample weight and location, number of days bottled, and analysis time, the spectral data are then analyzed to estimate the radium concentration. The algorithm used to estimate the radium concentration converts the counts/min/g to pCi/g for the sample and corrects for the radon ingrowth. The radon ingrowth is a function of how long the sample has been bottled. When sample analysis has been completed, the results are printed to provide a hard copy of the sample analysis.

*Health and Safety Research Division.

1.4.6 A WIRELESS IN-CORE NEUTRON FLUX MONITOR WITH ULTRASONIC SIGNAL TRANSMISSION FOR CRBRP INITIAL CORE LOADING

J. M. Rochelle* G. W. Allin
M. M. Chiles E. J. Kennedy

A wireless, in-core, low-level flux monitor (LLFM) has been developed for installation in the Clinch River Breeder Reactor Plant (CRBRP) during initial core loading to augment ex-vessel source range flux monitors.

A secondary project objective has been to study the combined effects of elevated temperature and high radiation levels on key electronic components needed for a wireless in-core LLFM capable of operating during CRBR fuel reloading operations. This phase of the project was conducted by the Electrical Engineering Department of the University of Tennessee, Knoxville.

This project included the design, fabrication, and functional testing of a proof-of-principle prototype version of an initial core loading in-core LLMF that (1) operates at 230°C, (2) transmits accurate neutron flux information via an ultrasonic data link, (3) is powerable from a 1.7-W radioisotope thermionic generator (RTG), and (4) is capable of mechanically interfacing with CRBR core assembly handling machines. The prototype thus embodies a system design, a mechanical configuration, and fabrication technologies that are directly translatable to the production of a fully qualified in-core LLFM suitable for actual plant installation.

A 24-h test was conducted with the assembled prototype fully immersed in a bath of 230°C peanut oil. For this test, the monitor was externally powered via wires because the required RTG has not yet been procured. Also, the ultrasonic transmitter surfaces were not passivated as would probably be required for 230°C sodium service.

*The University of Tennessee, Knoxville.

1.4.7 CONSTANT-CURRENT, PULSE-MODULATED HELIUM IONIZATION DETECTION

R. S. Brazell* R. A. Todd

The helium ionization detector (HID) is one of the most sensitive detectors currently available for gas chromatography. Its ionization efficiency has been estimated to be approximately 5% as compared to 5×10^{-4} percent for a flame ionization detector. Despite its sensitivity and a universal response mechanism, it has not been widely used, owing primarily to a lack of stability and reliability. Conventionally, it has been operated only in a dc mode, applying a constant polarizing voltage across the cell and measuring the output current continuously. Recent modification of the detector to operate in a pulsed mode configured the detector, electrometer, and a specially designed high-voltage pulser in a closed-loop system. The cell current is maintained at a fixed level and variations in frequency are monitored. Since the HID exhibits a low background current with high-purity helium carrier gas, the highest frequency of operation is obtained at the lowest concentration of an analyte. The overall effect of pulsed operation has been to improve stability and increase the dynamic range. In addition, preliminary findings suggest an increase in sensitivity over dc operation. Advanced development of the closed-loop version of the pulse-modulated HID is in progress and is being transferred to several commercial analytical instrument manufacturers to bring this type of detection to the commercial marketplace.

*Analytical Chemistry Division.

1.4.8 NEW DESIGN FOR HELIUM IONIZATION DETECTION

R. S. Brazell* **R. A. Todd**

[Summary of *J. Chromatography*. 257–68 (1984)]

A voltage pulse generator with variable width and interval adjust has been designed and coupled to a helium ionization detector to examine the response characteristics of sampling the detector cell's output current in a discontinuous mode. The pulser is capable of operating from 0 to 500 V at less than 1 kHz up to 333 kHz at the highest voltage. The response of the modified detector to a standard gas mixture containing Ne, H_2, Ar, O_2, N_2 and CH_4 has been examined as a function of frequency, duty cycle, and voltage. An inversion in the signal polarity for some gases was observed at certain frequency and duty cycle combinations. Noise and background current levels were significantly reduced in the pulsed mode as compared to dc operation. It has also been determined that the detector can be operated at higher voltages in the pulsed mode before the cell current breaks down.

*Analytical Chemistry Division.

1.4.9 A STUDY OF CYLINDRICAL, ENERGY-PROPORTIONAL PULSE-HEIGHT DETECTORS FOR MEASURING MICRODOSIMETRIC QUANTITIES

A. S. Todo* **H. A. Wright†**
J. E. Turner† **J. W. Poston‡**
R. N. Hamm† **M. M. Chiles**

[Abstract of paper presented at Symposium on Microdosimetry, Juelich, West Germany, September 27–October 1, 1982)

A study has been carried out on the use of cylindrical, energy-proportional pulse-height detectors for determining microdosimetric quantities. This paper reports the results of using a Hurst chamber to obtain neutron LET spectra and a commercial CH_4 chamber to obtain neutron energy spectra. This work represents an extension of earlier application of Monte Carlo techniques to the unfolding of LET spectra. The method depends on knowledge of the track-length distribution of charged particles in the chambers, coupled with the measured pulse-height spectra. By several examples, it is shown that LET spectra inferred from measurements with the Hurst chamber do not depend critically on the track-length distribution. Calculations for monoenergetic neutrons incident in the CH_4 chamber show that it provides a good energy resolution up to ~2 MeV. Comparisons are made of the effects of different assumptions about the direction of the incident neutrons on the unfolded energy spectrum. Results are presented of neutron energy spectra unfolded from measurements made with the CH_4 chamber exposed to neutrons from the Health Physics Research Reactor.

*Instituto de Pesqugas Energéticas, (Institute for Energy Research), Brazil.
†Health and Safety Research Division.
‡Georgia Institute of Technology.

1.4.10 ADDITIONAL PROJECTS

Optical Position Detector. Using a circuit patented by D. R. McNeilly that will accurately determine the distance of a phototransistor from an infrared LED, a position detection system has been designed for the Analytical Chemistry Division. The system is used to determine the rate of movement of a boundary layer by following it with a spotting telescope.

The telescope typically covers a 10-cm length. With a calibration curve, the boundary layer position can be determined to about 0.1 mm. The phototransistor uses a No. 88 Wratten gelatin filter to reduce sensitivity to ambient light. *(M. S. Emery)*

Buffer Amplifier/Cable Design. A NIM-packaged instrument was designed to provide fan-out capabilities for preamplifiers used in radiation monitoring applications. A frequently occurring problem has been the necessity of sensing the output of a single detector with two or more monitoring systems. The buffer amplifier/cable driver provides two low-impedance output channels with unity gain for each high-impedance input. Each module is implemented with four input circuits. *(R. T. Roseberry)*

Telephone Line Tester. A small, inexpensive telephone line tester was built that would use only four steps to sort the four wires of a four-wire dedicated telephone installation into a pair of properly polarized transmission wires and a pair of reception wires. This line tester would be used to facilitate attaching a badge reader-controller at a remote site to a host computer asynchronous communication port. Lines are identified by the illumination of light-emitting diodes on the test box. The use of the test box is not limited to the badge reader application but may be used in any situation where the telephone lines require proper identification. *(C. R. Mitchell)*

Mechanical Development Projects. A principal weld joint design was changed on the FC-3 high-temperature fission counter. A design review was conducted and the completed counter has since passed rigorous tests at the design operating temperature of 650°C.

The fast-neutron detector design was completed which mounted the preamplifiers onto the top header. Only minor internal changes were made from the ultrahigh-sensitivity fission counter design, which is very similar in construction. The completed detector has been sent to Princeton University for use in an experiment being conducted there.

Materials have been ordered and are being received for fabricating a third small-angle neutron-scattering, position-sensitive proportional counter (SANS-3). The basic design of the containing vessel will remain unchanged. The welded-in diaphragm and the serrated metal-to-metal sealing arrangement are principal design features that contribute to making this a one-of-a-kind research tool. *(G. W. Allin)*

A Class II security repository was designed for storing thermocouples containing precious metals used in the AIRS program. Two of these units, 6 in. in diameter by 20 ft long, were installed in the Metrology Laboratory in Building 3500.

An experimental positioning device was designed and fabricated for use in a sonic tomography experiment. It consisted of a linear array of 24 transducers on 4-in. centers capable of being rotated about an elevated specimen under study. A stepper motor-driven linear translator was provided to move a transmitter tangentially to the transducer array path.

A computer-controlled positioning system has been designed for inspecting graphite/ceramic materials by the Metals and Ceramics Division using either an ultrasonics or an eddy current transducer. This system has three-axis capability in addition to a rotary drive positioning arrangement for inspecting parts up to 22 in. diam and 28 in. long.

Subcriticality test hardware was designed for establishing the safe loading characteristics of a storage vault to be used for fissile materials.

Monitoring Equipment. The gas proportional alpha survey meter has been plagued over the years with a faulty gas flow control valve which often leaks upon shutoff. After the gas supply is depleted, the meter is rendered useless until refilled with gas. A very simple, inexpensive part has been designed to fit within the existing valve that has eliminated this problem. Not only has this reduced maintenance of these units, but it has also reduced the instances of health physics personnel responding to a call with a faulty survey meter.

A number of minor improvements made to the fallout monitor drives are certain to reduce the maintenance cost of these units.

A replacement diaphragm for the tritium monitor pump was devised to facilitate its replacement with a minimum of cost and downtime.

The selection of a different replacement tube used in the toxic monitor pinch valve has reduced the frequency of replacement of this tube. Also, the newly selected tube costs only a fraction of the amount the original equipment manufacturer was charging for a replacement tube. *(G. W. Allin)*

PERALS II Alpha Scintillation Pulse-Shape Discriminator. A pulse-shape discrimination circuit used for alpha scintillation counting has been designed and is being constructed to improve system performance by stabilizing gain and reducing noise. Fast MECL discriminators for leading edge constant fraction discrimination were employed as well as a delay line shaping amplifier. A fast time-to-pulse-height converter output signal with a front panel single-channel analyzer gate control was included. The unit is housed in a single-width NIM and is an upgrade replacement for a unit that received a 1980 IR-100 award. *(R. A. Todd, W. J. McDowell*)*

Autoranging Count Rate Meter for Waste Operations. A smart, microprocessor-based field count rate meter with autoranging capability (Q-5968) has been designed, built, and field tested. This count rate meter monitors radiation levels of process effluents at ORNL. The instrument includes an adjustable high voltage dc-to-dc converter to bias detectors, detector buffer amplifier, digital counter/timer interface, a key pad, and interface-to-program instrument functions to allow calibration. The meter also has an 8-bit microcomputer programmed in floating-point BASIC, a 16-character alphanumeric display for operator interface, and a D/A converter to provide a pseudo-logarithmic output current (either 0 to 1 mA or 0 to 20 mA) for telecom transmission of count rate information back to a central monitoring computer system. The instrument incorporates self-testing concepts to simplify production checkout and maintenance. *(R. A. Todd)*

Ultrahigh-Sensitivity Fission Counter Thick-Film Hybrid Preamplifiers. A special low-noise, high-bandwidth voltage-sensitive preamplifier, based on a discrete component preamplifier design by M. K. Kopp, has been fabricated using thick-film hybrid microcircuit techniques. Certain requirements for buffering the output signals from the ultrahigh-sensitivity fission counter (UHSFC) were best met by using four identical low-noise amplifiers operating in parallel and summing their outputs into a very similar fifth low-noise summing amplifier. Because many similar amplifier subcircuits are used, the production of UHSFC preamplifiers was adapted to thick-film hybrid techniques. After a common layout of the Q-5967 UHSFC hybrid subcircuit amplifier was complete, fairly large quantities of amplifier subcircuits were very economical to produce. Thick-film hybrid techniques produced the additional advantages of lower noise and higher bandwidth operation when compared to the original discrete prototype preamplifier. A total of 20 hybrid subcircuit amplifiers have been produced and 2 integrated UHSFC preamplifiers have been delivered. *(R. E. Cooper, M. S. Emery)*

Ultrahigh-Sensitivity Fission Counter Electronics. A system of support electronics has been developed in conjunction with the development of an ultrahigh-sensitivity fission counter for the CRBR and the Fusion Energy Division.

The electronics system developed for each UHSFC included two low-noise, low-impedance, wide-bandwidth preamplifiers, two unipolar pulse shaping amplifiers, two low-level leading edge discriminators, and one time coincidence gate generator. The low-noise, low-impedance preamplifiers (Q5967) were implemented using thick-film techniques combined with etched wiring board interconnection and packaged in small preamplifier boxes mounted close to the UHSFC. The two pulse-shaping amplifiers were modified ORTEC Model 574 timing amplifiers. Leading edge discriminators were ORNL designs incorporating ECL logic and comparators. These leading edge discriminators were combined with the coincidence gate generator in a single NIM.

Two UHSFC systems have been built and tested, the first for CRBR and the second for neutron monitoring in fusion energy experiments. *(R. A. Todd, M. S. Emery, R. E. Cooper)*

Computer-Aided Measurement Loop of Transistor Parameters (CAMELOT). Computer-aided analysis and design must be based on good modeling to produce useful results. The parameter characterization of discrete transistors (bipolar, JFET, MOSFET) is by far the most time-consuming and technically demanding part of using circuit analysis programs such as SPICE, SUPREM, or SCEPTRE.

The proposed development of an automated transistor measurement system will deduce the SPICE parameters directly. The system will be microcomputer controlled and will use modular sources and measurement blocks to provide voltages, currents, or waveforms and the electronics to measure device responses. A software package to unfold the parameters from the data will be developed. The system will be aimed at a broad range of devices from small-signal to high-current power devices.

As an initial step in the development of a SPICE parameter tester, a number of the basic measurement blocks have been developed and are being used in semiautomatic transistor parameter testing. *(R. A. Todd)*

Twelve-Input RC Time Constant Unit. A new 12-input RC time constant pulse-shaping summing amplifier has been designed for a new series of experiments. The Q-5993 is a three-wide NIM which functionally replaces 12 Q-5789 single-wide NIM moduled and an extra summing amplifier module. The experiment for which the Q-5993 is being built will employ six of these time constant units in two NIM bins. Employing the Q-5789 modules, 6 summing amplifier modules, and at least 7 or 8 NIM bins to perform the equivalent function. In addition, production of Q-5789 has been stopped because an operational module used in its circuit is no longer manufactured. The Q-5993 employs a widely available monolithic op-amp replacement. The Q-5993 will also accept TTL or NIM fast inputs without switch or jumper changes. *(M. S. Emery)*

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*Analytical Chemistry Division.

1.5 Computer Systems

1.5.0 OVERVIEW

The Computer Systems Group develops both hardware and software. During this reporting period, software was developed to translate CAMAC local area network (LAN) interrupts into global event flags that allowed an application program to sleep in a wait-for-flag state. Other software was developed to support CAMAC operations in an expanded RT-11 operating system running in an LSI-11 computer. Fortran-callable subroutines were developed to support a TN-7200 multichannel analyzer through terminal input.

Microcomputer software tasks included (1) development of an operating system for an 8088/8086 microcomputer, (2) generation of 6809 Assembly language software (using the OS9 operating system) for memory diagnostics in a 1-Mbyte system, (3) generation of a forward/reverse Fast Fourier Transform program using the 9511 math processor, (4) development of a HPIB device driver to be used as a C language procedure, and (5) modification of a 6809 OS9 shell program to allow command storage.

Hardware development included an improved version of a programmable amplifier and its computer interface for control in a noise analysis system. System upgrade equipment selections, specifications, cost estimates, and procurement approval documents were prepared for projects for Y-12 Engineering. Design studies to provide uniform field operations of the CADRE system at ten U.S. Border Patrol sites were made for the U.S. Immigration and Naturalization Service. A design report was issued for Tempest requirements so that one processor of an installed dual IBM 3033 computer system with a shared communication facility could meet RED/BLACK security requirements.

1.5.1 RSX-11M INTERRUPT-HANDLING TASK FOR A GENERALIZED MULTICRATE CAMAC SYSTEM

D. E. Smith D. E. McMillan

A task has been written for RSX-11M, Version 4 or later, that allows application programs to relate specified CAMAC interrupts to global event flags. This work was performed in support of the port to be operated at the NSLS at Brookhaven National Laboratory by the ORNL Metals and Ceramics Division.

Because of the diverse nature of CAMAC modules and their programming, it is not practical for commercial vendors to supply interrupt handlers with the driver software for CAMAC crate controllers. While certain events, such as ADC end-of-conversion, must be handled quickly by custom machine language code, another class of events which mark changes in states—such as the end of stepper-motor travel, the completion of a preset time, or count interval—need not receive such prompt service. An application program needs to know when such events occur, but computer resources are wasted in a time-sharing environment by continually testing a CAMAC module's status register. The RSX-11M operating system allows programs awaiting event flags to become inoperative during the wait, thus allowing other programs to run. A mechanism that relates event flags to CAMAC requests allows optimum use of computer resources.

RSX-11M global event flags are available to all programs in the system. The interrupt-handling task written for this project connects to the CAMAC interrupt vectors for one or two crates and, by means of data tables, relates CAMAC interrupts to up to 16 global event flags. Any application program may use CAMAC interrupts by supplying the table information to the interrupt handler through operating system calls. These calls are available to both machine language and FORTRAN programs. A response is supplied to the calling program to verify acceptance of the data or, should a failure occur, to indicate the reason. Data supplied to the interrupt handler allow specification, in CAMAC NAF (number, address, function code) terms, of the CAMAC dataway cycle needed to identify the condition of interest and a second dataway cycle necessary to clear the interrupt condition. An unidentified interrupt will cause an end to the interrupt-handler operation and set an error global event flag. The handler may be restarted by command when the interrupt condition is cleared.

The interrupt handler has been used to control the position of four motors in interrelated motion while operating a display which continually monitors various experimental conditions.

1.5.2 ORNL IBM 3033 SECURITY FEASIBILITY STUDY

D. E. Smith

A feasibility study was undertaken to evaluate the problems associated with satisfying military security criteria and the Tempest requirements necessary to process classified information at the ORNL 3033 computing center.

Several different security countermeasures must be implemented for computer storage or processing of classified data. The study evaluated security requirements for personnel, communications hardware and software, and administration as well as Tempest safeguards. This feasibility study, which was performed for the Computing and Telecommunications Division, indicated that the ORNL IBM 3033 computing center was unsatisfactory for processing classified information.

1.5.3 IMMIGRATION AND NATURALIZATION SERVICE CADRE SYSTEM

E. Madden J. W. Reynolds
D. E. McMillan D. E. Smith

The U.S. Immigration and Naturalization Service is expanding and upgrading the Border Patrol Computer-Assisted Detection and Reporting Enhancement (CADRE) system. This system uses various sensors placed at known or expected border crossing sites to advise dispatchers of potential illegal activity. The system is installed at several Border Patrol Stations, and the purpose of this project is to review the existing system and derive a uniform design that will use the best of current computer technology. The newly designed system will be placed at ten Border Patrol sites. To assure continued uniform performance, an additional system at ORNL will be used to develop and test system improvements and distribute them to the operating sites.

Field visits and reviews of previous specifications have resulted in the preparation of new hardware and system software specifications. The design is based on standardized terminals which will provide the operator interface. These terminals may be either local or remote, and various computer security levels will provide needed access to dispatch operators, field agents, and management. The field sensors provide alarm information which is interfaced to the computer by a serial ASCII link. This alarm information must be presented to the dispatch operator for action. Dispatch involves radio contact with field agents and often results in inquiries to state, national, and INS databases. Since the CADRE terminal has become the focus of operator activity, the design of the new CADRE system has been expanded to include the operator's console that houses the CADRE terminal and a portion of the dispatch radio gear.

The project is nearly ready to procure computer hardware and system software. During the next year, application programs will be developed and the first field system will be installed at Tucson, Arizona. Development work for other sites will continue as each state law enforcement database will require a unique protocol. Digital mobile radio is expected to be available soon, and integration of these units into CADRE will improve operator efficiency.

1.5.4 CONTINUOUS ONLINE SURVEILLANCE

G. W. Turner C. M. Smith

A statistically based pattern recognition system was developed at ORNL by the I&C Surveillance and Diagnostic Group and support for continuous online surveillance has been provided by the Computer Systems Group. Support was primarily in three areas: engineering support of field installations, development of a second-generation programmable amplifier module, and development of a second-generation data acquisition/control processing system.

The system was developed to allow continuous, online, unattended surveillance of dynamic reactor signals. The system user is provided with a detailed record of the power spectral density (PSD) values of the signals and their statistical characteristics. PSD measurements on process signals are the performance signatures that characterize the "health" of the monitored equipment. Statistical methods provide a quantitative basis for automating the detection of suspect conditions. Through statistical comparison of current PSDs, the system can detect changes in the monitored reactor signals. The historical record of PSDs is catalogued along with information that reflects the current operating state of the reactor, since these conditions may affect the PSD signatures from monitored signals.

The support for field installations includes online systems at TVA's Sequoyah Nuclear Plant, the Fast Flux Test Facility (FFTF) at Hanford, Washington, and a scheduled installation at Peachbottom Nuclear Plant in Pennsylvania. Repair and engineering upgrade support is provided for the 16-channel programmable amplifier/signal-conditioning systems and the 72 amplifier modules installed in them. The programmable amplifiers (developed by I&C Division) have the following functions under program control: channel selection (0 to 15), overvoltage limits (1 V, 2 V, 5 V, 10 V), amplifier gain (1 to 1024), single-ended or differential input, ac or dc input signal coupling, and sample or hold mode. The 16 amplifier modules reside on a custom-built bus and communicate with the computer system via parallel interface modules.

The development of a second generation of programmable amplifiers preserved compatibility between both module generations and incorporated several changes which improved calibration, serviceability, and linearity. The first- and second-generation modules may be mixed on the same bus. The following changes were made:

- Reed relays provide power failure (signal loading) protection.
- A common amplifier is used for the test and signal input.
- A single-chip, laser-trimmed, differential instrumentation amplifier is used.
- Flip-flops are used on computer inputs to latch the signals.
- Thirteen test points are available.
- Offset trim of the Burr Brown Programmable Gain Amplifier is rearranged to produce more accuracy.
- Output data routing and input grounding selection are now switchable.

A second-generation software system that implements diagnostic as well as surveillance capabilities was developed by the Surveillance and Diagnostic Group. This system is capable of running "expert system programs." The expert system allows the computer to make decisions (based on both database and input information) at the level of a nuclear reactor noise analysis expert. The new system is able to handle these decisions because it no longer has the overhead required to do the analysis or the data acquisition; the analysis is handled by an array processor, and the data acquisition is done with a microcomputer-controlled subsystem. This leaves the DEC-11/24 computer system free to run the expert system. The system software is being developed and tested by the Surveillance and Diagnostic Group. Customer application programs are now being specified and developed.

The development of the second-generation data acquisition and control processing system included modification and development of hardware necessary to allow the off-loading of the analysis and data acquisition tasks. Several DEC modules were modified for improved operation of the control interface. All hardware has been installed, documented, and tested.

1.5.5 ADDITIONAL PROJECTS

Y-12 Plant Development Division Computer Acquisition. Assistance was provided to Y-12 Engineering by estimating the effort required, designing system configurations, writing specifications, and writing necessary approval documents for the purchase of three computer systems for the computer upgrade portion of the Y-12 Plant Development Division's production capability restoration project. *(R. T. Roseberry)*

Revision of RT11 System to Accommodate* CAMAC *and Existing Plotting Programs. An existing package of plotting programs which were developed at ORGDP for RT11 systems was needed to evaluate results from laser-induced fluorescence CAMAC instrumentation. The CAMAC crate controller is based upon an LSI-11 and was running a basic version of RT11. An expanded

RT11 system was generated to support the plotting software and make better use of existing disk storage facilities. This work was performed for the Centrifuge Physics Department of the ORGDP Separation Systems Division. *(D. E. McMillan)*

An FFT Program for a 6809 Processor and a 9511 Math Processor Running Under OS9 BASIC. Analysis of centrifuge test data requires conversion of input values into the frequency domain. To accomplish this, a forward/inverse FFT program was developed in 6809 machine language using specially written subroutines that drive a 9511 math processor chip. The program was written to optimize transform execution speed while allowing users to perform transforms with a BASIC subroutine call. This work was done for the ORGDP Separations Systems Division. *(D. E. McMillan)*

Modification of OS9 Shell Program to Allow Command Storage. Several microcomputer systems at ORGDP use the UNIX-like OS9 operating system. The system frequently requires operators to repeat multicharacter command strings during a session. The shell program, which handles operator input, was modified to provide ten storage registers into which commonly used command strings could be stored and recalled by using the storage register number. Several of the registers also contain default strings. This work was done for the ORGDP Separations Systems Division. *(D. E. McMillan)*

CAMAC Timer/Scaler System Hardware and Software. Hardware and software were provided to acquire up to 12 channels of scaler data using either a preset time or preset count in a control channel. Three CAMAC modules provide the hardware, and the software was written in PDP-11 machine language as a set of FORTRAN callable subroutines that allow the user complete control and readout from a FORTRAN program. This work was done for the National Synchrotron Light Source (NSLS) Group of the ORNL Metals and Ceramics Division. *(D. E. McMillan)*

Program to Transfer MCA Data to a PDP-11 Over a Terminal Interface. A TN-7200 multichannel analyzer was acquired as a setup device and for use as an intermediate data display device for the ORNL port at the NSLS. The analyzer is capable of remote operation from a computer terminal. Programs were written in PDP-11 machine language to allow a user to operate the analyzer from a PDP-11 terminal as if the terminal were connected directly to the analyzer. Data may be transferred between the analyzer and computer files in either direction. FORTRAN-callable subroutines were written to allow operation of the analyzer from user FORTRAN programs. This work was performed for the NSLS Group of the ORNL Metals and Ceramics Division. *(D. E. McMillan)*

Operating System for Small 8088/8086 Microcomputer Systems. An operating system for 8088/8086 microcomputer systems with not more than 64 Kbytes of total address space has been developed. This system provides for logical unit input-output operation, timing, flags, and event definition with subroutine execution at event time. A monitor program supports break points and memory/register examination and modification. The system has been written with conditional code such that it will support systems with varying hardware configurations and either memory or I/O-mapped peripheral devices. This work was performed for the Y-12 Plant Safeguards and Security Division. *(D. E. McMillan)*

PDP-11/23 Computer System Upgrade for ORNL Operations Division. Several peripherals were added to the ORNL Operations Division PDP-11/23 at the ORR. A link to the PDP-10 was installed to increase data analysis, and a Tektronix 4662 plotter with supporting Tektronix Plot 10 Easy Graphing software were installed. The PDP-11/23 memory was expanded from 64 to 128 Kbytes, which allows support of the Tektronix software as well as support of the PDP-10 link and several CAMAC modules.

As a separate function, a CAMAC module and an ORNL stepping-motor control were added to allow the system to perform automated flux wire scanning. *(G. W. Turner)*

Y-12 Plant Interactive Graphics System. A cost estimate was prepared for Y-12 Engineering for support of the CADAM and APT graphic languages on an IBM 4341 computer system and the ANVIL graphic language on a DEC VAX 11/780. Project responsibility was then passed to the Computing and Telecommunications Division

(CTD) personnel responsible for preliminary testing of graphic languages. *(J. W. Reynolds)*

Memory Diagnostic Software for a 6809-Based Computer System. Work was performed for the Centrifuge Physics Department of the ORGDP Separation Systems Division to develop a diagnostic program to verify the integrity of system memory for a 6809-based computer system. The program tests the full 2-Mbyte memory space available in the system along with the memory management hardware. In addition, a memory map of the system is produced and all contiguous memory segments are identified on a terminal. The program is loaded under the OS9 operating system and relocates itself after testing an area large enough to accept the program. Testing continues until either the user-specified number of passes is completed or a control sequence is entered from a terminal. Error information includes the failing address, content, pattern, and state of the memory management unit. Options include specifying the number of errors per 4-K block before printout is suppressed and specifying the number of test passes through memory. The program also gives the current number of passes completed and the total number of errors encountered when a control sequence is entered from a terminal. The program is written in 6809 assembly language and requires approximately 2 Kbytes of memory space for execution. *(R. A. Willems)*

A C-Callable (HPIB) Device Driver for a 6809-Based Computer System. A device driver was written for the Centrifuge Physics Department of the ORGDP Separation Systems Division to provide the mechanism for accessing the Hewlett-Packard interface bus (HPIB) from a 6809-based computer system.

The device driver communicates to commercially available hardware and resides under the OS9 operating system. The current implementation recognizes ten commands that range from performing data transfers in either ASCII or binary format to serial or parallel polling of instruments on the bus. The software is designed to be called from the C programming language and appears as a procedure. Error checking is performed on the parameters passed to the driver, and codes are returned to indicate the success or failure of the command. The program is written in 6809 assembly language and requires approximately 1 Kbyte of system memory. *(R. A. Willems)*

Vacuum Ultraviolet Synchrotron Software Development. Software was developed to test and evaluate a PDP-11/23 computer-based CAMAC data acquisition and control system in support of the vacuum ultraviolet synchrotron at the NSLS Facility at Brookhaven National Laboratory. The software developed included example routines and tasks for use as building blocks by application programmers. This work was performed for the Surface and Catalysis Group in the ORNL Solid State Division. *(D. E. Smith)*

Data Management Software for Processing Output from the ORNL Data Logger. The ORNL data logger is used by hydrologists of the Environmental Sciences Division for measuring the moisture content of soils. Sensor data from the instrument are stored on digital cassette tape.

To allow for a more flexible means of handling these data, a program was developed to extract the information from the tape and place it on floppy disks. Binary data records from the tape are read by an Apple computer and converted to an ASCII disk file. The program allows the hydrologist to format the information in engineering units and perform routine checks on the data. A commercially available file transfer program is used to transmit the disk files to the DEC PDP-10 for analysis and storage. *(R. A. Willems)*

Conceptual Design and Cost Estimate for a 16-Channel Sample/Hold Interface to a PDP-11/34. At the request of the I&C Division Surveillance and Diagnostic Group, a formal estimate was generated for a 16-channel sample/hold interface to a PDP-11/34. The conceptual design was to install an interface on the 11/34 Unibus®. The 16-channel interface would have three modes: normal-gated bus data, mix of individual sample or hold, or all 16 channels in sample or hold. This control would be synchronized with the existing DEC 16-channel, 12-bit A/D board.

Conceptual sketches were drawn, parts were defined, and a formal cost estimate was made. *(G. W. Turner)*

Fabrication of a Programmable Function Generator for Japan Atomic Energy Research Institute. A CAMAC module described in ORNL/TM-7363 was duplicated for the JAERI project. The module basically can store and independently execute a program (CAMAC loaded and controlled) to drive a DAC which generates a −10 to +10-V analog signal. The module stores the program in a 1-K × 12-bit RAM. The 1-MHz clock can be divided into segments between 1 to 2^{16}, and there are two independent programmable synchronization signals. A variety of LAM and status control are available visually and on the CAMAC Dataway.

However, enhancements were necessary to allow the module to operate in this experiment. An addition was designed that would allow the unit to be halted and the DAC output zeroed via an additional CAMAC control signal. Another addition was made to allow, via CAMAC control, the LAM status word to be read onto the Dataway. *(G. W. Turner)*

Upgrade of Small-Angle Neutron Scattering System Motor Driver. The motor-driven multiplexer controls 16 X and 16 Y stepping motors via a computer control at HFIR. Because of the affects of neutron bombardment, the system had to be reconfigured. In the original configuration the stepping-motor diodes were at the field locations. It was obvious that the neutrons were causing considerable failures in the diodes, resulting in nonoperable motors. These 128 diodes had to be relocated in the motor-driven cabinet with the solid state relays. An eight-channel printed circuit board was designed and implemented. The system utilizes four of these boards to address the 32 motors. This modularizes the system, allowing much greater servicing efficiency.

The modifications were coordinated by the I&C Division to be implemented during a scheduled maintenance shutdown of the HFIR. By making the modifications during this time, no user time was lost. *(G. W. Turner, R. T. Roseberry)*

ORR Mechanical Development Support. The 24-in. butterfly control valve in the ORR secondary cooling system was removed for repair after 22 years of service. This valve had been fitted with inboard nylon bushings only two years after its initial installation. These bushings have now failed and are in the process of being replaced. A standby unit has been placed in service temporarily. *(G. W. Allin)*

1.6 Security

1.6.0 OVERVIEW

The work described in this Section for the report period covers three broad areas: (1) on-going installations of badge reader equipment at the K-25 and Y-12 plants, (2) new development and design work in badge reader related security areas, and (3) continued support and planning for security alarm monitoring at the X-10 Plant.

A Martin Marietta Energy Systems badge reader system was developed and installed for employee entry at perimeter portals at the ORGD Plant in 1982. The badge readers for door control of entry access to the centrifuge buildings at the K-25 Plant were installed in 1984. Badge readers were also implemented in the material access areas of the Y-12 Plant in portals to control and monitor entry/exit to the area. The badge reader system was also installed at all the exclusion area entry portals of the Y-12 Plant in 1984 and full use of badge readers for employee entry is planned for all Y-12 Plant portals in 1985.

Exploration of new techniques and development of new devices to solve security-related problems with badging systems continued during this reporting period. A personal identification entry keypad that can be a modular extension of the badge reader was developed. A significant instrument development was a bubble-memory-based badge reader controller that can support a portable database and can be used for access control to special areas and also can be used remotely at personnel collection points to account for personnel during crisis situations. Also developed was a badge reader that has an integrated modular radiation detector assembly that can be used to monitor the radioactive count from the indium foil in the Martin Marietta security badges while the badge identity is recorded.

Investigative work was begun on the use of optical video disk drives for storage of employee and visitor pictures that can be recalled automatically and displayed at selected portal sites whenever a

Martin Marietta Energy System badge is read at an area entry portal. The implementation of this technology will provide positive identification of persons entering selected security areas.

Support was provided for the X-10 Plant security alarm monitoring system which monitors and reports site alarms to guard headquarters. Preliminary work was begun on a backup alarm-monitoring system to be located in the planned Laboratory Emergency Response Center.

1.6.1 A BADGE READER CONTROLLER WITH BUBBLE MEMORY CASSETTE STORAGE

D. E. McMillan

As new applications for machine readable personnel badges have been proposed, the need for a flexible badge reader controller capable of operation without a host computer system has become apparent. The 8088/8086 family of microprocessors was chosen for the controller design because of its diverse means of system expansion. In addition to the choice between the 8- or 16-bit bus, the family allows functional expansion with reduced board space through the 80188/80186 processors. Low-power operation may be attained by 8088/8086 family implementations in CMOS which are presently becoming available.

A nonvolatile memory system is required for many badge reader applications, both as a read-only database and as a read-write storage medium. A bubble memory system, which features removable cassettes, was chosen for this storage. Each cassette will hold 32 Kbytes of data. Nontechnical personnel may move the cassette to another computer system when no communication channel is available, thus allowing constant access to the reader data.

The controller has been designed to be powered by 12-V automotive systems in order to offer maximum controller availability in an emergency. A small battery internal to the controller powers a clock/calendar circuit so that times may be recorded without resetting the system clock after a power interruption.

A flexible computer system requires a software base as general purpose as possible. A review of available operating systems showed that an operating system with suitable response time and communication handling capability was not commercially available. Therefore, an operating system is being designed based on previous experience with badge reader controllers. This operating system uses logical unit calls to allow applications to be written independently of the details of I/O programming. The operating system handles interrupts, timing, and marking of significant events. A library of conversion and formatting routines is available through system calls.

Three similar prototypes have been produced and will be evaluated in criticality evacuation exercises. The identity of each employee reaching an assembly point will be recorded in the bubble cassette. The cassette will be returned to the security system host computer to be read and compared with the personnel listed as present in the evacuated areas. Missing personnel may be identified quickly in this manner.

1.6.2 APPLICATIONS OF THE OPTICAL DISK AND VIDEODISK

D. E. Smith

Videodisk and optical disk technology is expanding rapidly, and applications of this new technology are found in a wide variety of uses such as interactive educational programs, document storage and retrieval, data storage for computer systems, digital audio-video movies and documentries, and arcade games. Three different types of applications under investigation are discussed below. The work is supported by Martin Marietta Energy Systems Security and Safeguards.

A videodisk personnel identification system (VPIS) is intended to be integrated with the existing badge reader system to give positive identification of personnel. Implementation of the VPIS will result in displaying a person's stored photograph and associated personnel file to the guard after the person passes his badge through the badge reader. A VPIS computer will control access to the video database from optical disk and videodisk players as well as communicate with the host computer in the badge reader system. The VPIS will not only provide positive personnel identification but will also provide an employee video database that management can use for instant recall of an employee's photograph and associated personnel information.

Surrogate travel is a method of vicariously transversing a travel route by viewing a recorded video of the route. This viewing allows assessment of anticipated actions by viewing archived information of building interiors and site topography to prepare for an emergency such as fire, nuclear incident, or terrorist activity. With the aid of computer application software, it is possible to become familiar with a building prior to actually entering it. A low-cost personal computer interfaced to an optical disk or videodisk player with a previously recorded disk showing the area to be viewed is an efficient method of implementing surrogate travel.

Interactive training is a method whereby a person views a video recording of a procedure or process which he is to learn. In this self-guided professional training, the video pauses to question the person on previously viewed material at each step. A correct response allows the video to proceed, whereas an incorrect response causes the video to replay previous material. Videodisk players are currently used for interactive training by the auto industry, the military, and the retail industry.

1.6.3 SUPPORT OF THE SECURITY ALARM MONITORING SYSTEM

J. W. Reynolds

The support of the security alarm monitoring (SAM) system included working in the areas of hardware testing, monitoring and repairing software during and after the warranty period, training of Level 2 and 3 SAM operators, writing operating procedures for both normal and abnormal operations, and defining both hardware and software upgrades to the system.

Some hardware support items include documenting a premises control test box and test FID that was used for the quality assurance testing of the system before acceptance by the Security Division, replacing a communication line driver with a short-haul modem for increased reliability, and replacing the disk drives with a larger size for logging files longer than one day.

The system software was modified during the warranty period under the direction of Brown-Boveri personnel to correct reported errors. Continuing support after the warranty period has been provided.

Operating procedures were written for the Level 2 (alarm database entry and modifications) and Level 3 (normal operation) SAM operators. Training was provided for four Level 3 SAM operators and two Level 2 SAM operators.

1.6.4 BADGE READER SYSTEM FOR ENTRY CONTROL OF DOORS AT THE CENTRIFUGE BUILDINGS

E. Madden

R. G. Affel *	C. R. Mitchell
G. W. Allin	Y. H. Etheridge
D. E. McMillan	J. W. Simmons †

The Martin Marietta badge reader system became operational at all ORGDP perimeter portals in June 1982. The system provided for the automatic machine inspection of all badges and the issuance of employee and visitor temporary badges.

Although the centrifuge buildings lie within the perimeter fence of ORGDP, they are zoned at a higher level of security than the general areas within ORGDP. The project to implement door control at the centrifuge buildings was begun in February 1983. Lockwood Greene Engineering prepared the installation drawings. The Instrumentation and Controls Division delivered on schedule to ORGDP Engineering all badge reader equipment. Rust Engineering Company began installation of the control boxes, conduit, and cable in November 1983. Following installation of this equipment, ORGDP maintenance personnel began installing and checking readers and control board electronics and checking telephone lines. New door hardware, electric door strikes, exit crash bars, and cylindrical locksets equipped with the switches required for secure door control were required. Door hardware was received and installation began in May 1984. The centrifuge doors are controlled by the same computer system used with the perimeter portal badge readers; additional serial communication channels were added for the centrifuge doors. The computer system was assigned control of the 34 centrifuge doors in August 1984.

The system tests a badge via communication with a master database. If entry is authorized, the door strike is activated for a time sufficient for the door to be opened. The system monitors the door through use of a number of inspection switches.

Many door conditions, such as door open too long, improper closure, invalid entry, exit, door not locked, and door not entered are reported for alarm and appropriate action.

*Employee Relations Division.

†Computing and Telecommunications Division.

1.6.5 BADGE READER IMPLEMENTATION PROGRAM AT THE Y-12 PLANT

E. Madden

R. G. Affel D. E. McMillan

G. W. Allin C. R. Mitchell

The program to implement badge reader-controlled entry at the Y-12 Plant was begun in 1982. The program was conceived as a three-phase undertaking. The first phase was to be the implementation of the badge reader system in the MAA at the Y-12 Plant. The second phase was to be the implementation of the badge reader system at the outer perimeter portals of the Y-12 Plant. (Implementation of the badge reader system at the perimeter portals would allow employees who had lost or forgotten their badge to be assigned temporary machine-readable badges at the outer portals as well as provide facilities for inspection of employee badges.) The third phase of the project was to be the implementation of badge readers at the inner plant portals located between the various security zones. Approximately 30 portals will be provided with badge reader employee access control.

Each MAA portal is equipped with an area entry reader and an area exit reader for use in automatic inspection of employee badges. The security inspector at each portal is supplied with a dual display unit to monitor the entry and exit lanes at the portal. The system automatically provides a real-time, updated roster display of the population present in an area at any time. The CRT display can be placed in the plant protection communication control room or in the office of the supervisor in charge of the specified area. The system monitors and alarms violations of the two-man area occupancy rule.

Prior to activation of the badge readers at the perimeter portals, a biology area rotogate, the door to the plant protection communications room, and doors to the Y-12 Plant shift supervisor's office were placed under badge reader control.

Each perimeter portal requires an entry badge reader for employee access control and a badge reader for the security inspector's use in controling and monitoring activity. The security inspector is also provided with an enrollment keypad for assigning temporary and visitor badges. Each perimeter portal that can assign temporary visitor badges is also equipped with a printer.

The software for this system was developed by the Computing and Telecommunications Division and was placed in operation in April 1984. The applications software is the same as that running at ORGDP for badge reader operation. Two PDP-11/44 computers (one a backup) were installed and placed in operation in March 1984. All MAA areas were in operation in April 1984, and the exclusion area perimeter portals were placed in operation October 1, 1984.

1.6.6 THE USE OF MULTIPLE CABLES VERSUS A MULTICHANNEL CABLE FOR TELEVISION SIGNAL TRANSMISSION

J. A. Russell, Jr. G. M. Fuller, Sr.*

(Abstract of paper presented at 1984 Carnahan Conference on Security Technology, Lexington, Kentucky, May 16–18, 1984)

This paper outlines and discusses the basis for selecting two different systems [a multichannel radio frequency (rf) cable system and a multichannel baseband system] for television signal transmission at two separate installations. Even though the purpose of the two systems was very similar, several aspects of their differing present and future needs led designers to choose different signal transmission systems.

The two television monitoring systems discussed here are now in operation at Oak Ridge National Laboratory, which is a large research laboratory, and at the Oak Ridge Y-12 Plant, an installation which operates very much like an industrial complex. This paper presents design considerations including the size of the two systems (e.g., the number of cameras and the length of cable runs), overall system flexibility and reliability, booster amplifier requirements, cable requirements, relative costs, and future expansion (including possible camera relocation and revised monitoring requirements). The operating costs of the respective systems are also discussed.

*Y-12 Plant Security Division.

1.6.7 ADDITIONAL PROJECTS

Operational Systems Hardware Support for the Security Badge Reader at the Three Oak Ridge Plants. The I&C Computer Systems Development Group has played a major role in the implementation of security badge reader systems at the three Oak Ridge Plants. This group conducted the surveys required at all sites for engineering installation drawings which were completed by this group and provided engineering assistance to the maintenance groups who installed the equipment. The Computer Systems Development Group supervised the final checkout of the security badge reader system and continues to provide extensive help and consultation to the maintenance groups. *(C. R. Mitchell)*

Interface Design for Computer Control of Security Badge Encoded Module Tester. Each encoded module used in an employee identification badge must be individually tested prior to insertion into a badge. The quality of each encoded badge module is statistically evaluated after being read a predetermined number of times at various thresholds of sensitivity. The encoded module tester consists of a motor-driven mechanical module transport, electronic read head, variable sensitivity amplifier, control circuitry, and computer interface circuitry. The number of times the encoded module is read and the threshold at which it is read are controlled by a computer through the computer interface. *(C. R. Mitchell)*

Evaluation of Infrared Motion Detectors for Use with Security Badge Reader Door Controllers. Infrared motion detectors were tested for use with a security badge reader door controller. The infrared motion detector was used to detect persons leaving a room or building. Because the motion detector used had a very narrow range of coverage, it was pointed toward the doorknob to detect the presence of a hand in the vicinity of the doorknob. The motion detectors used in the evaluations proved to be reliable, but other considerations made them impractical for most applications, especially applications involving heavy traffic. *(C. R. Mitchell)*

Evaluation of Door Hardware for Use with Badge Reader Door Controllers. The security badge reader lends itself readily to uses involving the opening and closing of doors and the monitoring of traffic through doors.

The diversity of door types and door hardware makes instrumenting any door a special case. To meet these special requirements, numerous methods of modifying the existing door hardware were investigated. Commercially available hardware with proper monitoring contacts was also investigated. As a general rule, existing hardware was found to be difficult to modify, and the existing hardware was replaced with commercially available hardware. *(C. R. Mitchell)*

Development of a Personal Identification Keypad for Use with the Security Badge Reader. An extremely rugged, weatherproof keypad was developed for use with the security badge reader. The keys are built up from miniature microswitches mounted on a printed circuit board and placed beneath a thin film of Mylar on which the keypad positions are printed. Mechanical coupling to the switches is provided through the Mylar film, which also seals the unit from the weather. The keypad housing is machined from 6061-T6 aluminum and may be retrofit to the standard badge reader housing. *(C. R. Mitchell, A. A. Smith)*

Design of a Wear Plate for the Badge Reader. The original enclosure for the security badge reader was fabricated from 6061-T6 aluminum and finished with a Type II, Class I anodic coating. The Type II anodic coating did not withstand the harsh wear created by the repeated passage of security badges through the read slot of the badge reader. To overcome this problem, the badge readers were retrofit with a wear plate machined from 6061-T6 aluminum and anodized to a depth of 3.5 mils using a Type III hard coating method of anodizing. The wear plate withstands 100,000 passes through a badge reader and when worn out may easily be replaced in the field. *(C. R. Mitchell)*

Development of Dual Display for Use at Y-12 Plant Material Access Areas. The logging of both entry and egress in the Y-12 plant materials access areas (MAAs) required the development of a dual display that could be attached to the serial data port of the security badge reader control box. Firmware within the control box and routing logic within the dual display control logic route information to the proper display. The dual display uses two badge reader/display modules housed in a common enclosure mounted in a swinging bracket. *(D. E. McMillan, A. A. Smith, C. R. Mitchell)*

Programmable Primary/Secondary Computer Communications Switch. The security computer system at the Y-12 Plant has a redundant computer for emergency backup. The badge readers are connected to the primary computer system via a communications panel. An instrument was required to switch the readers between the primary and secondary computers under program control.

An instrument was designed to control a 34-pole switch used to route the readers to either computer. The instrument uses two 8748 microcomputers to communicate with either computer via a serial data link. Software to control the switch and monitor the status of the control microcomputer was written in 8048 machine language to emulate a serial communication interface. *(G. W. Turner, D. E. McMillan)*

Y-12 Plant Security System Upgrade. A preliminary cost estimate for a fully redundant alarm monitoring system was prepared for Y-12 Engineering. The estimate consisted of a conceptual block diagram; a description of the system; a list of material with estimated costs; a work-hour estimate for design, installation, and checkout; and a review study of possible communication configurations. *(J. W. Reynolds)*

A Criticality Accident Badge Reader/Detector System. A badge reader/detector system is being developed to aid in determining radiation exposure to personnel in the event of a criticality incident. A gamma ray detector is incorporated into a specially configured Martin Marietta Energy Systems badge reader to obtain radiation dose rate information from an embedded indium foil contained in every employee's badge. The detector portion of this system consists of a G-M tube and a switching-regulated high-voltage power supply. A TTL-level pulse train, proportional to the counts/min of the G-M tube, will be sent to a standard badge reader system microcomputer where it will be counted and compared to an alarm count-rate limit to determine the employee's proximity to the criticality event. The prototype of this detector system has been built and tested. *(G. T. Alley, D. E. McMillan)*

Badge Modifications. The unified security badge format was changed to incorporate the Martin Marietta logo with a medium blue background. No other changes to the format were necessary other than the wording of the message on the back. A logo decal was designed to cover the old logo on the front of the existing badges. The black background makes it readily identifiable as a temporary issue. Another decal was designed to cover the old message on the back with the new message. The use of these decals eliminated the necessity of immediate replacement of the existing badges, which resulted in a significant cost saving. *(G. W. Allin)*

Activities in Support of the ORNL Laboratory Protection Division. The Laboratory Protection Division uses numerous electronic devices in its daily operations. These include security alarms, a security alarm monitoring computer, a closed-circuit rf cable television system, and extensive radio communications equipment. The I&C Special Electronics Engineering Group has supported the Laboratory Protection Division in each of these areas. Activities have included assistance with the repair of these systems, development of cost estimates for alarm and video installations, design of alarm systems, design of several equipment panels, and design of a computer interface for the FR&C signals at the emergency control center. *(J. A. Russell, R. I. Crutcher, T. R. Barclay, L. D. Hunt)*

Serial Data Remote Temperature Monitor. An instrument was required to monitor the outside temperature and, on request, transmit it over a serial data line. The device consists of a field-located temperature transducer, conditioning electronics, a 12-bit ADC, and a serial UART. The probe has a range of −40 to +60°C, and temperature is transmitted in two ASCII bytes. These units are presently in use on the badge reader systems at ORGDP, ORNL, and the Y-12 Plant. *(G. W. Turner, D. E. McMillan)*

1.7 Environmental Monitoring

1.7.0 OVERVIEW

The I&C Division has an active program in support of the Department of Environmental Management (DEM) of the ORNL Environmental and Occupational Safety Division. More than a dozen I&C staff members have contributed to the upgrading of ORNL's environmental monitoring system. The effort on data systems development was continued from the initial work for local area monitor station 7 (LAM-7). Three new water quality monitoring stations were designed and installed at White Oak Dam, White Oak Creek, and Melton Branch.

Ten new perimeter air monitor (PAM) stations have been designed and installed to replace outdated units in the field. An existing SO_2 monitor at the Y-12 Plant was interfaced to a new data network, enabling it to report measurements to DEM at the X-10 site. Work was also undertaken to write maintenance and procedures manuals for existing systems, which had not been done previously. Various team members also wrote manuals for the water quality monitors and PAMs. Both DEM and Engineering were assisted by supplying conceptual design reports and line-item funding proposals for the major DEM upgrades. Several of these projects will be discussed in more detail in this section. *(C. C. Hall, M. S. Blair, D. R. Miller, G. W. Allin, G. A. Colman, V. C. Miller, B. h Fulcher, E. R. Rohrer, I. E. Williams, M. L. Bauer)*

1.7.1 ENGINEERING SUPPORT FOR THE WASTE OPERATIONS UPGRADE PROJECT

R. T. Roseberry	**D. E. Gray***
C. C. Hall	**S. H. Merriman†**
D. E. Smith	**L. C. Lasher‡**
C. S. Meadors*	**T. L. Scanlan‡**

Engineering support was provided to the ORNL Operations Division and ORNL Engineering for the conceptual design, performance specifications, lists of existing equipment, and contractor monitoring for upgrading the data acquisition system for waste monitoring at ORNL. Details of the computer system architecture, including the suggested communication protocol, the number and general capability of data concentrators, a detailed data environment description, and a general operations system philosophy, were supplied for use in the detailed specifications for competitive-bid purchase of the system.

The system vendor's progress was monitored through monthly design and progress review meetings at the production site which provided an overview of both hardware and software. Greater than usual familiarity with the complete system prior to acceptance testing allowed detailed and thorough testing, resulting in the discovery and correction of several problems prior to shipment and installation. Hardware was assembled and delivered to the vendor to provide several signals of each of the types that would be encountered in the data environment at the Laboratory, thus tests represented realistic operating conditions.

Engineering support was provided throughout installation and on-site testing of the completed system, and necessary hardware design of additions and modifications was also provided.

*Engineering Division
†Computing and Telecommunications Division.
‡Operations Division.

1.7.2 PROCESS WASTE TREATMENT PLANT EFFLUENT MONITOR

R. T. Roseberry	**J. M. Chilton***
G. W. Allin	**T. S. Mackey†**
M. M. Chiles	**A. L. Rivera†**

A monitoring system has been designed for determining the presence of ^{137}Cs in the effluent from the process waste treatment plant. The design is capable of fully automating the sampling and measurement functions, but the initial installation will be manual.

A sample from the column or columns in service is taken into a holding tank where it remains for about ~30 min. The sample is then transferred into a modified Marinelli beaker for counting, and a new sample is taken for holding. Following an ~30-min count, the sample is drained from the beaker, the beaker is flushed, and the current contents of the holding tank is transferred to the beaker.

A pulse-height analyzer, capable of controlling the automated process, will run an analysis to determine the presence and concentration of ^{137}Cs. Based upon this analysis, the operator will know when to change columns to optimize column life, yet minimize the discharge of ^{137}Cs. The remote analyzer will transfer the raw data as well as the results of analysis to a host located at the waste operations control center for further analysis and storage.

*Chemical Technology Division.
†Operations Division.

1.7.3 STREAM MONITORING STATIONS

C. C. Hall
M. S. Blair D. R. Miller

Three stream monitoring stations were replaced by ORNL Engineering for The ORNL Operations Division. These stations were station three at White Oak Creek (WOC), station four at Melton Branch (MB) and station five at White Oak Dam (WOD).

New weirs, equipment shelters, and flow instrumentation were installed at each station. Sampling equipment was installed to collect water samples proportional to streamflow. A water quality monitor was installed at White Oak Dam to monitor pH, conductivity, temperature, dissolved oxygen, and turbidity. Existing water quality instruments were moved from the old location to the new stations at Melton Branch and White Oak Creek. These instruments measured pH, dissolved oxygen, and temperature at Melton Branch and pH, dissolved oxygen, conductivity and temperature at White Oak Creek. New beta and gamma radiation monitors were installed at White Oak Dam, the existing beta-gamma and alpha monitors were moved to the new station at Melton Branch, and the existing beta-gamma monitor was moved to the new station at White Oak Creek. Several alarm contacts connected in series provide a single-alarm signal which is telemetered to the waste operations control center via a data concentrator.

When the project was nearly completed, the Environmental and Occupational Safety Division (E&OSD) requested that all signals telemetered to the WOC from WOD also be telemetered to the E&OSD computer and that alarm signals be telemetered as individual signals rather than a single signal. It was also requested that the Melton Branch and White Oak stations be upgraded to provide monitoring functions identical to those at WOD.

A microprocessor monitors all data and alarm signals at each station. When station upgrading is complete, all signals will be telemetered to the E&OSD computer. The following data signals are transmitted:

1. gamma radiation spectra,
2. beta radiation,
3. stream flow (three ranges—low, intermediate and high),
4. tailwater level,
5. pH,
6. conductivity,
7. water temperature,
8. disolved oxygen, and
9. turbidity.

The following alarm signals are transmitted:

1. sample bottle full,
2. samples pump inoperative,
3. floor drain overflow,
4. water quality monitor low sample flow,
5. gamma monitor low sample flow,
6. beta monitor low sample flow,
7. detector flush water tank low level, and
8. abnormal shelter temperature (low setpoint, 35°F; high setpoint, 110°F.

The detector flushing sequence will be controlled by the microprocessor during radiation background determinations.

1.7.4 WATER QUALITY DETECTORS

G. A. Colman

The first major upgrade of the ORNL water quality monitoring system since 1972 was started in the second quarter of FY 1983. New broad-crested weirs were installed at White Oak Creek and Melton Branch to accommodate worst-case flooding without loss of equipment or loss of stream level data.

In addition to new water quality equipment (see 1.7.3), state-of-the-art, real-time gamma and beta monitors have been designed, developed, and installed. The gamma detector consists of a 3 in. × 3 in. NaI detector enclosed in a Marinelli beaker. The system is stabilized with an ^{241}Am seed in the crystal, which provides a continuous train of high-energy pulses to an automatic gain-controlled amplifier. A Tracor-Northern TN-7200 MCA is used to accumulate a spectrum. The beta monitor consists of a 6-in.-diam CaF_2NaI phoswitch detector. It is enclosed in an in-house designed sampler that allows the water sample to come within 0.1 in. of the detector face. The sample cup design ensures uniform water flow and minimizes the chance that the water flow will come in contact with the detector's face. The electronics consist of an automatic gain-controlled amplifier tied to an ^{241}Am seed and a pulse-shape analyzer. which separates beta-induced pulses from gamma-induced pulses.

The system is expected to measure reliably many isotopes of interest to the 0.1 MPC level.

As an earlier part of this effort, a ZnS/NE102 Phoswitch detector was designed, developed, and tested for use as an alpha-beta detector. Pulse-shape discrimination allows alpha and beta activities to be measured simultaneously and recorded separately. The use of thin films and low-Z materials makes the detector relatively insensitive to gamma radiation. It is particularly useful in applications where alpha-in-air measurements must be made because air attenuation makes pulse height discrimination with conventional detectors impossible.

In order to better model and design these units, a theoretical model was developed that will calculate the beta response of various detectors with windows. An HP 87 desktop computer was programmed to implement the model. Calibration data from G-M tubes and Phoswitch detectors were used to confirm the agreement of the experimental data with the model.

1.7.5 PERIMETER AIR MONITORS

C. C. Hall **M. S. Blair**
G. A. Colman **B. H. Fulcher**

The PAM system is being upgraded by replacing stations that are approximately 23 years old with new monitoring stations at ten locations as follows:

PAM 31	Kerr Hollow on Bethel Valley Road
PAM 33	Gallaher (on Watts Bar Lake at old Gallaher Bridge site)
PAM 34	White Oak Dam
PAM 36	Oak Ridge Turnpike
PAM 40	East of Y-12 Plant
PAM 41	Museum of Science and Energy
PAM 42	Blair Gate
PAM 43	North of K-33
PAM 44	Experimental Gas Cooled Reactor
PAM 45	Bear Creek Road (West of Y-12 Plant)

Each station consists of a particulate, iodine and gas (PIG) cart, a gross gamma monitor, a rain gage, a wet and dry precipitation collector, a particulate and iodine collection system that collects samples for laboratory analysis, a sampling manifold assembly, and a weatherproof enclosure installed on a fenced concrete pad.

The PIG cart consists of a particulate monitor, with a moving filter tape and radiation detector that continuously monitors the tape for radioactive airborne particles; an iodine monitor that collects radioiodine in a continuously monitored charcoal trap; and a gas monitor that collects a volume of air which is monitored for noble gas by a third radiation detector. The PIG cart contains an air-handling system for moving air samples through the radiation monitors at a constant flow rate.

The gross gamma monitor measures the gross gamma background radiation at each PAM station. The range of the monitor is from 1 μR/h to 100 mR/h.

The tipping bucket rain gage operates switch contacts each time 0.01 in. of rain is collected. Thermostatically controlled heaters convert solid precipitation to measurable liquid.

The wet and dry precipitation collector collects solid particles on sticky paper during dry periods and collects liquid samples during rainy periods. During dry periods, the liquid collector is covered by the sticky paper holder. A moisture sensor operates a mechanism that moves the sticky paper from over the liquid collector to beneath a cover during periods of rain.

A Hollingsworth and Vase (H&V) filter paper holder is mounted on an outside wall of the PAM shelter. The filter holder is connected to a charcoal filter with plastic tubing. A sample pump equipped with a flow controller pulls a sample of air through the H&V filter paper and charcoal to collect particulate matter and radioiodine for laboratory analysis.

A sampling manifold provides four individual sampling ports. One sampling port has a flowmeter with a range of 30 to 140 cc/min; two ports have flowmeters with ranges of 0.15 to 1.8 scfm; and one port has a flowmeter with a range of 0.6 to 6 scfm. A diaphragm vacuum pump with a capacity of 6.6 scfm is used to move air samples through the manifold.

A weatherproof shelter houses the PIG cart and the sampler cabinet, which contains the sampler pump, sample manifold, and manifold pump. The shelter is 8 ft × 8 ft × 7 ft high and has 2 in. of foam insulation sandwiched between fiberglass panels. The shelters have thermostatically controlled exhaust fans and space heaters.

Signals are telemetered from each PAM station via phone lines to the E&OSD host computer. Data signals transmitted are radioactive particulates, radioiodine, noble gases of ^{85}Kr and ^{133}Xe, gamma background radiation, and precipitation rate. Alarm signals are samples pump inoperative, manifold pump inoperative, abnormal shelter temperature (low alarm at 35°F, high alarm at 110°F), and shelter door open.

1.7.6 COMPILATION OF FIELD PROCEDURES FOR PERIODIC INSPECTION OF ORNL STACK MONITORS

B. H. Fulcher

Field procedures for periodic inspection of ORNL stack monitors have been compiled under the title "Routine Maintenance of Gaseous Waste Monitors" (April 1984). The document, sponsored by the ORNL Operations Division, is a written guideline for maintenance personnel of the Radiation Monitoring Group and a record for future reference. Information was acquired primarily through the Radiation Monitoring Group and the I&C Special Electronics Group. Editing was done by the I&C Special Electronics Group.

The field procedures include routine checks of the radiation monitors at ORNL stacks 2026, 3020, 3039, (ORELA), 7503 (MSRE), and 7911 (HFIR). These locations house monitors for some or all of the following types of radiation and gaseous waste monitors: alpha, beta-gamma, iodine, and inert gas. Specifically, the document gives instructions for checking the correct operation of count rate meters, monitors, annunciators, and alarms. The field procedures also include safety precautions pertinent to working on the stacks by identifying associated drawings and radioactive sources used in checking the monitors. It also lists persons responsible for the repair of system components such as pumps, phone lines, and motors.

1.7.7 ENVIRONMENTAL MONITOR REMOTE COMPUTER SYSTEM

M. S. Blair

A major effort of the DEM upgrade centered on a new data acquisition and analysis system. I&C Division held the major responsibility for the remote data acquisition computer. The remote computer consists of four Multibus circuit boards housed in an Intel ISBC-660 system chassis which contains the power supplies and an eight-slot Multibus card cage and backplane. The four Multibus circuit boards used in the system are an 80/30 single-board computer, 116B memory and I/O expansion board, an eight-channel analog input board (Data Translation DT1742), and a custom interface board. The 80/30 single-board computer has an 8085A central processing unit, 16 Kbytes of RAM, sockets for 8 Kbytes of EPROM, and serial and parallel I/O ports. The 116B memory and I/O expansion board provides an additional 16 Kbytes of RAM and sockets for 16 Kbytes of EPROM. The serial ports on the 80/30 board are used to communicate with the host system, and the expansion board serial port is used to control a multichannel analyzer (Tracor-Northern 7200). The custom interface board is used for counter inputs and provides for computer-controlled relay outputs needed at the remote location.

The software developed for the environmental monitoring system consists of a special communications protocol that transfers binary data from the remote computer to the host computer as printable ASCII characters. This protocol, named Zero Compressed Variable Length Word, was adopted to reduce the number of characters required to represent binary data. After the host has downloaded operating parameters, the remote system can operate as a stand-alone data acquisition system in the event communication with the host is lost. Some of the features of this system are that all alarms at the remote location are transferred to the host, the data channels can be selectively enabled and disabled from the host, and the data can be stored for a day in the remote when the communications or the host is down.

1.7.8 APPLICATION OF COMPUTERS IN A RADIOLOGICAL SURVEY PROGRAM

B. A. Berven*
M. S. Blair **R. W. Doane***
C. A. Little* **P. T. Perdue***

(Abstract of paper presented at the Seventeenth Midyear Meeting of the Health Physics Society, Pasco, Washington, February 5–9, 1984)

Computers have become increasingly important in data analysis and data management as well as assisting in report preparation in the Oak Ridge National Laboratory (ORNL) Radiological Survey Activities (RASA) Program. The primary function of the RASA program is to collect, analyze, report, and manage data collected to characterize the radiological condition of potentially contaminated sites identified in the Department of Energy's (DOE) remedial action programs.

Three different computer systems are routinely utilized in ORNL/RASA operations. Two of these systems are employed in specific functions. A Nuclear Data (ND) 682 is used to perform isotopic analysis of gamma spectroscopic data generated by high-purity germanium detectors for air, water, and soil samples. The ND682 employs a 16,000-channel analyzer that is routinely used with four germanium spectrometers. Word processing and data management are accomplished using the INtext system implemented on a DEC PDP 11 computer.

A group of personal computers are used to perform a diverse number of functions. These computer systems are Commodore Business Machines (CBM) Model 8032 with a dual floppy disk storage medium and line printers (with optional X-Y plotters). The CBMs are utilized for: (1) data analysis—raw data from radiation detection instrumentation are stored and manipulated with customized computer programs; (2) data reduction—raw data are converted into report-ready tables using customized programs; (3) data management—radionuclide data on each air, water, and soil sample are stored on diskettes along with location of archived samples; and (4) program management—site surveys and report status are tracked by computer files as well as program budget information to provide contemporary information of program status.

*Health and Safety Research Division.

1.7.9 SPECIFIC USES OF A DATA MANAGEMENT SYSTEM FOR DATA REDUCTION AND TABULATION

C. A. Little*
M. S. Blair T. R. Barclay

(Abstract of a paper presented at Seventeenth Midyear Topical Meeting of the Health Physics Society, Pasco, Washington, February 5-9, 1984)

The Remedial Action Survey and Certification Activities (RASCA) group processes large amounts of data for each of the many properties surveyed each year. In previous years, data manipultion (e.g., converting from cpm to R/hr) was performed using hand calculators. A system has recently been developed which largely automates the conversion of all field data and their tabulation for reporting purposes. The system consists of three items of hardware and two items of software. The hardware includes a Commodore Business Machines (CBM) Model 8032, an 8050 dual 5½-in. floppy disk drive and a Gemini dot-matrix printer. The software includes a commercial data management system, Manager (developed by Canadian Micro Distributors) and an in-house program (DATA TABLES) written to read the Manager files and print the tables. Manager is a very flexible data management system that allows entry of data into sequential files which are sortable over any selected variable. Data are entered into the sequential file and stored on a floppy disk for use at a later time. When all data have been correctly edited and proofed, the DATA TABLES program is invoked to read the sequential files and print out report-ready tables. Efficiency, and especially, accuracy in preparing data for reporting have been greatly increased.

*Health and Safety Research Division.

1.7.10 A COMPUTER-CONTROLLED SYSTEM FOR RAPID SOIL ANALYSIS OF ^{226}Ra

R. W. Doane*
B. A. Berven* M. S. Blair

(Abstract of paper presented at Seventeenth Midyear Topical Meeting of the Health Physics Society, Pasco, Washington, February 5-9, 1984)

A computer-controlled multichannel analysis system has been developed by the Radiological Survey Activities (RASA) Group at Oak Ridge National Laboratory (ORNL) for the Department of Energy (DOE) in support of DOE's remedial action programs. The purpose of this system is to provide a rapid estimate of the ^{266}Ra concentration in soil samples using a 6 in. × 9 in. NaI(Tl) crystal containing a 3.25-in. deep by 3.6-in. diameter well. This gamma detection system is controlled by a minicomputer with a dual floppy disk storage medium, line printer, and optional X-Y plotter. A two-chip interface was also designed at ORNL which handles all control signals generated from the computer keyboard. These computer-generated control signals are processed in machine language for rapid data transfer, and BASIC language is used for data processing.

The computer system is a Commodore Business Machines (CBM) Model 8032 personal computer with CBM peripherals. Control and data signals are utilized via the parallel users port to the interface unit. The analog-to-digital converter (ADC) is controlled in machine language, bootstrapped to high memory, and is addressed through the BASIC program. The BASIC program is designed to be "user friendly" and provides the operator with several modes of operation such as background and analysis acquisition. Any number of energy regions-of-interest (ROI) may be analyzed with automatic background subtraction.

*Health and Safety Research Division.

1.8 FEMA Engineering Support

1.8.0 OVERVIEW

Engineering support has been provided for several projects for the Federal Emergency Management Agency (FEMA). Support for the pilot plant located at Rolla, North Dakota, for the production of low-cost 200-mR dosimeters includes the construction and testing of two ^{137}Cs calibrators and the design and testing of the safety interlock system for two calibration rooms. Other areas of support for this project are the selection and purchase of computer hardware and software for four microcomputer systems, generation of computer programs to define detailed dosimeter assembly procedures, and development of a spreadsheet analysis program to determine the cost of manufacturing one dosimeter.

Another area of support is the execution of onsite surveys and design of an EMP protection plan for FEMA-designated commercial AM/FM radio stations and Emergency Operating Centers (EOCs) throughout the United States. A technical manual on EMP protection is in preparation. Two other training manuals relating to state emergency operations are also being written. A monolithic electrometer for the CDV-715 survey meter and a radiation monitoring instrument for the radiation detector for meteor burst transmission system are in the design stage.

1.8.1 DOSIMETER MANUFACTURING MANAGEMENT SUPPORT

J. M. Madison

A spreadsheet analysis program and a set of dosimeter assembly procedures have been written to support operation of the FEMA low-cost dosimeter pilot production plant at Rolla, North Dakota.

The spreadsheet analysis program was written to determine the cost of materials and labor for one assembled and tested unit. Yield factors are included at each inspection point to show accumulated material and labor losses based on rejected subassemblies at the various stages of assembly. All materials and the cost per unit of material are listed in a table which serves as a look-up table for the program. Another look-up table lists the employees by identification number and hourly pay rate. The program is based on some 68 defined job functions called job tasks, and each job task is also assigned an employee ID number according to which employee performs the task, the specific materials and quantities of materials used, and the time required for completion. Based on this information, the look-up tables, and the yield factors, the program calculates labor time, labor costs, and material costs, to arrive at the total cost of a dosimeter.

The assembly procedure defines all of the various job tasks such as molding and assembling the plastic parts, testing, and inspection. The procedure also includes a detailed set of sequential instructions on how each job function is to be performed. The appendixes list information that would be too cumbersome to include in the sequential instruction set.

1.8.2 FEMA EMP PROTECTION PROGRAM

R. I. Crutcher

The FEMA EMP protection program has the goal of providing EMP protection to selected radio broadcast stations and EOCs. Tasks of the program include surveying radio broadcast stations and EOCs, supplying and controlling parts, writing an EMP technical manual, and conducting EMP training schools.

The training schools comprised six one-week sessions and included both classroom lectures and facility surveys. Site surveys have been made on 7 EOCs and 12 EBS facilities. An EMP analyst surveys the facility and equipment and writes an engineering report recommending implementation of specific protective measures.

At the EOC, the parts were installed as recommended in the survey report, and the installation was tested to verify performance of the protection design.

A technical training manual is being written to serve as the basis for the FEMA EMP protection program. This document covers EMP theory, protection methods, survey methods, report writing, and parts installation techniques. It will serve both as a training manual for courses and as a reference manual for applied EMP engineering.

1.8.3 FEMA DETECTOR ASSESSMENT AND DEVELOPMENT FACILITY

M. M. Chiles
H. R. Brashear C. E. Fowler
G. A. Colman R. E. Zedler

As part of the FEMA Program at ORNL, a Detector Assessment and Development Facility was established to assist FEMA and the U.S. military services in investigating problems involving radiation detectors. The following activities of this facility have been part of this support program.

Electronic equipment was procured for testing G-M tubes. The equipment as shown in the block diagram (Fig. 1.8-1) included a microcomputer (HP 87), remotely controllable high-voltage power supply, power supply control programmer, G-M tube preamp, discriminator, timer-scaler, H.V. meter, a printer, and a plotter. This electronic system was programmed to acquire data automatically from a G-M tube or proportional chamber and plot a count rate versus voltage plateau curve. It also was programmed to acquire data automatically and plot an integral count rate versus pulse height bias curve from a radiation detector.

Several halogen-quenched G-M tubes (type JAN 7616), which were manufactured by a commercial company, were received from the Naval Electronic Systems Laboratory for evaluation. According to Navy laboratory reports these tubes underwent a change in starting voltage as they aged, and this drastically affected the mode of operation in the RADIAC instrument. Tests on these tubes indicate that they presently start the Geiger avalanche well below 680 V, which makes them unusable for the RADIAC application. A typical plateau curve is shown as No. 1 in Fig. 1.8-2.

Data for plateau curves on the tubes delivered for evaluation were collected and stored on floppy disk. The circuit for testing the JAN 7616 tubes was modified to simulate the operational circuit in the

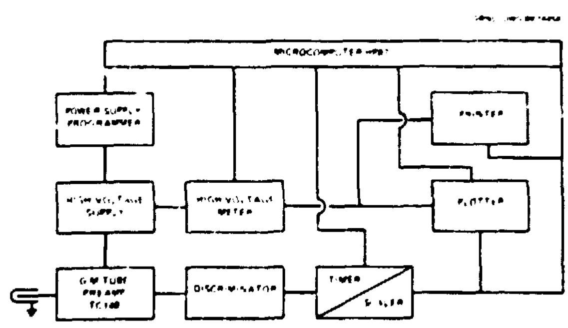

Fig. 1.8-1. G-M tube test station.

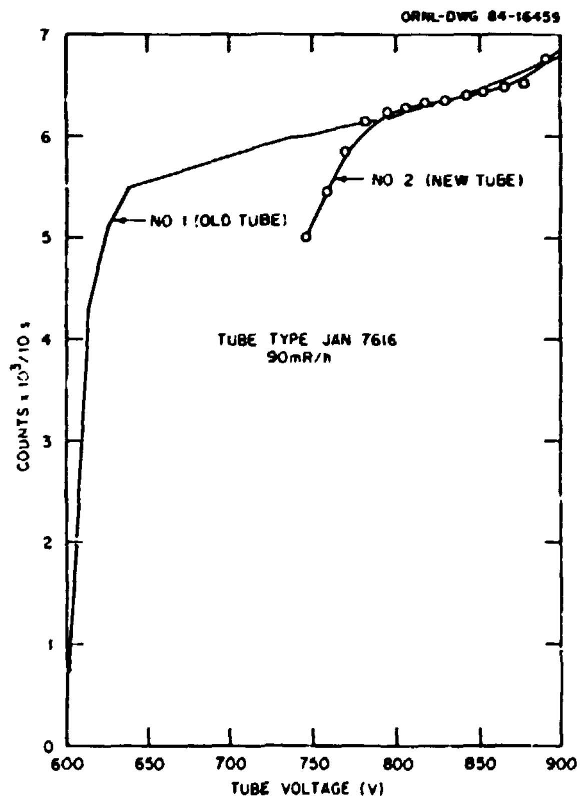

Fig. 1.8-2. Plateau curve for 7616 G-M tubes.

RADIAC instruments, but there was no significant change in the plateau curves. Also, test circuits were designed to investigate the timing profile, pulse shape, and other characteristics while voltage was varied over the specified range of operation.

Some new JAN 7616 G-M tubes were purchased from LND, Inc., and were tested to determine their operating characteristics for comparison with the old tubes rejected from the RADIAC instruments. A typical plateau curve is No. 2 in Fig. 1.8-2.

The count rate versus voltage plateau curves for the new tubes began above 770 V, which indicated that they would operate satisfactorily in the RADIAC instruments. The new tubes were tested again six months later (December 1983) and recently tested again at the end of one year of shelf life. From these tests it was evident that a gradual decrease in the starting voltage had occurred with these tubes as they aged. The curves for the six tubes, shown in Fig 1.8-3 indicate the reduction of the 750-V point on the leading edge of the original (June 1983) plateau curves. Five tubes had a voltage drop of approximately 15 V, and one changed about 30 V over the 12-month period.

Another G-M tube, Thompson 3GB70, was tested for the U.S. Navy. Several samples were tested and the plateau curves plotted; a typical curve is shown in Fig. 1.8-4.

A corrosion-resistant vacuum and gas-handling system was designed for possible handling of halogen gases for G-M tube fabrication. The manifold system was designed to use commercially available,

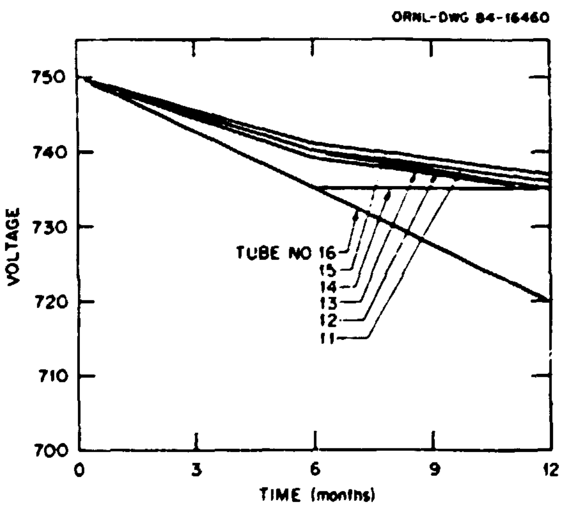

Fig. 1.8-3. Change in plateau starting voltage over time.

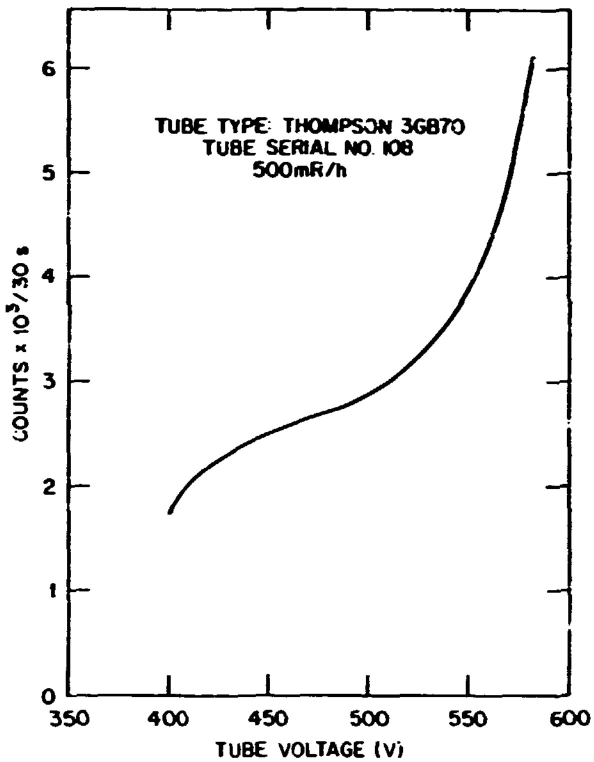

Fig. 1.8-4. Plateau curve for 3GB70 G-M tube.

close-coupled tube fittings and valves that resulted in a small-volume system.

A survey was conducted to identify current manufacturers of halogen G-M tubes. The following companies responded to our survey:

- Amberex Electronic Corporation
- Centronic
- Dosimeter Corporation of America
- Hamamatsu Corporation
- The Harshaw Chemical Company
- LND, Inc.
- Radiation Analysis, Inc.
- TGM Detectors, Inc.

Two cadmium tungstate scintillation (DISCO) detectors were purchased for evaluation. One unit has an operational amplifier built in, whereas the other unit has only a scintillator and photodiode. The detector without a preamplifier is sensitive to room light and therefore was installed in a light-tight box for testing. That detector has been tested in the current mode of operation versus gamma radiation exposure from ^{137}Cs source, and a plot of its response is shown on Fig. 1.8-5. It also was

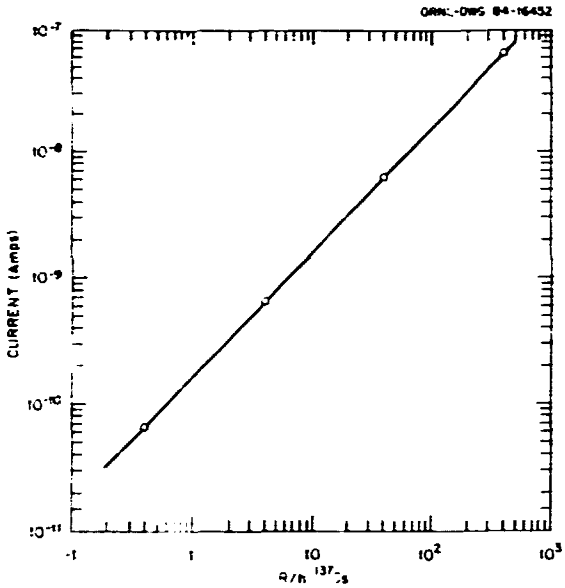

Fig. 1.8-5. Response of DISCO detector.

tested in the pulse mode of operation versus gamma radiation from a ^{60}Co source; its response is shown on Fig. 1.8-6. The lower curve represents its response with no bias voltage on the photodiode, and the upper curve represents its response with a −3-V bias on the photodiode. The Harshaw Chemical Company Model DISCO 100 cadmium tungstate scintillation detector, which contains an operational amplifier, was tested in the CDV 794 calibrator. The detector had a very linear response from the ^{137}Cs source shown (see Fig. 1.8-7).

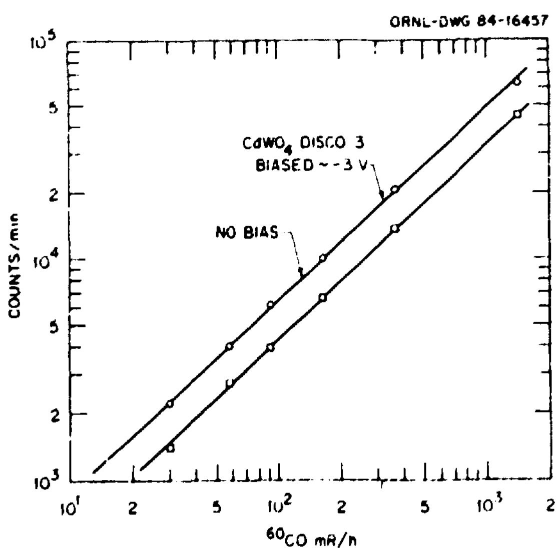

Fig. 1.8-6. Pulse-mode response of DISCO detector.

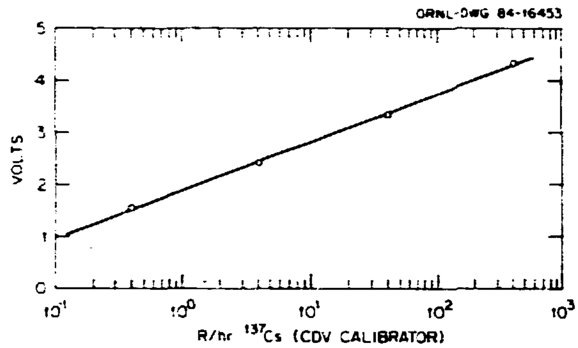

Fig. 1.8-7. Response of Model 100 DISCO with integral amplifier.

1.8.4 ADDITIONAL PROJECTS

Calibrator Design Review. A design review was conducted for the Federal Emergency Management Agency (FEMA) of a calibrator to be used at a radiation dosimeter production facility. Two calibrators were built and tested, and some operational problems that developed were subsequently corrected. *(G. W. Allin)*

Safety Interlock System for FEMA Dosimeter Calibration Rooms. A safety interlock system was designed for dosimeter calibration rooms at the dosimeter plant at Rolla, North Dakota. The system was designed to protect plant personnel against radiation exposures. Dual components were used in critical portions of the system such that a single component failure would not jeopardize personnel safety. *(C. C. Hall)*

Dosimeter Assembly Procedures and Bid Release Package. FEMA personnel and Rolla plant management were assisted in generating the necessary manufacturing documentation for a 200-mR dosimeter bid package release. The package included a detailed assembly procedure and spreadsheet analysis programs to determine the manufacturing and materials cost for the dosimeters. *(J. M. Madison)*

Four PC Computer Systems for Integration of Management Data in Dosimeter Manufacturing. Hardware and software were selected and purchased for four computer systems for FEMA to be used in the manufacture of dosimeters at Rolla, North Dakota. Two of the computers are located at

FEMA headquarters in Washington, D.C., one at the Rolla site, and one at ORNL. Modem connections permit the transfer of information among the three sites. *(J. M. Madison)*

Training Manuals for FEMA. Two manuals being written for FEMA by I&C, *Procedures and Regulations for the Care, Use, and Control of the FEMA Radiation Training Source Sets* and *The Care and Use of the CDV-790 Calibrator*, are nearing completion. These manuals will be used to train state emergency personnel in the proper use and care of radiation survey instruments. *(J. M. Madison)*

EMP Protection Certification Training. Three I&C Division staff members associated with FEMA projects attended a FEMA training program on EMP protection conducted in Washington, D.C. The purpose of the program was to train a small group of personnel to protect FEMA-designated commercial AM and FM radio stations and county EOCs from EMP. *(J. M. Madison)*

AM/FM Radio Station EMP Protection Surveys. Several FEMA-designated AM and FM radio stations were surveyed, and detailed protection plans were designed that specify the FEMA-approved components necessary to protect the stations from EMP. *(J. M. Madison)*

Design of a Monolithic Electrometer for CDV-715 Retrofit. A monolithic electrometer chip circuit has been designed and proposed as a retrofit chip to replace active circuitry in the CDV-715, an ion-chamber survey meter. The maintenance and component availability problems of the present circuit (i.e., high-megohm resistors, electrometer tubes, calibration potentiometers, and switch leakage) are solved by the proposed two-chip system.

The electrometer circuit uses a dielectrically isolated BIMOS process that provides a low-leakage input with logarithmic feedback elements. The antilog second stage yields a front-end current gain of 10,000; thus the chip is suitable for a universal current gain stage for electrometer applications. Discrete prototype versions were built and tested using the existing case, ion chamber, and meter with good results.

A dc-dc converter design operates from one D cell and provides a regulated ±6-V supply and a +75-V output for the ion chamber bias. This second chip could become a universal building block for low-power, battery-operated portable instrumentation.

The production cost of the electrometer chip is estimated to be $17 to $20 in quantities of 50,000. Initial development costs would be approximately $287,000 for the first functionally equivalent samples. Total retrofit costs, including board-level replacement, will be approximately $50 per instrument. Although initial costs are high, they become a small percentage of the total program when amortized over the large number of CDV-715 instruments in the field (>450,000). *(Richard A. Todd)*

Radiation Detector for Meteor Burst Transmission System. An instrument has been designed for remote radiation monitoring in conjunction with a meteor-burst transmission system. The radiation monitoring instrument uses a G-M tube detector and counter to gather periodic data on the radioactivity at the selected remote site. These data are then processed with an RCA 185600 single-board computer and sent to the meteor-burst transmission system via an RS-232 interface provided on the microcomputer board. The instrument runs from a single 12-V, 25-μA power source deriving an internal power supply for G-M tube high voltage, microcomputer, and RS 232. *(J. E. Phelps, H. N. Wilson, F. W. Manning)*

1.9 Facility and System Engineering Support

1.9.0 OVERVIEW

Support is provided to ORNL in a wide variety of areas. Some user facility support is discussed in Sect. 1.2 as well as in other sections. This section will describe support of such facilities as the Gas Centrifuge Enrichment Project, the new multiplant broadband cable network, the ORNL radio system, the Small-Angle Neutron Scattering Facility, and the Wide-Angle Neutron Diffractometer System. This work represents a broad area of expertise within this section and within the I&C Division.

1.9.1 ENGINEERING COORDINATION FOR U.S. ENRICHMENT SAFEGUARDS PROGRAM AT THE GAS CENTRIFUGE ENRICHMENT PROJECT

J. A. Russell

Engineering coordination and procurement activities are important to the success of the program to assure Gas Centrifuge Enrichement Project (GCEP) compliance with Department of Energy domestic safeguards requirements and to provide International Atomic Energy Agency (IAEA) inspection capability to deter and detect the diversion of nuclear material and the production of highly enriched nuclear materials.

Domestic safeguards at the Portsmouth, Ohio GCEP involve tracking material flow through the plant, determining the enrichment of all major and minor flow streams, establishing effective material transfer accountability, and establishing an effective record system.

The GCEP will be required to track all special nuclear materials tranfers and process flows and to comply with DOE domestic safeguards requirements. The means to achieve safeguards compliance are presently being developed through a cooperative program being carried out by Goodyear and Martin Marietta technical forces. Methods of determining material flow balances are being developed. Critical vessels in the Feed/Withdrawal Building will be identified, and their volumes will be verified by test to confirm calculated volume values prior to introduction of UF_6 into the process streams.

International safeguards involve monitoring by representatives of the IAEA for verification that no highly enriched nuclear material is being produced and that the quantity and enrichment of nuclear material being produced at the plant does not exceed declared values. Implementation of an effective international safeguards system involves providing a means of measuring the enrichment of feed, product, and tails streams; measuring the weight and enrichment of material in feed, product, and tails cylinders; and providing a means of IAEA inspector verification that there are no undeclared diversion paths in the plant. All activities involving IAEA personnel must incorporate measures to prevent the disclosure of sensitive technology or classified information.

Engineering coordination and technical support activities were carried out as described below.

Gamma-ray measurement technology for the Limited Frequency-Unannounced Access strategy inspections at GCEP by the IAEA including participation by Brookhaven National Laboratory, Los Alamos National Laboratory, and Martin Marietta Energy Systems, Inc., was coordinated. This activity encompassed development of the strategy, design, and fabrication of prototype portable gamma ray instruments, field testing of the instruments, and verification of operating procedures. A monitoring system was developed for continuous automatic measurement of the enrichment of gases flowing in the feed, product, tails, and spare tails interplant pipeway. Design of this system, known as the enrichment monitoring system, included the design and fabrication of in-line gaseous UF_6 enrichment monitors for the feed, product, tails and spare tails lines; an enrichment monitor processor; a computer-based controller and data conditioner for the enrichment monitors; and an integrated data acquisition system (a computer-based data processor, data management, storage, and report generator). The enrichment monitoring system will operate full time and will be used by the IAEA to verify plant production activities between inspections. Primary design and fabrication of components were performed by Los Alamos National Laboratory and Sandia National Laboratories.

Design of the IAEA Inspectorate Facility, which is a separate building at the plant, incorporates office/laboratory, process, and utility facilities and equipment for use by IAEA inspectors. Design of the facility and the interconnecting piping between the in-line gaseous UF_6 enrichment monitors and the GCEP interconnecting process pipeway system was performed by Fluor Engineers, Inc., under an extension of an existing contract for the Feed/Withdrawal Building. Considerable design interfacing and coordination of participant activities were required. Construction of the facility has been deferred until approximately 1988.

Tamper-safing hardware and an intrusion detection system were designed and fabricated by Sandia for the Inspectorate Facility and for selected components in the GCEP Feed/Withdrawal Building. The purpose of these tamper protection measures is to enable IAEA verification that no unauthorized changes are made in the process or in the enrichment monitoring system between inspection visits. The intrusion detection system uses a number of passive motion detectors to sense the presence of someone in the facility, log the time and date of the intrusion on tape, activate one or more television cameras, and record the scene on an automatic videotape recorder for later assessment by the inspector. Alarm information will also be transferred to the enrichment monitoring system, where it will also be stored on tape.

A prototype vapor-phase UF_6 sampling cart was designed and constructed at ORGDP. The cart will be used to obtain gas-phase samples of product, tails, and feed material stored in cylinders at the GCEP. Because of the size and weight of the cylinders (approximately 10–14 tons each) and difficulties encountered in moving the cylinders, the sampling cart will be used to obtain the samples without moving the cylinders. The sampling cart has an on-board vacuum pump, valving, a vacuum gage, and the interconnecting tubing required to obtain samples. An auxiliary 120-V, 60-Hz gasoline-driven power generator will be supplied with the sampling cart to permit vacuum pump operation and gas line heat tracing at locations isolated from the plant electrical system. The cart is presently undergoing field testing at ORGDP.

A control console is being designed by Martin Marietta for a prototype load-cell-based weighing system (LCBWS) to be used in verifying the declared UF_6 cylinder masses. The console will enable quick and accurate determination of cylinder weights. UF_6 cylinders (weighing 10–14 tons each) will be lifted by a crane. Mass measurements will be made utilizing strain gage type load cells installed in the lifting accessory. The prototype LCBWS has been designed and fabricated by Brookhaven National Laboratory. The prototype (less the control console) is presently being field tested at ORGDP to demonstrate its accuracy, applicability, and optimization of measurement electronics for future design. Field testing will enable optimization of IAEA Inspector interfacing.

An Integrated System Test Plan (ISTP) was developed for verification that the GCEP is operating within declared limits as to the amount and enrichment of plant production. Preliminary studies are under way to identify critical vessels and a means of determining vessel volumes. A domestic ISTP will also be developed to demonstrate that domestic safeguards requirements will be met by accountability procedures. This work cannot be completed until domestic safeguards procedures for the plant have been developed and approved.

1.9.2 UNITED STATES ENRICHMENT SAFEGUARDS PROGRAM

J. R. Tarrant

Implementation of effective nuclear materials safeguards for control and accountability of all nuclear materials at uranium enrichment plants is a prime objective of the U.S. Department of Energy. Toward this end, DOE policy guidelines require that each facility handling and/or processing nuclear materials under DOE jurisdiction be designed to facilitate the use and integration of nuclear materials control and accountability measures and subsystems that satisfy DOE objectives for management of its facilities, for protecting public health and safety, and for maintaining the common defense and security of the United States. The objective of the Enrichment Safeguards Program (ESP) is to ensure that appropriate measures for domestic nuclear materials control and accountability and international safeguards are integrated into the GCEP Plant at Portsmouth, Ohio. In this regard, the I&C Division provides support to the ESP at the ORGDP both in specialized instrument development and in maintenance requirements for related special components.

Enrichment Monitor Testing. The enrichment monitoring system provides the IAEA with a method for conducting effective nuclear materials accountability verifications at large-capacity gas centrifuge enrichment plants while reducing the impact of the safeguards verifications on the facility operator and the resources required by the IAEA to complete its verification activities. In the in-line enrichment monitor, the vapor phase enrichment is determined by combining germanium detector–based gamma ray measurements of ^{235}U and total uranium concentrations. The ^{235}U concentration is determined from a measurement of the 185.7-keV gamma rays emitted in the decay of ^{235}U, and the total uranium concentration is determined by measuring the transmission through the UF_6 gas of 60-keV gamma rays from an external ^{241}Am source.

Tests of a vapor phase UF_6 enrichment monitor preprototype were completed in 1983. This monitor was designed by Los Alamos National Laboratory and had been installed for testing in the Feed and Withdrawal Building at ORGDP. The information acquired in these tests was used in the design and construction of a monitor prototype for use in the planned IAEA Inspectorate Facility, Building

X-1030 at the GCEP. This monitor prototype was installed in the Withdrawal/Desublimation Test Facility at the ORGDP for stability and calibration tests, in which samples of UF_6 of varying ^{235}U enrichment were circulated through the monitor at various pressures in a test loop with piping features and pumps similar to the sampling loops planned for use at the GCEP. This phase of the testing has been completed together with plans for installation of the monitor prototype in one of the feed lines to the ORGDP cascade for long-term tests and evaluation.

Enrichment Monitor Processor. Completion of GCEP Phase II construction will require eight enrichment monitors. These monitors will report data, various alarm conditions, and complete gamma spectra to the enrichment monitor processor for storage. The processor utilizes the DEC RXS-11M Version 4.1, a standard DEC LSI-11/23 operating system, for task scheduling and task communications. The system is menu driven to provide a user-friendly environment for operators with minimal training. The menu displays the options available to the operator and responds to requests. Options include updating the authentication keys, generating reports, and shutting down the processor system. The processor is configured using standard data-processing equipment and could fulfill many data-processing requirements. It is structured to support extensive I/O requirements and can serve as a data collection center supporting many different instruments located hundreds of feet from the processor. The processor authenticates the data received and transmits them to a larger archival system (the integrated data acquisition system) for long-term storage and anomaly searches.

Maintenance Manual for Special Components in the IAEA Inspectorate Facility. A manual was issued covering maintenance requirements for the special components to be included in the IAEA Inspectorate Facility at the GCEP. Special components include the enrichment monitors, the enrichment monitor processor, the integrated data acquisition system, and the intrusion monitoring system.

Methods are described that provide necessary preventive maintenance without compromising the security of the facility or of the information and instruments in use by IAEA. Estimates are also given of the manpower and associated skills required for these tasks. Figures outlining the areas in the building open to unaccompanied maintenance personnel are included as well as the portions of the facility requiring IAEA inspector presence during entry and occupancy. Efforts to minimize the effects of the maintenance task on the operating contractor have also been made.

1.9.3 ASSESSMENT OF SAFEGUARDS REQUIREMENTS FOR THE ADVANCED GAS CENTRIFUGE ENRICHMENT PLANT AND THE ATOMIC VAPOR LASER ISOTOPE SEPARATION PLANT

J. A. Russell

The chairman of the Enrichment Process Evaluation Board (PEB) has identified the need for a safeguards assessment of the technological requirement for the AVLIS and AGCEP processes. Brookhaven National Laboratory is conducting the evaluation with support from Los Alamos National Laboratory, Sandia National Laboratories, and Martin Marietta Energy Systems, Inc. Martin Marietta is a key contributor to the assessment because of its direct involvement in GCEP safeguards and an in-depth understanding of DOE and IAEA safeguards requirements.

The goal of the study is to provide the PEB with an interim assessment of the Domestic Safeguards and Security and International Safeguards approaches needed to achieve comparable effectiveness for the production plant designs. Because of the limited time available for the assessment it will be limited to the determination of the relative ease or difficulty of implementing safeguards to each process.

1.9.4 WIDE-ANGLE NEUTRON DIFFRACTOMETER INSTRUMENTATION

R. T. Roseberry

H. R. Child*	**R. M. Moon***
G. C. Guerrant	**K. H. Valentine**
M. K. Kopp	**J. A. Williams**

Instrumentation was provided for the wide-angle neutron diffractometer installation at HB-4A in the High Flux Isotope Reactor (HFIR) beam room. The facility is a joint effort of the ORNL Solid State Physics and Chemistry divisions, and the Japan Atomic Energy Research Institute. The instrumentation supports two separate neutron scattering instruments, the wide-angle neutron diffractometer (WAND) and a four-circle, single-crystal diffractometer. either of which (but not both) can be positioned on the beam line.

Data collection and experiment timing are accomplished with CAMAC hardware interfaced to a host PDP 11/44. The CAMAC hardware is common to both instruments, while motor driver/multiplexor systems for each instrument use separate serial ports to the host.

Data collection from the curved linear position-sensitive detector of the WAND is accomplished by a direct time digitizer driving a bank of histogramming memories in the CAMAC system. The start-stop pulses for the time digitizer are derived from a 1-wide NIM packaged dual timing single-channel analyzer. Data are collected in CAMAC scalers from the single-channel analyzer of the single-crystal diffractometer. One monitor counter is common to both instruments.

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*Solid State Division.

1.9.5 ENGINEERING SUPPORT FOR THE ORNL EMERGENCY RESPONSE CENTER

R. T. Roseberry C. S. Meadors*
J. W. Reynolds J. L. Murphy*

Support was provided the ORNL Laboratory Protection Division and ORNL Engineering in the preparation of performance specifications for the data acquisition system for the ORNL Emergency Response Center. Lists and descriptions of existing equipment as well as necessary new equipment were compiled to provide prospective vendors with sufficient information to design the control room consoles.

The system will be compatible with the existing Waste Operations Control Center and will be able to communicate with the data environment, thus allowing future implementation of the data links necessary for redundancy. Data links were required for communication with existing host computers for the Meteorological Data System, the Environmental Monitoring System, and the Waste Operations Control Center.

As part of the complete instrumentation package, the hardware and software necessary to provide redundancy for the Security Access Monitor and Control computer system were described. When completed, the ORNL Emergency Response Center instrumentation will provide timely display of all monitored data in formats that should greatly assist the Laboratory Shift Supervisors in routine control and management of ORNL utility systems, monitoring systems, off-hours operations, and minor emergencies, as well as permitting rapid and intelligent evaluation by ORNL management in making decisions that would be necessary in situation management.

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*ORNL Engineering.

1.9.6 REDESIGN OF THE HFIR PRODUCTION MODEL HOMOGENEITY SCANNER

J. W. Reynolds

Since two production model scanners were placed in production at the Metals and Controls, Inc., facility in Attleboro, Mass., they have been used to examine 150,000 fuel plates for HFIR (540 fuel plates per core) and 50,000 fuel plates for the National Bureau of Standards, Omega West, High-Flux Beam, and Oak Ridge Research reactors. The redesigned units are in production at the Babcock & Wilcox Naval Nuclear Fuel Division facility in Lynchburg, Virginia.

The redesign of the HFIR homogeneity scanner was needed because it will continue in operation until at least 1990, and replacement parts for the scanner electronics (which were designed in the mid-60s) can no longer be purchased. A limited supply of old parts was still available when the redesign was begun.

Evaluation of the scanners in December 1982 resolved problems with undocumented field modifications and temporary changes made for a high-fired/burned-oxide experiment at Metals and Controls, Inc. The inspection resulted in a recommendation to replace the power supplies for the photomultiplier high voltage and the regulated 50 kV to the X-ray tube, calibrate the Honeywell stripchart recorder, and check the calibration of the system to the original standards. The strip chart recorders were also replaced during testing of the new electronics.

At a later date, the photomultiplier plastic scintillator was also checked for radiation damage. The plastic scintillators were replaced, and a photomultiplier tube was ordered to replace the RCA 2020 photomultiplier. Testing of the replacement photomultiplier has not been completed.

The gaging and function control chassis were redesigned with an etched wiring board (EWB) containing the integrated circuits for each of the original chassis in a new chassis that occupied 75% less space. The interface between the scan-control chassis, a relay-operated sequencer, and the function-control chassis was also replaced with integrated circuits on an EWB.

The regulated 50-kV X-ray tube power supply will be replaced during the early part of the next reporting period.

1.9.7 A BROADBAND MIDSPLIT CABLE TELEVISION TRUNK FOR VIDEO AND DATA TRANSMISSION

J. L. Lovvorn   R. I. Crutcher

Expertise was developed in CATV technology for video and data transmission at the request of the Martin Marietta Energy Systems Network Coordinating Committee. Specifications were written for ORNL Engineering for a broadband, midsplit cable television trunk line within the X-10 site and to the Y-12 site, and within the eastern part of Y-12 and to the Fusion Engineering Design Center in the city industrial park. Technical expertise and close follow-up was provided during the placing of the contract and the installation of the system by a contractor.

Extensive testing of the broadband cable television system was necessary to determine that the system would perform in the manner intended. Structural return loss (SRL) measurements were performed on the coaxial cables at the time they were received and again after the cables were installed. Because of the before-and-after testing procedure, the integrity of the coaxial cables was excellent.

Construction progress and methods were monitored and input given to ORNL Engineering as required to assure construction to specifications.

After the system was made operational by the contractor, acceptance testing was performed to determine that the system met specifications. Tests on the active system included system flatness response, carrier-to-noise ratio, cross modulation, composite triple beat, second-order intermodulation, hum modulation, and signal leakage. The cable system checked out well within specifications on all of these measurements, indicating that the design and installation were highly acceptable.

Extensions to this trunk system to the K-25 site from the X-10 site and to the DOE ORO and Technical Information Center from the Y-12 site are in the process of being built. Our work has served as the model for these extensions. Liaison with the respective engineering organizations is being maintained, and consulting is provided on request.

1.9.8 ORNL RADIO SYSTEM MANAGEMENT

J. A. Russell   R. I. Crutcher

Responsibility for operation of the ORNL two-way FM radio systems was delegated to the I&C Division after the retirement of the previous radio system manager. All systems of the Oak Ridge Operations networks were upgraded, including a major reconstruction of all ORNL networks. A primary consideration in implementing the changes involved maintaining effective emergency communications during the changeover.

The master radio plan for ORNL called for construction of new repeater facilities at Melton Hill and at Building 3017; the replacement of all main base and repeater stations with new equipment; and the implementation of digital voice encryption, tone remote control, and selective tone encoding. These upgrades were done on the Security network (OR 020), the Health Physics network (OR 023), and the ORNL stations using the DOE Security network (OR 001) and the alternate Security network (OR 002). Network repeater frequencies were changed on the Health Physics network (OR 023) and the Plant and Equipment network (OR 028). The alternate Security network (OR 002) was converted to a repeater system, and the capability for communications on the DOE Security network (OR 001) was added to most of the security and emergency vehicles. Approximately 150 radio units at ORNL were more than 10 years old, and these were replaced with new equipment as part of the project.

The radio system upgrade brought an increase in the amount and complexity of equipment in the ORNL radio system. Many parts of the system represent state-of-the-art technology, and the changeover required extensive engineering design and support to make it operational.

A change of radio frequencies and a decrease in repeater frequency pair spacings created a need for cavity filter networks at the main transmitter sites. These systems were designed to minimize interference among networks. The assignment of new frequencies meant problems with intermodulation interference. Computer analysis was performed on the frequency combinations for each Oak Ridge plant site to determine what frequencies would cause interference. The frequency assignments were then changed or cavity filters were installed to minimize the intermodulation products.

Normal radio system management activities during the reporting period included the evaluation of need for new equipment and procurement of new radio equipment meeting ORNL requirements other than those in the Master Radio Plan Project.

1.9.9 INTERMD: A COMPUTER PROGRAM TO PREDICT INTERMODULATION PRODUCT GENERATION ON TWO-WAY FM RADIO FREQUENCIES

J. A. Russell **A. L. Case**

(Abstract of ORNL/TM-9213, July 1984)

This report describes a computer program which was developed at the Oak Ridge National Laboratory to perform calculations on groups of two-way FM radio frequency assignments to determine if interference might be generated when two or more of the networks are used at the same time. Intermodulation products can be generated in a variety of ways, but the results have the same effect: the radio frequency signal generated appears to the receiver as a signal that cannot be distinguished from a signal actually transmitted on the receiver's input frequency.

The purpose of INTERMD, the computer program described here, is to enable rapid determination, by calculation, of possible frequency combinations which could cause interference.

1.9.10 ACQUISITION OF A Y-12 PLANT MAINTENANCE SIMULATOR SYSTEM

D. E. Smith

Acquisition of a maintenance simulator system upgraded the Y-12's Plant Maintenance Division's capability and efficiency in maintaining existing computer systems in the production line facilities of the Y-12 Plant. The acquisition included (1) a VAX-11/750 computer system with 2 Mbytes of memory, two 205-Mbyte disk drives, one 80-Mbyte disk drive, one 10.4-Mbyte disk drive, one 160-Mbyte Winchester disk drive, one 40-Mbyte magnetic tape, and one terminal; and (2) a PDP-11/44 computer system with 512 Mbytes of memory, two 10-Mbyte disk drives, a 31.2-Mbyte Winchester/floppy disk system, and a terminal. The total cost of equipment acquisition was $187,000, and the work was supported under Y-12 Engineering.

The computer systems in the production line facilities are an integral part of Y-12 Plant operations and require a responsive turnaround. The equipment procured on this acquisition allows the repair of similar computer systems in the production line facilities by using the echelon approach to computer maintenance, a maintenance progression that replaces the defective module in the field and returns it to the shop where the defective components are located and replaced. Using the maintenance simulator system, skilled maintenance personnel perform detailed subassembly diagnostics that can identify the individual failed component and repair the unit. The repaired subassembly is tested in the simulator to verify its reliability before the unit is returned to the field.

The echelon approach to maintenance using the maintenance simulator system allows the return of production equipment to service with minimum downtime, requires a minimum number of spare parts, optimizes the use of skilled maintenance personnel, and allows efficient diagnostic repair and verification.

1.9.11 LARGE-AREA PROPORTIONAL COUNTER CAMERA

W. T. Clay
G. W. Allin **C. E. Fowler, Jr.**

Two multiwire position-sensitive proportional counters (PSPC) were developed, tested, and installed at ORNL, one in the SANS Facility at the HFIR and the second at the original fixed-distance SANS facility at the ORR. A third SANS PSPC is now being constructed for use as a spare at either facility. Maintenance is also provided on these two units.

The PSPC is based on the RC encoding and time-difference decoding method to measure the spatial coordinates of the interaction loci of individual scattered neutrons. The active area of the PSPC is 65 cm × 65 cm, and the active depth is 3.6 cm. The spatial uncertainty in both coordinates is approximately 1.0 cm (FWHM) for thermal neutrons; thus, a matrix of 64 × 64 picture elements is resolved. The count rate capability for randomly detected neutrons is 10^4 counts/s, with <3% coincidence loss. The PSPC fill-gas composition has been changed from a mixture of ^{3}He, Xe, and CO_2 to a mixture of ^{3}He plus 36% CF_4 (ref. 1) at 3 atm absolute. The results are increased spatial resolution, increased count rate capabilities, and reduced gamma photon sensitivity. The detection efficiency is approximately 90% for 2.6-keV neutrons from the scattering experiments.

Operationally, the new PSPC is identical to the other two counters. Two major changes—a welded diaphragm and a new electrical feed-through design—were made. These and other changes will reduce fabrication problems, reduce costs, and produce a more reliable instrument.

1. M. K. Kopp et al., *Nucl. Instrum. Methods* **201**, 395–401 (1982).

1.9.12 PLAN FOR RADIONUCLIDE TRACER STUDIES OF THE RESIDENCE TIME DISTRIBUTION IN THE WILSONVILLE DISSOLVER AND PREHEATER

R. L. Jolley* — **J. M. Begovich***
H. R. Brashear — **N. Case**†
T. G. Clark‡ — **J. F. Emery****
B. D. Patton* — **B. R. Rogers***
J. F. Villiers-Fisher* — **J. S. Watson***

(Abstract of ORNL/TM-8777, December 1983)

Stimulus-response measurements using radiotracers to measure residence time distribution (RTD) and hydrodynamic parameters for the preheaters and dissolvers at the Ft. Lewis Solvent Refined Coal (SRC) and the Exxon Donor Solvent (EDS) coal conversion pilot plants are reviewed.

A plan is also presented for a series of radioactive tracer studies proposed for the Advanced Coal Liquefaction Facility at Wilsonville, Alabama, to measure the RTD for the preheater and dissolvers in the SRC-I mode. The tracer for the gas phase will be ^{133}Xe, and ^{198}Au (on carbonized resin or as an aqueous colloidal suspension) will be used as the slurry tracer. Four experimental phases are recommended for the RTD tracer studies: (1) preheater; (2) dissolver with 100% takeoff; (3) dissolver with 100% takeoff and solids withdrawal; and (4) dissolver with 50% takeoff. Eighteen gas-tracer and 22 liquid-tracer injections are projected to accomplish the four experimental phases. Two to four tracer injections are projected for preliminary tests to ensure the capability of safe injection of the radiotracers and the collection of statistically significant data. A complete projected cost and time schedule is provided, including procurement of necessary components, preparation of the radiotracers, assembly and testing of tracer injection apparatus and detection systems, onsite work and tracer injections, laboratory experimentation, data analysis, and report writing.

*Chemical Technology Division.
†Isotopes Division.
‡Environmental and Occupational Safety Division.
**Analytical Chemistry Division.

1.9.13 COMPARISON OF MEASURED AND CALCULATED ^{238}U CAPTURE SELF-INDICATION RATIOS FROM 4 TO 10 keV

R. B. Perez*
G. de Saussure* — **J. L. Munoz-Cobos**†
J. T. Yang† — **J. H. Todd**

[Abstract of *Trans. Am. Nucl. Soc.* **44**, 537–38 (1983)]

From 4 to 149 keV, the ^{238}U cross sections are represented in ENDF/B-V by unresolved-resonance parameters (URPs). The purpose of this representation is to enable the calculation of resonance self-protection as a function of temperature and dilution. Since the UPRs are not defined unambiguously by the cross-section data, it is important that the unresolved representation be tested with appropriate experiments, such as capture self-indication ratio (SIR) measurements. In this paper, we compare ^{238}U capture SIR measurements in the 4- to 10-keV energy range with calculations done with ENDF/B-V and with recently published resolved-resonance parameters. Our findings underscore the need to extend the ^{238}U resolved-resonance repre-

sentation of ENDF/B to higher energies if the 1% accuracies in computed ^{238}U self-shielding factors requested by reactor designers are to be achieved.

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*Engineering Physics and Mathematics Division.
†Institute of Nuclear Research, Taiwan.
‡Polytechnic University of Valencia, Spain.

1.9.14 ADDITIONAL PROJECTS

Changes and Additions to Facility Radiation and Containment Systems. Changes, ranging from minor to moderate, were made in seven systems. Drawings for all systems were revised to reflect these changes. *(C. C. Hall)*

Television Support Services for the Hydrofracture Facility. Video support services were supplied to the Operations Division in their effort to repair the injection well at the Hydrofracture Facility. An underwater television camera was obtained from the Army Corps of Engineers for the first inspections of the well. During redrilling operations, a camera system was borrowed from TVA. A radiation-hardened underwater camera system was specified and ordered for use in the later phases of the well inspection and for inspection of reactors at ORNL. The Special Electronics Engineering Group was involved in locating these cameras, writing the specifications for ordering the camera and parts, designing cable-handling mechanisms for the contaminated camera cable, and providing engineering support to operate and maintain the camera during the well-logging session. *(R. I. Crutcher, J. L. Lovvorn, L. D. Hunt)*

Audiovisual and Computer Equipment Searches, Procurement, and Installation. Audiovisual equipment and personal computer peripherals have been researched, procured, and/or installed for several projects at ORNL during this reporting period. The products and projects include public address systems for plant buses; monitors, VCRs, and cameras for conference rooms and training programs; closed-circuit camera systems; ink-jet printers, digitizing tablets, and plotters for an IBM personal computer; and specially adapted slide projection systems. *(B. H. Fulcher, L. D. Hunt, J. L. Lovvorn)*

Maintenance and Installation of Position-Sensitive Proportional Counters (PSPCs). Members of the I&C Special Electronics Group have provided engineering support on associated signal processing instrumentation of PSPCs for the ORNL Solid State Division. The work included field evaluation, maintenance, and alignment of the HFIR one-dimensional PSPC, the high-voltage laboratory Small-Angle X-Ray Scattering (SAXS) PSPC, and the HFIR Small-Angle Neutron Scattering (SANS) PSPC. In addition, group members supported the reinstallation and performance checkout of the SANS detector at the ORR. *(B. H. Fulcher)*

Positioning Documents Beneath a Forox Model SS Slide and Strip Copy Camera. A method was devised to use a Spinwriter Model 3510 Printer to position documents beneath the lens of a Forox Model SS strip and animation copy camera for copying onto 16-mm film. The documents to be copied are mounted on fanfold paper, and the formfeed of the printer is used to move each document into position beneath the camera. Proper positioning of the documents beneath the camera was accomplished by attaching a specially fabricated metal holder to the printer. Although this particular system was operated manually, it could be fully automated to allow copying a large quantity of material without the constant attention of an operator. *(C. R. Mitchell)*

Sample Changer and Brown Recorder Interface to an Apple Computer. An instrument was required to allow an Apple computer to control a sample changer driven by an ac synchronous motor. A computer interface was designed and built allowing start/stop control of the motor using solid state ac switches.

A switching arrangement was implemented that allowed the goniometer motor to be driven from either the Ortec 6713 axis controller or the added Superior Electric ST101A motor controller (ST101A is controlled from the Apple). The Brown recorder chart drive is controlled from the Ortec axis controller or, if in the Superior Electric position, from the Apple. This arrangement allows the recorder and the goniometer to be shared by two data collection/control systems.

This work was performed for the ORNL Analytical Chemistry Division. *(R. T. Roseberry, G. W. Turner)*

Specification and Procurement of an Alpha-Counting System. Functional specifications were prepared for the ORNL Analytical Chemistry Division for the purchase of a four-channel alpha spectrometry system to replace an antiquated single-detector system that was being operated three shifts each day. *(R. T. Roseberry)*

Small-Angle Scattering Facilities Support. Support has been provided to the Small-Angle Neutron and X-ray scattering user facilities at ORR, HFIR, and the High-Voltage Laboratory. All three of these facilities have been upgraded within the past two years, resulting in a higher percentage of operating time available to users. *(R. T. Roseberry)*

Proposal for Data Acquisition and Control Equipment at the Tower Shielding Facility. At the request of the ORNL Engineering Physics and Mathematics Division, a proposal was generated describing the equipment required and giving an estimate of the cost of the upgrading the present TSF data acquisition and control system. The proposal included a Nuclear Data ND62M multichannel analyzer and computer system, and was to include a portable data base, a hard-copy unit, a computer link, and a stepping-motor control driven from the ND62M.

A conceptual block diagram, bill of materials, and formal cost estimate were generated and submitted. The upgrade has not yet begun. *(R. T. Roseberry, G. W. Turner)*

Estimate and Schedule for Procurement and Installation of a Numerically Controlled Milling Machine. At the request of the Y-12 Plant Fabrication Division, a conceptual design and formal cost estimate were generated to rebuild and upgrade controls on a Gorton milling machine located in Building 9201-1. The I&C Division was acting for the Computer Applications Branch of Y-12 Engineering. In-house rebuilding of the machine itself was coordinated with several engineering disciplines at the Y-12 Plant. A General Electric numerical controller was proposed and priced. A schedule including details and milestone dates was generated using schedules from all project contributors.

However, enhancements were necessary to allow the module to operate in this experiment. An addition was designed that would allow the unit to be halted and the DAC output zeroed via an additional CAMAC control signal. Another addition was made to allow, via CAMAC control, the LAM status word to be read onto the Dataway. *(G. W. Turner)*

Upgrade of Small-Angle Neutron Scattering System Motor Driver. The motor-driver multiplexer controls 16 X and 16 Y stepping motors via a computer control at HFIR. Because of the affects of neutron bombardment, the system had to be reconfigured. In the original configuration the stepping-motor diodes were at the field locations. It was obvious that the neutrons were causing considerable failures in the diodes, resulting in nonoperable motors. These 128 diodes had to be relocated in the motor-driver cabinet with the solid state relays. An eight-channel printed circuit board was designed and implemented. The system utilizes four of these boards to address the 32 motors. This modularizes the system, allowing much greater servicing efficiency.

The modifications were coordinated by the I&C Division to be implemented during the scheduled maintenance shutdown for the HFIR. By performing the modifications during this time, no actual system-user time was lost. *(G. W. Turner, R. T. Roseberry)*

ORNL Accelerators and Sources Safety Review Committee. The ORNL Accelerators and Sources Safety Review Committee is one of several ORNL Directors Review Committees which periodically review major production and research operations at ORNL for compliance with ANSI 3.1-1978, safety (and especially radiation safety) including adherence to the policy of maintaining personnel exposures as low as reasonably acceptable (ALARA). This committee is responsible for reviewing operations of all ORNL accelerators and all radiation sources used for the purpose of irradiation. Each facility was reviewed at least once during the past two years. In addition, special reviews were held on any facility which was modified or for which new or different experiments were proposed. The most notable facility change involved the Holifield Heavy Ion Facility, which underwent construction of the Tandem Van de Graaff generator and installation of capability to introduce accelerated particles into ORIC. The committee participated in reviews of the Facility Safety Analysis Report and the Operational Safety Report. *(J. A. Russell, T. A. Lewis)*

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1. G. W. Turner et al., ORNL/TM-7363, December 1984.

Section 2

MEASUREMENT AND CONTROLS ENGINEERING

2.0. Overview

2.1. Atomic Vapor Laser Isotope Separation (AVLIS) Program

2.2. Advanced Instrumentation for Reflood Studies (AIRS) Program

2.3. Support for Large-Scale Engineering Projects

2.4. Energy, Conservation, and Electric Power Systems

2.5. Computer Systems and Communications

2.6. Microprocessor and Desktop Computer Support

2.7. Robotics and Electromechanics

2.8. Sensor and Instrument Development

2.9. Engineering Support

2.10. Special Projects

2. MEASUREMENT AND CONTROLS ENGINEERING

2.0 SECTION OVERVIEW

C. A. Mossman

The work of the Measurement and Controls Engineering Section (MACES)* covers an extremely broad spectrum which includes the development and application of real-time computer systems, robotic and electromechanical systems, new and unique sensors and instruments, and basic metrology research. In addition, all types of commercial instruments and controls are applied to the specific needs of Martin Marietta Energy Systems research and production organizations in all three Oak Ridge plants. The Section is currently supporting the organizing of a Personal Computer Support Center to assist users in all areas of personal computer hardware and software selection and application. Other areas of development and expansion include artificial intelligence, electromagnetic interference studies, simulation modeling, and data acquisition and analysis. During this reporting period, MACES has continued to be heavily involved in the Atomic Vapor Laser Isotope Separation (AVLIS) Program, the Consolidated Fuels Reprocessing Program (CFRP) and the Advanced Instrumentation for Reflood Studies (AIRS) Program.

ACCOMPLISHMENT HIGHLIGHTS

- The exceptional performance of the MACES team in providing instrumentation and controls development for the AVLIS Program was instrumental in achieving all program milestones ahead of schedule.
- Two MACES engineers (together with one engineer in the ORNL Fuel Recycle Division) won an I-R 100 Award for developing the first digitally controlled servomanipulator system.
- A team of MACES engineers has accomplished the successful control of the world's first modular manipulator (the advanced servomanipulator) and is developing unique and improved teleoperator control systems.
- The AIRS program has continued successfully, and completion of program commitments have been on time and within budget.
- A joint University of Tennessee-ORNL Measurement and Control Engineering Center was conceived, and this Section is leading the organizational planning necessary to establish the Center.
- A team was established to study all aspects of electromagnetic interference (EMI) phenomena, perform tests to detect potential EMI problems, and develop engineering techniques for eliminating EMI effects in practical plant and process situations.
- Both hardware and software for the CFRP disassembly and cutting control system have been developed, procured, installed, checked out, and integrated into a working system on, or ahead of, scheduled milestones.
- A MACES/RIS team developed, installed, and successfully operated the ORNL/Interplant Broadband Network link between the X-10 and Y-12 sites.
- Large data-acquisition systems for PTS and THORS were delivered and installed ahead of schedule and within budget.
- A team of MACES engineers working on EURI with the Y-12 Plant Development Division has successfully resolved several difficult measurement problems and has developed, installed, and operated a prototype automatic control system that has dramatically improved the performance of the existing enriched uranium recovery process.

*The acronym list at the end of this report may be folded out for reference.

FUTURE TRENDS

- **Increased involvement in defense-related work and work for other government agencies, as support for energy research and development continues to decline.**
- **Expanded role in the application of personal computers to laboratory experiment control and data acquisition and analysis.**
- **Increased involvement in upgrading, automation, and computer control of production plants for the Y-12 Computer Integrated Manufacturing Plan.**
- **Continued involvement in research, development, and application of computer-based systems for real-time measurement, control, and information processing.**
- **Continued development of expertise in electromagnetic interference (EMI) and electromagnetic pulse (EMP) engineering and problem solving for the three Oak Ridge plants.**
- **Continued involvement in the instrumentation and computer engineering development required by advanced isotope separation programs.**
- **Increased development of advanced robotic systems and teleoperators for harsh and hazardous environments and for situations requiring remote maintenance.**
- **Accelerated development of microprocessor-based smart instruments and control systems.**

SECTION ORGANIZATION

The activities of the Section are carried out by seven working groups and three major programs which report to Section management.

Real-Time Computer Systems Group

The objective of this group is to provide research, development, and application of computer-based systems for the real-time measurement, control, and information processing necessary to meet Martin Marietta Energy Systems' requirements for online experimental data. This group performs functions encompassing all facets of hardware and software development from definition of requirements and concepts through equipment procurement or fabrication and software implementation.

The group presently uses off-the-shelf minicomputer technology to build online real-time data acquisition and analysis systems for all types of experimental work throughout the three Oak Ridge plants. Data systems have been built for reactor safety research experiments, aquatic ecology research, and bioinstrumentation research, to name a few. This group has the expertise to perform complete computer systems jobs; its state-of-the-art expertise in low-level and high-speed analog input systems is especially noteworthy. In the past two years, this same expertise has also been provided to the AVLIS Program at ORGDP and to various groups at the Y-12 Plant. In addition, the group provides leadership in local area networks and computer communications.

Microprocessor and Desktop Computer Group

The objectives of this group, which was formed in July 1983, are threefold: (1) to provide application engineering support for the laboratory automation needs of ORNL research divisions through the use of laboratory desktop computers, (2) to provide a full spectrum of support for the users of personal computers (PCs), and (3) to provide microprocessor-based hardware and software support for studies in the areas of robotic manipulator control systems and artificial intelligence (AI) concepts.

The laboratory automation effort involves primarily the application of Hewlett-Packard computers to the custom needs of individual research groups. The PC support effort provides assistance to PC users of the ORNL research and clerical staff. The robotic manipulator hardware and software work includes multiple, interconnected microprocessors for which software is being written in the FORTH language. The AI effort includes study of microprocessor implementation of the parallel processing needs of OPS, the expert systems language.

Process Systems Development and Research Support Group (X-10)

The overall objective of this group is to provide systems engineering for the development, application, and support of measurement and automatic control systems implemented to meet the research and development goals of ORNL. The functions necessary to meet this objective include problem definition, concept synthesis, design, implementation, startup, and follow-on maintenance.

This group uses commercially available hardware and software when appropriate as a basis for building measurement, control, actuator, and operator interface subsystems. Current projects include support for the CFRP, Energy Division conservation and building materials programs, laboratory facility upgrades in environmental monitoring and radiochemical processing, and the AVLIS Program.

Process Systems Development and Research Support Group (Y-12)

The objective of this group is to perform instrumentation and control system research, design, development and application engineering in support of a wide variety of projects being conducted by the ORNL Engineering Technology and Energy divisions, the Y-12 Plant Development and Metal Preparation divisions, and the AVLIS Division at ORGDP.

This group performs measurement and control engineering work in support of projects such as AVLIS, manufacturing automation upgrade (Y-12 Plant), Component Flow Test Facility, Pressurized Thermal Shock (PTS) Test Facility, heavy section steel technology, Large Coil Test Facility, Thermal-Hydraulic Out-of-Reactor Safety (THORS) Facility, and enriched uranium recovery improvement (EURI).

Robotics and Electromechanics Group

This group was formed to emphasize the Section's increasing research and development effort in robotics-related technology. The group supports the CFRP, the Center for Engineering Systems Advanced Research (CESAR), and the Y-12 Plant Development Division. Its objective is to perform advanced robotic systems engineering by maintaining expertise in manipulator design, robot sensors, and robot controls and electronics. The group has an international reputation for its work in microprocessor-based digital control of force-reflecting servomanipulators, for which it received a 1984 I R 100 Award. Basic research in the areas of compliant manipulator control, force control, and manipulator optimization is in progress.

Instrument Development Group

The objective of this group is to provide special device and instrumentation system development and application engineering in support of both individual researchers and major projects and programs in the three Oak Ridge plants. The group assesses technological advances, new concepts, and new components and applies their advantages in the development of new instruments. Other responsibilities include support of AVLIS, CFRP, the Consolidated Edison uranium solidification program (CEUSP), enriched uranium recovery improvements (EURI) at the Y-12 Plant, and other programs The group supplies special electronics, optical and image processing systems, special chemical analysis instruments, microprocessor software and hardware, and general instrument engineering support to a wide variety of customers.

. subgroup on electromagnetic interference studies is responsible for testing all equipment in the Gas Centrifuge Enrichment Plant (GCEP) at Portsmouth, Ohio, for conducted and radiated emissions and for susceptibility to conducted and radiated emissions. The same subgroup has broad responsibilities in Tempest, which deals with testing and assessment of compr mising emanations from information processing equipment.)

Measurement Research Group

The basic objectives of the Measurement Research Group are to improve and extend sensor and instrument ranges through research and development and to provide instrument and measurement evaluation, calibration, and consultation services.

This group performs continuing activities related to sensor evaluations and development, encompassing a wide range of physical properties measurements including (1) thermometry, (2) pressure and vacuum, (3) heat and energy, (4) fluid flow, and (5) liquid level and density. Sensor development and evaluation covers all aspects of sensor performance and implementation considerations such as materials, fabrication methodology, error sources, and failure modes.

Atomic Vapor Laser Isotope Separation Program

The instrumentation-related objectives of the AVLIS Program are to provide measurement, control, and data acquisition and analysis for all appropriate process parameters, primarily those concerned with materials-handling issues such as injecting uranium into the process, generating an atomic vapor with acceptable properties, separating the product from tails, and withdrawing the product and tails from the process.

Work is now in progress on the Materials Handling Demonstration Module (MHDM). The I&C Division was instrumental in the achievement of the first three major MHDM milestones: separator facility in operation, vaporizer in operation, and the liquid reflux milestone. Current emphasis is on the March 1985 operations demonstration milestone, which will be a factor considered in the DOE process of selection between the Advanced Gas Centrifuge (AGC) separation and AVLIS. If AVLIS is selected, a phased production facility is planned.

Consolidated Fuel Reprocessing Program

The overall instrumentation-related objective of the CFRP is the development of an improved technology base for instrumentation, control, and data- or information-handling functions associated with all aspects of nuclear fuel reprocessing.

Long-range plans for this program have been developed, and work is in progress for the development of (1) improved process control and information-management techniques using digital technology, (2) new remote process measurement systems, and (3) automated (robotic) remote maintenance viewing and handling systems. Improved operator interfacing concepts using video terminals and color graphics are being studied and implemented.

Successful research on in-line analytical instruments will have significant impact on process operations and safeguards. Prototypical measurement and control systems for a commercial plant have been incorporated into the Integrated Process Demonstration Facility, which is now in operation.

Advanced Instrumentation for Reflood Studies Program

The objective of the AIRS Program is the development and implementation of two-phase flow measurement systems to be used in joint United States–Japanese–West German pressurized water reactor safety research under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC). This program is managed by the I&C Division and is supported by significant work in the ORNL Engineering Technology Division.

Instrumentation developed by ORNL has been installed in two West German (FRG) test facilities (PKL-II at Erlangen and UPTF at Mannheim) and in two Japanese facilities at Tokai (the Cylindrical Core Test Facility and the Slab Core Test Facility). In addition, instrumentation has been installed at the Massachusetts Institute of Technology; at the Technical University of Hannover, FRG; and at the Karlstein Test Facility, FRG, to provide information in support of the German and Japanese testing effort.

2.1.0 OVERVIEW

D. W. McDonald

The AVLIS Program continues to enjoy the distinction of presenting a challenge that generates excitement, enthusiasm, and commitment. This section highlights the achievements of those concerned with measuring and controlling AVLIS phenomena.

The four-year partnership between AVLIS and the I&C MACE Section continues to be one of mutual benefit, with a strong technical team well integrated and into program goals and challenges as a tangible result. The efforts under MACES technical leadership have benefitted from early long-range planning and the anticipation of technical and programmatic redirection. The culmination of our efforts has been an Integrated Control and Measurement (ICAM) system installed and running on the MHDM. This achievement has allowed the program to meet all demonstration milestones thus far. The ICAM system is the tool with which the program probes the process for basic physics, process performance, and engineering validation information.

The key to our present success has been the concept of phased implementation. All AVLIS subsystems have been designed in a modular fashion in order that minimum sets of hardware and software can be implemented and incremental enhancements added later. This offers tremendous programmatic flexibility in the face of budget fluctuations and changes in technical direction.

The MHDM ICAM system is a superset of the EB-I ICAM system described in the previous I&C progress report[1] and a subset of the proposed AVLIS plant ICAM system. Special features of the MHDM ICAM system include:

- a network of VAX-class computers at the highest level of the architecture,
- a database size of approximately 3000 points updated in real time in each VAX,
- a touch panel/color graphics operator interface with display change capability in less than 2 s,
- automatic "hold at present condition" and switch to manual control on computer fail,
- automatic "reflex" actions to protect equipment and personnel upon detection of certain failure,
- built-in process evaluators (PEV) and "predictors" to assist operators in assessing the state of the process and dedicated loop controllers (DLC) to handle nonlinear and multistate control loops.

The lower levels of the hardware architecture are represented by Fig. 2.1-1. Ultimately, the ICAM system will control the AVLIS process based upon

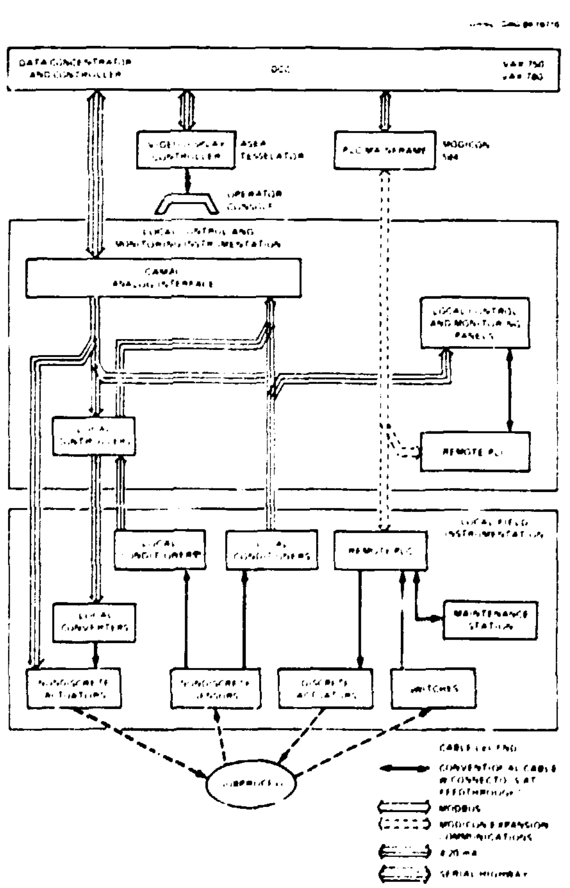

Fig. 2.1-1. Lower level of ICAM hardware architecture.

1. F. R. Mynatt, ORNL-5931/V1, December 1982, pp. 103 4.

a constrained minimization algorithm in which an operating point (in an acceptable operating region) will be maintained to minimize economic cost in terms of both operating costs and maximum component lifetimes.

2.1.1 SOFTWARE DEVELOPMENT STATUS AND ISSUES

W. W. Manges

In late 1980 the AVLIS instrumentation and controls team began to formulate a strategy for implementing an AVLIS plant control system. The current MHDM effort represents the second stage of the implementation plan. The role of the data systems team is to assure that the plan provides the base of computer hardware and software on which to build the ICAM system. The diagram in Fig. 2.1-2 illustrates the overall instrumentation implementation strategy.

The MHDM Facility is dedicated to the issues of separator module control. Solutions developed for MHDM will be available for use in subsequent facilities.

The development of software in such an environment depends on minimizing wasted effort while providing early functionality. The first software implementation, which was for the EB-1 Facility, was used as a base for software development for the MHDM Facility. The important issues were prototyped on the early system and scaled up and refined on MHDM. This strategy substantially reduces the risk in each new implementation. Data acquisition software were prototyped, as well as some concepts in the area of operator's interface and setpoint control. Current efforts include using some of these early ideas while refining or abandoning others. Speeding up the operator's interface and grouping setpoints for control are two examples of improvements currently being implemented on MHDM.

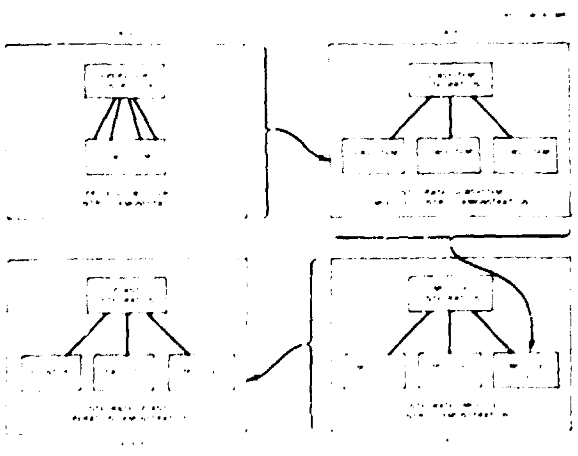

Fig. 2.1-2. Implementation strategy.

The goal of providing early functionality carries with it the risk of exposing the software team to the criticism of providing less than perfect software. The success of this approach therefore depends on the extensive cooperation and support of the customer organization. The AVLIS Program has been instrumental in whatever success the software team has enjoyed in this endeavor. The advantages of this approach become more apparent with each upgrade.

2.1.2 THE USE OF MICROPOWER PASCAL IN CONTROL APPLICATIONS

J. A. McEvers
K. P. Manoni A. G. Sutton

There are particular control problems which require a combination of sequential and continuous control and the ability to respond rapidly to abnormal events commonly referred to as exceptions. Just such a problem existed in the control of the filament power circuitry in the AVLIS electron beam (E-beam) controller (see 2.1.4, "Development of an Electron Beam Controller").

As a possible solution to this problem, it was decided to implement each controller as a small, self-contained instrument with facilities for communicating with a larger, central control system. An LSI-11/23 computer system running Micro-Power/Pascal was chosen for this application because it provided the advantages of a high-level language in a priority scheduled, multitasking operating system that promised to support the exception-handling requirement while providing easy access to the analog and digital process interfaces.

The choice of MicroPower/Pascal for the application was based in part on the ability to program the majority of the application in a high-level language such as Pascal while still having access to assembly language capabilities if needed. Probably the single most favorable element in this choice was the ability to place all control software in read-only-memory (ROM), thereby permitting the instrument to be treated as a stand-alone unit without the need of diskette, disk, or tape drives.

The programming was done as structured blocks called processes in Pascal, with each process being assigned a specific function. Maximum use is made of the concurrent processing facilities of the MicroPower/Pascal package. As events occur, one or more processes is initiated to handle a particular situation. The processes run simultaneously until they are no longer needed, at which time the process or processes terminate or go into a dormant state until needed again.

Although some type of host computer system is required to perform the source code generation, compilation, and executable image building, MicroPower/Pascal is well suited for this and similar applications because of its ability to perform as described above, the availability of a library of mathematical and input/output routines, the structured nature of the language, and its ability to freely comment on the code.

2.1.3 MHDM HEATER CONTROL INSTRUMENTATION

P. G. Herndon G. W. Greene

The MHDM heater control system is composed of several hundred temperature-measurement loops that transmit signals to a programmable controller (PLC) and several hundred heater power control loops that receive command signals from the PLC. Each temperature-measurement loop consists of a thermocouple element and either a temperature controller or a temperature transmitter, while each heater power control loop consists of a phase-fired SCR power modulator unit and a power measurement transducer, which also transmit signals to the PLC. All measurement signals are converted to 4 to 20 mA proportional to the measurement for transmission to the PLC or the control room, and all components are designed to provide complete ohmic isolation between the measurement sensors and the control room receiving instruments.

The power modulators for this system are capable of delivering megawatts of precisely controlled power to the heater loads so that the system temperature is automatically maintained at the desired value.

The SCR power controller and measurement transducer systems were mounted in nine cabinets, wired, calibrated, and tested by the vendor. The temperature controllers, transmitters, and other measurement signal-conditioning components were mounted in four cabinets assembled in the Martin Marietta shops.

2.1.4 DEVELOPMENT OF AN ELECTRON BEAM CONTROLLER

M. L. Bauer
A. G. Sutton J. T. Greer*

Work was begun three years ago to design and build a computer-based emission controller for the E-beam guns. An earlier effort to implement analog controllers for the E-beam guns proved that nonlinearities and the time-variant nature of the problem required the use of digital techniques with graceful exception handling.

The digital emission controller is the present user interface to the E-beam control system. It accepts operator input for setpoint changes and display by reading and interpreting control panel switches through its GORDOS digital input interface. Operator feedback is provided for analog values through the Data Translation 4- to 20-mA outputs and panel meters, and discrete feedback is provided indirectly through the GORDOS digital output interface via a programmable controller (PLC). The present design can support conversion to an operator interface on the host VAX computer, where the remote setpoints are accepted as 4- to 20-mA signals through the Data Translation analog input interface.

Process control is achieved by simultaneously providing control signals to the high-voltage regulator cart and the gun filament power supply. The same digital and analog interfaces are used for process control and operator interface. Feedback signals are used for process control, exception detection, and exception handling where the time constants of the system are significantly longer than the 16-ms cycle time of the software. Exception handling requiring faster response (notably high-voltage arc protection) is handled by control circuitry in the field device.

The combined choice of computer, language, and operating system has proven flexible enough to allow reprogramming between runs as close together as five days to improve exception detection and exception-handling strategies based on operating experience. Version 3 has supported runs during the last three months without any modification, including operating the E-beam guns above design power for time periods of 10 h and multiples thereof. Minor improvements suggested by operating experience will be incorporated in Version 4, which is being designed to provide enhanced exception handling including operator intervention in all operating modes. Version 4 software enhancements will be needed to control the gun system to provide stable control and minimum operator fatigue during the runs exceeding 100 h that are planned for early 1985.

*ORGDP ALVIS Division.

2.1.5 DEVELOPMENT OF A HIGH-VOLTAGE REGULATOR

M. L. Bauer
J. T. Greer* W. H. Andrews

Because high-voltage regulator carts with new features were required for MHDM to integrate their operation into the ICAM architecture, overall redesign of the AVLIS Core Program carts was completed in 1983. Requirements of the new design were higher reliability, higher potential operating point, higher degree of equipment safety, and faster response time.

The new design incorporated a more robust tube that had a higher plate voltage specification as well as higher gain. The EIMAC 4CW100,000E is a water-cooled, 100,000-W plate dissipation tetrode designed for dc and rf service to 100 MHz. The rest of the electronics, including the grid driver and control circuits, are solid state. A new high-voltage divider with good frequency compensation was built, and new control circuitry was designed and fabricated. Computer models of the E-beam system and the new electronics were generated and used to optimize the response of the regulator. The new units were built in the shells of the old carts, thereby maintaining the mechanical interfaces to the rest of the system. This also allowed some testing of the carts on the AVLIS Core Program systems, although some bugs were not found until full-power testing on MHDM. Internal tuning between and during runs has allowed the high-voltage carts to operate in the integrated E-beam control system above design power for tens of hours. Work now in progress will allow the new high-voltage tetrode carts to operate well in excess of the 100 h planned for runs in early 1985.

*ORGDP AVLIS Division.

2.1.6 DEVELOPMENT OF A DYE LASER CONTROL SYSTEM

D. R. Patek

In order to integrate lasers into the overall AVLIS ICAM architecture, Model CR-699-29 Autoscan lasers manufactured by Coherent were retrofitted with a CAMAC-based system utilizing a Digital Equipment Corporation (DEC) PDP 11/23 minicomputer as a DLC. Currently, three lasers are controlled by the DLC as an integral part of the AVLIS experimental laser laboratory control system (see Sect. 2.1.23), and additional lasers may readily be incorporated into the existing system. Functionally, the control system allows the operator to remotely select the frequency of each laser to within 40 MHz. Also, all lasers may be swept linearly over a frequency range of up to 30 GHz simultaneously, and between sweep operations, the control system compensates for frequency drift in each of the lasers. Planned future enhancements include automatic frequency calibration and the employment of additional actuators for laser components not currently under automated control.

Each ring dye laser supplied by Coherent is equipped with a control system that consists of an Apple II computer programmed in BASIC and Assembler languages. The Apple II is connected with a custom interface board that provides it with the necessary analog-to-digital (A/D) (both 8- and 12-bit resolution), digital-to-analog (D/A) (both 12- and 16-bit resolution), signal conditioning, and transistor-transistor logic (TTL) digital input/output (I/O). For operation, seven signals are derived from PIN photodiodes located on the laser optical "head." Signals from four photodiodes located in the laser wavemeter provide the DLC with sufficient data for the calculation of laser wavelength to less than 2.4×10^{-4} nm at 600 nm. Wavelength determined in a stepwise fashion is the primary feedback required for frequency control algorithms. The remaining photodiode signals are required to maintain stable laser operation. The operational frequency of the laser is set through control of a birefringent filter (via a stepping motor), a thin etalon, and a Brewster plate (both under galvometric control). Power for these is actually provided by circuits in a separate electronics frequency stabilization controller package supplied with the laser.

To perform this retrofit, the laser was simply disconnected from the Apple II interface board and connected to a fabricated adaptor that interfaces it with the appropriate commercially available CAMAC modules. In the current configuration, which consists of three lasers, a signal-conditioning module and a LeCroy 8212A 32-channel fast data logger together provide A/D functionality. Scanning drive signal voltages are provided using a LeCroy 8601 function generator, and a Kinetic Systems 3112 12-bit D/A module provides drive voltage to the piezoelectric drives. Digital I/O is provided via standard 48-bit resistor modules. Laser control algorithms for the DLC written in FORTRAN-77 under RSX11M were adapted from those of the Apple II-based system. A standard CAMAC driver was employed.

2.1.7 INTEGRATING PLCs INTO COMPUTER-BASED MEASUREMENT AND CONTROL SYSTEMS

W. W. Manges
D. H. Thompson* R. W. Tucker, Jr.

Studying the issues involved in controlling the AVLIS process in 1977 made it obvious that both general-purpose computers and PLCs would have a role. Prototyping some of the basic components began later that year.

The first PLCs were installed in the AVLIS Core Program in 1980. Extensive use was made of these highly reliable systems for controlling sequential operations and monitoring permissives. This proved to be an effective method of inhibiting operations that might cause problems in the system. At about the same time, a small computer was used to prototype the supervisory measurement and control functions because it was recognized that the flexibility offered by a general-purpose computer would be needed to progress from the existing small-scale facilities to a full-scale demonstration plant. As expected, the use of both types of instrumentation systems for one facility gave a reliable yet flexible design. Prototyping the communication network that would be necessary in a plant-scale facility was made possible by using host computer software available from the manufacturer. The host had access to any information to which the PLC had access, and the operator's displays could present this information in the same way as data obtained by the host from other sources. A hardware interrupt technique was implemented, permitting the host to respond immediately to changes occurring in the systems monitored by the PLC. Thus process-level instruments could be read directly and did not have to be duplicated.

It was not until the next implementation of the ICAM design in the MHDM Facility that two-way communication was established. In 1984 a system was built to control the power to a series of heaters inside the MHDM vessel. The design, for which an early prototype was implemented, allows a flexible operator interface controlled by the host, but the PLC monitors the final control output. This helps ensure that any failures in the host will not compromise the integrity of the heaters. Three PLCs are currently involved in the MHDM vessel, and each one is accessible as a source for data or a repository for outgoing setpoints. The use of the PLC as a reliable front end and the general-purpose computer as the host has already proven to be a successful design and will be expanded into other subsystems in MHDM.

*ORNL Engineering.

2.1.8 DEVELOPING INSTRUMENTATION AND ELECTRICAL CRITERIA, HARDWARE, AND SOFTWARE FOR A DEMONSTRATION FACILITY

R. W. Tucker, Jr.
D. H. Gray* W. W. Manges

One of the more significant challenges to the the AVLIS Instrumentation Group during the past two years was the development of instrumentation and electrical criteria for the Materials Handling Demonstration Module (MHDM) and the ensuing design of the hardware and software systems required to meet the criteria. The MHDM represented the first large-scale facility to be built for the purpose of demonstrating the materials-handling aspects of the AVLIS process, and thus it included all of the challenges of specifying and designing a pilot facility. To add to the challenge, major strides made during the development period in the area of process science resulted in frequent changes to the baseline requirements for the facility. Furthermore, a wide range of both short-term and long-term goals for the facility were still being refined as the program itself matured. All of these factors, as well as the very size of the facility, presented a major challenge to those responsible for the instrumentation and electrical systems.

To meet this challenge, MACES engineers became intimately involved in the science of the process and the operation of the existing, smaller-scale AVLIS Core Program facilities, then located at the Y-12 Plant. Where appropriate, concepts envisioned for the MHDM were prototyped on the Core Program facilities and refined as necessary at the smaller scale. A by-product of this involvement was a significant improvement in Core Program operations. Applying the knowledge gained from close involvement with the Core Program, as well as a general knowledge of instrumentation and electrical equipment, the task of developing criteria for the MHDM was begun. Individuals who had been closely involved in the Core Program became the instrumentation and electrical systems "customer," representing the AVLIS Program and providing the interface between the program and the various design groups assigned to the MHDM.

To accomplish the task, the MHDM Facility was divided into logical subsystems and criteria were established for each subsystem. A key issue in the development of the criteria for each subsystem was integration. In the completed facility, all subsystems had to perform together in an integrated manner to demonstrate control of the entire process rather than segmented control of subsystems. To this end, the criteria for each subsystem included as reference a set of standards known as the "AVLIS Integrated Control and Measurement (ICAM) Philosophy." These standards, developed from general knowledge and the experience gained in the Core Program, ensured the uniformity of functions within, and interfaces between, the various subsystems. Close involvement with the design groups was maintained throughout the course of the design effort. In subsystems where significant development work was involved, such as the data system and the emission controller, design work was performed by the AVLIS/MACES instrumentation group. The remainder was performed by the appropriate departments of the Engineering Division. To combat the problems caused by the dynamic nature of the criteria, frequent design reviews were held with participation by members of the design groups, the AVLIS Operations Group. As a result of this coordinated effort, all designs were completed in a timely manner, and no major revisions were required once construction and operations began.

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2.1.9 USING COMMERCIAL DATABASE MANIPULATION TOOLS IN A REAL-TIME ENVIRONMENT

R. M. Taft
J. A. Ryon M. Defenderfer*

The AVLIS program uses several commercially available software packages to create and support databases, that are then manipulated by data acquisition software in real time. The major task of creating and updating the database is performed by using DATATRIEVE (DTR), a program marketed by Digital Equipment Corporation. The DTR program is supported by several other programs, namely the Common Data Dictionary (CDD) and the Terminal Data Management System (TDMS).

The DTR program builds a database using information supplied by the programmer concerning the size of each information block, the type of data to be expected, and acceptable values. The programmer is not required to format input data.

The CDD program keeps a system record of the database as it has been defined and protects the data from accidental corruption. CDD also maintains a list of all descriptors (names) that have been defined and files them as procedures, forms, tables, domains, and so forth. This list produces a type of automatic documentation, thereby greatly simplifying the job of the maintenance programmer.

The TDMS program allows the programmer to define a "form," which will appear on the terminal screen and prompt the user (as distinct from the programmer) for appropriate inputs. It will also do a limited amount of data checking and verifying; for example, TDMS can define "must-fill" fields (fields which must have data input before the program can proceed). It can also check input values for acceptable range.

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Another automated database manipulation program used on the AVLIS system is Application Development Environment (ADE). This database creation and manipulation program shares some features with DTR but is easier to learn. There are some database size restrictions in ADE, but ADE files that outgrow the restrictions can be converted to DTR files with just one command.

The use of database manipulation programs on minicomputers is fairly new and, until recently, very little had been done in real time. Part of the task in AVLIS was to find usable database-management programs that could be managed by process operators inexperienced in the use of computers. After some initial difficulty in implementation, we have found that DTR, CDD, and TDMS are useful and offer advantages such as ease of user training, commonality of usage, and ease of program modification. ADE has a more restricted use, but it has proved to be a worthwhile addition to existing database-management software.

Training in the use of DTR can be handled through regularly scheduled courses taught in-house, thereby reducing the need for special training of users and operators. Users can attend these in-house courses at their own convenience, and the team's responsibility for training is limited to instruction in the special features and problems of its particular database. This has proved to be a practical method of producing proficient operators in a short period of time.

2.1.10 HUMAN INTERFACE ISSUES FOR A LARGE-SCALE FACILITY

J. M. Heidle* W. W. Manges

The human interface design for the AVLIS Program has evolved with the goal of accommodating immediate needs for data display and control while addressing issues that will be significant in a large-scale operational environment.

An important design issue is the selection of hardware for the human interface. The AVLIS human interface design employs touch-sensitive screen overlay devices for most control functions. This technique eliminates the need for typing commands, which is a tiring and error-prone means of input. By presenting the user with command menus containing only those choices appropriate at that moment of operation, the user is spared the frustration of remembering and typing lengthy commands and is protected from the danger of entering invalid or incorrect commands. No user interaction or familiarity with the operating system is required.

Flexible control over displays at the operator station is a feature with multiple benefits. Allowing the user to redirect the control context of any touch device at the operator station to any display screen permits the user to instantly configure the display system as he or she prefers. Furthermore, it allows an operator at a station with fewer touch devices than display screens to control all of the display screens (only one touch control device is actually required per station). Finally, the redirection feature is important in an industrial environment because it makes all devices in the display system functionally equivalent; that is, all may serve as backup devices to one another if any one touch device or display screen fails.

Another area of emphasis is the optimization of machine response time to user commands. This optimization can be achieved by considering separately each of the following items, which must be handled simultaneously in an advanced human interface design.

- Event-driven display output (menus), which must ensure that the user is never given an unsafe or invalid option. However, all static portions of control menus or data displays should be downloaded from the system host to local memory storage in the display system to minimize the impact on the host computer.
- Periodic data input (process data and status) for updating periodic display fields with current process information.
- Periodic display output (updated display fields). Downloading is used to minimize I/O overhead for these display fields.
- Receiving and interpreting asynchronous commands (user input), which represents a higher priority task than display output, and indeed drives all program action.
- Event-driven data input (process data and status), which is gathered to provide permissives, that ensure safe and stable operator control.
- Event-driven data output (control data), which is verified by the permissives (described in the previous item) before being changed.

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- Event-driven interprocess communication (software control data), which includes all communication between the human interface program and other software in a multiprogramming-operating system environment, including other human interface processes operating concurrently.

All data manipulation by the human interface process should be classified into one of the foregoing categories, prioritized for safety and efficiency of operation, and processed at appropriate data rates.

EB-1 served as an early test bed for the concepts discussed here. By using simple hardware and limiting available options, each of the tasks listed on MHDM has been demonstrated. The speed of the interface is hardware dependent, however, and prototypic hardware for testing is just now beginning to be installed.

2.1.11 INCORPORATING EXPERIMENTAL SUPPORT IN A LARGE PROCESS CONTROL SYSTEM

W. D. Zacheow

The AVLIS MHDM data acquisition and control system provides facilities for monitoring and controlling experiments during an MHDM run. These facilities consist of both dedicated and general-purpose hardware and software that is integrated into the AVLIS MHDM ICAM system. The hardware for connecting the experiments to the system includes a CAMAC fiber-optic serial highway system and CAMAC process interface modules, Modicon 584 PLCs, and several varieties of experimenter interfaces for display and control of the experiments.

The CAMAC system provides analog input, analog output, digital input, and digital output modules for acquiring data and driving experiment inputs; it also supports transient digitizer and complex function generator CAMAC modules for experiments requiring fast waveform generation and acquisition. The PLC system sequences experiment operations and provides setpoints for setpoint controllers; it can also provide the experimenter with information about the status of sequenced MHDM operations.

The experimenter's interfaces range from a sophisticated chief experimenter's console with multiple color displays and touch panel input to VT 100 type terminals. The chief experimenter's console allows the chief experimenter to monitor and control experiments with the same features and functions used to control the process from the operator's console. A subset of these features, namely graphic display of experiment and process data, can be accessed from any Tektronix-compatible graphics terminal. A second subset of the experimenter's console can be accessed from any VT 100-compatible terminal. These features include a touch panel emulator that allows individual experimenters to start and stop data displays, trend plots, printed data logs, and periodic data snapshots, as well as examine and modify data-point values and limits. The secondary experimenter interfaces allow several experimenters to view the progress of experiments from a convenient location rather than crowding around the chief experimenter's console.

2.1.12 SCALING UP TO A PLANT-SCALE PROTOTYPE

W. W. Manges

The AVLIS ICAM system was first installed on the EB-1 Facility in 1980 with the assumption that eventually a full-scale plant would be built. This belief gave everyone involved a common goal toward which to strive. It also ensured that if any of the compromises made for short-term functionality would inhibit progress toward the long-range goal, they were made for a very good reason.

By emphasizing instrumentation system modularity matched to the process, communication issues could be minimized and intelligence distributed to where it would contribute the most toward achieving goals. The diagram in Fig. 2.1-3 illustrates the

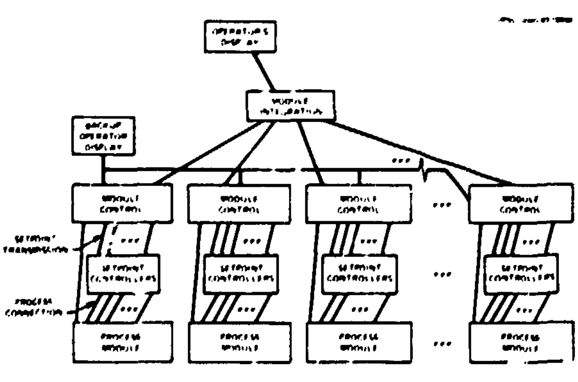

Fig. 2.1-3. ICAM architecture.

module matching incorporated into the ICAM design.

Designs were (and still are) directed toward a full-scale plant but with the knowledge that in the interim all facilities will be used for development. The goal was therefore to prototype for the plant but include the provisions necessary for development. Distributed design was stressed, but every effort was made to avoid erecting barriers to obtaining data from the lower levels, because it was not certain what data from these low levels would prove critical to the control of the process.

The first implementation was in a DEC LSI 11/23 for EB-1, which was expanded to a VAX 11/750 for the first implementation in the MHDM Facility. Additional VAXs are being added as needed for the ancilliary operations on MHDM. The key to the design is to plan for both repetition of all instrumentation modules and expansion of individual ones. This two-dimensional flexibility offers assurance that the design is a viable one.

2.1.13 CONSTRUCTION, CHECKOUT, AND STARTUP OF A LARGE-SCALE AVLIS FACILITY

R. W. Tucker, Jr. R. W. Tucker, Sr.

The challenge of designing a facility as complex as the MHDM is equaled only by the challenge of turning such a design into reality. The MHDM development and design effort involved numerous individuals over a period of several years and continued well into the construction phase of the project. The task at hand became the successful coordination of construction and checkout of each subsystem, incorporating development items into the subsystems, and finally integrating the subsystems into an operational facility. The need for an organized effort was magnified by an extremely aggressive schedule, which was brought about by an accelerated AVLIS Program plan.

To ensure successful and timely completion of the construction and startup phases of MHDM, an AVLIS Program team was formed comprising the head of MHDM Operations, the principle engineer, the instrumentation and electrical systems manager, and a facility engineer to coordinate the effort. Working together, this team formulated an integrated plan for completion of construction, checkout, and startup of the MHDM Facility.

Although many of the major components of the MHDM Facility were fabricated in-house, almost all of the actual construction at the facility site was carried out by contractors. To maximize their effectiveness, the instrumentation and electrical systems manager and the facility engineer moved to the construction site at ORGDP and became closely involved with the construction itself. This involvement allowed rapid resolution of problems as they arose. Another benefit was that checkout of completed subsystems could begin while construction on other subsystems was still in progress.

To complete the checkout and startup of the facility, a detailed schedule was developed describing the activities to be completed on a weekly basis. Designers who had responsibilities for the various subsystems were asked to submit test procedures for checking out their respective systems. Procedures for checking integration of the subsystems were developed by the test and checkout team. With the close cooperation of the various design groups and the ORGDP Development Maintenance organization, the checkout and startup phase of the MHDM Facility was completed in 18 weeks—almost two months ahead of schedule.

2.1.14 EB-I THERMAL CHARACTERIZATION MODEL

G. O. Allgood

One of the control requirements for the AVLIS process is identification and implementation of a closed-loop thermal control package that is consistent with overall process objectives. To achieve this requires a model that accurately predicts the thermal response of the system to changes in the energy balance. A method to facilitate this characterization on MHDM was developed on the EB-I experimental facility.

The model was developed using the temperature gradient vector (partial derivatives) in a closed-form solution to predict steady-state and transient temperatures in the system in response to power step changes. The model is a lumped-parameter predictor based on first-order ordinary differential equations linearized about an operating point. The temperature gradient vector is a real-time calculation based on a system energy balance and uses temperature measurements in feedback to determine the reasonableness of the model (parameter estimation). Inherent to this method is a rotational transformation to decouple the states as defined by the model.

This method was used in four experimental runs to effect thermal control of the EB-I experimental facility. The absolute and incremental error for predicted temperature changes is a mean of 0.05% and 0.02% and a variance of 0.5% and 0.2% respectively.

2.1.15 THE USE OF PROCESS EVALUATORS (PEVs) FOR PROCESS CONTROL AND OPTIMIZATION

J. T. Greer* G. O. Allgood

Process control of the AVLIS process is intimately related to process science and process economics. In order to make control decisions that will accomplish the desired integrated system performance, PEVs are used by the AVLIS process control system. Process evaluators are hardware or software modules used to calculate a parameter that cannot be measured directly on the basis of several independent measurements. PEVs are used to (1) interpret and condense data, (2) give a qualitative interpretation of the state of the system, (3) determine optimal states with appropriate mapping information, (4) estimate and evaluate high-order control decisions, and (5) provide exception-handling control decisions. These concepts are applicable to time-variant multivariable control problems with limited process variable accessibility. Economic optimization can be obtained more easily through PEVs while still allowing adaptation to process variability.

Figure 2.1-4 is a simplified logic diagram showing how PEV fits into the AVLIS control structure. The PEV is made up of several subsystem PEVs that provide information for the higher-level integrated and optimal control PEVs located at higher control levels. The outputs of PEVs are called pseudopoints and are stored in the main database along with other process data.

In order to perform optimal control on any process, there must exist some prior knowledge as to how the process variables can be used to evaluate performance. PEVs are used within the process control structure to interpret process data to determine the true state of the process. The state of the process can be viewed as an n-dimensional vector with transitional characteristics based upon the dynamics of the process. Once the desired state is known, it is the function of the controller to move to the new state with the least possible perturbation.

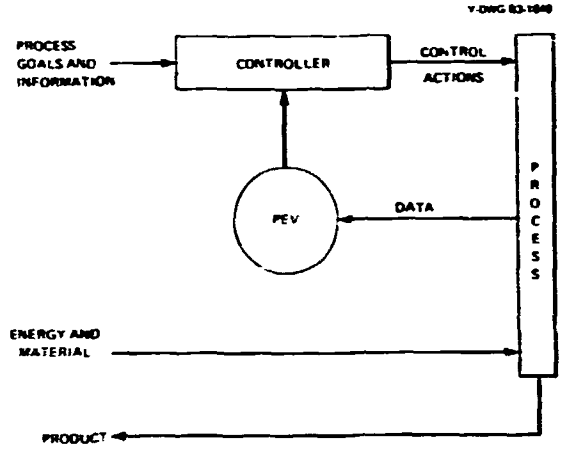

Fig. 2.1-4. Process evaluation (PEV) is the "interpreter" of the process data.

Optimization is the realization of the economic and operational goals of the AVLIS process with the best and most efficient net results. The capability of the control system must include the ability to analyze requests and produce the desired state and necessary control actions that best represent the overall goals.

The AVLIS process has several control modes, each of which relates to a different goal and/or control scenario; two examples are startup and steady-state. The PEV is used to determine control mode, necessary state transition, necessary control actions, and the path the state controller needs to accommodate. Figure 2.1-5 shows a logic representation of state transition and mode control. The

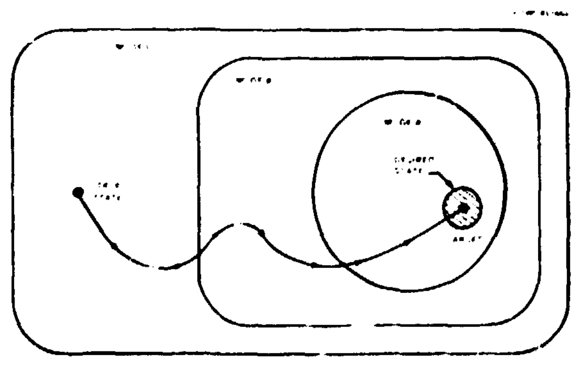

Fig. 2.1-5. Controller determines mode path desired state and control status.

optimal control region is determined by the PEVs, while the state controller executes the appropriate control actions to accomplish overall system goals.

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2.1.16 HEATER SPECIFICATIONS AND DEVELOPMENT

G. O. Allgood F. R. Gibson

The research and development effort undertaken to design satisfactory heaters for MHDM covered a complete heater system including heater case, filament, filament support, and heater leads.

Heater development for MHDM encompassed unusual constraints: The heaters would be exposed to a hostile environment of high system temperature for a period of several days with some thermal cycling, high vacuum, presence of uranium vapors, and some mechanical vibration; and they would require high reliability and moderately high heat density. Some of the more obvious constraints included physically and thermally matching the heaters to what was to be heated and electrically matching them to their respective power supplies and control circuits.

This work began with a study of available heaters and heater materials, specifically material properties such as vapor pressure, recrystallization temperature, ductile-to-brittle temperature, electrical resistivity, thermal expansion coefficient, resistance to thermal shock, and melting points. Several heater designs were tested in conditions approximating those in MHDM. These tests offered the added advantage of providing many hours of operating experience with the heater design that finally was chosen.

2.1.17 PUMPING SYSTEM FOR LIQUID METAL

G. O. Allgood C. L. Carnal*

An effort was undertaken to develop a liquid metal pumping system using a flat linear induction pump as the metering device. This task involved a literature search and, given a set of criteria, a scoping exercise using first principles to determine specific pump parameters.

*Tennessee Technological University.

The specifics of the analysis involved defining the physical and electrical structure of the pump as well as its performance parameters. Areas of importance in the study were reliability, maintenance requirements, controllability, and efficiency. These parameters defined the operational capability of the device and determined its effective use in the system environment.

Continuation of this development effort has been postponed pending DOE process selection, which is scheduled for 1985.

2.1.18 MHDM THERMAL MANAGEMENT SYSTEM

G. O. Allgood D. H. Gray*

An important aspect of the MHDM ICAM is the sensing and controlling of the system's thermal profile. The issues involved in this task range from experimentation in support of heater development to human-machine interface requirements.

The MHDM thermal management system is designed around the ICAM philosophy, which provides for system improvements and integration to be accomplished in an efficient manner based on a set of well-defined criteria. The system is a distributed control hierarchy that takes advantage of the natural segmentation of the system's thermal aspects. The approach is to define system criteria and requirements, provide functionality through instrumentation and hardware, integrate it into a complete thermal control package, and then integrate this subsystem into the overall MHDM ICAM system.

The key to the success of the thermal management system is the proper definition of the MHDM operational states for thermal control, which can be broken down into four distinct areas:

- definition of system operational modes;
- definition of system variables and parameters used in measurement, diagnostics, and process control;
- formal definition and classification of failure modes and response actions to be taken; and
- classification of system disturbances and the control response to each one.

(Note that each operational mode will have associated with it its own distinct failures and disturbances, each requiring different control laws.)

*Y-12 Engineering.

Hardware concerns were with issues of reliability, functionality, integration, logistics, and reconfiguration capability. These issues significantly influenced the overall design because they are important to the successful operation of the system. A key achievement was optimization of the system's reliability through hardware and software, particularly the elimination of known single-point failures. An important facet of the design is the inherent capability to determine system integrity through diagnostics and sensing.

Software considerations required defining the basic software structure for accommodating control capability and determining an optimum display system for the operators. This involved establishing the basic functionality for display and control, developing real-time thermal process evaluators to determine the qualitative as well as quantitative aspects of the system, and defining the interaction of the thermal control system with the overall ICAM system.

2.1.19 CONTROLS DEVELOPMENT IN A DEMONSTRATION FACILITY

G. O. Allgood J. T. Greer*

The process control strategy for AVLIS is based on three distinct functional levels: regulatory, integrated, and optimizing. The repetitive and regulatory tasks are accomplished by a regulatory control composed of loop controllers, PLCs, and intelligent control boxes. Typically, a setpoint is the only input required at the regulatory level, and outputs containing status information from this level are used as needed by higher control elements. The integrated control level is primarily responsible for maintaining or modifying a process state and orchestrating the elements of the regulatory level, while optimizing the control level is primarily responsible for the net process performance and interfacing high-level goals and commands into the overall control system. *Figure 2.1-6 is a logical diagram* of this interaction and level concept. It must be kept in mind that the function of each level may or may not be contained in the same computer; it may be in the module control computer (MCC), data concentrator and controller (DCC), or some other location. There is significant overlap in data acquisition functions and in the locations where process performance models are run.

As Fig. 2.1-6 illustrates, bulk process data processing is handled at the lower control levels and more qualitative performance analysis at the higher levels. Note, too, that the supervisory function is not a control level but rather an interface to the overall control. The reasons may not be obvious at this point, but one can well imagine that control tasks will not be limited to any one level and therefore require total control system operability.

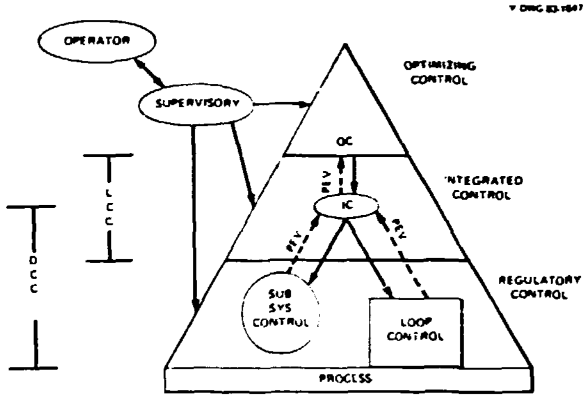

Fig. 2.1-6. Hierarchical control.

Another important aspect of an advanced control system is the human-machine interface. Figure 2.1-7 shows a more detailed representation of the supervisory/human-machine interface and illustrates that the operator is providing high-level control information and in turn requires that high-level *information be provided to him.*

The operator provides very important management goals but is able to digest only a very limited quantity of information. The important point illustrated in Fig. 2.1-7 is the interpretation required

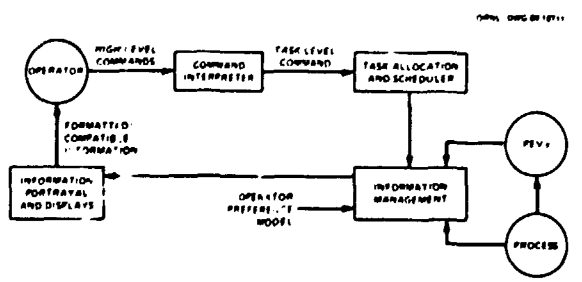

Fig. 2.1-7. Supervisor/human-machine interface.

*ORGDP AVLIS Division.

before individual tasks can be executed. Furthermore, these tasks must be consistent with the overall goals of process operation and other tasks being executed within the system. The operator therefore requires a very condensed but accurate version of the overall process state. This interpretation is done qualitatively and quantitatively in terms of the overall performance goals of the process.

To implement such a control structure will require many hours of development because of the mass of data involved and the complexity of the process, and successful completion of this task will require both extensive preplanning and phased implementation. Also, the dynamic nature of the process requires that flexibility be designed into the structure to allow for real-time performance evaluation of each operational control phase. The development cycle as described in this approach will require an extensive development period before final implementation and demonstration.

2.1.20 ELECTROMAGNETIC NOISE CHARACTERIZATION IN MHDM

J. L. Horton

Electromagnetic noise in the MHDM Facility comes from two major sources: arcing (within the vessel) of the dc voltage used on the uranium vapor-producing electron guns, and firing of the phase-fired silicon-controlled rectifiers (SCRs) used for emission filament control and numerous other heaters. The SCR noise is significant but has not been a real electromagnetic interference (EMI) problem. The high-voltage arcing noise is more severe and has in the past produced problems (since corrected) in several measurement and control systems. Most subsystems have been immune, however, due to the use of fiber optics and isolating the 4- to 20-mA transmitters. Oscilloscopes and spectrum analyzers have been used with wide-frequency-response voltage dividers and current transformers to characterize the conducted transients at numerous locations within the high-voltage system, while pickup coils have been used for radiated EMI. Characterization of the electromagnetic noise and an understanding of its source was a necessary prerequisite to eliminating EMI in these systems.

2.1.21 MAGNETIC FIELD CONTROL IN MHDM

K. R. Carr

Improvements were made to the control system used for regulation of current in the MHDM magnetic field coils. This system provides a magnetic field for the proper trajectory of the electron beam (E-beam) in the vessel. Control system improvements were necessary because of deficiencies in the original current control circuits in the commercial power supplies; the current control was erratic at times and was highly susceptible to the effects of electrical noise.

The control circuits were modified and a high-output (2.5 V/A as compared to the original 1 mV/A) feedback scheme was implemented to provide the following improvements and meet all functional and performance requirements:

1. provision for adjusting remote setpoints from the computer-based control system,
2. activation and rescaling of previously designed equipment to allow manual adjustment of setpoints from the control room,
3. coil current control stability several times greater than actually required, and
4. excellent immunity of the coil current control to any effects of occasional E-beam system arcs.

System performance is presently a 0.25-A decrease in coil current in the first 30 min, then controlled within ±0.02 A thereafter; this can be further improved to a 0.05-A decrease in the first 30 min, then controlled within ±0.02 A thereafter. The required current control stability is only ±0.1 A, and the 30-min stabilization period with the existing feedback scheme is inconsequential because during normal operation the coil current systems are energized for more than 30 min before the final setpoint of coil current is made. Therefore, the systems presently installed are adequate. However, better feedback components have been ordered that will make more stable control available if this is necessary in any future AVLIS applications. The AVLIS Program has several power supplies of the type used in this application.

The immunity of the control system to nearby arcs of several hundred amps in circuits at several thousand kilovolts was verified by data from measurement instrumentation and also by visual observation of the E-beam through a viewing port; the path of the E-beam did not change perceptibly during periods of the most intense arcing.

2.1.22 AVLIS LASER DATA ACQUISITION AND CONTROL SOFTWARE

T. E. Gill*[†]

Laser data acquisition and control software for AVLIS was designed to provide experimenter-friendly control of the laser data acquisition system hardware, control the actual data acquisition, and give to the experimenter automatic and manual data-reduction capabilities on the acquired data. Laser system setup and control using this software package is described elsewhere (see 2.1.23) and will not be discussed further here other than to say that these control routines are selected from the same menus used to perform data acquisition and reduction.

Data acquisition is accomplished through the use of CAMAC style acquisition modules, specifically the LeCroy 8212/A data logger with its associated 8800/12 memory modules. Scan requests by the system are passed to a laser DLC, and the acquisition hardware is supplied with 1024 timed pulses, which it uses to trigger data acquisition. Acquired data can be read from the data logger; data from selected scans will be automatically reduced for use by the MHDM system operators, and, if desired, all channels may be written to file. Up to 32 selected process point values can be stored with his sweep data. The software system provides the ability to take scans automatically at some set user-selectable interval and write to file only those scans that will require future analysis. This scanning/data reduction routine, although controlled by the main analysis and control program, is a separate, free-running program and therefore does not interfere with analysis programs running concurrently.

The data analysis section of the software is composed of 67 routines, which provide the experimenter with all of the calculation tools required to examine acquired data. The routines allow the user to read raw data files, reduce the absorption data using Gaussian curve approximation and fitting, manipulate raw or reduced data using all standard arithmetic operators (including positive and negative nonlinear functions), and save or plot the resulting vectors. Since each routine can be called by a single command line which is interpreted by the software, a "command file" feature is included which allows the user to perform multiple operations on data without having to type in every line. The plotting package provides multicolored plots on a Tektronix 4100 Series terminal. Up to five different plots on each graph, plotted as either X-Y or Y-time, are supported with the capability to print the graph on a hard-copy unit. As part of this package, a routine will automatically perform all data reduction on an entire run of raw sweep absorption data. This feature enables the user to plot the entire run in the form of a time trend and manipulate that data as any other data vector.

*Midwest Technical, Inc.

[†]Work performed under subcontract to ORNL (M. J. Roberts, project leader).

2.1.23 DIAGNOSTIC LASER CONTROL SYSTEM

T. E. Gill* D. R. Patek

The Diagnostic Laser Control System was designed to permit an AVLIS operator or experimenter to select a specific laser/experiment configuration and have the system automatically set the associated hardware to provide the data desired. The system is based on the use of a VAX as the laser diagnostic data concentrator and controller (LD/DCC), a PDP 11/23-based dye laser control system as a dedicated loop controller (DLC), Tektronix 4100 Series graphics terminals, and CAMAC type final element data acquisition and control equipment. Optical and electronic switching techniques provide a high degree of flexibility in the selection of diagnostic laser/experiment configurations.

The system, which is shown in Fig. 2.1-8, is composed of two sections—the DCC in a master-slave configuration with the DLC, and the CAMAC control and data acquisition hardware connected directly to the LD/DCC. The first subsystem, the dye laser controller, is described elsewhere (Sect. 2.1.6). The remaining subsystem is controlled

*Midwest Technical, Inc.

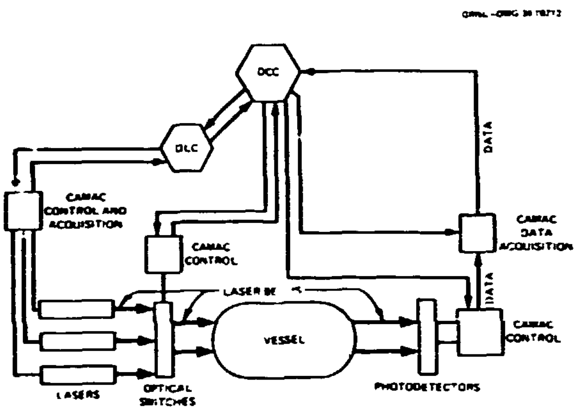

Fig. 2.1-8. Diagnostic laser control system.

directly by the LD/DCC and consists of CAMAC network supporting data-acquisition modules and input and output register modules. These input and output modules are used as switches to route the data signals to the proper data-acquisition modules as well as control the single-pole/double-throw optical switches that route the laser beams. Through the use of menu-driven software and interactive graphics, the experimenter/operator can either build a new configuration or select an already existing one. Joystick cursor control in association with a "connect the blocks" interactive graphics format (see Fig. 2.1-9) enables the user to set up quickly and store (if desired) new laser/experiment configurations. The information required to define a configuration includes optical switch settings, laser wavelengths, and experiment path lengths. With this information, the system sets the optical and electronic switches required to send the proper laser beams to the selected experiments and route the resulting data signals to the proper data-acquisition hardware.

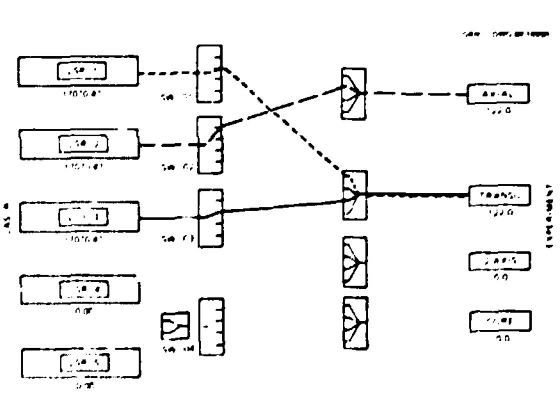

Fig. 2.1-9. Illustration of interactive graphics display.

2.1.24 CONNECTOR AND FEEDTHROUGH DEVELOPMENT FOR MHDM

M. B. Herskovitz H. E. Cochran*

The very high product throughput of the AVLIS process implies a significant loss of revenue when the module is not operating. Thus, the time required to shut down an operating module, remove its internals, install new internal hardware, and restart the module must be minimized. The time required to disconnect instrument and power connections and accurately reconnect them is an issue in AVLIS because of the large number of sensors and heaters involved. In 1982 a development effort was begun to address these issues, which involved sensors, connectors, feedthroughs, and cables.

The process conditions that affect connectors, feedthroughs, and cables depend on their physical location:

A. Temperature. The outside of the vessel is at an ambient temperature of approximately 20°C, while the ambient temperature inside the vessel ranges from 200 to 400°C.
B. Pressure. While the outside of the vessel is at one atm, an internal vacuum range from 10^{-5} to 10^{-7} torr is required.

Working closely with vendors experienced in this area has made it possible to procure high-density feedthroughs and connectors, which are compatible with process requirements and enhance quick turnaround. These components have been delivered and installed on MHDM.

*Consultant.

2.1.25 EXPERT PERSON TRAINING FOR MHDM

R. W. Tucker, Sr.

With the increase in both the frequency and duration of MHDM runs requiring multishift operation, a need developed for additional qualified instrumentation personnel to provide consultation and support during runs. This need gave rise to the "expert person" training program.

An expert person is an instrumentation engineer trained in the details of hardware and software for the MHDM system. The expert person is responsible for

- educating the operations staff on the use of the ICAM system during runs,
- serving as an on-site consultant to the maintenance organization to identify and solve any instrumentation-related problems (including PLC software and DCC hardware and software), and
- most importantly, constantly searching out data errors and discrepancies and observing operational response to the ICAM system in order to identify improvements to the ICAM development team.

The expert person effort involved four phases: selection, training, certification, and implementation. In the training effort, the following items were covered on a subsystem-by-subsystem basis: functional description, major components, critical measurements, typical values, common problems, fault-isolation techniques, subsystem interfaces, and functional verification techniques. Each person completing the training has a hard copy of (or knows where to find) all drawings, operating procedures, functional descriptions, calibration information, PLC flowsheets, and software flowsheets. The expert person must know the consequences of possible actions and always must take the minimum action necessary to keep a run going. Training continues in the field preceding and during each run. When appropriate, candidates are sent to special schools such as the Modicon PLC school or the DEC VAX school.

It is anticipated that expert person candidates will progress at their own pace. The I&C MHDM chief engineer will decide when a candidate is ready to assume the responsibility as an expert person. A certified expert person will have the ultimate responsibility for preventing the termination of an MHDM run as a result of instrumentation-related failure.

2.1.26 DEVELOPMENT OF A HIGH-VOLTAGE ISOLATED THERMOCOUPLE AMPLIFIER

M. L. Bauer

A high-voltage isolated thermocouple amplifier was designed and constructed in order to measure the temperature of vessel internal structures at elevated temperatures and voltages. The amplifier was specified to withstand pulsed voltages of thousands of volts and to interface to type S thermocouples with errors of less than 0.5 % at high temperatures. A Burr-Brown Model 3656 isolation amplifier was used with a gain-of-one-hundred front end using a Precision Monolithic, Inc. PMI OP-07 amplifier. Drift was a significant problem since the sensitivity with type S TCs is only 10 μV/°C. An insulated nulling switch was built into the unit to allow nulling of offset errors. Drift was on the order of 1°C per degree C of ambient change. A six-channel unit was built for EB-1, and only one channel failed during one year of operation with pulsed high voltage.

2.1.27 DEVELOPMENT OF AN INTEGRATED CONTROL AND MEASUREMENT SYSTEM

W. W. Manges

(Abstract of thesis for the Master of Science Degree, The University of Tennessee, Knoxville, January 1984)

This thesis presents a tutorial on the issues involved in the development of a minicomputer-based, distributed intelligence data acquisition and process control system to support complex experimental facilities. The particular system discussed in this thesis is under development for the Atomic Vapor Laser Isotope Separation (AVLIS) Program at the Oak Ridge Gaseous Diffusion Plant (ORGDP). In the AVLIS program, we were very careful to integrate the computer sections of the implementation into the instrumentation system rather than adding them as an appendage. We then addressed the reliability and availability of the system as a separate concern. Thus, our concept of a integrated control and measurement (ICAM) system forms the basis for this thesis.

This thesis details the logic and philosophy that went into the development of this system and explains why the commercially available turn-key systems generally are not suitable. Also, the issues involved in the specification of the components for such an integrated system are emphasized. Finally, this document is based on my experience and expertise as well as that of respected experts in the field and input from colleagues in the Instrumentation and Controls Division at Oak Ridge National Laboratory.

2.2 Advanced Instrumentation for Reflood Studies (AIRS) Program

2.2.0 OVERVIEW

M. B. Herskovitz

The AIRS Program is part of an international effort to characterize loss-of-coolant accidents (LOCAs) in PWRs. West Germany, Japan, and the United States have joined forces to examine the problem because the overall cost of this research is greater than any one country can support. Representing the United States, the NRC furnishes advanced instrumentation and analyses of results to obtain improved computer codes while West Germany and Japan provide test facilities and conduct experimentation. ORNL has developed (1) film and impedance probes to measure the void fraction of steam and water mixtures, two-phase fluid velocity, film thickness, and film velocity; (2) strain-gage-based instruments: drag body transducers to measure momentum flux and breakthrough detectors to distinguish water flow from the upper plenum to the reactor core; and (3) fast-responding differential pressure measurement systems. The instrument systems provided by ORNL, including the sensors and electronics, have been developed specifically for these studies and provide measurement capability not previously available. Software was also developed to print out process variables in engineering units.

Film and impedance probes have been installed in the Japanese Slab Core and Cylindrical Core Test Facilities and in the German PKL-II Test Facility. The strain-gage-based breakthrough detector and drag body systems will be installed in the Japanese Slab Core Test Facility III experiments, the West German Upper Plenum Test Facility (UPTF), and the Kraftwerk Union (KWU) Test Facility at Karlstein, West Germany; a single drag body will be installed at the Technical University at Hannover; and a drag body has been supplied to MIT. Differential pressure instrument systems will be installed in the UPTF and at Karlstein.

New cermet materials (about 0.5% platinum in aluminum oxide) and a new brazing alloy (49% copper, 49% titanium, and 2% beryllium) were developed to meet the extremely harsh environmental requirements for film and impedance probes. These sensors were exposed to high-velocity steam and water (an erosive mixture) at high temperatures (up to 900°C) and to thermal transients of −200°C/s.

Metal-sheathed strain gages were developed for use with drag body and breakthrough detector instrumentation. These units operate continuously at 220°C and are capable of short-term operation at 350°C.

2.2.1 TIE PLATE DRAG BODY TRANSDUCERS AND BREAKTHROUGH DETECTORS

J. E. Smith*	H. R. Payne†
D. G. Thomas*	T. M. Cate

During the previous reporting period, a force transducer was developed for measuring two-phase flow drag resistance (Cr^2) in the tie plate of a reactor end box. It included the following special features:

- Existing hardware was used as part of the transducer to provide a nonintrusive presence in the end box.
- Special thermal compensation of unique, weldable strain gages was developed in cooperation with the strain gage manufacturer.
- Remote sensing of excitation voltage was included to minimize thermal effects in the lead wires.
- Transducer materials were chosen that would compensate for thermal sensitivity changes.
- All electrical components were completely encapsulated in Inconel 600 for survival in a steam and water environment.

The force transducer was successfully tested in the instrument development loop (IDL), and production for the UPTF in Mannheim was begun in late 1982.

A drag-flag type transducer for detecting water breakthrough in the end box [breakthrough detector (BTD)], utilizing similar strain gage technology, was developed, tested successfully, and chosen from among several alternatives for use in the UPTF.

A decision was made by KWU to increase the size of the holes in the UPTF end-box tie plate, thereby decreasing the drag force (Cr^2) for a given flow. This change in design in turn required an increase in the sensitivity of both the tie-plate drag body and the BTD. Fabrication of 50% of the drag body transducers for the UPTF was complete at the time these changes were made.

A prototype of each instrument with a modified sensing element was fabricated and tested in the IDL under steam and water conditions for survivability and functional compliance. An accelerated fabrication and testing schedule was initiated in order to meet the delivery requirements without affecting the UPTF schedule.

The decision was also made to conduct the two-phase flow calibration tests at KWU facilities in Karlstein instead of performing additional tests in the IDL at ORNL. End-box instrumentation for KWU and another experiment at the Technical University of Hannover were added to the scope of ORNL work.

Special electronic units (AIRS 20s) were developed and produced to utilize the special features of the transducers and to accommodate the conditions at the UPTF site. (See 2.2.2 for details).

All instruments, associated electronics, test modules, and spare parts were delivered on schedule by the end of June 1984. The instruments at the KWU and Hannover were installed in June and are operating satisfactorily.

The instruments at the UPTF have been calibrated and mounted on dummy-bundle end-box assemblies and will be installed in the test vessel beginning in October 1984. The installation is expected to be completed in March 1985.

*Engineering Technology Division.
†Y-12 Engineering.

2.2.2 UPPER PLENUM TEST FACILITY DRAG BODY AND BREAKTHROUGH DETECTOR ELECTRONICS DEVELOPMENT

W. F. Bethmann, Jr.
B. A. Denning D. R. McNeilly

The previous I&C Division progress report[1] stated that the final configuration of a strain-gage-based amplifier and signal-conditioning electronics were being designed. Six prototypical units were subsequently fabricated for preliminary testing to document the final design for functional operation. These electronic circuits are housed in single-width nuclear instrument modules (NIM) for compactness and ease of mounting. They are called AIRS 20 strain-gage amplifiers, hereafter referred to as AIRS 20s. To date, 194 of them have been fabricated and functionally tested. They were installed in NIM bins and mounted in instrument cabinets designed for the UPTF in Mannheim, West Germany. These instrument cabinets are now in place at UPTF, and preacceptance testing is being performed. Drift testing and power-up failure testing were performed in order to eliminate or repair any component failures.

An interesting feature of the AIRS 20 is the incorporation of a portable data acquisition system to receive valuable test points on the AIRS 20 printed circuit board via a connector mounted on the front panel. All important test points in the AIRS 20 are available at this connector. The data acquisition system is a valuable device for data logging and file management as well as AIRS 20 troubleshooting. It has the capability of giving a shunt calibration signal, triggered locally or remotely. The main data acquisition system at UPTF will provide remote triggering of the shunt calibration through a fan-out circuit built into the instrument cabinets. Visual indication of this calibration is available in each instrument cabinet. Another feature of the AIRS 20 module is provision for dual buffered outputs, one for data acquisition and the other for the feedback control system at the UPTF.

A small instrument and electronic system as described above will be designed for the Slab Core Test Facility III in Tokai, Japan. Approximately ten AIRS 20 modules will be required, and all specialized features will be included.

1. F. R. Mynatt, ORNL-5931/VI, December 1982.

2.2.3 UPTF DIFFERENTIAL PRESSURE MEASUREMENT SYSTEM

W. L. Zabriskie H. R. Payne*

The UPTF at Manneheim is a large experimental facility of the International 2D/3D Program that is investigating LOCAs in PWRs. ORNL is supplying 50 fast-responding differential pressure measurement systems (DPMS) for this facility through the AIRS Program.

The DPMS supports the investigation of refill-reflood dynamics by measuring the pressure drop across vent valves (5 systems); across a tie plate (a perforated plate in the upper end box of a fuel bundle) (9 systems); and above tie plates into the upper plenum (36 systems). Major constraints on these measurements are the operating environment, the small magnitude of the pressure signal, and the relatively high frequency response required.

Development activities in previous years had identified the characteristics of a system necessary to meet the constraints. These system characteristics include pressure transducers with exceptionally high resonant frequencies located outside the test vessel but linked to it by fluid-filled sensing lines. To prevent flashing in the sensing lines during depressurization of the test vessel, the sensing lines must be purged continuously.

Designs incorporating these system characteristics were developed and went through several iterations with the test facility designers. These designs call for purge blocks, which control the flow of pressurized fluid in the sensing lines; measurement blocks, which incorporate the pressure transducers and service manifolds close to the test vessel; and electronics blocks, in which signal processing is accomplished.

These designs were fabricated at ORNL and shipped to the UPTF. Subsequently, the systems were installed and checked out by ORNL personnel. The 50 measurement systems are ready for final checkout during the facility shakedown tests in 1985.

*Y-12 Engineering.

2.2.4 UPTF AUTOMATIC CALIBRATION SYSTEM

P. L. Butler

This unit is designed to provide testing of a total strain gage measurement system or any of its individual components. Values such as resistance or voltage of a strain gage element, amplifier, connective cable, or associated temperature sensor can be measured and logged, and the information can be used as a chronological quality assurance record. This documentation is extremely useful when successive construction and installation steps are required and one wishes to demonstrate that all components function properly from initial acceptance to operation of the system. When the strain gage amplifier was designed, a front-mounted electrical connector was included to make the important amplifier parameters available to the tester by means of a cable.

The tester system consists of an assembly of computer-controlled hardware and associated programs for data acquisition and data-logging tasks. The hardware used in the amplifier tester was manufactured by Hewlett-Packard and consists of an HP 87 computer, disk drive, printer, and an HP 3421A data acquisition system. All equipment is packaged in a transit case for easy transportation and setup.

For any instrument of this type, the user interface is one of the prime considerations because it will be used by many persons with widely varying degrees of experience with such equipment. A menu-driven user interface was therefore chosen for the AIRS amplifier tester. The user is presented with the current mode of operation in a consistent manner at all times, and thus is not surprised when he tries functions not used before. Another advantage of a consistent menu-driven user interface is that manuals will not be required in the field.

The function of the AIRS amplifier tester is to record data for 160 strain elements and associated amplifiers and log it onto diskettes. A running record is kept of all operations; it can be printed or plotted whenever the user requires. The types of data collected include such items as strain-gage bridge resistance, calibration curves, amplifier test conditions, and amplifier test results. At all times, the tester will keep track of user actions and ask for verification if the user requests something that is not reasonable.

The AIRS amplifier tester has proven to be useful, especially with the addition of a 15-Mbyte Winchester disk drive to provide the huge amount of data storage required.

2.2.5 UPTF DATA ANALYSIS PROGRAMS

J. E. Hardy
W. F. Bethmann W. P. Murray*

ORNL has supplied 130 force and 50 differential pressure transducers, along with 130 thermocouples, to the UPTF, which is a large experimental reflood test facility. The data reduction software for these sensors and an electronic calibration program were also provided by ORNL. The software package consisted of a series of subroutines written by ORNL and Idaho National Engineering Laboratory (INEL) to operate under the control of a main program written by INEL.

Five different subroutines are used to calculate the required two-phase flow parameters from the raw data. Three subroutines were written by ORNL and two by INEL. A sixth routine, which is a stand-alone program, runs a calibration scheme for the signal-conditioning electronics of the force transducers. The five subroutines accept sensor data, along with certain other calibration and control parameters, and compute desired flow parameters. Manipulation and storage of subroutine input and output data are controlled by the main program.

*Roane State Community College.

2.2.6 DATA ANALYSIS AT THE PKL-II TEST FACILITY, THE SLAB CORE TEST FACILITY (SCTF), AND THE CYLINDRICAL CORE TEST FACILITY (CCTF)

J. E. Hardy W. F. Bethmann

ORNL was charged with two program responsibilities in the data analysis area. The first was to ensure that the software developed by ORNL was operating correctly on the computer systems at the Japanese and West German test facilities, and the second was to evaluate the performance of the ORNL sensors during the refill-reflood testing. To fulfill these responsibilities, ORNL sensor data were analyzed simultaneously at a foreign test facility and at ORNL. The results from the two analyses were compared and sensor performance was evaluated. This procedure was followed for two PLK-II tests, three SCTF runs, and four CCTF experiments.

After some minor changes in the software at both ORNL and the foreign installations, detailed reviews of data from each sensor type showed that the software installed on the foreign computer systems was producing the same results as the data reduction programs at ORNL.

In judging the performance of the ORNL instrumentation, two criteria were used whenever feasible. First, the data were checked to see if they were within physical limits; for example, the void fraction should fall between 0 and 1, and the film thickness should be positive and fall between 0.1 and 8.0 mm. If the data appeared suspicious, calibration values were studied to determine the reason for the questionable data. (Perhaps sensor failure had occurred or incorrect calibration data were obtained.) Second, the probe data were compared to similar instrumentation values. For example, the void fraction measurement from an in-core flag probe is compared to the void fraction determined from a differential pressure transducer. In this type of comparison, it must be kept in mind that the ORNL sensors measure a very local condition (small measuring volume), whereas most of the other transducers in the test facilities monitor a more global region. An exact agreement is not expected under these conditions.

Analysis of the data from the three test facilities indicates that the ORNL instrumentation produced reasonable results and fairly good agreement with similar instrument measurements. The ORNL sensors exhibited effects of the major thermal hydraulic phenomenological events occurring during a refill-reflood experiment. These events included initial presence of water, rewetting, flow oscillations, and flow concentration distributions. Trends discernible in the ORNL sensor output followed trends in similar instrumentation very well. Some differences from conventional instrument outputs were noted, such as the earlier rewetting of unheated flag probes as compared to heated rods, but these discrepancies could be attributed mostly to differences in measuring location and measuring volume.

Although sensor failures did occur at all three test facilities, the number of failures was not unexpected or unreasonable considering the geometrical constraints and environmental conditions under which the probes operated. Generally, when a probe was functional, the data from that sensor were reasonable and agreed qualitatively with events occurring during the experiments. For the first time, usable and valuable in-core data were obtained during a refill-reflood test. Also, many other in-vessel measurements were provided by ORNL instrumentation. The results from all of these instruments will enhance the understanding of simulated PWRs during refill-reflood conditions under a postulated LOCA.

The five subroutines are ENGTC, ENGDP, ENGDT, DBZERO, and DBLOAD; the stand-alone program is AIRS20CAL.

- Subroutine ENGTC (INEL) accepts a calibrated raw data value and converts it to a temperature value in SI engineering units (EU). The temperature is calculated using a fourth-order fit.
- Subroutine ENGDP (ORNL) accepts a calibrated raw data value and converts it to a differential pressure in SI units. The software allows for forward and reverse flow calibration factors to be applied to the sensor calibration and test data.
- Subroutine ENGDP (INEL) accepts a calibrated raw data value from a force transducer and converts that value to an SI force point. This program allows for forward and reverse flow calibra-

tion constants. The output from this program is a thermally uncorrected force value.

- Subroutine DBZERO (ORNL) calculates coefficients for a least-squares curve fit to data from a drag body or breakthrough detector. The data required are the sensor temperature and corresponding uncorrected force value. This subroutine must be run for each force transducer.
- Subroutine DBLOAD (ORNL) calculates the thermally corrected force from a drag body or breakthrough detector. The thermal correction is accomplished using the curve found by DBZERO and the sensor thermocouple. Since this routine employs curve coefficients determined in DBZERO, DBZERO must be run before DBLOAD.
- The program AIRS20CAL will automatically, through the main data acquisition system, do a four-point calibration of the force transducer signal-conditioning electronics. The program will record a zero value, a plus calibration point, a minus calibration point, and a final zero value. These four points will be recorded and stored before and after each test. Zero and calibration data will be compared to laboratory-determined values, and electronics with significant zero drift or calibration deviations will be flagged as suspect. Calibration data and comparisons are stored in a file that can be retrieved for post-test review.

2.2.7 ORNL INSTRUMENTATION PERFORMANCE FOR SLAB CORE TEST FACILITY (SCTF)—CORE 1 REFLOOD TEST FACILITY

J. E. Hardy
R. A. Hess J. O. Hylton

(Abstract of NUREG/CR-3286, ORNL/TM-8762, November 1983)

Instrumentation was developed for making measurements in experimental refill-reflood test facilities. These unique instrumentation systems were designed to survive the severe environmental conditions that exist during a simulated pressurized water reactor LOCA. Measurement of in-vessel fluid phenomena such as two-phase flow velocity and void fraction and film thickness and film velocity are required for better understanding of reactor behavior during LOCAs. The AIRS Program fabricated and delivered instrumentation systems and data reduction software algorithms that allowed the above measurements to be made. Data produced by AIRS sensors during three experimental runs in the Japanese Slab Core Test Facility are presented. Although many of the sensors failed before any useful data could be obtained, the remaining probes gave encouraging and useful results. These results are the first of their kind produced during a simulated refill-reflood stage of a LOCA near actual thermohydrodynamic conditions.

2.3 Support for Large-Scale Engineering Projects

2.3.1 THE HRB-17/18 GAS ANALYSIS AND MOISTURE INJECTION SYSTEM

R. E. Harper
W. A. Bird R. E. Hutchens
D. R. McNeilly R. W. Jones

Information is needed on the behavior of failed trisocoated, dense UCO_2 particles in a moist environment. Two capsules, designated HRB-17 and -18, will be irradiated in positions RB-5 and -7 at the High Flux Isotope Reactor (HFIR) with specified amounts of moisture injection in each capsule. During irradiation, the fission gas release-to-birth (R/B) rate and the effluent gases that may result from fuel hydrolysis will be carefully measured and analyzed. The I&C Division is responsible for the design, installation, and maintenance of experiment control, moisture injection, gas measurement, and data acquisition for these experiments.

The moisture injection and gas analysis system will serve both capsules while they are being irradiated simultaneously. Both capsules will be operated at a fuel inner radius temperature of 800°C using a helium or helium/neon mixture to attain the desired temperature. Unless moisture is deliberately injected, the moisture content of the gas mixture will be maintained at <2 ppm H_2O. Moisture levels in the control gas will be established with a temperature-controlled saturator that provides a specific dew point thus assuring specific moisture levels at specific temperatures. In each cycle, 100 ppm of moisture will be injected into HRB-17, and 10,000 ppm of moisture will be injected into HRB-18 in one cycle only. During irradiation, any fuel reactions will be monitored by analyzing the effluent control gases for moisture and any gaseous products that may result from hydrolysis. Since the moisture content of the gas mixture is strongly dependent on the temperature and pressure inside the saturator, precise temperature control is needed. This is accomplished by determining the dew point from a chromel-alumel thermocouple inside the saturator and verifying these results by measuring absolute moisture content with an electrolytic trace moisture analyzer.

Reactive gas release from hydrolyzed fuel is monitored by gas chromatography. Effluent gases of interest are CO, CO_2, O_2, H_2, N_2, and CH_4. All of these gases except hydrogen may easily be measured using gas chromatography. A separate instrument for detecting 1 to 100 ppm hydrogen was developed for this task.

The HRB facility control room provides the necessary equipment to accomplish the desired temperature and moisture control, measurement, and data aquisition.

2.3.2 CORE SUPPORT PERFORMANCE TEST

P. G. Herndon

The design, installation, and successful operation of instrumentation and control systems for the Core Support Performance Test (CSPT)[1] were completed in March 1983. The CSPT will test graphite elements of the High-Temperature Gas-Cooled Reactor (HTGR) core support structure by subjecting them to a controlled environment at HTGR operating conditions. The concentration of water, hydrogen, and carbon dioxide is controlled so that 6 months of test operation simulates 40 years of reactor operation.

The CSPT, which is an addition to the Component Flow Test Loop (CFTL),[2] required extensive modifications to the loop control system in order to accommodate a 500-kW heater installed in the test section, and two 4-in. pneumatically actuated flow control valves added in the loop. An impurities control and measurement system was also provided. The impurity control system generates and injects trace quantities of impurities into the circulating helium. The impurity concentration is controlled by a feed and bleed method. A $108 thousand state-of-the-art automated process gas chromatograph measures the impurity concentration of CO, H_2, CH_4, and Ar. Electrolytic, electromechanical, and capacitance techniques are used to measure the concentrations of oxygen and water.

The CSPT was run in the CFTL, which is a high-pressure high-temperature, high-power, closed-circuit gas loop. The $10 million loop (about $3 million of which was for instrumentation), conceived as the Core Flow Test Loop, was designed to the requirements for testing simulated segments of the core assemblies of the Gas-Cooled Fast Reactor (GCFR). Thus, the loop includes such features as a 640-channel data acquisition system and a direct digital control system capable of generating and recording the fast transients in pressure, temperature, and flow that can be imposed on the test object. Major features of the 4-in.- and 6-in.-diam, 304H stainless steel pipe loop are gas-bearing, variable-speed circulators[3] vortex shedding flowmeters (100:1 flow range at an accuracy of 1% of reading[4,5]), nuclear quality (N-Stamp) flow control valves, a 4.4-MW air-cooled heat exchanger, and a 16-in.-diam test vessel. At the termination of the GCFR program, the CFTL was assigned to the HTGR Program under the new designation Component Flow Test Loop.

1. J. P. Sanders, A. G. Grindell, and W. P. Eatherly, "Core Support Performance Test in the Component Flow Test Loop," *Gas-Cooled Reactor Today*, Vol. 1, Proceedings of the Conference held in Bristol, September 20–24, 1982, BNES.

2. W. R. Huntley and A. G. Grindell, "System Design Description for GCFR-Core Flow Test Loop," ORNL/TM-7455 (December 1980).

3. H. C. Young and A. O. White, "Gas-Bearing Circulators for HTR Component Flow Test Loop," paper to be presented at ASME Winter Annual Meeting, New Orleans, Louisiana, December 10–14, 1984.

4. S. P. Baker, R. M. Ennis, Jr., and P. G. Gerndon, "Application of a Vortex Shedding Flowmeter to the Wide Range Measurement of High Temperature Gas Flow," *Flow 81: Its Measurement and Control in Science and Industry*, Vol. 2, Instrument Society of America (1981).

5. S. P. Baker, R. M. Ennis, Jr., and P. G. Herndon, "Development of a Wide Range Vortex Shedding Flowmeter for High Temperature Helium Gas," ORNL/TM-7794 (July 1981).

2.3.3 PRESSURIZED THERMAL SHOCK TEST FACILITY

T. Cate
P. G. Herndon F. R. Gibson

Design, construction and startup of the pressurized thermal shock test facility was completed. The facility is designed to subject a highly instrumented thick test vessel to conditions of thermomechanical stresses and fractures characteristic of realistic overcooling accidents.

Five modular instrument panels were fabricated, providing a five-zone programmable temperature control system for the outer test vessel, flow controls, pressure controls, and other control and monitoring functions. In addition, cabling and interconnection interfacing was provided for connecting 30 loop parameter signals and approximately 140 specimen sensor signals to a computer-based data acquisition system and redundant data logger.

Operational assistance was provided during the PTSE-0 and PTSE-1 experiments, both of which were successfully completed. The total instrumentation effort in support of this experimental program has been in excess of four person years.

2.3.4 TEC-ORNL CONFIRMATORY TEST PROGRAM FOR RADIAL GAMMA THERMOMETER SENSOR

P. G. Herndon

The ORNL Forced Convection Test Facility (FCTL) was reactivated after 10 years in standby. The facility has been used to implement a test program carried out by ORNL and Technology for Energy Corp. to qualify gamma thermometers as monitors of inadequate core cooling in Arkansas Power and Light Company's ANO-1 and ANO-2 PWRs. The FCTL facility is a high-pressure, high-temperature, forced-circulation water loop capable of depressurization tests simulating a loss-of-coolant accident in a PWR. The loop can be operated at temperatures and pressures up to 650°F and 2250 psig with a water flow through the test section of up to 112 gal/min at variable test section power inputs up to 140 kW.

All existing instrumentation for the measurement and control of flow, pressure, temperature, and power was placed in operating condition. This included a 128-channel DEC PDP-8E computer-controlled data acquisition system. An additional 256 input channels were installed to accommodate 350 new temperature, power, and flow measurements transmitted from the gamma thermometer test piece. An automatic flow measurement and control system consisting of two turbine flowmeters and two high-pressure valves was also designed and installed in the reflood water supply system, which was a new addition to the existing system. The test program was successfully concluded.

2.3.5 IN-PILE IRRADIATION TESTS

W. A. Bird
R. R. Bentz D. R. McNeilly

In-pile experiments are conducted at the HFIR and the ORR. Modifications are being completed at the HFIR for experiments designated HRB-17 and -18.[1] These experiments are a continuation of a series of irradiation tests of HTGR fuel materials. The data acquisition system has been updated to receive and store data on an Autodata-10 data logger, which is connected by a data communication link to the ORR Data Acquisition System (ORRDAC).

Tritium Oak Ridge Reactor Experiment No. 1 (TRIO-01) at the ORR was a cooperative project between ORNL and Argonne National Laboratory. Self-powered neutron detectors were used to measure neutron flux levels near the experiment's capsule. The tritium-producing experiment went into operation in March 1983 and was removed in June 19%.

A series of magnetic fusion energy (MFE) experiments, designated MFE4A, MFE4B modified, MFE4B, MFE4B modified, and MFE4J, have also been in operation at the ORR. The MFE4A modified, MFE4B modified, and MFE4J experiments are in irradiation at the present time. The TRIO-01 facility was modified to receive the MFE4J experiment.

The Light Water Reactor Pressure Vessel Facility[2] was modified to receive the Heavy Section Steel (HSST) Irradiation Test. A Molytek Model 2702 solid-state recorder replaces two Minneapolis Honeywell strip chart recorders on this experiment for test and evaluation purposes. This recorder monitors temperatures and provides alarms.

1. J. W. Cunningham, ORNL-5482, November 1978, p. 53.
2. J. W. Cunningham and J. M. Jansen, ORNL-5482, November 1978, p. 53.

2.3.6 COMPUTER-INTEGRATED MANUFACTURING PROJECT FOR Y-12 PLANT METAL PREPARATION DIVISION

2.3.6.0 OVERVIEW

S. S. Gould

In February 1984, the Metal Preparation Division at the Oak Ridge Y-12 Plant requested a team of ORNL I&C engineers to survey manufacturing automation needs of the divisional manufacturing facilities and prepare a preliminary design plan to meet those requirements. An I&C team was established to develop a design philosophy and a preliminary cost estimate for the implementation, and to identify primary vendor hardware for standardization throughout the Division.

The I&C team inspected the Division's 20 process operation areas, which are spread throughout

12 buildings. The operations were found to vary significantly and included ceramic, arc melt, plating, forming, chemical, uranium enrichment and recovery, casting, special processing, foundry, rolling mill, and biological degradation operations. Moreover, in each area the equipment was very diverse in operation, function, and technological evolution (i.e., approximately 400 pieces of equipment included 100 different variations using controls of 1950 to 1980 vintage). Following this survey, the I&C team developed an overall process control philosophy for the computer-integrated manufacturing (CIM) design of the Metal Preparation Division.

A proposal was generated detailing the level of I&C effort required to provide the Metal Preparation Division with a comprehensive CIM plan supported by documentation aids such as block diagrams, instrument flow diagrams, worksheet information on sensors and controls, and a preliminary cost estimate to implement the overall plan (Fig. 2.3-1). An I&C management review team was established to provide overall guidance and direction. The proposed plan was implemented in Building 9204-4 Forming Operations areas to provide benchmark information as to the required resources to implement the overall CIM plan for the Metal Preparation Division.

The CIM design for the Metal Preparations Division is 15% complete (Building 9204-4 and 9204-2 Forming Operations) as illustrated in Fig. 2.3-1. Plans are in place to complete an additional 45% during this fiscal year (Building 9215 Process Areas; 9201-5N, 9204-4, 9201-2 Plating Shops; and 9204-2 Chemical Operations). It has been estimated that a total of 10 work years will be required to complete the overall CIM design plan.

Additional support was requested to help apply the CIM design philosophy to ongoing procurements and installations in various shops under the direction of Engineering personnel. Also, a study

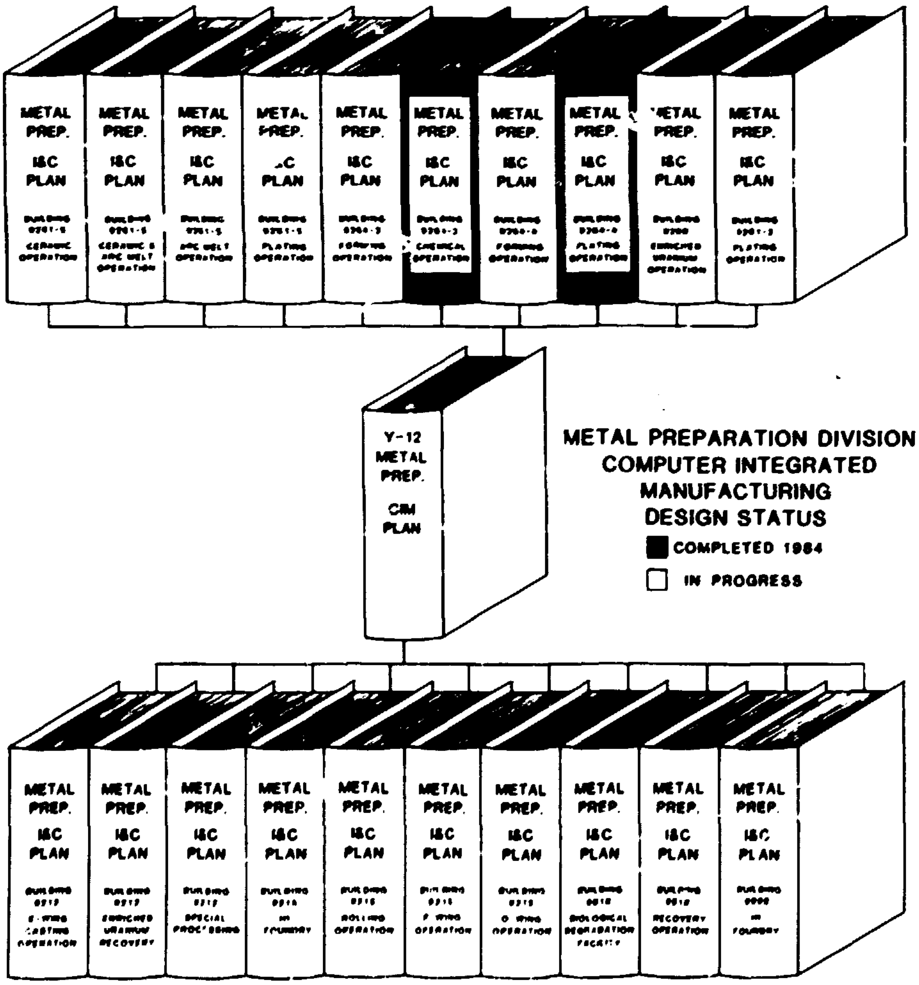

Fig. 2.3-1. Overall plan: computer-integrated manufacturing project for Y-12 Plant Metal Preparation Division.

was completed to identify process control vendors who offered suitable hardware systems for the implementation of the CIM plans. This information was presented to Purchasing and to various Y-12 divisions and committees for review and acceptance. The recommended equipment interface system hardware features have been identified for Building 9204-4 Forming Operations and incorporated in the procurement specifications for competitive bidding. Upgrading and automating furnaces in Buildings 9212 and 9998 is in progress, and I&C is heavily involved in the design and installation of that equipment.

2.3.6.1 PROCESS CONTROL SYSTEM EVALUATION FOR METAL PREPARATION DIVISION MANUFACTURING AUTOMATION

S. P. Baker
S. S. Gould F. R. Ruppel

A team of I&C engineers has developed a model of functional requirements for the various area operations throughout the Y-12 Plant Metal Preparation Division based on existing equipment and the requirements of Y-12 divisional standardization committees, organizations, and area operations supervisors and operators. Acceptable hardware vendors were identified for a number of applications such as

- a programmable controller for relay logic and fast interlocking,
- a small and medium advanced process control system for very independent process equipment control where decentralized process control is required,
- personal computers for local graphical procedures display,
- medium and large *minicomputers* for area or shop processors,
- a distributed process control system for the large interdependent chemical process.

The area requiring most attention was the small-to-medium process control system. The team spent a great deal of time comparing vendor equipment with the model of requirements to determine a best fit and to identify acceptable procurement methods for acquiring the hardware.

Early in February 1984, the Y-12 Plant Metal Preparation Division requested that a team of I&C engineers take an in-depth look at their overall manufacturing automation plan. Over the ensuing six months, the I&C team evaluated the offerings of 42 process control vendors and evaluated and ranked their control systems based on a baseline automation philosophy and statement of requirements. Of the 42 vendors surveyed, only five passed the six Go/No-Go criteria (host, stand-alone, non-volatile memory, fill-in-the-blank connect-the-block, vendor track record, and a cost of $50,000 or less). Team members visited the manufacturing facilities and held discussions about product offerings in the near term as well as the flexibilities of the products to meet very demanding advanced control schemes. The vendors then visited the installation for follow-up discussions to ensure that inadequacies could be overcome. The five vendors were scored according to their ability to meet 18 additional requirements:

- gateway cost,
- plant license cost,
- controllers supported per local area network,
- typical system cost,
- ability to display in-house-generated graphics/text procedures,
- ability to document easily the code in a meaningful way,
- number and flexibility of process control algorithms,
- maximum application size constraints,
- ease of display generation,
- cost of redundancy,
- mean-time-between-failure and mean-time-to-repair indexes,
- availability of online and self-test diagnostics,
- human/machine interface,
- levels of access security,
- floating-point mathematics,
- system scan time,
- local nonrotating, nonvolatile variable storage capacities, and
- environmental rating.

The highest ranked vendor could meet 82% of the advance control system requirements. This evaluation process is documented with the rank and scoring of each process control vendor's system.

A functional specification for the small-to-medium process control hardware was developed for use in specifications. A conceptual design and layout of an equipment interface system (EIS) was developed to house the controller and all support peripherals, and this functional specification was incorporated into engineering specifications. The functional specification was written in a form that would readily lend itself to cut-and-paste use for inclusion in all future Building 9204-4 Forming Operation procurements and equipment retrofit operations.

A test and evaluation EIS was ordered by the I&C Division, and a second, fully redundant system was ordered by the Metal Preparation Division for software development and as a training aid to familiarize personnel with its overall capabilities.

2.3.6.2 COMPUTER-INTEGRATED MANUFACTURING DESIGN PLAN AND IMPLEMENTATION

S. P. Becker S. C. Rogers
S. S. Gould E. C. Keith
F. R. Ruppel M. E. Greene

The first two Y-12 Plant Metal Preparation Division processing areas to be assessed by the I&C Division for a comprehensive CIM design plan and cost-estimate support documentation were the Building 9204-4 and 9204-2 Forming Operations. Implementation plans have been formulated, and equipment specifications and procurement activities are under way.

A survey of Building 9204-4 Forming Operations identified 22 pieces of equipment for manufacturing automation retrofit (Fig. 2.3-2): 7 furnaces (3 types), 10 ovens (4 types), 3 presses (7500-, 1500-, and 1000-ton), and 2 salt baths. The operation is very manual-intensive. Parts are conveyed from location to location and loaded into equipment via operator-driven modified fork lift trucks. Also, the instrumentation and controls hardware in this area is very antiquated.

Worksheets detailing the replacement of outdated items such as pneumatic controls and indicating new measurement and control instrumentation were drawn up for each system, including instrumentation and controls flow diagrams. The environment was found to be very hot and greasy with an abundance of airborne particulates and some caustic fumes, which indicated the need for National Electrical Manufacturers' Association (NEMA) 4 or 12 ratings on all control cabinets.

A preliminary design cost estimate was presented to the Metal Preparation Division for approval. Automated material-handling considerations are currently under way. This is the first shop being considered for upgrading, and the effort is still in its infancy but is expected to grow into a significant task.

Three new furnace specifications that follow this design approach are presently in the bid cycle. Thirteen additional equipment specifications have been scheduled over the next few years including six furnace and two press retrofits.

Unit operations in the Building 9204-2 Forming Operations were surveyed, and 44 pieces of equipment were identified for manufacturing automation retrofit. The complexity and diversity of systems in this area range from a single video display terminal with a bar-code reader for data entry to isostatic pressure vessel systems that require 32,000 psig heated mineral oil (Fig. 2.3-3).

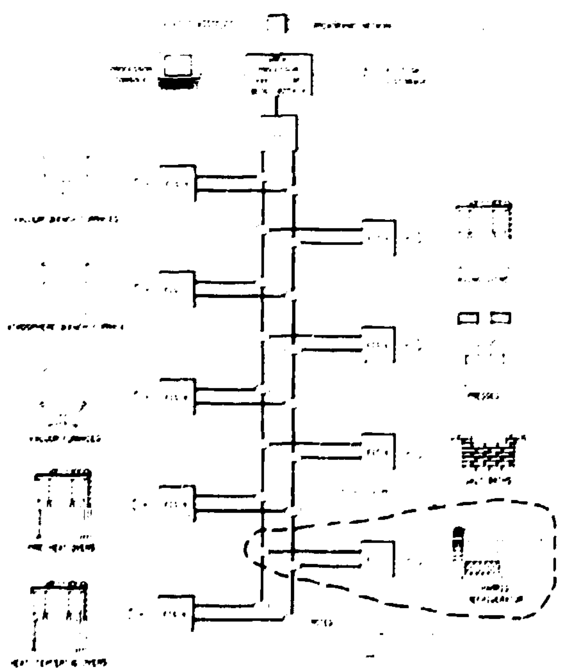

Fig. 2.3-2. Equipment to be included in CIM retrofit of Building 9204-4 Forming Operations.

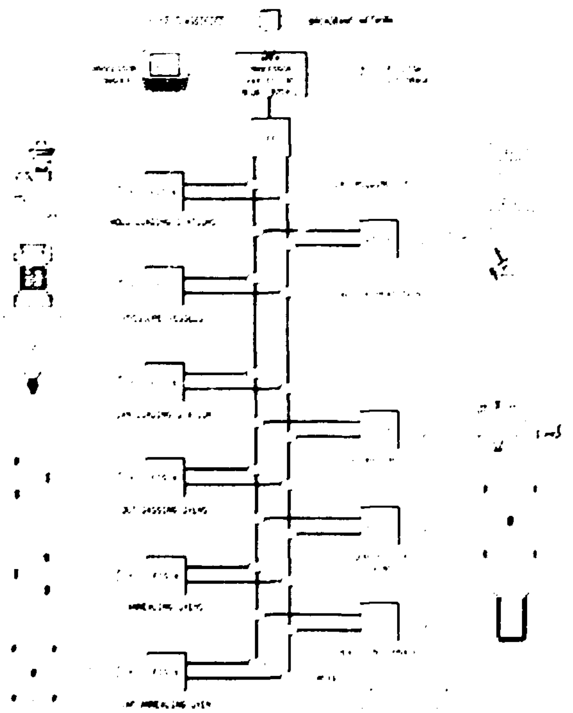

Fig. 2.3-3. Equipment to be included in CIM retrofit of Building 9204-2 Forming Operations.

The preliminary design package currently undergoing peer and management review includes an overall networking drawing, equipment instrument flow diagrams and the associated parameter worksheet summary, a bill of materials, and cost-estimate sheets.

Retrofit has begun on the outgassing ovens, which do not include the CIM approach but do use modern control hardware. Plans to integrate these ovens with the overall approach have been completed. Procurement of some new hardware has been scheduled, and additional acquisition will be scheduled on the basis of the preliminary design cost estimate.

2.3.6.3 BUILDINGS 9212 AND 9998 CASTING FURNACE DESIGN IMPLEMENTATION

A. H. Anderson R. M. Burnett

Engineering assistance is being provided on design, procurement, installation, checkout, and operation of the instrumentation for an automated control and data acquisition system for retrofitting casting furnaces in the East and West lines of Building 9212, and large and medium casters in Building 9998.

Design drawings, cabling lists, fabrication procedures, and bills of material were issued as procurement packages and field cabling packages. The procurement packages for programmable controller panel assemblies, I/O cabinets, and operator panels were issued for each of the five jobs. Field cabling drawing packages for the contractor were issued for the East and West lines and for the large casters in Building 9998.

Installation is complete and checkout is in progress on integration of the automated control instrumentation with the existing instrumentation for upgrading the East line furnaces. The automated control instrumentation was delivered and is ready for installation on the large casters in Building 9998. Fabrication by the subcontractor and checkout by Y-12 Engineering have been completed for the instrumentation of the West lines and some large casters.

Control thermocouple redesign is in progress in the Y-12 Development Division. This new thermocouple assembly and retractor will allow a single outer protecting tube to be replaced upon failure or erosion without replacing the entire assembly.

2.3.7 INTERNATIONAL FUSION SUPERCONDUCTING MAGNET TEST FACILITY

2.3.7.0 OVERVIEW

S. S. Gould R. L. Hassard

The ORNL International Fusion Superconducting Magnet Test Facility (IFSMTF), formerly the Large Coil Test Facility (LCTF), is an experimental facility designed and constructed to test large superconducting magnetic coils of the type and size that could be used in magnetic containment fusion applications. The eight T coils, supplied by Japan, Switzerland, West Germany, and three U.S. firms representing various design approaches (General Dynamics-Convair, Westinghouse, and General Electric/Martin Marietta Energy Systems), will be arranged in a six-coil toroidal array to test the design strengths and weaknesses of each coil.

The facility has undergone a number of successful shakedown tests with three of the six coils; shakedown testing is ahead of schedule at the present time. The remaining three coils will be added to the facility in early spring 1985.

I&C Division involvement has centered on data acquisition, display, and analysis of the 2500 coil and facility sensors. The partial toroidal array shakedown tests used a DEC PDP-11/60 with six LSI-11/23 front-end processors, a facility scanner (FX SYSTEMS 2000), a slow coil data acquisition system (Analogic 5400), and data display and analysis peripherals that were installed and implemented with a high degree of application programming. For the full toroidal array, a CAMAC 5-Mbaud optical fiber linkup to a redundant DEC VAX-11/780 system has been installed to supply the data analysis and display requirements of the facility. The DEC LSI-11/23 systems were supplied with direct-memory-access (DMA) channels to the VAX-11/780 systems via the CAMAC high-speed optical fiber data link. The VAX-11/780 system is on loan from the Fusion Energy Division's Advance Toroidal Facility (AFT), which is located one-half mile from the IFSMTF. All hardware and software subsystems were heavily tested following a previously approved quality assurance document, which was filed along with the software users and programmer's manual.

All out-of-vacuum-vessel sensor cabling and information drawings (more than 300) were issued at the sensor/patching/signal-conditioning level.

The drawings were checked against the actual installation and revised as required. Sensor channels were checked out through to the database and display software. All hardware and software checkout was documented in quality assurance documents.

2.3.7.1 COMPUTER-BASED DATA ACQUISITION SYSTEM IN THE LARGE COIL TEST FACILITY

S. S. Gould
L. R. Layman* D. L. Million*

[Abstract of *IEEE 10th Symp. on Fusion Eng.*, 905 (December 1983)]

The utilization of computers for data acquisition and control is of paramount importance on large-scale fusion experiments because they feature the ability to acquire data from a large number of sensors at various sample rates and provide for flexible data interpretation, presentation, reduction, and analysis. In the Large Coil Test Facility (LCTF) a Digital Equipment Corporation (DEC) PDP-11/60 host computer with the DEC RSX-11M operating system coordinates the activities of five DEC LSI-11/23 front-end processors (FEP) via direct memory access (DMA) communication links. This provides host control of scheduled data acquisition and FEP event-triggered data collection tasks. Four of the five FEPs have no operating system. The executable program image is down-line loaded from the host. This stand-alone software permits data acquisition rates of up to 1000 samples/second for 64 fast diagnostic channels. The remaining FEP has an RSX-11S operating system and services 500 slow diagnostic channels on an Analogic Model 5400 at up to 5 channels/second and 800 facility channels from an FX Systems 2000 at a rate of less than once every three minutes. Data display is in both numeric (trend log and tabular) and graphical format (e.g., as a function of time or of another channel, stripchart, or bar graph representation on either hard copy or storage tube). Data is stored in raw data format, along with the necessary interpretation data bases, on disk or magnetic tape, and/or is transferred to a DECsystem10 via a high-speed link for further reduction and analysis. A sixth LSI-11/23 is used as a satellite processor for driving a DEC VT-11 graphics terminal for simulated real-time display and a CAMAC system used in a voltage compensation circuit calibration. Software utilities are provided for maintenance of the data files, strain gauge bridge balancing, sensor signal conditioning calibration, and channel/sensor assignments for given test configurations. This software/hardware implementation has provided a versatile distributed data acquisition and control system with display features for the initial testing sequence of the Large Coil Program (LCP). A remote dual DEC VAX-11/780 system implementation will be utilized for the main testing sequence, with the PDP-11/60 as backup support.

*Computing and Telecommunications Division.

2.3.7.2 SUBSCALE TEST OF THE LCTF QUENCH DETECTION SYSTEM

P. L. Walstrom*
S. S. Gould L. R. Layman†

(Abstract of Fusion Energy Division draft report, January 1983)

This paper reports the experimental effort put forth in the test and evaluation of the proposed Large Coil Test Facility (LCTF) quench detection design. In the LCTF, six superconducting coils, each with an independent power source, are to be operated in a toroidal array. As a result, the voltage across a pair of voltage taps on the windings of the coil has independently time-varying components caused by inductive coupling with changing currents in its neighbors. These inductive components must be subtracted from the voltage tap signal to yield the normal zone voltage. A system employing pickup coils was chosen for use in the LCTF. This approach is described along with experimental data supporting its validity.

*Fusion Energy Division.
†Computing and Telecommunications Division.

2.3.8 ENRICHED URANIUM RECOVERY IMPROVEMENTS

W. H. Andrews
S. P. Baker R. L. Durall

The Enriched Uranium Recovery Improvement (EURI) Program is a $55 million upgrade of the Y-12 Plant enriched uranium recovery process. A team of I&C engineers, working with the Y-12

Development Division, has successfully resolved most of the significant instrumentation and control issues facing the project at its inception. These issues included a number of very difficult measurement problems, the selection of the automatic control system to be used, prototyping the selected control system on the existing chemical recovery process, and acceptance of the proposed control system by the operating division.

A major task in the Enriched Uranium Recovery Improvements (EURI) Program is automation of the secondary extraction systems. Implementing automatic control is a challenge because of low flow rates, slow system response, a corrosive environment, unusual online analytical measurement requirements, and criticality safety concerns.

These systems traditionally have been difficult to control manually and have required experienced operators to obtain a quality product and reasonable throughput. The difficulty has resulted in part from a lack of information concerning conditions both in and between the columns. The approach taken to address this problem included determining what information would be most useful, providing instrumentation for obtaining that information on a prototypic system, and using that information to configure control loops that would allow automatic (but not unattended) operation of the columns. Continuous data logging, in-line sensor calibration, and an effective operator interface were other important goals.

One of the two secondary extraction systems has been selected for use in prototyping control strategies, instrumentation, software algorithms, hydrodynamic design, and final control element application. This system has been modified and extensively instrumented with sensors for flow, interface level, temperature, pH, pressure, density, optical turbidity, and uranium concentrations. The sensors are monitored by a DEC Model LSI 11/23 microcomputer (soon to be upgraded to an LSI 11/73), and certain of these measurements are used by the computer in the process control algorithms. A colorgraphics operator interface has been installed to provide the operator with important status information in tabular, graphic, and pictorial format.

The heart of the EURI instrumentation system is a distributed process control system. Recommendations based on developmental experience with this system have been provided to Y-12 Engineering for incorporation into the pre-Title I design. An additional benefit of this work is the availability of the upgraded system for use by the operating personnel, which will allow them considerable experience with the new control techniques before the extensive EURI renovations begin in FY 1986.

After an evaluation of existing commercially available distributed systems was completed, a recommendation to purchase a system of this type was made to Y-12 Engineering and to the customer, the Y-12 Metal Preparation Division. Our recommendation was adopted, and information was supplied to Y-12 Engineering for inclusion in a specification for procurement of a system in FY 1985 for delivery by FY 1986.

2.3.9 ABSORPTION HEAT PUMP TEST

F. R. Gibson W. A. Bird

The Absorption Heat Pump Test (AHPT) is an ORNL Energy Division experiment. The absorption heat pump is used for raising industrial waste heat to process steam temperatures. The heat pump uses lithium bromide and water as the working medium, and it is designed to operate with waste water temperatures ranging from 60 to 100°C (140 to 212°F). Advantageously, most of the energy for operation comes from the waste heat, with only low inputs of electrical energy required for parasitics; electrical coefficients of performance (COP) ranging from 50 to 85 have been demonstrated.

The AHPT instrumentation requires very accurate temperature measurements, which are achieved with individually calibrated RTDs using information contained in a memory resident instrument database (IDB) to convert each sensor measurement independently. Using this method, a temperature accuracy of ±0.022°C is obtained over the range 0 to 120°C.

A data acquisition and analysis system was designed and developed for the AHPT facility. It is made up of a Hewlett-Packard 9826 computer, a GO3497A data acquisition and control unit, a HP 3456A digital voltmeter, and a HP 2673A printer and was designed to acquire raw data (27 temperatures, 3 pressures, 5 flows, and other miscellaneous measurements) and convert them to engineering units.

Software was developed to allow a person with little or no computer experience to monitor a test, save test data on disk, load previous test data from disk, run special test analyses, log real-time data, and make plots of selected data. Because most of the data acquisition software is generic, with only small modifications the data acquisition system can be used with other experiments.

2.3.10 FACILITY DESCRIPTION—THTF MOD 3 ORNL PWR BDHT SEPARATE-EFFECTS PROGRAM

D. K. Felde*

R. L. Durall **D. J. Fraysier***
S. S. Gould **E. C. Keith**
G. S. Mailen* **L. J. Ott***
A. G. Sutton **J. E. Wolfe***

(Abstract of NUREG/CR-2640, ORNL/TM-7842, September 1982)

This report describes the Thermal-Hydraulic Test Facility (THTF) as modified for tests with Bundle 3, a 64-rod bundle of indirectly electrically heated fuel rod simulators. The report provides a description of the basic facility and instrumentation as well as a test-specific facility description for each of the primary tests run at the THTF during the operational period from June 1979 to February 1981. The primary tests include the Small-Break Loss-of-Coolant Accident (LOCA)-I Test Series (3.02.10C-H), the transient Upflow Film Boiling Tests (3.03.6AR, 3.06.6B, 3.08.6C), the Steady-State Upflow Film Boiling Test Series (3.07.9-), the Double-Ended Cold-Leg Break Test (3.05.5B), the Small-Break LOCA-II Test Series (3.09.10I-X), and the Intermediate-Flow Heat Transfer Test Series (3.10.11A-H). Two major modifications made to the bundle and test section over this period are also described.

*Engineering Technology Division.

2.3.11 ADVANCED TWO-PHASE FLOW INSTRUMENTATION PROGRAM QUARTERLY PROGRESS REPORT FOR JANUARY–MARCH 1982

J. E. Hardy **S. C. Rogers**
G. N. Miller **W. L. Zabriskie**

(Abstract of NUREG/CR-2752, Vol. 1, ORNL/TM-8365, July 1982)

The performance of the Westinghouse reactor vessel level indicating system (RVLIS) was analyzed for a series of tests in the Semiscale Test Facility. A summary of the results and conclusions from those small-break simulation experiments is presented. The Westinghouse RVLIS indicated a level measurement that was lower than the vessel coolant level for all tests. The RVLIS indication was at times higher than the vessel collapsed liquid level. This discrepancy was apparently created by structural differences in the Semiscale Facility and a Westinghouse PWR. Modifications were made to Semiscale to better simulate a Westinghouse PWR, and a retest was completed. The RVLIS measurement showed much better agreement with the vessel collapsed liquid level for this retest.

In addition to the RVLIS analysis, an ultrasonic sensor is being developed to measure simultaneously the level, temperature, and density of the fluid in which it is immersed. The sensor is a thin, rectangular stainless steel ribbon, which acts as a waveguide and is housed in a perforated tube. The waveguide is coupled to a section of magnetostrictive material, which is surrounded by a pair of magnetic-coil transducers. These transducers are excited in an alternating sequence to interrogate the sensor with both torsional ultrasonic waves, using the Wiedemann effect, and extensional ultrasonic waves, using the Joule effect. The measured torsional wave transit time is a function of the density, level, and temperature of the field surrounding the waveguide. The measured extensional wave transit time is a function of the temperature of the waveguide only. The sensor is divided into zones by

the introduction of reflecting surfaces at measured intervals along its length. Consequently, the transit times from each reflecting surface can be analyzed to yield temperature and density profiles along the length of the sensor. Improvements in acoustic wave dampener and transducer-sensor interface designs enhance the compatibility of the probe with high-temperature, high-radiation, water-steam environments and increase the likelihood of survival in such environments. Design and breadboard of a high-voltage pulser for driving the magnetic-coil transducer have resulted in an order of magnitude increase in signal strength. This increased signal strength is needed to improve signal-to-noise ratio and to ensure minimum attenuation of acoustic waves transmitted over long waveguides. Preliminary design is in progress for a new electronics package that will make multiple zone measurements faster and more flexible, allow output data to be displayed in real-time engineering units, and improve dynamic response, resolution, and accuracy.

2.3.12 ANALYSIS OF THE PERFORMANCE OF THE WESTINGHOUSE REACTOR VESSEL LEVEL INDICATING SYSTEM FOR TESTS AT SEMISCALE

J. E. Hardy G. N. Miller

(Abstract of NUREG/CR-2720, ORNL/TM-8336, October 1982)

The Westinghouse reactor vessel level indicating system (RVLIS), a differential pressure level measurement system, was tested at Semiscale. This report contains the analyses of these tests and the conclusions of these analyses. The tests performed included small break and intermediate break tests. Also, frequency response and natural break and intermediate were run and analyzed. The RVLIS always indicated a level less than the two-phase froth level. The RVLIS output in early small break tests indicated a level of 200 cm greater than actual collapsed liquid level. This discrepancy was caused by structural differences between Semiscale and a Westinghouse reactor. Once modifications were made so that Semiscale better simulated a Westinghouse PWR, the maximum difference between RVLIS and Semiscale instrumentation was 30 cm or 3%, which is less than the stated uncertainty of the Westinghouse RVLIS.

2.3.13 STUDY OF HEAT AND MASS TRANSFER IN A VERTICAL-TUBE EVAPORATIVE COOLER

H. Perez-Blanco* W. A. Bird

(Abstract of *Proc. Am. Soc. Mech. Eng.* **106** 210–15, 1984; also ORNL/TM-8150, June 1982)

Evaporative coolers are three-fluid heat exchangers used to reject heat to the environment. A mixture of air and recirculating water is used as the cooling medium. These coolers are considered viable routes for improving thermal efficiencies of power-generating and refrigeration cycles. In this paper, the heat and mass transfer processes taking place in a vertical-tube evaporative cooler are studied. A steady-state, one-dimensional model of cooler performance is formulated and is validated by experimental measurements, taken in a single-tube exchanger, of the controlling heat and mass transfer coefficients. These coefficients occur at the air-water interface. Heat fluxes and enhancement ratios for conditions of interest are measured and calculated, and the results are compared and discussed. The model is found to adequately predict heat exchanger performance.

*Energy Division.

2.4 Energy, Conservation, and Electric Power Systems

2.4.1 MEASUREMENT SYSTEM FOR JOINT INSTITUTE FOR HEAVY ION RESEARCH

D. R. Miller G. S. Canright
C. T. Alexander J. E. Christian*

An instrumentation and monitoring system was developed for use in an earth-sheltered office-living quarters facility. The instrumentation was selected and configured to achieve the initial goal of gathering data on the performance of earth-sheltered buildings, specifically the contribution of earth-sheltering techniques to energy savings. The 4000-ft^2 building is located east of Building 6000 at ORNL. It is equipped with a commercial heat pump for space conditioning and utilizes passive solar heating in the living quarters.

Sensors are thermocouples, heat flux meters, moisture sensors, electric power submeters, solar pyranometer, air flow meters, and a weather station. Central data collection was done with a calculating data logger, the Acurex Autodata Ten/10, which is located in the northwest corner of the building and has a capacity of 300 signal input channels and 700 calculated channels. For archive and analysis, data are automatically transmitted from the data logger over a dedicated phone line to a MACES PDP 11/34 computer in Building 3500. Data are organized and stored on disk as files, each containing data for one week. Software for this task was developed jointly by I&C and Energy Division personnel.

Of special interest was the thermal profile of a typical cross section of the building and earth in the first few horizontal and vertical meters. As a result of this interest, a highly instrumented plane was included. In it were 62 temperature sensors, 17 heat flux meters, and 8 moisture sensors. This plane extended from 1 m in front of the building to 8 m behind it. Highest sensor density was in the first 2 m under the floor and a similar distance from the bermed north wall.

Some of the needed measurements required special installation techniques. Thermal models required accurately placed and evenly spaced thermocouples as deep as 5.8 m. A PVC pipe assembly was built with small-diameter pipe within larger pipe in order to ensure accurately placed sensors with exactly 1-m spacing. These assemblies were placed in small-diameter holes and capped with a weatherproof junction box at the surface.

A second problem was that of accurately positioning delicate heatflux sensors in the boundary between the styrofoam panels and the gravel under the poured concrete floor. This was done by developing a technique for mounting the 2 × 2-in. sensor in a concrete assembly 4 × 12 × 12 in. These were placed under the styrofoam just prior to having the contractor pour the floor. Laboratory measurements verified that the final assemblies retained the specified heat flux sensitivity.

Two full years of data have been taken, and a formal report has been issued.[1]

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*Energy Division.

1. J. E. Christian, ORNL/CON-151, July 1984.

2.4.2 SOIL MOISTURE SENSOR ELECTRONICS SYSTEM

P. D. Ewing

M. S. Hileman C. J. Remenyik

The soil moisture sensor electronics system, a spinoff of the AIRS technology, is a signal-processing system used as an interface between measurement probes and a data acquisition system. It measures the admittance of soil and processes that, reading into a linear dc output, can be transformed by a calibration algorithm into a moisture content by weight percentage. Components of the system are a soil moisture sensor module and a 1-kHz oscillator.

The soil moisture sensor module consists of two channels, each of which outputs a dc level directly proportional to the admittance of a soil moisture sensor probe. The sensor module is essentially a modified AIRS-6 admittance ratio module with a gain adjustment potentiometer added in the feedback loop to replace the Hi probe. The soil moisture sensor probe is the Lo probe input. The 1-kHz oscillator is an AIRS-8 module and provides the basic sine-wave reference signal used in the soil sensor module. From soil calibration data obtained in-house, a temperature-dependent algorithm was derived to determine the moisture content of soil. This algorithm is applicable to moisture content levels of 20% (where saturation occurs) and below.

The primary application of the soil moisture sensor system will be to aid in evaluating the efficiency of earth-coupled heat pumps. To date, these systems have been installed at three sites: One system is in use at the TECH houses in Knoxville and two systems are in use at Niagara Mohawk Power Company sites in Syracuse, New York. This system is still in the development stage, and data are being collected on the three installations to be followed up by analysis to verify the accuracy of the soil moisture measurements.

2.4.3 INSTRUMENTATION FOR ROOFING TEST FACILITY

D. R. Miller J. E. Hardy

A roof thermal research apparatus (RTRA) was constructed to study various thermal models for and insulation effects on flat roofs, primarily for energy conservation. Some of the main objectives of the test facility program were to determine optimum roof insulation thickness, to study moisture effects on thermal performance, and to study the effect of insulation on the durability and service life of a flat roof. Instrumentation was provided to help achieve these goals. In addition to the instrumentation, a system was synthesized to obtain and store test data for an analysis database.

The instrumentation installed at the RTRA can be divided into three areas: a weather station, load beams, and temperature-measuring devices. Five measurements constitute the weather station data: outside air temperature, relative humidity, wind speed, wind direction, and barometric pressure. Eight load beams were installed, four each on two roof sections (panels). These load beams measure the weight of a panel and were used in determining the amount of moisture in a panel. Finally, approximately thirty thermocouples were provided to measure various air and surface temperatures.

The data acquisition system at the RTRA consisted of an Autodata Ten/10, several distributed data acquisition and control networks (Netpacs), an IBM PC, and a DEC PDP-11/34 computer. The Autodata Netpac accepts remote input analog voltages and thermocouples. The Autodata system utilizes remote modules to measure, linearize, and transmit input signals to the central host, the Autodata Ten/10. The Autodata receives the signals into a buffer memory, then transmits them to either the local IBM or the PDP-11/34 via serial interface and modem. The PDP-11/34 located in Building 3500 is used for archival storage; the IBM serves as a backup or for special short-term experiments.

The IBM PC can access the data files stored on the PDP-11/34, manipulate the data using user-developed software, and display the results on the P[illegible] printer or plotter.

2.4.4 ENERGY CONSERVATION INVESTMENT PROGRAM

D. R. Miller
M. W. Noakes F. R. Ruppel
M. S. Hileman I. E. Williams

The I&C Division joined with the ORNL Energy Division during the first quarter of FY 1984 in support of the U.S. Army's Energy Conservation Investment Program (ECIP). The U.S. Army Facilities Engineering Support Agency (FESA) at Fort Belvoir, Virginia, is responsible for implementing in existing Army facilities line item energy conservation retrofits which a standard life cycle analysis can show to be economically beneficial. The Congress stipulated in the ECIP funding authorization that all projects would conduct pre- and post-retrofit validation studies by an independent agency. It further stated that actual hard data would be collected in some instances to support paper validations.

ORNL is responsible for performing these validations, which require field measurements and analysis. Each year 10 to 15 projects are identified for retrofit, and 5 to 10 of these are identified for full validation. Seven line item projects are currently active and have validation plans developed by ORNL. These validation plans are developed and written into a formal proposal for FESA review and approval.

This work consists of gaining familiarity with the particular system to be reworked and devising an instrumentation plan and energy model which will permit an accurate assessment of energy flow to and from the system. Normally, an initial visit of one or two days to the site is sufficient to develop a rough plan. This outline is submitted to FESA for approval and then a follow-up visit is used to gather information for a formal design. The Energy Division simultaneously develops a plan for reporting the data that is submitted with the I&C plan as the Phase II design document. In most cases, procurement and installation are done by a subcontractor to the local Army District Engineers Office. At the completion of installation of analysis instrumentation, I&C makes a site visit to verify correct installation. This checkout is done in conjunction with startup of the data acquisition cycle for pre-retrofit data.

The first year of work included the following seven projects:

- Oakland Army Base, California: Lighting Retrofit
- Fort Huachuca, Arizona: Variable Air Volume HVAC Retrofit
- Fort Stewart, Georgia: Wood Burning Boiler Installation
- Fort Riley, Kansas: Ceiling/Roof Insulation Addition
- Fort Benning, Georgia: Solar Pond Heating 500,000 Gal. Water per day
- Fort Bragg, North Carolina: FM Radio Control of HVAC for 1200 Buildings;
- Fort Bragg, North Carolina: Steam Heating Plant Upgrade

2.4.5 DESIGN OF SOLAR TRACKER CONTROL SYSTEM

A. A. Shourbaji R. E. Hutchens

The solar tracker system is part of an experimental study of the feasibility of harnessing solar energy and addressing the technological aspects involved.

The tracker collector control system consists of two parts: control of the stepping motors which drive the collector along two axes (East-West and North-South), and safety interlocks, which will shut the system off and cause it to go to stow position (East) should a malfunction occur.

The tracking system consists of an array of light-sensitive photodetectors and associated logic circuits which drive two-axis stepping motors. The tracker can be operated in one of two modes, manual or automatic. In automatic mode, the tracker is controlled by a single photocell light meter which measures ambient light level and sets the tracker into one of three conditions: night, synthetic track (cloud cover), or automatic. When night is condition sensed, the tracker will go to stow (East) until the light level increases enough to wake the system. Under cloudy conditions, the system will track at a rate of .25°/min. In bright sunshine, the tracker will go into automatic track conditions.

2.4.6 INSTRUMENTATION FOR U.S. NAVY COGENERATION STUDIES

D. R. Miller I. E. Williams

As part of an effort to reduce energy consumption, the U.S. Navy is examining new energy conservation technologies, one of which is small-scale cogeneration.[1] Small cogeneration refers to electric generating capacities of less than 500 kW. The I&C Division effort is in connection with a study for preliminary assessment of the suitability and economic value of decentralized small-scale cogeneration. The U.S. Navy and the ORNL Energy Division initiated this study because the available information on domestic hot water usage in Navy buildings was of insufficient quality and reliability to confidently design a small cogeneration installation.

The purpose of this study was the development of high-quality domestic hot water usage data so that dispersed small cogeneration systems can be designed for certain types of Navy buildings. Three common U.S. Navy building types—hospitals, unaccompanied enlisted personnel housing, and unaccompanied officer personnel housing—are included in the study. Currently, domestic hot water usage is being measured at the hospital, the main enlisted personnel dining hall, and a barracks complex at the Memphis Naval Air Station at Millington, Tennessee. This facility was selected for this monitoring effort because the facility personnel exhibited a high degree of interest in the project and because of its relative nearness to ORNL.

The instrumentation selected by I&C Division for use on this study was subject to extremely restrictive requirements. The data must be of very high accuracy and must be collected over an interval sufficiently long to be statistically meaningful. Also, the total cost of all equipment and design must be very low. An extensive literature search produced a surprisingly suitable combination of a hot water Btu meter and an automatic data acquisition system. The Btu meter is manufactured in Europe, where community hot water is used with individual user metering. This vast market has driven down the cost to that comparable to the cost of watt-hour meters in the United States. In-house tests have yielded verified accuracies of within 1% for combined delta temperature and integrator. The flowmeters supplied are typical insertion full flowmeters and, according to vendor literature, yield accuracies of 0.5 to 3%.

A data acquistion system was selected which was developed for remote weather station applications. It is self-contained and battery powered, and accepts most common signal levels including pulse counting. The total cost of the Btu meter, data logger, and cassette data recorder was $3,000.

1. L. N. McCold and M. A. Karnitz, ORNL/CON-141, March 1984.

2.4.7 ELECTRICAL DISTRIBUTION SYSTEM MANAGMENT AND CONTROL

2.4.7.0 OVERVIEW

G. W. Wetherington, Jr.

The I&C Division is supplying ORNL Energy Division with technical expertise in real-time systems, software, and instrumentation in support of the Athens Automation and Control Experiment (AACE), a major research activity funded by DOE.

The purpose of this project is to investigate the effects of applying advanced monitoring and control technology to a typical electrical distribution network. More specifically, it is to determine the control techniques and level of hardware penetration required for improved operation and efficiency of the electric system. The experiment is being conducted on the Athens Utilities Board (AUB) electrical distribution system located in Athens, Tennessee. Other organizations assisting in the experiment include the Electric Power Research Institute (EPRI) and the University of California Jet Propulsion Laboratories (JPL).

Three major experimental areas have been identified as the primary focus of the AACE: (1) distribution switch automation, (2) voltage regulator and capacitor switching control, and (3) residential load management. The AACE is unique in that it is the first experiment to integrate all three of these areas. Two real-time automation systems will be used to implement the AACE. One, on the integrated electrical distribution and management system (IEDMS), is the actual control system that will be installed in Athens. The other, the Athens automation and control experiment test system (AACETS), is a general-purpose tool used to support the operation of the IEDMS, develop and test applications software targeted for the IEDMS, and acquire characterization data of the AUB electrical network. The AACETS is located in the I&C Division.

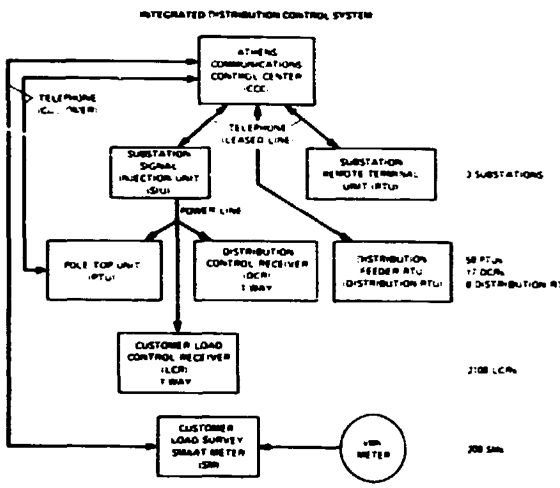

Fig. 2.4-1. Block diagram of the IEDMS configuration.

2.4.7.1 CONTROL SYSTEM FOR THE ATHENS, TENNESSEE, ELECTRICAL DISTRIBUTION NETWORK

G. R. Wetherington, Jr. R. R. Bentz
B. J. Bolfing E. R. Broadaway

The IEDMS is a distributed measurement and control system being procured to automate the AUB electrical distribution network in Athens, Tennessee. The IEDMS design, shown in Fig. 2.4-1, features a dual DEC PDP 11/44 minicomputer host configuration, communications equipment, and remote field processors that provide a total system field point count of 788 analog inputs, 1,152 contact inputs, and 6,812 contact outputs. Four types of field monitoring and control are provided. Remote terminal units (RTUs) are located in the substations and at key feeder points. The RTUs are polled by the host computer on a repetitive basis for the data monitored by these units. Pole-top units (PTUs) are located on the feeder branching points and subfeeders. The PTUs are not scanned, but transmit data to the host computer when a field condition exceeds a preset level or state. The technique of "calling in" by the PTUs is referred to as "reporting by exception." Smart meters replace the outdoor metering unit on residential households and provide remote monitoring of household load. Devices called load control receivers (LCRs) provide the capability to control (disable) three devices in a home. The IEDMS will include 11 TRUs, 58 PTUs, 200 smart meters, and 2100 LCRs.

The IDEMS will be installed throughout the 100-sq-mile AUB service area. The remote monitoring and control equipment communicates with the host computers via an encoded ripple signal technique that superimposes command data on the electric power network. The report-by-exception communications method and data preprocessors are employed to reduce the amount of data processing by host computers. A real-time hierarchical database monitoring and control software package, MODSCAN, is utilized to maintain up-to-date field information within the host computers. The IEDMS is being procured from Brown Boveri Corp. and is scheduled for installation in early 1985. Real-time control software for distribution automation and load management is being developed at ORNL by I&C Division and Energy Division personnel.

2.4.7.2 A SUPPORT SYSTEM FOR SOFTWARE DEVELOPMENT AND DATA ACQUISITION

G. R. Wetherington, Jr. E. R. Broadaway
R. R. Bentz B. J. Bolfing

The AACETS is an experimental software development and test system for support of the AACE. The AACETS serves as a proving ground for all software development activities associated with the IEDMS in Athens, Tennessee, and provides a tool for acquiring pre-experimental data from Athens for use in control analysis and modeling efforts. The AACETS has six major responsibilities:

1. Support the development of real-time control applications software, provide a mechanism for testing all applications software prior to installation on the Athens IEDMS,
2. Support the generation and maintenance of the IEDMS database and MODSCAN software,
3. Support the development of human-machine interface displays,
4. Serve as a training system for AACE project personnel, and
5. Provide for and support the acquisition of operational data from the Athens electrical network for characterization and modeling efforts prior to the installation of the IEDMS.

ORNL PHOTO 4964-84

Fig. 2.4-2. Supervisory control and data acquisition development system.

The AACETS comprises two major subsystems, a supervisory control and data acquisition (SCADA) system and smart test panel (STP). The SCADA subsystem shown in Fig. 2.4-2 is a scaled-down version of the IEDMS system. It is based on a DEC PDP 11/44 minicomputer that executes under the control of the RSX-11M real-time operating system. Online storage capacity is provided by 1 Mword of RAM and 242 Mbytes of disk storage. The IEDMS MODSCAN software is also included. Two colorgraphic terminals, two monochrome terminals, two event-logging printers, and a 600-line/min large-format printer are used for operator interfacing. A nine-track magnetic tape unit provides software transportability between AACETS and other computer systems. User and device access to the system is provided by 28 serial interfaces. Two RTUs (exactly like those that will be installed on telephone poles in Athens) serve as the real-world process interface for the SCADA subsystem. The RTUs convert analog and discrete information to digital form for subsequent processing by the MODSCAN software in the host computer. Also, if a control action is determined to be necessary, a command can be issued and processed by the MODSCAN software to cause a relay contact closure in an RTU. The combined process interface point count capacity is 40 analog inputs, 24 discrete (status) inputs, and 8 discrete (contact) outputs. The RTUs provide the interface to the STP, the other major AACETS subsystem.

The STP provides a mechanism for simulating, in a crude sense, the AUB electrical system. The results of the simulation are made available to the SCADA subsystem as interfacing signals (analog and discrete) exactly like those found in Athens. This configuration can duplicate all IEDMS system characteristics, from the process front end to the characteristics of the software. The STP is based on a commercial programmable controller (shown in Fig. 2.4-3) applied in a reversed role. Specifically,

ORNL PHOTO 4962-84

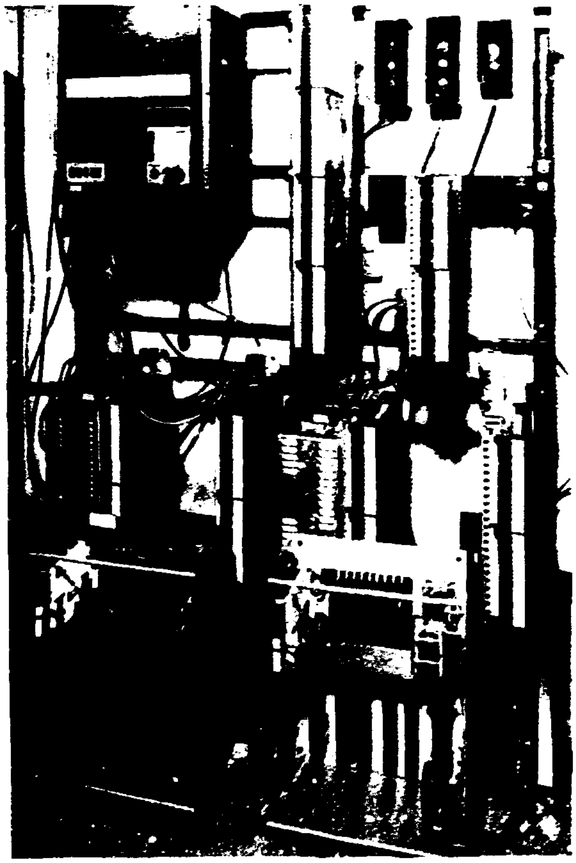

Fig. 2.4-3. Programmable controller and SCADA remote terminal units.

ORNL PHOTO 4960-84

Fig. 2.4-4. Smart test panel operator display.

the STP will perform those functions associated with the process that are monitored and controlled by the SCADA subsystem. A colorgraphic-based operator interface (Fig. 2.4-4) that features touch-screen operation is included as part of the STP to provide a compatible mode of operator interaction with the overall system.

In addition to providing software and systems support to the IEDMS, the AACETS also fulfills a key role in the support of the experimental planning and design efforts by acquiring operational and load usage data from Athens. Data acquisition is implemented over seven foreign-exchange telephone lines between the AACETS and the Athens area. One line is used to acquire data from the three Athens substations, and the other six lines acquire residential load data from 200 load-profile recorders located at selected residences.

2.4.7.3 IEDMS ACCEPTANCE TEST OUTLINE

S. L. Purucker* B. J. Bolfing

An outline was developed to initiate a step-by-step procedure for functionally testing all elements of the IEDMS. The functional testing is divided into four stages, which occur sequentially:

1. component factory test
2. integrated IEDMS factory test
3. partial field acceptance test
4. full field acceptance test

Component factory testing will test the functional characteristics of the IEDMS components. This testing is detailed in Part I of the outline.

The integrated IEDMS system factory tests will functionally test the IEDMS system with a subset of the field components. This will also retest the component field hardware on an integrated basis. This test plan is presented in Part II of the outline.

The partial field acceptance test will test a subset of the full IEDMS system under real-world, installed conditions. This test description is presented in Part III of the outline. The purpose of this test is to detect and correct problems early in the installation phase.

Finally, the full field acceptance test will verify the functionality of the fully installed IEDMS under real world conditions. Full field testing will emphasize communication of the full complement of field hardware with the central computer system. The ability of IEDMS to functionally perform in the field under fully loaded conditions as effectively as in the factory tests will be the primary objective of the full field acceptance test. This test is detailed in Part IV of the outline.

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*Energy Division.

2.4.8 TENNESSEE ENERGY CONSERVATION IN HOUSING (TECH)

D. J. Marshall R. A. Hess

The Tennessee Energy Conservation in Housing (TECH) site, a four-house complex located on the Knoxville Agricultural Campus of the University of Tennessee, is operated jointly with the University for research and evaluation of heat pump systems. The complex also includes the former Annual Cycle Energy System (ACES) house, which is now used in heat pump systems evaluation. The scope of the present investigation covers primarily ground-coupled, closed-loop, water source heat pump systems, with one house using a more conventional air source heat pump as an experimental control.

At this time three of the four houses have test systems installed. TECH House One has a horizontal loop, ground-coupled system; TECH House Two has a vertical loop ground-coupled system (installed in six wells ranging from 60 to 100 ft deep); and TECH House Three is being refitted with a two-speed air-source heat pump.

During this reporting period, I&C Division involvement has dealt mainly with instrumenting the heat exchangers (including buried piping) and updating and maintaining the existing instrumentation from previous experiments (weather data, power usage, etc.). The data channel count has increased during this period from approximately 160 in 1982 to approximately 400. No work was done on TECH House Four during the reporting period.

Two new devices were developed during this period: a system-run-time timer for horizontal ground-coupled systems, and an improved heat-power multiplication interface. Both developments resulted from a need to accommodate transient effects during startup of ground-coupled systems and during transition periods on the air source system.

2.4.9 RESEARCH FOR RETROFIT ENERGY CONSERVATION IN HOUSING

D. J. Marshall L. D. Hunt

This three-house complex located at Karns, Tennessee, was previously used as a geothermal heat-recovery demonstration project. It is now dedicated to the evaluation of retrofit energy conservation methods. Work performed during the current reporting period will establish a base with which to compare the effects of subsequent modifications. In addition, several experiments have been performed to measure the outgassing of formaldehyde from the construction materials of the houses with respect to temperature and humidity changes in the interior of the houses.

The I&C Division contributions to this project include design of relative humidity sensors, procurement and setup of uninterruptible power supplies for the data acquisition systems, procurement and calibration of thermocouples, installation of signal cables for humidity sensors and thermocouples, assistance to the ORNL Energy Division in setup of the computer systems, and assurance of current calibrations of all instrumentation.

2.4.10 ENERGY MONITOR FOR BUILDING 4500 SOUTH

J. O. Hylton
D. R. Miller J. E. Hardy

A portable energy monitor (PEM) was installed in Building 4500 South to measure energy usage. Initially, a baseline energy usage will be determined for each season, and resulting database will be used for comparison when modifications are made to any of the building's energy consumers. Thus, a quantitative assessment of savings can be calculated for any subsequent energy conservation action.

The PEM is a microprocessor-based monitor which can accept up to 8 RTDs and 16 analog inputs. Data are transmitted through a serial port to a teletype printer after each programmed interval, with computations in engineering units. Analog input channels include provision for flowmeter output, watt, and var signals from five power transducers.

The PEM will report data in several forms. The parameters can be reported periodically (e.g., every 2 h) or on operator demand. A daily report generated automatically summarizes the energy usage each day, and trend reports (graphs) on a particular sensor can be generated on demand. The PEM will also enter a diagnostics mode for investigating suspicious signal values from any input sensor.

Sensor installation in Building 4500 South included two turbine flowmeters to monitor the chill water flow and the steam flow; three RTDs to measure the chill water return, supply temperatures, and steam temperature; one wet bulb-dry bulb RTD device; and four power monitors. The cooling energy supplied to the building was calculated using the temperature difference between the return and the supply chill water and the chill water flow rate. The steam energy was determined using the steam turbine output and an RTD, which was used to calculate a steam flow density. The wet bulb-dry bulb device measured wet bulb and dry bulb temperature conditions in the outside air, which are useful when comparing respective daily energy loads to outside environmental conditions. The power monitors measure electric power input to the building.

With the PEM, the heat energy (steam), cooling load (chill water), and electric power (power monitors) are measured for Building 4500 South. A daily energy usage report is generated and logged on the teletype printer. After compilation of sufficient energy usage values, a database can be used to evaluate future energy conservation modifications to Building 4500 South.

2.4.11 LOAD MANAGEMENT: CUSTOMER OPTIONS

J. P. Stovall* J. M. McIntyre

(Abstract of paper presented at World Energy Engineering Congress, September 14–17, 1982)

Load management offers residential customers an opportunity to reduce energy costs by changing their pattern of electrical energy usage in a way to assist the electric utility to more effectively and efficiently provide electric service. Two customer load management options will be discussed in this paper. The first option is customer energy storage for space heating and water heating. The benefits or costs of such equipment will depend upon the penetration of installed units, their load characteristics and hours of operation, and the load characteristics of the particular utility. The second option is a residential demand limiter, which is being demonstrated by Omaha Public Power District. The demand limiter is set by the customer to the desired level of demand, which is related to the expected monthly bill and then controlled by the utility to limit demand when most beneficial to the utility system.

*Energy Division.

2.4.12 COAL BENEFICIATION—THE CINDERELLA TECHNOLOGY

S. P. N. Singh*
J. C. Moyers[†] K. R. Carr

(Paper presented at DOE Coal Combustion and Applications Working Group Meeting, Livingston, New Jersey, December 9, 1982)

A brief introduction to coal beneficiation processes is given. This paper includes brief summaries of current commercial practices and several developmental coal cleaning methods. Coal beneficiation economics and research needs are also discussed.

It is felt that coal beneficiation can play a significant role in the increased usage of coal to meet the nation's future energy needs. Fertile areas for coal beneficiation research and development are suggested, such as increased automation of coal cleaning circuits and novel coal cleaning methods to increase the recovery of higher quality coal.

*Chemical Technology Division.
†Engineering Technology Division.

2.4.13 CONTROL SCHEMES FOR COAL LIQUEFACTION

G. E. Oswald* K. H. Lin*
H. D. Cochran, Jr.† K. R. Carr

(Abstract of ORNL/TM-8534, February 1983)

This brief study was aimed at identifying instrumentation and control schemes which might improve the yields, product quality, or operability of direct coal liquefaction plants. The 6000 tons per day (TPD) SRC-I (solvent refined coal) demonstration plant Phase I design was chosen as the base case for this study because, to date, it is the most complete commercial design. Advanced and innovative control schemes are described for the solvent refined coal SRC-I demonstration project. These control scenarios have the potential for making significant improvements in product yields and quality, process reliability and operability, and process efficiency. Also, descriptions are given of the operating principle for the specialized on-line measurement instruments required. This report describes a recommended approach for the continued development of control schemes for coal liquefaction. Because of the similarities between the major direct liquefaction processes (SRC, H-Coal, and Exxon Donor Solvent), most of the control schemes proposed in this study should have generic application. It is anticipated that similar control schemes may also prove advantageous in advanced direct liquefaction processes such as the two-stage liquefaction processes currently under development by Lummus, Kerr-McGee, Chevron, and Hydrocarbon Research, Inc.

*Chemical Technology Division.
†Consultant.

2.4.14 INSTRUMENTATION IMPULSE LINE PLUGGING IN COAL LIQUEFACTION PROCESS APPLICATIONS

K. R. Carr

(Abstract of ORNL/TM-8511, February 1983)

Instrumentation impulse line systems in coal liquefaction process applications were studied for the purpose of seeking methods by which the problem of line plugging can be alleviated or eliminated. The emphasis was on purged systems in which ~1/2-in.-diam lines carry a purge fluid at a low flow rate (~2 gph or 5 scfm) to provide a pressure transmitting medium between a process solids-bearing liquid and the measuring instrument. Plugging of impulse lines is a maintenance harassment and can cause periods of degraded measurements accuracy in coal liquefaction as well as other important industries, such as petroleum refining. A coal liquefaction demonstration plant may have as many as 2000 purged impulse lines.

The approach taken in this work was to compile information on purged instrumentation impulse line systems design and operating experience, to formulate and record recommended practices for coal liquefaction processes, and to define possibilities for alternative systems. This effort did not involve experimental work except for a laboratory bench demonstration of the possibilities of magnetically-coupled mechanical drives, but does provide the background and basis for the testing and development of improved systems in any continuation of the project. Sources of information utilized were the personnel of five operating coal liquefaction facilities (four plant visits were made), applications engineers for suppliers of pressure measurement and flow control equipment, process control engineers in petroleum refining, and the literature.

This report includes a description of the purged impulse lines application and problems, a summary of recommended practices for purged impulse line systems in coal liquefaction processes based on a compilation of operating experiences, and a discussion of possibilities for unpurged impulse lines systems which should be experimentally evaluated in process locations which might yield the greatest

potential benefit. The possibilities considered are pressure transmitters with remote diaphragm seals, high temperature (1000°F) rated pressure transducers for direct connection to the process, magnetically-coupled mechanical drives to detect and prevent plugging, and containment of the process material by a cylindrical seal which is rotated to reduce measurement error that would be caused by friction in the axial direction. Also, the study identified a development need for a purge fluid flow rate controller to be used in conventional impulse lines.

2.4.15. EFFICIENCY OF HEATING SYSTEM MEASURED BEST BY HEAT OUTPUT METERS

V. R. Brantley* D. R. Miller

[Abstract of *Ind. Res. Dev.* 25(12), 78–81 (1983)]

Measuring the heat output from central-forced-air and heat-pump-based heating systems in a conventional manner can be a time-consuming and often inaccurate process. The preferred method for determining system performance is to obtain data from actual field measurements rather than to extrapolate laboratory data. This allows researchers to more-accurately map energy consumption patterns and evaluate energy conservation strategies.

Consequently, a simple, accurate device for making such measurements has long been needed by researchers and engineers who are charged with cutting energy costs and/or improving heating system performance.

To meet this need, we have designed two instruments capable of making direct heat output measurements. The COP meter makes field measurements of the coefficient of performance from heat pumps. The Btu meter, on which the COP meter is based, measures heat output from any central forced-air-distribution heating system.

*Engineering Technology Division.

2.4.16 ADDITIONAL PROJECTS

Acquisition of Data from Instrumentation in Remote Substations. Data from remote locations is frequently needed at ORNL to support experiments. Several methods have been used in the past to provide the most cost-effective solution for individual needs. The AACE requires the acquisition of distribution feeder and weather data from the three main AUB substations, a distance of 55 miles from ORNL. A remote monitoring system based on commercially available hardware from Acurex has been developed to acquire the needed data. A DEC PDP-11/44 minicomputer located at ORNL with FORTRAN and the RSX11M operating system is used to call the remote monitoring units for needed data. Software has been developed that will command the remote units to scan the input channels and transmit the information back to the host PDP-11/44 computer. This is done using a dial-up telephone line with an autodial modem on the computer end and an autoanswer modem on the remote end. The software will handle a 16-digit telephone number, allowing FTS or direct-dial long distance as well as local or foreign-exchange calls. Configuration options for the remote units include voltage, thermocouple, current, and contact input intermixable on a single card of 20 channels; RTD, high-voltage, and contact output cards are also available.

These data are being acquired to develop load forecast models prior to installation of the IEDMS. A one-year "head-start" on actual network behavior is made possible in the experimental test program. *(E. R. Broadaway, G. R. Wetherington, Jr., R. R. Bentz)*

Acquisition of Data on Residential Appliance Energy Usage. A system for acquisition of residential appliance energy usage data has been configured at ORNL utilizing hardware and software developed by Robinton Products, Inc. This system allows up to four selected residential appliances (such as hot water heaters and heat pumps) at each of 200 selected residences in Athens, Tennessee, to be monitored by a load profile recorder (LPR). Each LPR contains a modem connected to the residential telephone line and has a local memory capable of storing up to 24 h of data taken at 1-min intervals from each of 4 different appliances. The AACETS DEC PDP-11/44 minicomputer located at ORNL acquires the LPR information daily and stores the appliance energy usage data on disk. Calling is done within a preset time window, currently between the hours of 12 midnight and 5 a.m. Data are later transferred to magnetic tape in an IBM-compatible format for subsequent analysis and long-term storage.

This information will be used to characterize home energy consumption and thereby aid in the development of improved control algorithms for peak-load management. *(E. R. Broadaway, G. R. Wetherington, Jr., R. R. Bentz)*

2.5 Computer Systems and Communications

2.5.1 A MICROCOMPUTER-CONTROLLED ELECTRONIC BULLETIN BOARD

D. R. Patek
J. M. Jansen W. B. Ewbank*
J. L. Redford J. S. Wright†

An electronic bulletin board system based on the inexpensive Commodore 64 (C64) microcomputer and commercially available television sets has been developed by the Instrumentation and Controls Division as an information distribution system for the ORNL Information Division. The system, which is diagrammed in Fig. 2.5-1, is called the "Inside Channel."

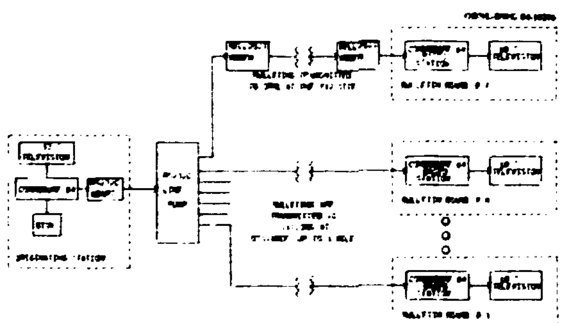

Fig. 2.5-1. Block diagram of the ORNL "Inside Channel."

Text screens used as bulletins are assembled on a central C64 unit using menu-driven software, although text may be composed on the ORNL text-management system and downloaded to the central C64 unit. Each C64 can accommodate 12 screens of text, each containing up to twenty-four 40-character lines. Every text screen is transmitted with attributes to control its title, format, foreground and background colors, expiration date and time, and duration and frequency of bulletin display. The central C64 can be disconnected at any time after a full set of bulletins has been sent to the remote stations; however, to guard against power interruptions at one or more remote stations, the central C64 transmits its entire repertoire continuously throughout the day.

Bulletin board operation commences automatically when the system is switched on, and bulletin display begins as soon as at least one bulletin is received from the originating station. Each C64 unit will continue to run automatically as long as there is information in its memory, and it will restart automatically in case of a momentary power failure.

Each bulletin board consists of a C64 computer and a 19-inch color television set. The C64 is repackaged in a ventilated box and is usually located out of sight. A coaxial cable connects the signal from the C64 unit to the wall- or ceiling-mounted television, which is set on Channel 3 or 4. Minor modifications to the C64 consisted of two additional circuits, one to receive bulletins from the telephone lines and one to monitor computer operation and restart it in the event of a failure. The program, written in BASIC and Assembler language, is stored in read-only memory and is installed as a plug-in cartridge. The text screens are transmitted serially at 1200 baud to an electronic-signal booster ("pump") capable of driving the remote bulletin board stations over voice-grade telephone lines.

Seven bulletin boards are now operating as part of a pilot project to demonstrate and evaluate the system. Six of these are located at distances up to one mile from the central unit, while the seventh is located in the Fusion Energy Division at the Y-12 site and requires a pair of modems for data transmission. More stations may be added to this system if desired.

A six-month evaluation of this pilot system is now in progress, and future expansion and refinements will include consideration of new and changing technology and communication capabilities.

*Information Division.
†ORAU Trainee.

2.5.2 OAK RIDGE INTERPLANT BROADBAND CABLE LOCAL AREA NETWORK

J. M. Jansen, Jr. T. W. Hayes
J. L. Lovvorn R. W. Hayes
D. A. Clayton D. S. Chavis*
C. A. Smith D. F. Perey†

As computer systems have become smaller and more affordable over the past several years, the need to connect users to these facilities and the facilities to one another has increased significantly. To meet this need, a local area network based on broadband cable technology will be developed and installed over the next several years to interconnect the three Oak Ridge plant sites as well as the DOE sites in Oak Ridge. To date, 7 miles have been completed of the approximately 25 miles of trunk cable system that will eventually connect most major facilities in the three Oak Ridge plants. At this time some 50 users are passing data in a terminal-to-host computer environment on this cable system. Video conferences originating from the Central and East auditoriums in Building 4500N at ORNL have been broadcast on the cable system to staff members located in the Fusion Energy and Engineering Technology divisions at the Y-12 Plant site.

The Instrumentation and Controls Division has led the development, design, and installation of the data and video systems while Engineering has completed the initial trunk cable project connecting the X-10 site and ORNL facilities at the Y-12 site. An extension of the ORNL trunk cable into major facilities at ORGDP is scheduled for completion in January 1985, and an extension of the ORNL trunk from the Y-12 Plant to the DOE Oak Ridge Operations Office and Office of Scientific and Technical Information will be completed in mid-1985. During this time and continuing into FY 1986 and early FY 1987, many small distribution systems will be installed within buildings to provide cable system access to users not presently served.

Broadband technology was chosen because of its ability to bridge the large physical distance separating the Oak Ridge facilities and to provide many concurrent types of data and video services on one cable. The 300-MHz mid-split cable system being installed can serve approximately 10,000 terminal users simultaneously at transmission speeds up to 9600 baud. It will also accommodate six high-speed links operating at speeds up to 1.544 million characters/s and 150 medium-speed links operating at speeds up to 9600 baud for host computer interconnections. In addition to these capabilities, several vendors are planning to offer PC networks operating on cable channels reserved for that purpose. Three cable TV channels have been set aside for the broadcast of live seminars originating in the ORNL Central and East auditoriums, and training seminars and the Inside Channel will appear on the cable in early 1985. Five pairs of cable TV channels have been reserved for video teleconferencing and remote origination of video broadcasts.

Thus far, building distribution systems have been completed for the Fusion Engineering Design Center, Buildings 3546 and 3606, and portions of Building 3500. Installation has begun in Buildings 6025, 6002, and 6010 and portions of Buildings 9201-3 and 9201-2 at the Y-12 Plant site. All of these buildings will be completed when final amplifier components arrive in January 1985. Completion of the remainder of Building 3500 and portions of Building 9207 is anticipated in the early months of 1985. The main computer facilities at the ORNL site will be added to the network in early 1985 to allow users terminal access to the Digital Communications Associates (DCA) network from the broadband cable system. In addition, conceptual designs and project estimates have been completed for several of the larger buildings including 4500N, 4500S, 1505, 9201-2, 9201-3, and 9204-1.

*Co-op Student, Clemson University.
†Co-op Student, University of Tennessee, Knoxville.

2.5.3 PROGRAMMABLE CONTROLLERS AND THEIR APPLICATION AT ORNL

G. R. Wetherington, Jr.

Since the mid-1970s, programmable controller technology has been utilized to solve many of the process measurement and control problems encountered at ORNL. Programmable controllers have provided cost-effective off-the-shelf automation solutions that otherwise would have required custom micro- or minicomputer systems development. Utilization of programmable controllers has evolved from simple sequence control and interlocking applications to performance of complex control and data-processing functions. I&C Division has been able to exploit new capabilities in programmable controllers such as numeric and data processing, communications networking, and increased system size and processing speed. In addition, computer-based automated documentation systems have aided in the incorporation of this technology into laboratory experiments by providing the capability to document the programmable controller software with English-language descriptors, upload and download software to the programmable controller from remote locations, and perform logic and state comparisons between online systems and reference logic files stored in the computer. Typical applications by I&C include the automation of complex electro/hydromechanical systems, multi-axis supervisory servocontrol, large-system process and personnel safety interlocks, automated testing, reactor power control, and process simulation. A programmable controller development system is shown in Fig. 2.5-2. This system and others like it have made it possible to accomplish extensive software and system development offline and prior to installation. They also are useful for personnel training and troubleshooting system problems in a controlled environment.

ORNL PHOTO 1885-83

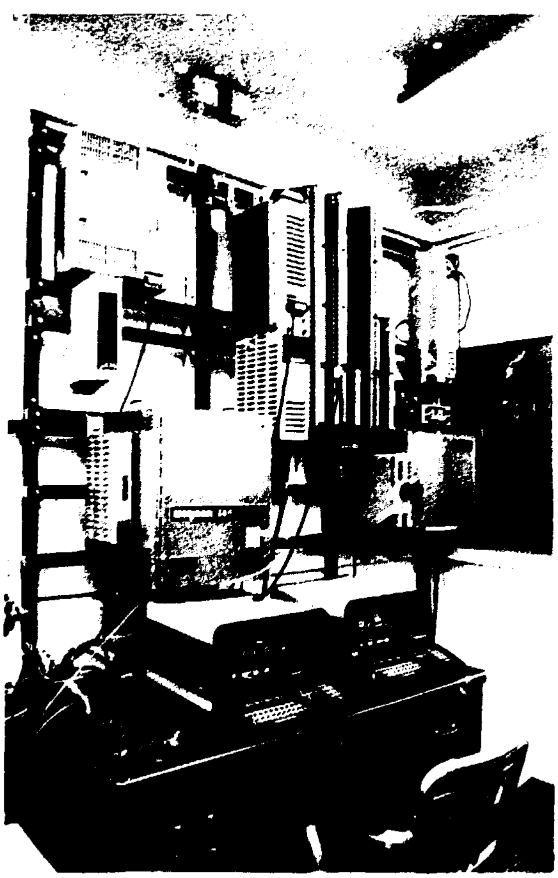

Fig. 2.5-2. A programmable controller development system.

2.5.4 FOUR-PLANT MEDICAL AND INDUSTRIAL HYGIENE COMPUTER SYSTEM

R. L. Simpson S. M. Odom

During this reporting period, the four-plant medical and industrial hygiene computer system was upgraded with additional storage capacity, terminal access ports, and new functional capabilities. To ensure higher system availability, the computer and supporting equipment were moved into a facility with improved temperature and humidity control and better fire protection.

The system was updated with two disk drives, increasing its capacity to more than 500 million characters of bulk data. A statistical multiplexer was installed, bringing to 48 the total number of ports available. With this multiplexer, 16 terminals may access the computer over one telephone line.

Video display terminals and printers were installed in each doctor's office at the ORNL and Y-12 health divisions, allowing each doctor to display laboratory results, clinical diagnosis, ECG diagnosis, X-ray diagnosis, and workplace exposure data during routine physical examinations. The symptoms and effects of acute and chronic exposure to hazardous materials are displayed with the workplace exposure data. This information comes from hazardous materials safety data sheets, which are also stored in the system.

A video display terminal installed in the reception area at the ORNL Health Center enables employees to access a coronary risk assessment program to determine the patient's probability of developing heart disease in the next six years. Various risk factors are correlated to weight and smoking status (which the employee enters), and laboratory results taken from the latest laboratory test.

The health divisions at ORNL, ORGDP, and Y-12 are using this system to schedule multiphasic physical examinations. Employees may be recalled on special as well as regular schedules. All forms and labels associated with multiphasic recall are printed with encoded information to indicate if special testing is required (such as for a respirator mask wearer, shift worker, materials access worker, etc.).

Several special-purpose programs were written and globals maintained to track all employees who need to be recalled for special physicals. These tracking programs ensure that all materials access area (MAA) and asbestos workers are coded for special multiphasic testing and that of all ECG charts are reviewed periodically and updated as needed.

The respective Industrial Hygiene Departments are adding terminals and printers to enable them to enter, display, and print data. The printers will be used to print short reports and lists. Management reports are printed each quarter to show the services provided employees and contractors, employees overdue for multiphasic exams, workload summary, number of laboratory and X-ray procedures performed, and contractors who are charged for services.

2.5.5 HUMAN-MACHINE INTERFACE FOR THE LIQUID NITROGEN/LIQUID HELIUM SYSTEMS OF THE LARGE COIL TEST FACILITY

D. R. Patek

A human-machine interface between operators and the Large Coil Test Facility (LCTF) liquid nitrogen and liquid helium control systems has been developed. The system consists of an Intelligent Systems Computer (ISC) Model 8063 intelligent colorgraphics terminal connected to a Modicon Model 584 PLC. The PLC system, which serves as the actual system controller, provides a two-way data I/O port to the ISC terminal over a hard-wired communications line employing the Modbus protocol. Using data obtained from the PLC, the ISC continuously displays overall system status, including exceptions. In addition, operators may effect system operation using a light pen to operate buttons on the ISC process displays.

Interface design specifications included requirements for speed, portability to other applications, and simplicity to permit inexperienced users (with a knowledge of the process) to design process displays in a short time without extensive use of the keyboard. The system that resulted is a package that includes an interactive menu-driven editor employing the light pen almost exclusively. Using this editor, the operator can generate displays containing static backgrounds and dynamically updatable numeric fields, vertical and horizontal bar graphs, and state-dependent text elements as well as user-definable, pen-sensitive regions. For each display, the operator must assign signal numbers to each of the dynamic elements and pen-sensitive elements in order to associate them with corresponding points in the PLC. The operator must also define the display characteristics of each dynamic element. As the final step in the editing process, displays are assembled and built into an operational system that can then be used by the control system human-machine interface in real time.

The real-time human-machine interface processor included in the package continuously acquired data from the PLC and displayed the data points that are present on the current display. Displays are selected from a menu that is always present in the lower portion of the screen. New completed displays are called up in approximately 2 s. System alarms (when present) appear in the current display, if they have been incorporated in that display, and also cause the menu item containing the name of the alarmed display to flash so that the operator may immediately call up and examine the appropriate display for possible alarm acknowledgment.

Figure 2.5-3 illustrates a run-time liquid nitrogen system (LN2) display. Date and time elements in the upper left are numeric fields updated from a clock in the PLC. Valves are shown to be "open" and "shut" by updatable text fields, while the states of the valves may be altered by actuating pen-sensitive fields overlaying the valve image. Horizontal bars associated with four of the valves are bar graph elements showing valve status (all closed in this picture). Temperature high alarms (TAH), pressure low alarms (PAL) and level alarm low (LAL) are shown as being annunciated; these fields would ordinarily be invisible.

ORNL PHOTO 7177-83

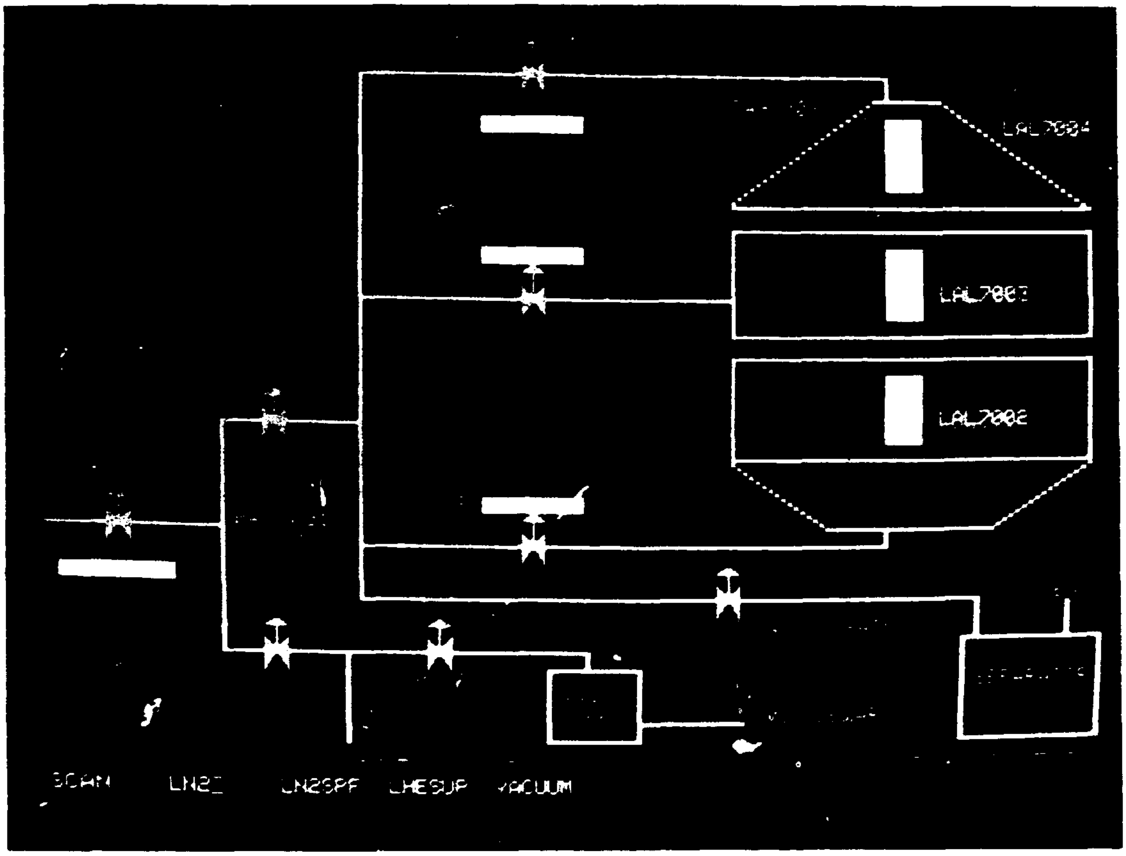

Fig. 2.5-3. Example of a typical process display.

2.5.6 DATA ACQUISITION SYSTEM FOR THE PRESSURIZED THERMAL SHOCK TEST FACILITY

R. R. Bentz
E. R. Broadaway S. Abraham*
R. W. Hayes F. R. Gibson

A computer-operated data acquisition system (CODAS) was developed to acquire the rapidly changing data taken from the pressurized thermal shock experimental tests at the ORGDP. The system was housed in a trailer for environmental protection as well as for providing portability to use it at the Y-12 site on smaller-scale experiments.

The CODAS (see Fig. 2.5-4) is configured with two magnetic tape drives for archival data storage and disk backup operations. Two 67-Mbyte removable disk drives contain the CODAS operating system and data acquisition code. Only one disk drive is required for CODAS operation, leaving the second drive completely available for online data acquisition and/or storage.

The analog input subsystem provides many unique capabilities such as (1) continuous operation at 10,000 samples/s, (2) hardware and software double buffering to protect against data loss, (3) maintenance of multiple scan lists, (4) precise time correlation between readings, and (5) a wide range of inputs (from ± 5 mV to ± 10 V).

The CODAS provides real-time, steady-state information to the test operators as well as archival storage of data to magnetic tape or disk files. Displays and/or periodic logs show current loop conditions to the operations, analysis, and I&C personnel. Plotting capabilities include the provision of online, real-time plots for immediate, quick-look analysis and comparison to prediction curves. The offline plotting routines provided by the CODAS

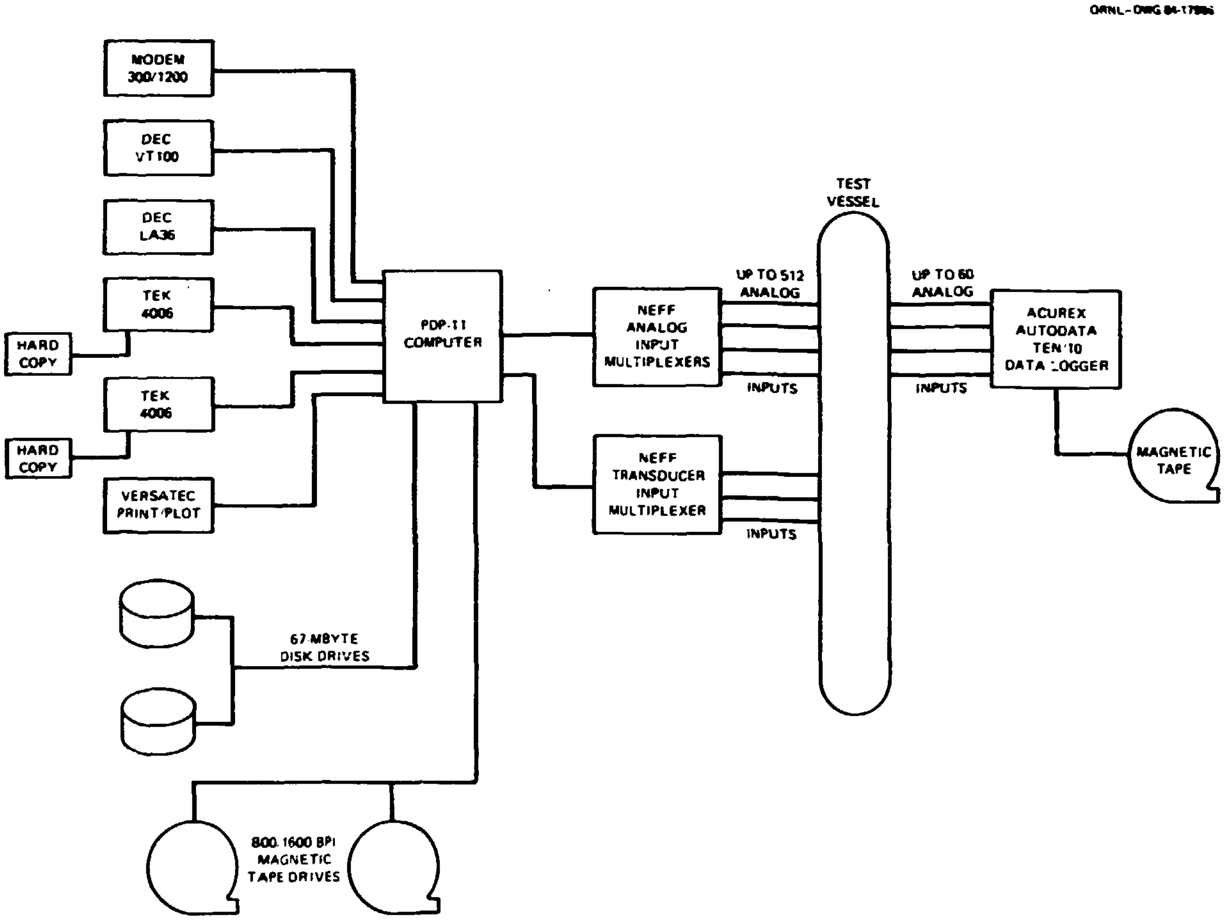

Fig. 2.5-4. Block diagram of data acquisition system for pressurized thermal shock facility.

give fast rough draft plots of data points from regions of interest, while extensive processing of data is handled at the central computing facilities.

The CODAS is also an element of the experiment safety system. Two limits (high and/or low) can be set for each channel to provide full checking during steady-state and/or transient operation. Out-of-limit signal conditions can be ORed and/or ANDed together to provide alarm action when specific data points or specific regions of the test loop exceed certain parameters. Hysteresis is built in to prevent noise from causing false alarms and alarm clearings for close-to-limit signal conditions.

The CODAS is entirely operator controlled; displays and periodic logs can easily be tailored to the current need. Assignment of the input wires can be changed to work around bad channels by simply modifying the database. System programming was done in the Flex structured programming language (a Fortran preprocessor) for ease of use and future modifications.

A redundant system, an Acurex Autodata Ten/10 programmable calculating data logger, monitors separate key system points of interest in parallel to the CODAS and backs up data acquisition. The data logger stores the data on a separate incremental magnetic tape recorder.

*Summer Research Intern.

2.5.7 DATA LOGGERS AS REMOTE FRONT ENDS FOR DATA ACQUISITION SYSTEMS

R. R. Bentz
J. B. Cordts K. J. Scott

The use of data loggers as remote inputs for data acquisition systems becomes more attractive as the price of a data logger decreases. The automatic conversion of voltage inputs to engineering units leaves less calculating to be done by the host computer. With the wide input voltage ranges (±50 mV to ±10 V), almost any type of sensor can be connected directly, thus eliminating instrumentation for conversion and temperature compensation.

Software has been developed to interface the Acurex Autodata Ten/10 programmable, calculating data logger family to a PDP-11 host computer. The FORTRAN-based software was designed to accept RS232-C output from the data logger via a terminal port as input to the computer. The data logger can be located locally and cabled directly to the terminal port, or it can be located miles away and be connected to the terminal port via telecommunications facilities.

Data input from the data logger is doubled buffered to prevent loss of data before storage in a disk file for later analysis. Each data set is date/time stamped, and each input sensor can have an associated label stored in the data file along with the data.

Remote programming of the data logger can be accomplished from the host computer. Data files associated with pages in the data logger are read, and the information is transmitted to the data logger via the RS232-C line as input to the data logger. This input data is echoed by the data logger and checked by the host to ensure proper programming results. This remote two-way communications package allows modifications to be made to the data logger programming without having to travel to the experiment site to change a sensor range or adjust parameter setpoints tied to analog output channels.

At ORNL, three sets of experimental data are currently being acquired remotely: (1) The Energy Division's Joint Institute Dormitory cooling season thermal performance test is storing the experimental data on an I&C Measurement and Controls Engineering Section Network (MACESNET) computer in Building 3500; (2) The Energy Division's Roofing Facility test data, located in Building 3114, is also being stored on an I&C MACESNET computer in Building 3500; (3) The Engineering Technology Division in-pile irradiation experiments at the HFIR Facility are placing remote data, directly into the computer database at the ORR in Building 3042, where it can be plotted and/or analyzed as any locally acquired data.

During procurement of a project data logger, the I&C Division can furnish a loaner data logger to provide a fast and reliable method of placing data acquisition online for slow to medium speed requirements (10 to 30 channels/s scan rate). Spare parts are maintained in-house to ensure maximum online time.

2.5.8 ADDITIONAL PROJECTS

Data Acquisition from a Mass Spectrometer. An efficient method is required to acquire data for storage and to control the data-acquisition hardware in order to use an IQ200 mass spectrometer to measure the absolute inventory of stable krypton and xenon isotopes in coated-particle fuel from high-temperature reactors (HTRs). To accomplish this, the IQ200 is interfaced with a DEC LSI-11/23 computer which uses FORTRAN language and the RT-11 operating system and has dual floppy disk drives. Data are acquired over an RS232C interface and stored on floppy disk for later analysis. Software was developed to control the IQ200 from the console terminal. The operator commands the system to acquire a specific number of sets of samples and tells it when to begin data acquisition. Termination of data acquisition may be done manually by the operator or automatically by the computer after a specified number of samples have been acquired. *(E. R. Broadway)*

CAMAC Module Data Acquisition. In order to provide automated data acquisition for thermal stress and strain tests on metal alloys, computer-automated measurement and control (CAMAC) modules, which use (standard analog-to-digital convertor (ADC), temperature, timing, and fast data-logging, were interfaced with a DEC LSI-11/23 computer. Data input to the CAMAC modules is from thermocouples and strain gages. The software developed to acquire data also controls the data acquisition rate and the length of experiments as specified by the experimenter.

The computer system uses FORTRAN language and the RSX11M operating system, and one Winchester hard disk drive and one floppy disk drive provide storage for programs, data, and the operating system. Data are acquired on the hard disk and transferred to the floppy disk for later analysis. In addition to the console terminal, the system includes a printing terminal and a plotting terminal with serial printer. Software was provided for linear and logarithmic plotting. The printing and plotting terminals may also be switched for use on the ORNL DEC-10 system. *(E. R. Broadway)*

2.6 Microprocessor and Desktop Computer Support

2.6.0 OVERVIEW

R. K. Adams
J. D. Allen, Jr.*
P. L. Butler
J. B. Harper
J. T. Hutton
J. L. Redford
R. W. Rochelle†
R. F. Spille
A. C. Zerby
S. Zimmerman

This group was formed in July 1983 to formalize the development and support activities that had previously been performed either on an ad hoc basis or in conjunction with other groups.

The primary goals of the group are threefold: (1) to provide application engineering support for the laboratory automation needs of the ORNL research divisions through the use of laboratory desktop computers, (2) to provide support for the users of PCs, and (3) to provide microprocessor-based hardware and software support for studies in the areas of robotic manipulator control systems and AI concepts.

The laboratory automation effort presently consists exclusively of the application of Hewlett-Packard computers to the custom needs of individual research groups. As additional experience in the use of third-party hardware and software for PCs is gained, we will begin to apply PCs to this need. This effort currently supports the equivalent of two full-time staff members (FTEs).

The PC support effort initially was targeted primarily for ORNL research and clerical staff. As the PC requirements of the entire Martin Marietta Energy Systems organization grew, however, requests to provide support to users outside ORNL increased. In August 1984, the group was asked to propose a new PC support structure for all three plant sites. That structure is scheduled to become operational in early 1985.

Microprocessor hardware and software work on robotic manipulator control systems is being performed for the I&C group working on nuclear fuel reprocessing. Hardware development includes multiple interconnected microprocessors. Software is being written in the FORTH language, which is ideal for the quick-response, real-world interface requirements of the project. This effort supports two FTEs.

The AI effort began as an informal study of the use of AI expert systems for measurement and controls applications. That effort has led to a study of microprocessor implementation of the parallel processing needs of the expert systems language, OPS, created at Carnegie-Mellon University. This effort supports one and one-half FTEs.

Individual reports in this section cover these topics in more detail.

*Consultant.
†The University of Tennessee, Knoxville.

2.6.1 EXPERT SYSTEM MACHINE

J. D. Allen, Jr.*
P. L. Butler
R. F. Spille
M. S. Blair

The I&C Division has undertaken the construction of a dedicated multiprocessor intended for the extremely high-speed execution of the class of AI programs known as expert systems. Final design work is in process for a prototype device which will consist of 128 Motorola Model 68000 central processing units (CPUs), 16 Mbytes of distributed memory, a host computer and user interface, and a specialized high-speed interface. Results of preliminary calculations suggest that an expert system of *n* rules can be processed by this device at speeds of the order of 20*n* those typical of conventional (serial) computer architectures. A subsystem is scheduled to be in operation for testing by early 1985. This subsystem will consist of the host processor, the high-speed interface, and at least one four-processor cell. Because the architecture can be extended beyond the initial design goal of 128 CPUs quite literally indefinitely, this four-processor cell must be very carefully evaluated to avoid large-scale propagation of design errors.

*Consultant.

2.6.2 ADVANTAGES OF THE FORTH COMPUTER PROGRAMMING LANGUAGE

R. K. Adams R. F. Spille

The BASIC program language is convenient to use and easy to debug because it runs as an interpretive language. To benefit from the speed of compiled BASIC, FORTRAN, or PASCAL, one must suffer the edit-compile-link sequence, which acts to discourage or defeat creative and productive programming. In addition, BASIC, FORTRAN, and PASCAL do not deal well with the need to process real-world data such as is required to communicate with computer interfaces needed for experiment data acquisition and control.

FORTH is a language which has been growing in popularity lately, and which we have used long enough for it to have passed the fad phase. FORTH was created by Charles H. Moore at Kitt Peak National Observatory as a control language for astronomical apparatus. It is interpretive, which greatly speeds development time, yet it shifts gears to become a threaded, incrementally compiled language for execution. Thus, its execution speed is near that of other compiled languages. FORTH has the added advantage that, even while programming at the highest interpretive level, one can write assembly language code (usually for the sake of execution speed or critical interrupt routines) that prior to execution is handled for assembly by the same process as the high-level commands. An added facet of the language is that it is extensible, which means that it can serve as a Meta language in defining or programming custom language applications.

FORTH is available for most processor CPUs, and excellent public domain versions are available. An active standards group seeks to promote rigid adherence to the FORTH language standard while at the same time seeking consensus input that keeps the standard from becoming stagnent. Applications of FORTH include projects such as (1) executive and applications programs on the multitasking, multiprocessor (Motorola Model 68000) robotic manipulator project, (2) Meta language, in which a microprocessor version of the AI expert systems language OPS has been coded, (3) the code in which a Tektronix 4000 Series terminal emulator for the IBM PC is being written, and (4) the multitasking executive and control implementation for laboratory automation using the IBM PC.

2.6.3 A FULL-SCREEN EDITOR AND FILE TRANSFORMATION PROGRAM FOR SCIENTIFIC DATA MANIPULATION

A. C. Zerby

Some computer files, although very useful to the computer, are difficult to access directly by the user. The Editor and File Transform Program was developed to allow this type of file, a BASIC "BDAT" file, to be accessed on HP Series 200 computers. In addition, the program provides the capability of reformatting data files for use by other software packages. BDAT files are data files that store information in a compact, space-efficient code. Although BDAT files are stored on disk in a special code, this program permits the files to be edited with an easy-to-use screen editor. Special function keys called softkeys provide cursor movement, command entry, and program control, and data files can be created, modified, and later extended in size if necessary.

All commands and selections are available through a menu of softkeys. The result is an easy-to-use system that doesn't require the user's remembering special commands because the softkeys guide the user through the program. An instruction manual is provided to show the general sequence in which these softkeys are used and to tell the user what the softkeys do.

The Editor and File Transform Program protects the user from possible program crashes by automatically checking for errors. The software checks input from the user in addition to verifying that a requested file exists on the disk and is in the correct format for the operation selected.

The editor can handle up to 999 observations and from 1 to 50 variables per observation. The total number of values the editor can handle (variables × observations) depends on the amount of memory in the system. A system running BASIC and with 768 Kbytes of memory will be able to handle up to about 10,000 values in one file.

Once the data have been edited, the file transform section allows the file to be changed to a different format. Three file formats are supported: editor files, data files, and statistics files. Editor files allow data to be presented visually in an easy-to-use screen editor format. Also, data files and statistics files can be changed temporarily to this format for editing. Creating a data file is accomplished by entering the numbers into the editor and then transforming the editor file to a data file. Data files can then be accessed randomly or serially by a BASIC program. Statistics files are supported by the Series 200 statistics package. Using a data file and the file transform program, the user can immediately access the data with the statistics package.

The Editor and File Transform Program currently works on both the HP 9816 and HP 9836 computers running BASIC 2.0 with extensions.

2.6.4 SUPPORT FOR HEWLETT-PACKARD DESKTOP COMPUTERS

J. T. Hutton J. B. Harper

Hewlett-Packard desktop computers have been used at ORNL since the HP 9825A became available in 1976. The combination of a wide selection of interfaces (IEEE-488 interface serial, 16-bit parallel, and BCD), high-speed operation (800 Kbytes/s DMA rate, 0.32 ms for real addition, 22 ms for cosine, 2.75 Kbytes/s record rate) and respectable calculation precision (12-digit, 10^{-99} to 10^{99}) resulted in a machine that could handle the whole job—fast real-time data acquisition and experiment control, powerful data manipulation and reduction, or high-quality graphic output for reports and presentations. At last count I&C was involved in the operation of more than thirty 9825-based systems. The current Hewlett-Packard machines most commonly used, HP 9816 and HP 9836, reflect a maturing process rather than a revolutionary one. Memory is now on the order of 1.5 Mbytes (up from 61 Kbytes for the HP 9825); RAM-based extended BASIC is usually the language system rather than ROM-based HPL, and mass storage is on dual 5.25- or 3.5-in. floppy disk rather than tape cartridge.

Support for this family of computers is continuous in two senses: older model computers continue to be supported (one current job uses an eight-year-old HP 9825 in a multicomputer network), and the newest models are put to work soon after introduction (a job using the new HP 9837 with 12-MHz clock, floating-point coprocessor, and 2 Mbytes of memory is now being purchased). Support includes assistance in buying the system, design of special-purpose electronics, writing of software with 10 to 90% user contribution, maintenance of failed system components, and management of a complete inventory of computer supplies in stores stock. Because the change in computers has been evolutionary, it has been feasible to develop sophisticated, highly modular system software that is applicable to more than one generation of computers. For instance, a graphics presentation package with high-quality ORNL style output is now in use on a number of jobs, but no single application could have financed the cost of its development. Customers for this system include the ORNL Metals and Ceramics, Chemistry, Environmental Sciences, and Solid State divisions and the Chem Tech and Separation Systems divisions at ORGDP.

2.6.5 DEVELOPMENT OF COORDINATED PERSONAL COMPUTER SUPPORT

R. K. Adams J. L. Redford
J. A. McEvers A. C. Zerby

In August 1984, the I&C Division was asked to propose a new structure for management of centralized personal computer support for all Martin Marietta Energy Systems Oak Ridge sites. Key elements of this support were identified as new user consultation, user training, and hardware setup in addition to the functions of hardware maintenance and hardware and software evaluation and procurement. Because there are several groups that are highly trained, motivated, and already providing PC services, it was proposed that management efforts center on the concept of coordinating the efforts of existing groups, providing strong leadership of the technical aspects of both hardware and software.

Centralization of the PC support effort is scheduled to begin with the opening of a PC Support Center at ORNL in January 1985, followed by the opening of satellite centers at the Y-12 and ORGDP sites as soon as possible thereafter. Centralized coordination of procurement and machine customization is expected to speed the delivery schedules and reduce the cost of the sizable number of PCs purchased each year.

2.6.6 SOFTWARE STEPPER-MOTOR CONTROL WITH FORTH

D. R. McNeilly

The FORTH language was used to implement software control of a stepper motor in a "smart instrument." The application required a device with the operating modes calibrate and run. The calibrate mode allows the user to preselect up to 2000 sequential stopping positions for a rotating table (angular resolution of 0.2°); the run mode then allows automatic movement sequentially through the selected series of stopping positions.

The system consists of the stepping motor, a shaft encoder, a motor-driver circuit, and a controller made up of an interface and a microprocessor. The interface, which is in the memory map of the microprocessor, converts the shaft encoder signals to a standard binary code and transmits digital pulses to the motor driver. The microprocessor is an

STD bus single-board computer with an on-board FORTH interpreter.

Because FORTH is a dictionary-oriented language that executes user-defined words (which are in turn defined by either primitive FORTH commands or other user-defined words), it was possible to implement the entire control program in less than 200 bytes of memory.

2.6.7 PERSONAL COMPUTER-BASED DISPLAY TOOLS FOR ANALYSIS AND DESIGN OF LARGE-SCALE SYSTEMS

W. B. Dress R. A. Kisner

A secondary goal of the large-plant control system study conducted for DOE was to investigate methods of providing the untutored user with a means of creating, modifying, and accessing a database image of an entire power plant—from a high-level overview down to detailed specifications (e.g., valve settings, parts specifications, data flows, and operational procedures). To demonstrate the potential of such a system, a graphics/text editor program was written in the FORTH language for an HP 9836 desktop computer. It allows PERT-like charts to be drawn, edited, moved about, annotated, stored, and linked to other charts. The links are arranged hierarchially so that each chart contains subcharts and the subcharts in turn contain sub-subcharts, and so on. This feature allows multiple layers of an assembly to be explored to any depth desired by accessing any of the subassemblies (daughters) for viewing and editing.

This program demonstrated that certain techniques of artificial intelligence (natural language processing, windowing, inheritance, augmentation, etc.), could be adapted profitably to the problems of database interfacing, interactive graphics display, and resolution of the search problems inherent in the implementation of such a systems-viewing program.

2.7 Robotics and Electromechanics

2.7.0 OVERVIEW

W. R. Hamel

The Robotics and Electromechanics Group is a new group within MACES, formed as a focus of the Division's robotics-related research and development activities. The group comprises manipulator and servocontrol specialists who are working on the development of advanced robotics and teleoperation concepts involving force-reflecting servomanipulators, distributed digital control systems, and video colorgraphic human-machine interfaces. These activities provide support for nearly eight FTEs in other groups such as the Instrument Development Group and the Microprocessor and Desktop Computer Group. Present funding comes predominantly from the Consolidated Fuel Reprocessing Program (CFRP) and the Center for Engineering Advanced Research (CESAR). The group's work in digital manipulator control is internationally recognized in the nuclear community and currently represents some of the most advanced parallel-microprocessor real-time control development being done at ORNL. One project has lead to an I·R 100 Award (see 2.7.9 and 2.7.10). New projects in the Oak Ridge area and in space and military applications are being pursued and will expand the activities of this group.

2.7.1 ADVANCED ROBOTICS WORKSPACE INTRUSION DETECTION DEVICE

H. L. Martin R. L. Anderson
W. B. Jatko W. R. Hamel

An advanced concept for robot safety applications has been developed for the Y-12 Plant Development Division. The new concept, called the workspace intrusion detection device (WIDD), uses computer vision technology to provide a flexible and programmable intrusion protection device. The objective of the WIDD is to demonstrate a vision system capable of detecting human intrusion into the working area of a robot. The WIDD senses any motion of foreign objects within an annular region surrounding the robot manipulator, and it signals the robot control system to cease motion when such motion is detected. Robotic operation will not resume until the foreign object has left the workspace region.

A commercial vision system manufactured by Industrial Robomation is the heart of the WIDD. Fisheye optics are used on a typical vidicon camera to provide a wide-angle field of view to completely encompass all robot motions. The software is implemented in FORTH language and facilitates generating variable masks to allow the system to be adapted to any robot. A systolic array processor allows the WIDD to scan the workspace at 6 Hz, which allows the system to detect intruding objects traveling at velocities up to 6 ft/s.

The WIDD will be functionally tested in a full-scale robotic work station at the Y-12 Plant in late 1984. The results of these tests will be used to complete refinements in the hardware and software. Software enhancements will be added which will allow intrusion masks to be reprogrammed easily for different robot geometries and applications. Provision will also be made for interconnecting the WIDD module to a central security station.

2.7.2 ROBOTICS-RELATED TECHNOLOGY IN THE NUCLEAR INDUSTRY

W. R. Hamel H. L. Martin

[Abstract of *Third in the SPIE Critical Reviews of Technology Series* **442**, Robotics and Remote Sensing Systems, 97–107 (August 1983)]

Teleoperated manipulators have been used for many years to perform tasks within hazardous environments. There are many similarities between teleoperators and robots, and these likenesses are delineated and reviewed. Applications and development activities in teleoperated systems are summarized on a worldwide basis. Teleoperator developments are examined for outer space, under water, and other hazardous environments. The unification of a robot and a teleoperator system into an autonomous, flexible machine is envisioned as the goal of future "telerobotic" research.

2.7.3 JOINING TELEOPERATION WITH ROBOTICS FOR ADVANCED MANIPULATION IN HOSTILE ENVIRONMENTS

H. L. Martin W. R. Hamel

[Abstract of *Proc. Robots 8 Conference* 1, 901–17 (1984)]

Advanced servomanipulators have been used for many years to perform remote handling tasks in hazardous environments. The development history of teleoperators is reviewed, and applications around the world are summarized. The effect of computer supervisory control is discussed, and similarities between robots and teleoperator research activities are delineated. With improved control strategies and system designs, the combination of positive attributes of robots with teleoperators will lead to advanced machines capable of autonomy in unstructured environments. This concept of a telerobot is introduced as a goal for future activities.

2.7.4 ADVANCED TELEOPERATION IN NUCLEAR APPLICATIONS

W. R. Hamel
M. J. Feldman* H. L. Martin

(Abstract of paper presented at *1984 International Computers in Engineering Conference and Exhibit*, Las Vegas, August 12–15, 1984)

A new generation of integrated remote maintenance systems is being developed to meet the needs of future nuclear fuel reprocessing at the Oak Ridge National Laboratory. Development activities cover all aspects of an advanced teleoperated maintenance system with particular emphasis on a new force-reflecting servomanipulator concept. The new manipulator, called the advanced servomanipulator, is microprocessor controlled and is designed to achieve force-reflection performance near that of mechanical master/slave manipulators. The advanced servomanipulator uses a gear-drive transmission which permits modularization for remote maintainability (by other advanced servomanipulators) and increases reliability. Human factors analysis has been used to develop an improved man/machine interface concept based upon color-graphic displays and menu-driven touch screens. Initial test and evaluation of two advanced servomanipulator slave arms and several other development components has begun.

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*Fuel Recycle Division.

2.7.5 THE ADVANCEMENT OF REMOTE SYSTEMS TECHNOLOGY: PAST PERSPECTIVES AND FUTURE PLANS

W. R. Hamel M. J. Feldman*

[Abstract of *Proc. ANS Topical Meeting on Robotics and Remote Handling in Hostile Environments*, 11–24 (April 1984)]

In the Consolidated Fuel Reprocessing Program at the Oak Ridge National Laboratory, a comprehensive remote systems development program has existed for the past five years. The new remote technology under development is expected to significantly improve remote operations by extending the range of admissible remote tasks and increasing remote work efficiency. The motivation and justification for the program are discussed by surveying the 40 years of remote operating experience which exists and considering the essential features of various old and new philosophies which have been, or are being, used in remote engineering. A future direction based upon the Remotex concept is explained, and recent progress in the development of an advanced servomanipulator-based maintenance concept is summarized to show that a new generation of remote systems capability is feasible through advanced technology.

*Fuel Recycle Division.

2.7.6 AN ADVANCED REMOTELY MAINTAINABLE FORCE-REFLECTING SERVOMANIPULATOR CONCEPT

D. P. Kuban* H. L. Martin

[Abstract of *Proc. 1984 ANS Topical Meeting on Robotics and Remote Handling in Hostile Environments*, 407–15 (April 1984)]

A remotely maintainable force-reflecting servomanipulator concept is being developed at the Oak Ridge National Laboratory as part of the Consolidated Fuel Reprocessing Program. This new manipulator addresses requirements of advanced nuclear fuel reprocessing with emphasis on force reflection, remote maintainability, reliability, radiation tolerance, and corrosion resistance. The advanced servomanipulator is uniquely subdivided into remotely replaceable modules which will permit in situ manipulator repair by spare module replacement. Manipulator modularization and increased reliability are accomplished through a force transmission system that uses gears and torque tubes. Digital control algorithms and mechanical precision are used to offset the increased backlash, friction, and inertia resulting from the gear drives. This results in the first remotely maintainable force-reflecting servomanipulator in the world.

*ORNL Engineering.

2.7.7 DYNAMIC MODELING OF COMPLEX MANIPULATORS WITH CENTRALIZED ACTUATORS

J. A. Euler*
S. M. Babcock W. R. Hamel

In conjunction with the development of the ASM for the CFRP, a task was undertaken to develop a kinematic and dynamic model of a manipulator with centralized actuators to provide insight into the cross-coupling between degrees of freedom and to support the development of algorithms to be used in its control. Three modes of operation of the manipulator were presumed to be possible: (1) master/slave, (2) robotic slave, and (3) master/slave with robotic constraints.

Kinematic analysis was conducted using homogeneous transformations for each link of the ASM, and all important products of the transformations and inverses were obtained in algebraic form. The inverse problem of determining the joint angles as a function of the configuration of the end effector was solved. Constraints on the joint variables to produce pure plane motion were considered for the third mode. Relationships between drive-motor motion and joint motion were determined, as well as those between drive-motor torques and joint torques, using the concept of virtual work. A dynamic model of the ASM was developed assuming drive train compliance but no drive train inertia. This model was formulated using a Euler-Lagrange approach.

General rotational transformations, differential transformations, and a vectorial representation of a plane were reviewed during the process of developing the kinematic and dynamic equations of motion. While nonlinearities such as gear backlash were not considered, this study provides a basis from which more complex manipulator models might be developed. In addition to providing input to control algorithm development, digital simulation of the manipulator is possible using the model developed.

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2.7.8 CONTROL AND ELECTRONIC SUBSYSTEMS FOR THE ADVANCED SERVOMANIPULATOR

H. L. Martin **S. M. Killough**
W. R. Hamel **R. F. Spille**

[Abstract of *Proc. ANS Topical Meeting on Robotics and Remote Handling in Hostile Environments*, 417–24 (April 1984)]

The advanced servomanipulator (ASM) represents a new generation of electrically driven force-reflecting manipulator systems designed to be remotely maintainable. This ASM is being developed to perform remote maintenance in a nuclear fuel reprocessing plant where human access is not allowed. The primary function of the manipulator control system is to maintain stable, accurate master/slave operation while providing sensitive force reflection to the operator. The control system is based upon tightly coupled distributed digital microprocessing methods.

The architectural structure of the control system is outlined and is compared to the previously developed Model M-2 control system, and justification for the advances incorporated into the ASM structure are given. The various modes of operation and diagnostics are described, and throughput requirements associated with joint servo-control and counter-balancing are discussed. The fundamental elements of the control system are reviewed, including the processor selection (Motorola MC68000) and the language (FORTH).

The purpose of this document is to review the design decisions and the resulting design selection to serve as a base for future improvements. Four main areas will be covered: (1) system overview, (2) hardware implementation, (3) software partitioning, and (4) remote electronics considerations. Each area will address the specifics of the selected equipment or the functional requirements of the control method.

2.7.9 CONTROL SOFTWARE ARCHITECTURE AND OPERATING MODES OF THE MODEL M-2 MAINTENANCE SYSTEM

P. E. Satterlee, Jr.
H. L. Martin **J. N. Herndon***

[Abstract of *Proc. ANS Topical Meeting on Robotics and Remote Handling in Hostile Environments*, 355–66 (April 1984)]

The Model M-2 maintenance system is the first completely digitally controlled servomanipulator. The M-2 system allows dexterous operations to be performed remotely using bilateral force-reflecting master/slave techniques, and its integrated operator interface takes advantage of touch-screen-driven menus to allow selection of all possible operating modes. The control system hardware for this system has been described previously.[1] This paper describes the architecture of the overall control system. The system's various modes of operation are identified, the software implementation of each is described, system diagnostic routines are described, and highlights of the computer-augmented operator interface are discussed.

*Fuel Recycle Division.

1. H. L. Martin, P. E. Satterlee, Jr., and B. J. Bolfing, "Distributed Digital Processing for Servomanipulator Control," *Trans. Am. Nucl. Soc.* 43, 752–53, November 1982.

2.7.10 THE STATE-OF-THE ART MODEL M-2 MAINTENANCE SYSTEM

J. N. Herndon*
D. G. Jelatis† **H. L. Martin**
C. E. Jennrich† **P. E. Satterlee, Jr.**

[Abstract of *Proc. 1984 ANS Topical Meeting on Robotics and Remote Handling in Hostile Environments*, 147–54 (April 1984)]

The Model M-2 Maintenance System is part of an ongoing program within the Consolidated Fuel Reprocessing Program (CFRP) at Oak Ridge

National Laboratory (ORNL) to improve remote manipulation technology for future nuclear fuel reprocessing and other remote applications. Techniques, equipment, and guidelines which can improve the efficiency of remote maintenance are being developed. The Model M-2 Maintenance System, installed in the Integrated Equipment Test (IET) Facility at ORNL, provides a complete, integrated remote maintenance system for the demonstration and development of remote maintenance techniques. The system comprises a pair of force-reflecting servomanipulator arms, television viewing, lighting, and auxiliary lifting capabilities, thereby allowing manlike maintenance operations to be executed remotely within the remote cell mockup area in the IET.

The Model M-2 Maintenance System incorporates an upgraded version of the proven Central Research Laboratories' Model M servomanipulator. Included are state-of-the-art brushless dc servomotors for improved performance, remotely removable wrist assemblies, geared azimuth drive, and a distributed microprocessor-based digital control system.

*Fuel Recycle Division.
†Sargent Industries, Inc., Central Research Laboratory.

2.7.11 HUMAN FACTORS IN REMOTE CONTROL ENGINEERING DEVELOPMENT ACTIVITIES

M. M. Clarke*
J. V. Draper* W. R. Hamel

[Abstract of *Trans. Am. Nucl. Soc.* 44, 564-65 (1983)]

The purpose of this presentation is to provide an overview of human factors engineering methodology developed at the Oak Ridge National Laboratory in the program's CFRP remote control engineering (RCE) task and to present some selected accomplishments.

The RCE overall effort includes conceptual design and development of advanced teleoperator systems based on electronic servomanipulators with associated advanced remote viewing capabilities. The human operator is an active component in these advanced systems and is as equally important as the systems' nonhuman components. Methodology and guidelines specific to integrating operators into remote systems have not been developed, and therefore are the thrust of the RCE effort.

Human factors engineering is basic to the development of efficient teleoperator systems for advanced fuel reprocessing. Work has been completed to ensure optimal integration of the operator into the remote system. Efforts have included the identification and allocation of tasks in the man/machine system, improvement of viewing system characteristics, and evaluation of all operator-related controls and displays.

*Oak Ridge Associated Universities.

2.7.12 AUTOMATIC CAMERA TRACKING FOR REMOTE MANIPULATORS

R. S. Stoughton*
H. L. Martin R. R. Bentz

[Abstract of *Proc. ANS Topical Meeting on Robotics and Remote Handling in Hostile Environments,* 383–93 (April 1984)]

The problem of automatic camera tracking of mobile objects is addressed with specific reference to remote manipulators and using either fixed or mobile cameras. The technique uses a kinematic approach employing 4 × 4 coordinate transformation matrices to solve for the needed camera PAN and TILT angles. No vision feedback systems are used, as the required input data are obtained entirely from position sensors from the manipulator and the camera-positioning system. All hardware requirements are generally satisfied by currently available remote manipulator systems with a supervisory computer.

The system discussed here implements linear plus on/off ("bang-bang") closed-loop control with a ±2-deg deadband. The deadband area is desirable to avoid operator "seasickness" caused by continuous camera movement. Programming considerations for camera control, including operator interface options, are discussed. The example problem presented is based on an actual implementation using a PDP 11/34 computer, a TeleOperator Systems SM-229 manipulator, and an Oak Ridge National Laboratory (ORNL) camera-positioning system.

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2.7.13 UPGRADE OF TELEOPERATOR SYSTEMS' MANIPULATOR CONTROL SYSTEM

S. M. Killough
W. R. Hamel H. L. Martin

A pair of TeleOperator Systems Model SM-229 master-slave servomanipulators have been on loan to the ORNL CFRP from the Princeton Plasma Physics Laboratory (PPPL). These manipulators have been used in remote control engineering development activities in the CFRP. PPPL requested that ORNL improve their electrical control system by developing a new digital control system based upon advanced servomanipulator (ASM) control system fuel developed in the CFRP. This upgrade project has now been completed and has been favorably reviewed by PPPL.

The new control system consists of a simplified version of the previous ASM control system. All four arms of Model SM-229, two slave arms and two master arms (Fig. 2.7-1), are controlled by a single equipment rack containing 28 servoamplifiers, power supplies, power supplies, and an Intel multibus-based computer rack. The operator interface is implemented through touch-screen displays and buttons on the manipulator's hand grips. The servoamplifiers are current loop, pulse-width modulated for precise control and high efficiency. The computer rack consists of three single-board computers and 28 channels of analog input and output to interface with the manipulator position sensors and servoamplifiers. The computers are based on Motorola 68000 microprocessors and are programmed in FORTH language.

Fig. 2.7-1. Improved TeleOperator Systems' Model SM-229 servomanipulator.

The advantages of the new system over the old analog system are improved reliability, improved operator interface, selectable force reflection ratios, improved indexing, and significantly reduced drift characteristics. Enhanced reliability and drift characteristics reduce downtime and maintenance costs. To enhance system maintainability, added diagnostic features have been provided in the operator interface. Human factors experiments have shown that the force-reflection quality of the servomanipulator has been improved greatly by the new control system allowing the operator to perform more delicate tasks than before. Also, the new indexing and force-reflection selection features will permit easier operation of the manipulator and thus will be less fatiguing to the operator.

Other organizations such as Los Alamos National Laboratory have expressed interest in the new control system.

2.7.14 ORNL CENTER FOR ENGINEERING SYSTEMS ADVANCED RESEARCH

W. R. Hamel S. M. Babcock

The ORNL Center for Engineering Systems Advanced Research (CESAR) was established by DOE in FY 1984 to carry out long-range energy-related research in intelligent control systems. These systems are intended to plan and perform a variety of tasks in unstructured environments. It is a cooperative effort under the leadership of the ORNL Engineering Physics and Mathematics Division, and the initial focus is on intelligent, autonomous, mobile robots. Instrumentation and Controls Division participation in CESAR began with significant contributions to the proposal for a center, the site review, and other required formalities. I&C Division experience in teleoperator research and development was an important factor in the establishment of CESAR at ORNL.

Since establishment of the Center, I&C has contributed to cooperative research with EPM Division personnel in the areas of dynamic modeling and control of manipulators and advanced computational architectures. In this role, I&C participation involved several joint publications (see 2.7.15, 2.7.16, and 2.7.17). This work included the development of an inverse dynamics algorithm for robotic control of manipulators designed for teleoperation.

In addition, the Center conducted a national workshop on intelligent machines, with participation by a large number of recognized experts in the areas of artificial intelligence and robotics. As a part of the Center's planning, I&C developed a proposed design for a laboratory to house its research experiments.

2.7.15 PARALLEL ALGORITHMS FOR ROBOTIC DYNAMICS

J. Barhen* S. M. Babcock

(Abstract of paper presented at "Robotics Research: The Next Five Years and Beyond," First World Conference on Robotics Research, August 14–16, 1984, Lehigh University, Pennsylvania)

The Department of Energy recently established a Center for Engineering Systems Advanced Research (CESAR) at the Oak Ridge National Laboratory (ORNL). The Center's charter is to conduct long-range, energy-related research in intelligent control systems. This paper reports initial results in developing parallel algorithms for efficiency enhancement in real-time solutions of manipulator dynamics equations. Two approaches to the solution of the inverse-dynamics problem are discussed. The first is concerned with the implementation of Newton-Euler equations in multiprocessor architecture with emphasis on asynchronous algorithms and interprocess communication. The alternative approach is based on an explicit state description of the manipulator dynamics, obtained using computer-assisted analytic simplifications of the symbolic Lagrange-Euler equations. Multicomputer and multiprocessor implementations are discussed. The construction of a compact knowledge-base in terms of associative memories is also suggested to allow solutions of the inverse dynamics based on similarity. Future directions are also outlined. This research is an integral part of a large systems integration effort with complementary tasks in strategy planning and sensor fusion.

*Engineering Physics and Mathematics Division.

2.7.16 BASIC RESEARCH ON INTELLIGENT ROBOTIC SYSTEMS OPERATING IN HOSTILE ENVIRONMENTS: NEW DEVELOPMENTS AT ORNL

J. Barhen* G. N. Saridis†
S. M. Babcock G. de Saussure*
W. R. Hamel A. D. Solomon*
E. M. Oblow* C. R. Weisbin*

(Abstract of paper presented at ANS Topical Meeting on Robotics in Hostile Environments, Gatlinburg, Tennessee, 105–16, April 23–27, 1984)

Robotics and artificial intelligence research carried out within the Center for Engineering Systems Advanced Research (CESAR) is presented. Activities focus on the development and demonstration of a comprehensive methodological framework for intelligent machines operating in unstructured hostile environments. Areas currently being addressed include mathematical modeling of robot dynamics, real-time control, "world" modeling, machine perception, and strategy planning.

*Engineering Physics and Mathematics.
†Rensselaer Polytechnic Institute, Troy, New York.

2.7.17 REAL-TIME ALGORITHMS FOR ROBOTIC CONTROL OF TELEOPERATORS

S. M. Babcock J. Barhen*

[Abstract of *Proc. Robots-8 Conference* 1, 19-72 through 19-78 (1984)]

The Department of Energy recently established a Center for Engineering Systems Advanced Research (CESAR) at the Oak Ridge National Laboratory. The Center's charter is to address long-range energy-related research in intelligent control systems operating in unstructured environments. The purpose of this paper is to report recent progress toward the development of real-time algorithms, incorporating inverse dynamics, for robotic control of manipulators with backdrivable actuation designed for teleoperation. Parallel state-representation dynamics, concurrent algorithms, and algorithms for manipulators with centralized actuation are discussed. This activity is part of a larger effort with complementary tasks in robot strategy planning, sensor fusion, etc.

*Engineering Physics and Mathematics Division.

2.7.18 REMOTE SYSTEMS TECHNOLOGY, OCCUPATIONAL RADIATION EXPOSURE, AND LIGHT WATER REACTORS*

W. R. Hamel B. D. Reid†

(Abstract of paper presented at The Workshop to Delineate the Economic, Technical, and Policy issues for Remote Maintenance in Energy Systems, Gainsville, Florida, March 9–10, 1981)

Oak Ridge National Laboratory has traditionally played a major role in the development of nuclear energy. Today, research and development activities cover a broad spectrum from fission fuel recycle through basic fusion research. Over the years, remote systems technology (RST) has been a major factor in the development and operation of facilities and equipment used in nuclear energy development. ORNL is presently performing a study for the US-DOE Office of Light Water Reactors which is relevant to this workshop.

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*Omitted from 1982 progress report.
†Oregon State University.

2.7.19 A FLEXIBLE DIGITAL CONTROL SYSTEM FOR ROBOTIC SYSTEMS

R. F. Spille
S. M. Killough H. L. Martin

The development of the advanced servomanipulator (ASM) made possible the subsequent development of a flexible digital control system for robotic systems. This implementation uses recent developments in software and hardware to provide an up-to-date, reliable control system for manipulator development. Its prime components are the FORTH programming language, the Motorola 68000 microprocessor, and the Multibus standard backplane.

Given the speed at which robotic systems must operate, it is generally recognized that control processors must be programmed in assembly language or a multiprocessing environment be used. Assembly language was ruled out because of the time and expense associated with software development, and a high-level language well suited to real-time control applications was sought. FORTH emerged as the language of choice because of several of its features which were specifically developed for computer control applications. It is interpretive, which greatly speeds development, and because it is a threaded compiler, its run-time execution speed is comparable to other compiled languages without the time-consuming edit-compile-debug cycle. Furthermore, FORTH makes it easier to work with multiple processors because it is also used in the operating system, and the source code is available to customize it as needed.

The Motorola 68000 microprocessor was chosen for the system processors because it is available as a single-board computer on several busses that support multiple processors. A version of the FORTH language with source codes is also available for this processor. The 68000 is a 16/32-bit architecture that is evolving toward full 32-bit implementations; this upward compatibility means that future projects can evolve with the state of the art without expending a great deal of money and manpower. In addition, execution speed can be increased easily with selected assembly language programming.

A market survey of the various microprocessor busses which support multiprocessing found that the Intel Multibus (IEEE-796) has an overwhelming share of the market. For our projects, this means that a wide choice of off-the-shelf industrial quality hardware is available.

A master/slave configuration of the control system consists of two multibus chassis, one for the master and one for the slave (see Fig. 2.7-2). The

ORNL-DWG 83-13453

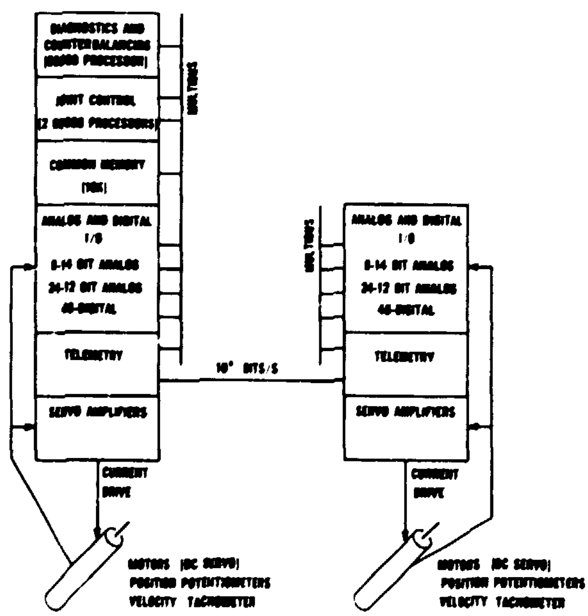

Fig. 2.7-2. Hardware system for master/slave electronics.

slave rack contains only the A/D, D/A, and high-speed serial link hardware and therefore can be radiation hardened. The master rack contains A/D and D/A for the master arms, the high-speed serial link, and four 68000 single-board computers with dual-port memory. Two 68000s are used for the joint servo-control, with each one handling four joint pairs. Another processor is responsible for static weight compensation and joint cross-coupling calculations. The fourth CPU is the link to the human-machine interface and also oversees system operation.

Because the system is composed of readily available parts, it can be duplicated easily for other sets of master/slave manipulators or robots without high fabrication costs.

2.8 Sensor and Instrument Development

2.8.1 REMOTE SENSOR AND CABLE IDENTIFIER CIRCUITS

C. A. Mossman
D. R. McNeilly G. N. Miller
W. B. Jatko R. L. Anderson

Large control systems require many cables for connecting transducers and actuators. Identifying, connecting, and verifying that the leads are connected to the correct inputs of the control system is a labor-intensive, time-consuming process. Typically, a multitude of drawings of process connections, terminal blocks, and cabling are required for the electricians installing the wiring from the control room to the sensors and actuators. In a large installation, hundreds and even thousands of such connections must be made. Not only is it time-consuming to trace, label, and verify these, but opportunities for error exist at each connection.

To reduce or eliminate these problems, we have developed a family of small, inexpensive, passive circuits that can be incorporated into sensors, actuators, or other control system components and cable connectors to provide remote identification of these points from a central location. Upon interrogation by the control system, the circuit responds with a unique identification code for that device or connector. After the interrogation process, the central control computer can construct a look-up table in an initialization procedure that locates each sensor and transducer. Thus, a control system equipped with the sensor identifiers is indifferent to which sensors were connected to particular signal cables; rather it configures itself in response to the existing wiring. Such identifier circuits can also drastically reduce design time by eliminating the need for detailed drawings of components such as cables and terminal block connections. Installation can be reduced to merely counting the number of cables required from the control system to various locations. After the initialization procedure, the system generates its own wiring diagrams if needed. The ability to check the identification of existing signal and actuator channels will increase the safety of complex control systems by eliminating design and wiring errors. In addition, rework or repair following a similar process can be speeded up greatly by eliminating the need for tracing old wiring or extracting such information from drawings that may not truly represent the existing system.

The details of the circuits that might be used can take several forms; at present an entirely digital integrated circuit on a chip is envisioned. Following are the most important features of this development.

1. It is a passive circuit, requiring no internal power supply.
2. All components of the digital circuit can be put on a single custom LSI chip.
3. The circuit could be made sufficiently small to be incorporated in the sensor connector.
4. After development of a custom chip, the cost of the circuit will be small.
5. The circuit can be retrofitted to existing sensor systems at relatively low cost by simply replacing the connectors.
6. Such a sensor-identification system can eliminate the expense of making detailed cabling diagrams.
7. With the sensor identification an integral part of the individual sensor circuit, wiring errors such as connecting the wrong cable to a sensor cannot occur; any cable may be connected to a

sensor, and on startup, the system controller will establish the identification of the sensors on each cable and store the information.

Such identification circuits are not necessarily limited to sensors. Any device could incorporate such a circuit and perhaps be interrogated through the power line connections. Such a device would necessarily be different from the sensor and actuator signal lead identifier circuits, since the digital circuit would have to be carefully isolated from power line currents, voltages, and frequencies.

These devices can be used in any facility having a large number of sensors. For example, the thermostats in buildings could be equipped with such identifiers. The main economic impact is elimination of wiring errors and reduction of design time by eliminating the necessity for detailed design and accounting of sensor cabling. Facilities that require maintenance such as power plants, ships, airplanes, factories, and process plants can be made safer by these devices because the identifier eliminates the possibility of incorrectly connecting or reconnecting cabling.

2.8.2 A DISTORTION-CORRECTED ULTRAWIDE-ANGLE VIDEO CAMERA SYSTEM

W. B. Jatko R. L. Anderson

A system to remove the spatial distortion from a wide-angle (fish-eye) television lens was devised that applies a correction signal to the camera deflection system. A system of this type also could be used to selectively magnify portions of the video scan (electronic zoom).

The distortion of a fish-eye lens causes picture information to be compressed proportional (nonlinearly) to the radial distance from the center of the image. Two correction signals are used to correct this distortion in a single axis. By injecting a correction signal, which is the inverse function of the taking lens, the picture output appears to be linear. This is accomplished by crossmodulating the vertical deflection with a vertical rate exponential waveform and a horizontal rate parabolic waveform. The horizontal deflection is similiarly crossmodulated with horizontal exponential and vertical parabolic waveforms.

A test system was built using a monochrome camera that corrected the distortion on the vertical axis. Several correction signals were tested to determine the optimum linearization of the scan. The technique was effective in correcting lens-induced distortion, but it created moire effects and brightness variations in the image. The brightness variations could be eliminated by Z-axis modulation using the electron scanning beam.

Further development will be required to include correction of the horizontal axis distortion because of additional hardware constraints imposed by the faster speed of the horizontal scanning cycle. The transconductance amplifier must provide a current through the inductive yoke proportional to a given input voltage. The rapidly changing input voltage requires the amplifier to supply large voltage changes across the yoke.

Further research on this system has been proposed.

2.8.3 ELECTRO-OPTICAL X-RAY INSPECTION OF CENTRIFUGE ROTORS

W. B. Jatko

One technique to nondestructively test materials for fractures and voids is to pass an X-ray beam through the material under test. The X-ray beam is then detected by a photoconductive sensor which will display the X-ray image onto a television screen. The operator views the television monitor to locate density variations in the material. Because the television brightness is inversely proportional to the material density, voids can be seen as higher brightness regions on the viewing screen. One limitation of this method is the relative insensitivity of the human eye to brightness variations. The human eye can resolve only about 30 different gray levels; therefore, subtle differences in density are often not discernable to the naked eye.

Flaw detection can be improved by implementing an analog-to-digital converter (ADC) to quantize the television signal from the X-ray imaging sensor (ADCs with 8-bit resolution are readily available). An 8-bit ADC will digitize the image into 256 discrete levels even though the human eye cannot discriminate each level. Since the eye is more sensitive to variations in color hue, improved detection is possible by correlating density levels to colors.

This method was implemented using a 68000-based host computer to control an image-processing subsystem. The image system takes the incoming television analog signal and digitizes it to 256 gray levels. The image is then stored in a 512 × 512-pixel array. To display the stored image, each pixel is serially sent to a digital-to-analog converter (DAC) to drive a conventional television monitor. By using a look-up map between the image array and the DAC, brightness changes can be made to simulate changes in color. This is known as pseudocoloring since color is artificially induced into a monochrome image.

The look-up map normally provides a linear one-to-one correspondence in the image array; that is, a digital representation of a pixel, which has a value of 200, will be converted to a voltage, which is 200/256 of the full-scale output voltage. The imaging system has three look-up maps and three DACs which drive the three primary television colors (red, green, and blue). A monochrome image is formed by putting identical linear maps into the three look-up maps. By rewriting the transfer maps in these look-up tables, changes in brightness of the input image are made to appear as color hue changes in the output image.

This technique allows the operator to detect small density changes in the material and consequently spot potentially dangerous flaws sooner than with conventional X-ray imaging.

2.8.4 COMPUTER CONTROL SYSTEM FOR A CONSTANT STRESS EXPERIMENT

R. E. Hutchens

In making biaxial tube stress-strain tests on pressurized cylindrical specimens, the materials testing laboratory of the ORNL Engineering Technology Division had a need to control the stress of test specimens. The stress, or force per unit cross-sectional area of a cylinder wall, is a function of the diameter and length of the cylinder, the pressure inside the cylinder, and the wall thickness. When making strain tests with constant pressure, the stress on the cylinder walls becomes increasingly greater as the walls yield and become thinner.

To test a cylindrical specimen until failure, some means was needed to control the pressure in the cylinder in order to maintain a constant stress as the cylinder walls yielded. The problem of measuring the pressure and strain and calculating the stress made the need for using a computer obvious. A Hewlett-Packard Model 87 desktop computer was chosen because of its moderate cost, simplicity of programming, and ease of interfacing hardware to peripheral devices. A Hewlett-Packard Model 3497A data acquisition/control unit is the interface between the HP 87 and the measurement and control devices. The HP 3497A and the HP 87 communicate via the HP IB or IEEE-488 bus.

Pressure is measured with a Heise precision digital pressure gage, and the pressure measurement from the Heise gage is transmitted to the HP 3497A voltmeter by means of a retransmitted voltage signal. The strain of the cylinder walls is measured by a Hitec capacitance strain gage and signal conditioner. A voltage proportional to the strain is transmitted to the HP 3497A voltmeter, and the pressure and strain signals to the HP 3479A are read by the HP 87 computer. The operator enters the initial dimensions of the cylinder into the computer. The pressure, strain, and initial dimensions of the cylinder are used to calculate the stress on the cylinder walls. A classical proportional-integral control algorithm is used to compare the calculated stress to a desired value (setpoint) and develop a control signal to control the pressure in the vessel. The output control signal is digitally transmitted to the HP 3497A, which in turn transmits a current signal to a Moore current-to-pressure converter. The resulting pressure signal from the current-to-pressure converter controls the nitrogen supply and exhaust valves that regulate the pressure in the cylinder.

This system has been installed and is being operationally tested. All hardware and software functions according to the integrated system design.

2.8.5 IN-LINE MEASUREMENT AND CONTROL OF URANIUM SOLUTIONS

D. D. McCue

Efficient spent nuclear reactor fuel reprocessing systems require continuous, real-time measurement of uranium at key control points throughout the facility. Many of the chemical processes are in hostile environments in the presence of high radioactivity, high temperatures, or corrosive atmospheres.

In the past, reprocessing systems were monitored by extracting a small amount of process material for chemical analysis in a "hot" cell by highly trained technicians. This method is not only costly and cumbersome; it also causes large inventories of special nuclear materials to accumulate in the reprocessing plant while operators await analytical results.

The first successful instrument capable of remote, continuous, unattended operation was developed at ORNL and installed in an operating reprocessing plant in August 1982. The device is a multistream fiber optic spectrophotometric instrument system for liquid phase processes. Its design is based on the use of long optical fibers to interface with the process piping and transmit analytical signals to and from the process environment. The balance of the instrument system, which is composed of a spectrophotometer, an electronic signal processor, and a dedicated minicomputer, is located in a control room or other benign area and may be as much as 100 m from the plant process. The fiber optic process interface device is designed to be disconnected from the process piping by means of a remote maintenance manipulator where an extreme environmental hazard exists. The instrument is capable of the simultaneous measurement of uranium concentration in three independent process streams. Up to five wavelengths are selected according to the composition of the process solutions.

The prototype instrument system was first subjected to field tests on the secondary extraction cycle of an active uranium recovery plant in August 1982. Four wavelengths (5 nm half-power bandwidth) were selected to measure the uranium concentration in both aqueous (4 to 5 M HNO_3 in water) and organic (26–32% tributyl phosphate in N-dodecane) process streams. The wavelengths selected for these applications are 416 nm for uranium, 426 nm for TBP and total nitrate, 403 nm for interfering contaminants, and 565 nm as a "blank." A summary of the in-line, continuous performance characteristics of the measurement system are

Stream	Range (g/L U)	Precision at 1 σ (g/L U)
Raffinate (aqueous)	0–30	.80
Extract (organic)	70–130	1.8
Feed (aqueous)	170–250	3.4

Instrument outputs are 4- to 20-mA signals proportional to uranium concentration for each stream independently.

Automatic control was successfully applied to the secondary extraction cycle of the plant in late 1983. The control objectives were to maximize both the product decontamination factor and overall uranium throughput.

Chemical process and automatic control development are continuing.

2.8.6 PHOTOMETRIC DETERMINATION OF URANIUM AND PLUTONIUM IN ORGANIC SOLUTIONS

D. D. McCue

Small quantities of spent nuclear fuel are often reprocessed in order to chemically isolate and recover plutonium and uranium. This process takes place in a small "hot" cell whose environment is hostile due to the presence of high radioactivity and corrosive atmospheres. A 16-stage mixer-settler is used as an extraction device. In each stage, the uranium/plutonium-bearing aqueous solution is contacted by an organic solvent that has a greater affinity for plutonium/uranium nitrate than does the aqueous solution. If the flow rates of the Pu/U aqueous feed and the raw organic solvent are correct, the organic solvent in each succeeding stage will be saturated until in the highest order stages nothing remains in the aqueous solution except fission products and other undesirable contaminants.

In order to properly control the feed and organic flow rates to the mixer-settler to prevent losses to the waste aqueous solvent, it is necessary to analyze the Pu/U concentration in a specific stage and automatically control the feed and/or organic flow rates on a continuous basis.

A modified version of an in-line uranium photometer previously developed at ORNL was installed in the facility in May 1984. The device is a multistream, fiber optic spectrophotometric instrument system for liquid phase processes. Its design is based on the use of long optical fibers to interface with the process and transmit analytical signals to and from the process environment. The balance of the instrument system, which comprises the spectrophotometer, an electronic signal processor, and a dedicated minicomputer, is located in a benign area some distance from the hot cell. The instrument is capable of simultaneous measurement of the concentration of Pu (valences IV and VI), and U (valence VI) independently in three separate stages. Four wavelengths (5 nm half-power bandwidth) were selected to measure Pu and U concentrations in the organic solvent. The wavelengths selected for these applications are 416 nm for U(VI), 660 nm for Pu(IV), 833 nm for PU(VI), and 580 nm as a spectrophotometric "blank." For this application, instrument performance is as follows:

Material	Range (g/L)	Precision at 1 σ (g/L)
Uranium VI	50–100	1.5
Plutonium IV	0–20	.3
Plutonium VI	<1	NA

Since it was very difficult to produce stable Pu(VI) samples for instrument calibration and, for the same reason, Pu(VI) was unlikely to occur in the mixer-settler during this particular run, evaluation was set aside.

A control algorithm was developed from a mixer-settler model and included in the instrument system computer software. Output from the photometer is a 4- to 20-mA signal proportional to control algorithm command and is used to position the organic flow valve.

Future extractions in this reprocessing facility will be controlled by this photometer system.

2.8.7 REMOTE ANALYZER FOR MULTICOMPONENT PROCESS STREAMS: RAMPS

D. T. Bostick*
J. E. Strain* R. E. Harper
D. D. McCue R. D. Seals†

(Abstract of paper presented at Industrial Research Institute Conference, "Spotlight on Oak Ridge," Oak Ridge, Tennessee, May 22–24, 1984)

RAMPS is an in-line multiwavelength, multichannel photometric system employing long fiber optic cables for determining the concentration of components in a flowing process stream. This instrument performs precise analysis of up to five major constituents in three different complex chemical process streams by utilizing the simplicity and reliability of absorption photometry with fiber optic signal transmission technology and state-of-the-art microprocessor instrument control and data processing. Analyses are repeated every eight seconds, with on-line computer readout of all concentrations.

The in-line cell assembly can be installed in virtually any type of hostile or hazardous process environment, including high radiation areas. It is connected to the optical and electronic equipment located 100 m or more away via armored quartz fiber optic cables. The cell is a flow-through design and is made entirely of highly resistant materials. Only the sapphire cell windows and the stainless steel body come in contact with the process stream. The optical path length of each cell can be adjusted individually to provide maximum sensitivity for each stream. The microprocessor-controlled instrument automatically corrects for changes in background, turbidity, cell window fouling, and source or detector fluctuations by using a dual-beam compensation technique.

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2.8.8 A NEW IN-LINE FIBER OPTIC SPECTROPHOTOMETER FOR REMOTE ANALYSIS AND PROCESS CONTROL

D. T. Bostick*
J. E. Strain*   M. L. Bauer
D. D. McCue   R. E. Harper

[Abstract of *Trends Anal. Chem.* 2(9), XII–XIII (1983)]

An in-line spectrophotometer has been developed for continuously measuring uranium and plutonium concentrations in process streams in fuel reprocessing plants. The new instrument uses single-strand quartz fiber optic light cables and a radiation-hardened in-line flow cell to make measurements not previously possible because of high radiation levels (approximately 10^5 R/h). The use of fiber optics also permits isolating radiation-sensitive optical and electronic components in a protected, accessible location.

Monochromatic light at selected wavelengths is produced by multiple narrowband interference filters in a rotating filter wheel. Light transmitted through the sample stream is detected by a photomultiplier tube, and the transmission data are stored and processed by an LSI-11 computer system. The microcomputer executes concentration algorithms and deconvolutes the spectra, outputs the concentration of the heavy metals to plant operating personnel, communicates with an executive computer system, stores trend data, and facilitates the updating of all calibration and other operating parameters from a user terminal.

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2.8.9 HYDROGEN DETECTION IN GAS CHROMATOGRAPHY

D. R. McNeilly   L. H. Thacker

Measuring hydrogen in the range 1 to 200 ppm in gas chromatography effluent streams with good resolution, at low cost, has not been possible in the past. This type of measurement was needed to analyze gases from an in-pile loop experiment. A mass spectrometer could give much greater resolution than was needed by the project but would be very large and expensive. On the other hand, a gas chromatograph would not give 1 ppm resolution, and hydrogen detection may be masked by the simultaneous elution of other gases from a given column. Solid state hydrogen leak detectors have somewhat unstable outputs but are very sensitive to low levels of hydrogen. Unfortunately, they are sensitive to hydrogen compounds also.

An improved hydrogen measurement system was developed by connecting a solid state hydrogen detector to the output of the chromatographic column, producing stable and repeatable results. There are several reasons for this: (1) The output of the chromatographic column (molecular sieve 5A) separates hydrogen from all other hydrogen compounds. (2) The output of the chromatographic columns separates hydrogen from oxygen, thus preventing the detector from acting as a catalyst to recombine hydrogen and oxygen and thereby produce water that would not be detected. (3) The chromatograph causes a pulsed change in the amount of hydrogen at the detector when hydrogen is eluted from the column; the magnitude of this change indicates the hydrogen concentration in a matter of seconds, eliminating the normal drift of the solid state sensor.

Several advantages of this method over previously existing hydrogen measuring devices are obvious: (1) If a chromatograph is currently being used to measure the concentration of other light gases in a gas mixture, the cost of adding a solid state hydrogen detector to the system is trivial. (2) If no chromatographic system exists, the column needed to separate hydrogen and the valve needed to inject a sample onto the column can be bought for less than $200. (3) The hydrogen detector is small (less than one cubic inch in physical size). (4) It allows a hydrogen measurement to be made in a range that previously only a mass spectrometer could measure.

2.8.10 A TORSIONAL-WAVE ULTRASONIC LEVEL, DENSITY, AND TEMPERATURE SENSOR

W. B. Dress   D. R. McNeilly

A continuation of previous work by G. N. Miller et al.,[1] and S. C. Rogers and G. N. Miller[2] realized the early promise of a torsional ultrasonic instrument for continuous measurement of the temperature, level, and density of a fluid surrounding a long, ribbon-like sensor. The technique, which employs torsional and extensional acoustic waves, has been developed for use as a level and temperature sensor. Intended applications include monitoring coolant level in power reactors while providing continuous measurements of temperature and density, thereby producing a real-time profile of these parameters along a chosen path through the reactor vessel.

A specialized circuit for generation and detection of acoustic pulses in alternating torsional and extensional modes was used with a microprocessor to control the sequence of data acquisition and averaging. The data were transmitted over a serial line to a host computer for display and archiving purposes. The instrument is currently under evaluation by TVA for use in some of their advanced reactor design work.

An extension of this work for NRC demonstrated the application of the technique to high-resolution density measurements for nonviscous fluids ranging from 0.5 to 3.0 specific gravity. Possible applications include online density measurements where high precision (to within 0.1% absolute and 0.05% relative) and temperature correction are required. Charge-state measurements of storage batteries, accountability monitoring of uranium salt solutions in storage tanks, and inventory control in fuel tanks are all potential applications. This work led to the design of some high-speed (100-MHz), specialized electronic modules necessary to obtain the precision and stability required by such measurements.

1. F. R. Mynatt, ORNL-5931/V1, December 1982, p. 143.
2. Ibid., p. 143.

2.8.11 ULTRASONIC AND EDDY CURRENT METHODS TO DETECT COMPLETENESS OF CUT IN REMOTE LASER DISASSEMBLY OF NUCLEAR FUEL ASSEMBLIES

W. B. Dress

The CFRP fuel disassembly program required a fast and reliable method of determining the quality of a laser cut in a fuel shroud. Our first task was to evaluate potential techniques of cut detection (primarily ultrasonic Rayleigh waves) and recommend the best candidates for eventual implementation.

A preliminary study by an outside contractor showed that the use of ultrasonic surface waves provided a positive indication of the no-cut situation, with attenuation in acoustic signal strength across a simulated fuel shroud as a cut between transmitter and receiver was produced. The problems of acoustic coupling to the rapidly moving shroud and quantative interpretation of the received signal were left to be worked out later. We subsequently showed that surface waves are indeed simple to generate, transmit across the shroud surface, and detect. The practical problems imposed by shroud surface temperature and roughness, together with a requirement of high cutting speed, ruled out the use of ultrasonic surface waves.

A second task evaluated alternative methods of cut detection. The method chosen for extensive testing was based on detection and analysis of eddy currents induced in the surface of the fuel shroud. The variation in amplitude and phase of an electromotive force induced in the shroud's surface by an alternating current can be correlated with the amount of material being removed while correcting for temperature effects. This method allows quantitative measurements of cut completeness and has the additional possibility of detecting fuel pins lying inside the assembly.

An outside consultant and equipment manufacturer provided an instrument for extensive evaluation. The main feature of this instrument was its ability to provide measurements of the required sensitivity in a piece of high-temperature, rapidly moving stainless steel.

2.8.12 INVESTIGATION OF DECALIBRATED NICROSIL VERSUS NISIL THERMOCOUPLES: QUANTITATIVE SIMS ANALYSIS USING INDEXED SENSITIVITY FACTORS AND OXYGEN FLOODING

W. H. Christie* **R. L. Anderson**
R. E. Eby* **T. G. Kollie†**

[Abstract of *Appl. Surf. Sci.* **18**, 287–98 (1984)]

Secondary ion mass spectrometry [SIMS] was used to determine the failure mode of sheathed Nicrosil versus Nisil thermocouples exposed to temperatures above 1000°C. Four thermocouples, two sheathed in Inconel-600 and two sheathed in type 304 stainless steel, were studied. Relative sensitivity factors, indexed by a matrix ion species ratio, were used to quantify SIMS data for the alloys studied. Oxygen pressure $\geq 2.7 \times 10^{-4}$ Pa in the sputtering region gave enhanced sensitivity and superior quantitative results compared to data obtained at instrument residual pressure. At sufficiently high oxygen surface coverage, the slope of the nonlinear sensitivity factor curves for the Nicrosil and Nisil alloys approached zero. Quantified SIMS data showed that these thermocouples decalibrated because significant alterations in the elemental composition of the Nicrosil and Nisil thermoelements occurred. The extent of the observed alteration was different for each thermocouple for a given time and temperature of exposures and was influenced by the particular sheath material used in the thermocouple construction.

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2.8.13 THERMOCOUPLE TESTS: A QUICK-LOOK REPORT ON FAILURES DURING LOSS-OF-FLUID TESTS L2-6 (LOFT L2-6)

R. L. Anderson C. P. Cannon*

(Abstract of ORNL/TM-8852, March 1984)

Tests were conducted to determine the operating limits of fuel cladding thermocouples installed inside the fuel rods for the loss-of-fluid test (LOFT) F2 fuel bundle test. The fuel cladding temperatures in the LOFT F2 fuel bundle are measured with thermocouples attached to the inside surface of the fuel cladding. From the point of attachment, the thermocouples are led through slots in the fuel pellets to the top of the fuel rod, where they exit. When the reactor is operating, the lengths of the thermocouples in the slots may be heated to temperatures as great as 2160°F.

This investigation was conducted to determine (a) the range of time and temperature exposure over which reliable performance can be expected for the dual diameter, 0.040/0.020-in.-diam, Inconel-clad, MgO-insulated, type K thermocouples installed in the LOFT F2 fuel bundle, and (b) the effect of reactor fuel preconditioning at various reactor power levels.

Grounded, ungrounded, and unjunctioned thermocouples were tested in temperature profiles estimated for reactor power levels of 8, 10, 12, and 14 kW/ft. The estimated peak temperature was 2160°F for the highest power level. The effects of fuel preconditioning for eight hours at peak temperatures of 1950°F were measured.

The results showed that (a) in expected LOFT F2 temperature profiles, thermocouple read-out errors remained less than 1% up to a peak temperature of 1900–1950°F; (b) thermocouple read-out errors from virtual junction effects increase rapidly with temperature above 1950°F; (c) wire breakage in peak temperature regions did not occur in any of the tests; and (d) thermocouple performance did not measureably improve nor degrade as a result of eight hours of preconditioning at 1950°F. The test data taken with the estimated profiles establish an upper bound on performance errors.

The results of the tests led to these conclusions: (a) thermocouple performance should be well behaved up to peak temperature of 1900–1950°F; (b) preconditioning at reactor power levels to 12 kW/ft (i.e., peak temperatures below 1900 1950°F) should neither degrade nor improve thermocouple performance; (c) preconditioning at power levels above 13 kW/ft (at temperatures above 2000°F) should not be attempted; and (d) both loop resistance and insulation resistance should be monitored in the F2 test.

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2.8.14 AN ULTRASONIC LEVEL AND TEMPERATURE SENSOR FOR POWER REACTOR APPLICATIONS

W. B. Dress G. N. Miller

[Abstract of *Trans. Am. Nucl. Soc.* **45**, 240 47, (1983); also NUREG/CR-3856, ORNL/TM-9236, August 1984]

An ultrasonic waveguide employing torsional and extensional acoustic waves has been developed for use as a level and temperature sensor in pressurized and boiling water nuclear power reactors. Features of the device include continuous measurement of level, density, and temperature producing a real-time profile of these parameters along a chosen path through the reactor vessel.

The next step toward a practical level sensor for use in a reactor vessel should concentrate on nuclear qualification in a joint effort with a vendor and a utility.

2.8.15 TORSIONAL ULTRASONIC TECHNIQUE FOR REACTOR VESSEL LIQUID LEVEL MEASUREMENT*

W. B. Dress

[Abstract in *Proc. 11th Water Reactor Safety Research Information Meeting, National Bureau of Standards* 5, NUREG/CP-0048, 242-49 (1984); also NUREG/CR-3113, ORNL/TM-8585, January 1983]

A liquid-level sensor based on the ultrasonic technique is a promising long-term solution for monitoring core cooling. It can display temperature and density profiles of high resolution along a chosen path through the reactor. The density data can be used to indicate voids (boiling), froth, and actual level as well as collapsed level. Correlation of these parameters with the outputs of other plant sensors provides event independence.

The continuous nature of the temperature, level, and density information is another advantage of the ultrasonic method over those indicating at a limited number of discrete points. Compatibility with current reactor designs and the ability to perform under both normal and accident conditions is realized by the simple, all metal construction of the sensor, and by isolation of the transducer from the reactor core area.

*Published in *Transactions 11th Water Reactor Safety Research and Information Meeting*, NUREG/CP-0047, under the title "An Ultrasonic Level and Temperature Sensor for Power Reactor Applications."

2.8.16 A HIGH-RESOLUTION ULTRASONIC DENSITOMETER

W. B. Dress

[Abstract of *IEEE 1983 Ultrason. Symp.*, 287 90 (1983)]

The velocity of torsional stress pulses in an ultrasonic waveguide of noncircular cross section is affected by the temperature and density of the surrounding medium. Measurement of the transit times of acoustic echoes from the ends of a sensor section are interpreted as level, density, and temperature of the fluid environment surrounding that section. This paper examines methods of making these measurements to obtain high resolution, temperature-corrected absolute and relative density and level determinations of the fluid. Possible applications include on-line process monitoring, a hand-held density probe for battery charge state indication, and precise inventory control for such diverse fluids as uranium salt solutions in accountability storage and gasoline in service station storage tanks.

2.8.17 CORRELATION OF THE ANALYTICAL SOLUTION WITH EXPERIMENTAL DATA ON THE ELECTROLYSIS POTENTIAL PROBE

William F. Bethmann, Jr.

(Abstract of NUREG/CR-3152, ORNL/TM-8650, June 1983)

In response to a loss-of-coolant accident (LOCA) in a water-cooled nuclear reactor, the reactor vessel is reflooded with water from standby storage tanks to carry off heat that would otherwise damage fuel rods, vessel, and other structures. During the latter phases of the reflooding, a mixture of steam and water flows between the structures and a flowing film of water adheres to the surfaces. To gain some knowledge about the behavior of these films and to aid heat transfer calculations in designing reactors, engineers have developed instruments for the measurement of film thickness, flow velocities, and mass flow rate in reactors and their simulators. The electrolysis potential (EP) probe is one such instrument and is designed to measure average liquid velocity inside the films. Development of the EP probe is based on the concept that current between the two electrodes of a sensor in contact with a water film will vary inversely with fluid velocity when an excitation voltage of sufficient magnitude to produce visible electrolysis is applied. A theoretical model for the probe was developed in an attempt to better understand the mechanisms producing the observed phenomena. Good correlation between theoretical calculations and experimental data has been difficult to achieve because the relationship is not straightforward; the measurement is dependent on the conductivity and thickness of the fluid and sensitive to parameters such as ion concentration, temperature, dielectric constant, and diffusion coefficient.

The EP probe was capable of measuring liquid film velocities over the range from 5 to 50 cm/s with an accuracy of $\sim\pm 5\%$ of reading under laboratory conditions. It should be noted, however, that field use proved to be impractical because of the extreme sensitivity to water chemistry which could not be adequately measured or controlled.

2.8.18 A PROBABILISTIC MODEL OF ANNULAR-DISPERSED FLOW IN A REACTOR SUBCHANNEL AS SEEN BY CYLINDRICAL GEOMETRY IMPEDANCE PROBES

G. O. Allgood M. J. Roberts

(Abstract of thesis for the Master of Science Degree,* The University of Tennessee, Knoxville, March 1983; also NUREG/CR-3622, ORNL/TM-8841, February 1984, and *Proc. 14th Annual Modeling and Scintillation Conference* 4, 1171-84, April 1983)

A probabilistic model of annular-dispersed flow in a reactor subchannel as seen by cylindrical geometry impedance probes is developed from a finite element model of these electrodes in an inhomogeneous, isotropic medium of water and steam. The model is based on a derived finite difference equation for the potential at the center of a cube in terms of the potentials of the adjacent cubes and their material properties (Ampere's circuital law, low-frequency case).

The probabilistic model returns admittance (or capacitance) signals for two sets of probes based on specified film and two-phase void fractions. These signals will have temporal variations based on the flow velocities, the probe separation distance, and the frequency content of signals. The model assumes one-dimensional flow.

*Presented by G. O. Allgood.

2.8.19 DEVELOPMENT OF A DIGITALLY BASED FILTER FOR NOISE REDUCTION IN PURGED DIP-TUBE LIQUID DENSITY MEASUREMENTS

G. R. Wetherington, Jr.

(Abstract of a thesis for the Master of Science Degree, The University of Tennessee, Knoxville, August 1983)

A digitally based noise reduction filter was developed to reduce the noise associated with a purged dip-tube density measurement. An experimental density probe and measurement system was constructed to observe the measurement process and develop the corresponding filter design. The resulting filter provides adequate noise attenuation while passing the desired density information. Filter implementation utilizes existing measurement system capacity without the addition of extra signal-conditioning hardware.

2.8.20 INVENTION OF A TUNABLE DAMPER FOR USE WITH AN ACOUSTIC WAVEGUIDE IN HOSTILE ENVIRONMENTS

S. C. Rogers

(Abstract of thesis for the Master of Science Degree, The University of Tennessee, Knoxville, December 1983; also ORNL/TM-9112, June 1984)

A damper was invented to remove undesirable stress pulses from an acoustic waveguide. The damper was designed to be tunable and constructed to withstand a corrosive or otherwise hostile environment. It serves to simplify the design and enhance the performance of a water-level measurement system, of which the damper and acoustic waveguide are integral parts.

An experimental damper was constructed and applied to an existing level probe and measurement system. The resulting damper, properly tuned, causes acoustic stress pulses which pass into it along the waveguide to be completely attenuated.

2.8.21 ADDITIONAL PROJECTS

Auto-Ranging Moisture Analyzer Electronics. An auto-ranging moisture analyzer was developed for the HFIR HRB-17,18 project. This instrument measures the content of water vapor (in ppm) in a flowing gas stream.

The instrument uses an electrolytic cell to generate an electrical current proportional to the vapor content of a gas flowing through the sensor. The current is converted to a voltage in a transresistance amplifier and used to drive a front-panel meter and a data recorder. The output voltage is also used to sense conditions requiring a range increase or decrease. The nominal output voltage range is 0 to 5 V dc; if the voltage increases beyond 4.5 V, a digital logic circuit will decrease the gain of the transresistance amplifier. Similiarly, if the output voltage decreases below 0.5 V, the transresistance gain is increased.

The amplifier gain control logic is selectable to allow for either manual or fully automatic operation. In addition, a protection network will sense an excess of vapor and will switch the electrolytic cell to maximum current operation to protect the cell from damage.

The instrument measures moisture in concentrations of 0 to 1000 ppm in five ranges with 10% accuracy. It provides TTL logic outputs to indicate the range factor to an external recorder. *(W. B. Jatko)*

Precision Ramp Generator. Many scientific and engineering experiments require the application of a precisely linear rate of change (a ramp function) of some variable. This linear relationship is usually obtained by electronically generating a voltage having a constant derivative with respect to time, and applying this voltage as the setpoint of the controller that controls the parameter of interest. A new and unique circuit has been developed to generate the linear setpoint voltage with greater precision and repeatability than was previously obtainable.

The generator uses a novel feedback circuit that forces the generator output to have a constant rate of change. A constant dV/dt is maintained by a differentiator in the feedback element. The ramp rate is variable and can begin from a preset voltage. These features enable the generator to have presettable, precisely repeatable output, allowing the user to fully control the test conditions.

The U.S. Department of Energy has applied for a patent on this device. *(W. B. Jatko, D. R. McNeilly, L. H. Thacker)*

VMOS Ultrasonic Pulse Driver. As part of the development of an ultrasonic in-core level, density, and temperature measurement system for nuclear reactors, it was necessary to magnetically prebias a magnetostrictive sensing rod. In order to accomplish this, the magnetic bias was established by passing a large electric current through the rod, which creates a magnetic field around the rod. An additional electric current was applied to generate a circular magnetic field, and the vector addition of the two magnetic fields caused a resultant helical field which induced a torsional distortion in the magnetostrictive material. The distortion propagated to the end of the rod and was reflected back. By measuring the time required for the distortion to travel down the rod, information about the rod's environment can be deduced.

A 30-A current pulse with a 10 μs duration was needed to establish the desired magnetic bias field. This was achieved by using vertical metal-oxide semiconductor (VMOS) transistors to drive the low-impedance metal rod. The VMOS device has the advantage of fast switching times and is free from secondary breakdown problems. VMOS devices were available which could carry 30 A in a single package. These devices were configured into a source-follower network with a conventional operational amplifier predrive stage.

In subsequent tests, the high-current drive stage performed satisfactorily and therefore was incorporated into the measurement instrumentation. *(W. B. Jatko)*

2.9 Engineering Support

2.9.1 ELECTROMAGNETIC INTERFERENCE STUDIES AND TESTING

P. D. Ewing
R. A. Hess **D. J. Marshall**
L. D. Hunt **E. E. Waugh**

The gas centrifuge enrichment program at ORGDP needed reasonable assurance that its large and expensive systems for uranium separation would operate properly together in a plant environment without interference caused by electromagnetic phenomena. ORGDP Engineering hired a consultant to develop criteria for standardized testing of components and systems based on MIL-Standard tests for electromagnetic compatibility. The contractor documented[1] the elements of good equipment design for electromagnetic compatibility and defined ten standard tests for determining both the conducted and radiated emissions from equipment and the susceptibility of equipment to radiated and conducted emissions.

The I&C EMI team continues its major task of performing these tests on GCEP equipment, at both the ORGDP and now primarily at the GCEP plant in Piketon, Ohio, under contract with the Goodyear Atomic Corp.

While the major EMI effort has been for GCEP, this team has also done work for other organizations at all three Oak Ridge plants. Furthermore, the scope of work of the EMI team has evolved from performing only EMI tests to assisting in EMI problem solving and on-site retrofitting (grounding, shielding, filtering, etc.). In the future, the EMI team expects to be involved in the evaluation of advanced gas centrifuge systems in both the design and design review phases.

Because a close relationship exists between Tempest testing and EMI testing, the I&C EMI team was selected by DOE to head the Tempest test team for the three Oak Ridge sites. The initial task will be zone testing at all three plants, which involves testing areas for their suitability for containing future equipment that might emanate. This is accomplished by putting an electromagnetic source inside the building and measuring the attenuation to sensors placed outside the building at the perimeter of the controlled space. A van has been equipped for zone testing, which is scheduled to begin in October 1984. In addition, the team has been designated to field test the new Y-12 broadband computer communications system. Various locations near the boundary of the exclusion area at Y-12 will be checked to detect any electromagnetic emanations from the cables carrying the wideband digital computer transmissions.

During FY 1985, three members of the EMI team will attend a five-week Tempest training course and will be trained to perform the full range of Tempest tests.

1. "Requirements & Guidelines for EMI Control in GCEP," K/PO-360, Rev.3, October 14, 1982.

2.9.2 GAS CENTRIFUGE ENRICHMENT PLANT PROCESS BUILDING DATA HIGHWAY STUDY

W. L. Zabriskie J. W. Hodges*

(Abstract of ORGDP Report K/D-5440, April 1983)

This study was initiated to determine if multiplexing alternatives could effect a cost reduction over the baseline design of the Gaseous Centrifuge Enrichment Plant. The alternatives consider replacing a status-reporting star network and four command buses with multiplexing hardware. Minimal modification to the current design is a constraint. Comparisons are based on design costs, procurement/fabrication costs, reliability, and electromagnetic interference (EMI) considerations. Two alternatives using star-connected loop architectures were examined. These designs were based on commercially available multiplexer products. The cost of loop communications at high data rates and the cost of general purpose, flexible hardware preclude cost savings with these approaches. No net savings result even when design costs are ignored. Two alternatives using a star-connected mux concentrator architecture were also examined. A system based on commercially available hardware still pays a cost penalty for its general purpose nature, although small savings are possible. A custom design, however, lowers the procurement costs significantly and results in net procurement cost savings of $1007 K per building. The design and certification costs, a one time effort that could total $1500 K, partially offsets these savings in Building 3. For Building 3 through 8, however, a total savings of $4542 K is projected. Reliability and EMI/RFI considerations are comparable to the baseline case. These results clearly show that a large potential savings can be realized by distributing the central command buses and status reporting network into the process.

*ORGDP Engineering Division.

2.9.3 ROTOR BALANCE CHECK STAND DRIVE CONTROL UNIT SOFTWARE DESCRIPTION

W. L. Zabriskie

A rotor balance check stand (RBCS) is used to test the dynamic balance properties of newly manufactured gas centrifuge rotors. New software has been written to control the drive control unit (DCU) of the RBCS. Under software control, the DCU provides outputs to the gas centrifuge rotor being tested in the RBCS. The control of the DCU is based on the concept of modes, and four modes are implemented in this software: automatic drive up, automatic drive down, park, and coast.

This revision of the DCU software includes substantial improvements over previous versions. Much of the error detection and command selection logic previously implemented in hardware is now performed in software. More reliable response to commands, more accurate measurement of rotor frequency and calculation of drive frequency, and improved response to alarm conditions have been implemented. In addition, structured design and improved documentation contribute to the ease of modifying and maintaining the software.

2.9.4 SOLUTION OF VISUAL 100 COMPUTER TERMINAL RELIABILITY PROBLEMS

W. B. Jatko

Frequent complaints regarding the reliability of the Visual Model VT 100 computer terminal suggested a possible flaw in electronic design. An extensive review of Maintenance Department records showed that nearly 50% of VT 100 failures were due to the power supply and that an additional 20% could be directly attributed to reduced power supply performance.

Analysis and subsequent experiments showed that the problems were caused by failures in a group of electrolytic capacitors on the power supply module because the original manufacturer had located these filter capacitors too near a large heat dissipator on the module. These capacitors were consequently operated at elevated temperatures, causing premature failures. Replacement capacitors placed in the same heat field would also fail early, usually within 15 months of continuous operation.

The replacement power supply that was developed eliminated heat generation and provided a greater electric current reserve. Minimal labor is required to place the new power supply modules in the existing wiring harness.

Eight terminals were equipped with the new power supplies and have been field tested for more than a year without a failure.

2.9.5 TRUPACT-I DROP TEST INSTRUMENTATION

C. T. Alexander **J. O. Hylton**
W. F. Bethmann, Jr. **J. B. Mitchell**

Engineering support was provided to the ORNL Chemical Technology Division to aid in testing the transuranic package transporter (TRUPACT-I). This package was designed by Sandia National Laboratories for the containment of low-level radioactive waste and was destructively tested at ORNL to verify its ability to satisfactorily withstand hypothetical accident conditions during shipment.

Tests were conducted on TRUPACT-I at the ORNL Tower Shielding Facility (TSF) to simulate these conditions. The TRUPACT-I was to be dropped on a nonyielding surface from a height of 30 ft and on a punch from 40 in., which tested the strength of different side panels. The total package weight was 50,000 lb. The TSF provided the equipment necessary to meet these height and weight requirements.

Each drop test performed at the TSF consisted of a series of synchronized events required for a successful drop and to obtain valuable data. This was accomplished through design of a microprocessor-based programmable controller housed in a portable carrying case called the drop test sequencer. The drop test sequencer would scan a set of status inputs and send control signals to peripherial devices according to its programmed logic. The drop test sequencer controlled such devices as magnetic tape recorders, high-speed photography and video equipment, and the drop mechanism. If an error status existed, the controller would stop the drop sequence before the drop mechanism was energized. The operator also had the authority to override the automatic control of the sequence, if necessary, at any time.

Many of the structural members of the TRUPACT-I were instrumented with strain gages and accelerometers. The signals from these instruments were monitored during each drop through an umbilical cord attached to the package and connected to the inputs of strain-gage amplifiers. The output signals from the input transient were recorded on frequency-modulated tape recorders.

Pictures were taken of each drop using high-speed photography and video equipment. Precise timing of start pulses to energize the cameras is very important. Due to startup time and film speed requirements, the drop test sequencer was programmed to correct for these time delays before energizing the drop mechanism.

The TRUPACT-I was suspended by two, three, or four ¾-in. steel cables, depending on the orientation of the package. Cable cutters were used to sever the suspension cables initiating the drop event. All cable cutters must fire simultaneously or the package would rotate while falling. A circuit in the drop mechanism monitored the cable cutter detonators for continuity and firing voltage. Powered by the sequencer, the drop mechanism gave a continuity check to the sequencer, enabling it to proceed thru its logic. If continuity was lost through any cable cutter, the countdown was halted. When the drop mechanism was energized either by the drop test sequencer or manually, it supplied the electric current required to detonate the cable cutters and release the TRUPACT-I.

2.9.6 HIGH-IMPACT TEST SEQUENCER

W. F. Bethmann
J. O. Hylton E. E. Waugh

A device has been designed to control the events associated with high-impact drop testing at the ORNL TSF. The need for a device of this type has increased because the TSF has taken the role of a user facility for high-impact and drop testing. This device, called the drop test sequencer, enhances the ability of TSF to accommodate drop testing by increasing data-handling capabilities and automatically controlling the drop sequence. In the past, the drop sequence was performed by verbal commands, thereby increasing the chances of communication error and losing valuable data from the drop.

The drop test sequencer is composed of several components housed in a portable carrying case and is designed to interface with several different devices used in drop testing. These peripherial devices include frequency modulated tape recorders, high-speed photography and video equipment, event alarms or lights, and the drop mechanism. The sequencer is designed around a Gould Modicon Micro 84 programmable logic controller. Other components integrated into the sequencer include an operator control panel, a programming panel, I/O connectors, electromechanical relays, audible alarms, and status indicator lights.

The operator can choose either manual or automatic operation. By sending start pulses and receiving status returns, the drop test sequencer can automatically control the drop sequence, stop all peripherial devices after the drop event, and reset itself. In manual operation, the operator has full control of the drop mechanism and all peripherial devices. The automatic timing for control is programmed prior to running the sequencer and may be changed between drops. A safety feature incorporated into the sequencer is a keylock switch which acts as a manually operated permissive interlock in the firing circuit. It is active both in the automatic and manual modes. The operator makes the final decision by moving the switch to "ARM" at some time during the countdown sequence.

2.9.7 CONSOLIDATED EDISON URANIUM SOLIDIFICATION PROGRAM

2.9.7.1 CEUSP INSTRUMENTATION

J. O. Hylton W. B. Jatko
D. R. Miller F. R. Ruppel
W. F. Bethmann I. E. Williams
A. J. Beal C. C. Hall

The Consolidated Edison Uranium Solidification Program (CEUSP) is a $17 million radiochemical processing project conducted at the Radiochemical Pilot Plant for the ORNL Chemical Technology Division. In addition to I&C, participants in the project are ORNL Engineering, Quality Assurance and Inspection, and Plant and Equipment personnel and the Rust Engineering Company. The MACES Field and Services Engineering Group is I&C's lead engineering group for this project. Other I&C groups have also been involved: Instrument Development, Special Electronics, Process Instrumentation and Panel Fabrication, and Radiation Monitoring.

The major I&C activity on the project to date has been assistance in design, installation, and calibration of more than 300 process and control panel instruments. Other activities include development of special instruments. An interface for the furnace temperature setpoint controller was designed and built to allow it to control the speed of the furnace feed-metering pump. In this manner, both the furnace temperature and the feed rate profile during a run can be preprogrammed. An instrument was developed to monitor feed tank depletion. This monitor samples readings from the tank level and density transmitters for several minutes and displays the average flow during the sampling period. Conventional, locally mounted flowmeters could not be used because the fluid is highly radioactive and the meter could not be serviced by a human if any problem developed. Therefore, existing remote bubble type level and density transmitters were selected to provide the necessary inputs to the flowrate computer.

2.9.7.2 CEUSP FLOWRATE MONITOR

W. B. Jatko

A flow measurement system was developed for the CEUSP to measure fluid flow rate by measuring fluid volume changes per unit of time in a containment vessel.

The instrument uses two differential pressure sensors in the vessel to measure fluid level. One sensor measures the weight of the fluid while the other measures its specific gravity. Fluid height is obtained by dividing the fluid's weight by its specific gravity. Since the volume of fluid is proportional to its height and fluid flow is the change in volume per unit of time, fluid weight and specific gravity can be used to determine the fluid flow rate.

After low-pass filtering, the 4- to 20-mA signals from the differential pressure cells are digitized by a 12-bit ADC. A single-board computer commands the ADC to sample the pressure cells every 6 s. Each sample is actually taken 15 times and averaged to minimize artifacts from the pressure measurements. After normalizing the samples to obtain fluid level, the digital value is stored in a memory array.

Since the sampling interval is known, the memory array can be thought of as a one-dimensional graph of fluid level versus time. Thus the flow rate is change in level per unit of time, or dL/dt. This can be approximated as the slope of the level versus time graph contained in the memory array. The single-board computer uses a linear least-squares-fit algorithm to calculate the fluid flow rate.

The memory array is sized to provide an estimate of the average flow rate over the previous 10-min interval. After some data smoothing, the flow rate is updated to the digital display. The current software yields flow measurements from 0 to 9.99 cm^3/min. Experimental tests have shown accuracy to be within 5% and limited by the pressure sensor accuracy. A running least-squares-fit algorithm permits 5% accurate measurements to be made within 3 min of startup.

2.9.8 CERAMICS TECHNOLOGY LABORATORY AUTOMATION

G. W. Allin J. A. McEvers
J. O. Hylton A. C. Zerby

The Ceramics Technology Laboratory in the ORNL Metals and Ceramics Division has begun to introduce more automation in its materials fabrication and inspection facilities. Several new inspection and testing machines have been obtained over the past few years, many of which are capable of being controlled or monitored by a computer. Also, several existing pieces of equipment (such as vacuum furnaces) have been modified by replacing the old instruments and controls with electronic controls that will be compatible with the proposed automation plan.

The initial effort was to install and make operational a local area network of HP 9816 computers. When completed, the network will consist of at least six computers.

One of the HP 9816 computers is presently being interfaced to a fractometer and will be used primarily for acquisition and analysis of displacement and load data taken from instruments on the machine.

The first system to be automated will be a nondestructive testing station which utilizes both eddy current and ultrasonic probes for inspection of parts. A three-coordinate scanning machine that can be controlled by the HP 9816 computer has been designed and assembled for testing. Computer interface hardware and control software is being developed and will soon be ready for testing.

2.9.9 METROLOGY RESEARCH AND DEVELOPMENT

2.9.9.1 METHODS OF CALIBRATION AT A NATIONAL LABORATORY

R. L. Anderson

(Abstract of paper presented at the Symposium on Applications of Radiation Thermometry, National Bureau of Standards, Gaithersburg, Maryland, May 8, 1984)

In a metrology laboratory in a research organization, requests for special or unusual calibrations are likely to occur. Also, researchers are frequently interested in obtaining the highest accuracy possible for a reasonable amount of money. This is in contrast to cases where the record of a traceable calibration is made something of a ritual to fulfill a quality assurance requirement. Thus calibrations in a large research laboratory are likely to be of a wide variety with an emphasis on optimization of cost versus accuracy.

The role of the ORNL Metrology Research and Development Laboratory (MRDL) is that of an intermediate link between the national measurement system maintained by NBS and the researcher in the laboratory. MRDL maintains primary NBS-calibrated standards, secondary laboratory standards, and frequently laboratory working standards. This involves monitoring the usage and performance of the primary standards and returning them to NBS as required. In addition, the NBS calibration must be transferred to the laboratory standards, and the ancillary measuring equipment must be maintained. Careful records are kept of these transactions so that a complete calibration and maintenance history is on file for each standard and instrument.

2.9.9.2 ACTIVITIES OF THE METROLOGY RESEARCH AND DEVELOPMENT LABORATORY

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

One of the two primary functions of the MRDL is to support the technical staff of the I&C Division and ORNL in the design and execution of experiments to obtain highly accurate data, measurements of physical quantities traceable to NBS, and special tests that require the accuracy or diversity of the measurement instrumentation available in the MRDL. The second primary function is to provide NBS-traceable calibrations of user instruments and sensors. A record of calibration types and quantities for the past four years is given in Table 2.9-1.

Table 2.9-1. Types and number of MDRL calibrations performed

	Fiscal year			
	1981	1982	1983	1984
Temperature				
Thermocouples	169	27	145	57
Resistance thermometers	35	53	39	65
Optical pyrometers	32	20	30	26
Measure "A-value" of windows	3	0	5	3
Temperature indicators	8	5	6	10
Transmitter test sets	5	4	13	7
Pressure	20	15	9	10
Vacuum	1	2	0	1
Force	5	3	5	4
Flow	5	3	9	13
Electrical				
Ammeters (including electrometers)	15	12	9	6
Voltmeters	2	2	2	2
Resistance	26	14	26	22
Standard cells	20	7	13	9
Digital multimeters	32	46	40	33
Potentiometers	10	6	8	3
Voltage and current sources	11	12	15	13
Counters/timers	1	4	5	3
Total calibrations	410	262	379	287

Several interesting trends can be gleaned from these data. The total number of calibrations has been approximately constant over the past four years. A significant fact not shown in the table, however, is that the number of personnel performing the calibrations has decreased from four in 1982 to two in 1984. The majority of the routine calibrations have been automated to some extent, and have increased calibration efficiency.

Many calibrations that depend on traceability through MRDL are performed for two groups: the I&C Division Field Shop and the Facilities Support Group. About 30 calibrations are performed each year on the standards used by the I&C Field Shop in Building 3500. This field shop, in turn, performed about 1600 calibrations. Over the past four years, MRDL has calibrated about 12 instruments a year for the Facilities Support and Reactor Maintenance Group. These groups have responsibility for calibrating approximately 6000 instruments, about 2000 of which are calibrated at three-month intervals, and another 1000 at the HIFR are calibrated or checked at six-month intervals.

In addition to the normal calibrations performed in MRDL, the special measurements listed in Table 2.9-2 were also performed.

Table 2.9-2. Special measurements performed in the MDRL

Controller evaluation
AVLIS connector tests
Volume of chamber
High Voltage cable breakdown
Powerline probe
Micro signal conditioners
Evaluate digital recorder
Repair galvanometer
Watt meter
Data logger
Frequency-to-voltage converter
Temperature sensors for gage blocks
Tests on pyrometer measurement of body temperature in a argon plasma near 350°C
FY 81-82
HP LCR meter
Evaluation of linear displacement probe
Hydrometer calibration
Calibration of oxygen analyzer
Calibration of electron gun (5 kV)
Calibration of vibration table
Calibration of calorimeter
IR tests of INEL thermocouples
Graphite compatibility tests on noble-metal sheathed type S and type B T/C
Differential pressure cell diaphragm displacement
Final tests of type K versus type N comparison

2.9.10 ADDITIONAL PROJECTS

Particle Velocity Measurement System. An instrument was developed for the ORNL Metals and Ceramics Division to determine and display the velocity of a .013 in. diam spherical pellet as it is being shot from a gas-fired gun toward a test specimen inside an electron microscope. Typical particle velocities are 150 ft/s. This work is being performed in an effort to correlate erosion of flue linings with particle velocities, densities, and lining materials.

To determine velocity, the path of the pellet is directed between two photoemitter-detector pairs spaced 1 in. apart. A counter is started when the light beam of the first emitter-detector pair is broken and is stopped when the beam of the second emitter is broken. The total number of counts accumulated represents the time of flight between the two devices.

The mechanical portion of the device consists of a brass tube 1½ in. long by ⅛ in. diam. The tube supports the photo-optic devices and directs the beams of light through .010-in.-diam holes. When the pellet is fired from the gun, it passes through a .015-in.-diam hole drilled lengthwise through the tube.

The electronic portion of the device includes a sensitive front-end amplifier to detect fluctuation of the sensing element current when the pellet breaks the light beams, two comparator/latches which activate when the beams are broken, and a 10-MHz clock/counter circuit. Due to limitations of the existing counter speed, the 10-MHz clock is divided into 1-MHz increments. The electronics package also includes logic to detect circuit faults and failures.

Work is continuing to improve the resolution and flexibility of this device. The 10-Mhz clock will be input to high-speed IC counters and the resulting count provided as input to a desktop computer to permit further analysis. *(R. G. Upton, J. A. McEvers)*

Carbon-Bonded Carbon Fiber Molding Process. A carbon-bonded carbon fiber (CBCF) molding process is used to fabricate thermal insulation disks and sleeves for the isotope fuel cells used in satellites to convert the heat of radioactive decay directly into electricity. Metals and Ceramics Division personnel had been operating the molding process manually, but, for quality assurance, they desired to automate the process so that critical variables could be recorded and controlled. I&C provided a system to control the level of the CBCF slurry in the molding tank and the flow of diluent through the molding cylinders. The system can control the differential pressure across the molding cylinders instead of the diluent flow, thereby allowing the process to be run at either constant flow or constant pressure. A two-channel digital controller was installed to allow the operator to initiate the process with the touch of a single button. Ultrasonic liquid level transmitters were used to monitor molding tank level and feed tank levels. A magnetic type flowmeter was used to monitor diluent flow, and a transmitter with a remote sensing diaphragm was used to monitor pressure. The four process variables are recorded simultaneously on a four-channel indicator-recorder. *(F. R. Ruppel, J. A. McEvers, J. O. Hylton)*

2.10 Special Projects

2.10.1 MEASUREMENT AND CONTROL ENGINEERING CENTER

R. L. Anderson

Through the initiative of various personnel in the ORNL Instrumentation and Controls Division, a university-industry cooperative research center in measurement and control engineering has been established in cooperation with the University of Tennessee, Knoxville (UTK) College of Engineering. Patterned after existing National Science Foundation centers, the Measurement and Control Engineering Center will be a joint research and educational initiative of the UTK College of Engineering, the ORNL Instrumentation and Controls Division, and industrial sponsors. The University is assuming responsibility for the academic program, and the I&C Division will provide major support in the form of access to extensive state-of-the-art research facilities and active participation by ORNL professional staff. Staff members from both institutions will propose and carry out research in measurement and control engineering. ORNL staff members chosen to participate will receive appointments as adjunct faculty in the College of Engineering with all of the rights and privileges of that position. These appointments will be implemented under released-time agreements with UTK, and the Center will pay the salaries of ORNL staff members during the released-time employment.

The principal objectives of the Center are to

1. Establish a comprehensive graduate curriculum in measurement and control engineering through coordination of existing graduate courses and establishment of additional courses as required in the appropriate departments of the UTK College of Engineering,
2. Coordinate the UTK use of existing facilities and personnel at ORNL and UTK and establish new facilities for a balanced program of basic and applied research to support the education program,
3. Provide U.S. industry access to a national center of excellence, and
4. Catalyze the development and marketing of new measurement and control concepts and instrumentation in the Tennessee Technology Corridor.

The Center will be a source of graduate measurement and control engineers who can move quickly into productive careers. Since there is no comparable program at any U.S. university, the route to professionalism has been largely through on-the-job training. The Center will narrow the gap between newly graduated and productive engineers. This is especially important because of the projected high demand for measurement and control engineers in the 1980s, particularly in rapidly growing high-technology areas such as automation and robotics. Having such a source of measurement and control engineers in close proximity is a major factor in the I&C Division's interest in initiating the program. The program can be used to evaluate students as prospective employees as well as provide educational opportunities for junior staff members.

This cooperative arrangement should provide invaluable experience to students because the Instrumentation and Controls Division, with a staff of nearly 400, is the largest integrated measurement and controls R&D organization in the United States. Activities in the Division include basic research on sensors and measurement techniques; applied research and development in the design, fabrication, and testing of state-of-the-art measurement and control systems; and support of instrumentation and measurement systems in basic and applied research and engineering environments at ORNL and at other facilities presently operated by Martin Marietta Energy Systems, Inc.

Comparable facilities to give students experience in state-of-the-art controls and measurements would be very expensive to establish and maintain; probably no university could undertake alone to provide such capabilities. This lack of modern instrumentation in U.S. colleges and universities is widely recognized as a national crisis in higher education. Through the involvement of ORNL, students associated with the Measurement and Control

Engineering Center will have access to state-of-the-art instrumentation and experimental facilities.

The unique combination of circumstances at UTK and ORNL provides a rare opportunity to expand the public service, research, technology transfer, and educational missions of both institutions. Research will provide new and improved technology, and education will provide manpower to fuel the growth of both the measurement and control industry and user industries. The Center will provide a focus for technology transfer and information exchange because, in addition to the research and educational activities, an extensive and continuing series of conferences, workshops, and short courses will be offered.

The Measurement and Control Engineering Research Center has been planned as one of the university-industry cooperative research centers partially funded by the National Science Foundation, and the center's planning office is now preparing a proposal to the NSF. ORNL has played an active role in this effort by providing professional staff for the planning office and by proposing to provide facilities and staff to the Center on an available basis. The Center will be a consortium of industrial sponsors who will provide continuing funding at an annual rate of fifty thousand dollars each. Membership fees, grants, and equipment gifts from manufacturers and users of measurement and control technologies will support research by the UTK staff (including the adjunct staff from ORNL) and graduate students. Advice and direction for the research and academic efforts will be provided by the industrial members of the Research Advisory Board. The director of the Center will oversee distribution of the funds.

At the Industry Workshop held at UTK/ORNL on July 10–11, 1984, the response of the industrial participants was quite favorable. Of 26 companies represented, 10 indicated that they would strongly recommend that their companies join the consortium. By the end of September 1984, the steering committee had evidence of strong to definite commitments from eight to twelve major U.S. companies, including Gulf Research, Alcoa, Koppers, Olin, Tennessee Eastman, Texas Instruments, Martin Marietta Energy Systems, Ford, International Paper, EG&G Ortec, Dow, and Armstrong World Industries. The response obtained during personal visits to major U.S. companies has further confirmed the conviction that the Measurement and Control Engineering Center has an opportunity to become a unique national resource because of its ties with ORNL. This is the only university-industry cooperative research center with such ties to a national laboratory, and several industry representatives have indicated that close ties with ORNL are a major attraction of the Center.

2.10.2 CROSS SECTIONS FOR DIELECTRONIC RECOMBINATIONS OF B^{2+} AND C^{3+} VIA $2s \rightarrow 2p$ EXCITATION

P. F. Dittner* C. Bottcher*
S. Datz* W. B. Dress
P. D. Miller* G. D. Alton*
C. D. Moak* N. Nešković†
P. H. Stelson* C. M. Fou‡

[Abstract in *Phys. Rev. Lett.* 51(1), 31–32 (1983)]

Dielectronic recombination cross sections for the Li-like ions B^{2+} and C^{3+} via $1s^22s \rightarrow 1s^22p$ excitation are reported. The amount of electron capture attending the passage of megaelectronvolt/(atomic mass unit) ion beams through a collinear, magnetically confined, space-charge-limited electron beam is observed as a function of relative energy. The results agree well with distorted-wave calculations.

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2.10.3 A MEASUREMENT OF PARITY NON-CONSERVING NEUTRON SPIN ROTATION IN LEAD AND TIN

B. Heckel et al.*† W. B. Dress

[Abstract of *Phys Lett.* 119B(4, 5, 6) (December 1982)]

The rotation, ϕ_{PNC}, of a neutron beam polarization vector due to parity non-conserving forces is observed in natural Pb and Sn targets. The following values for ϕ_{PNC}/l in units of 10^{-6} rad/cm are found: Pb: $+(2.24 \pm 0.33)$, and Sn: $-(3.19 \pm 0.40)$. A positive sign corresponds to a right-handed rotation of the neutron spin about its momentum.

*Harvard University.
†Only the first author and I&C Division authors are listed here.

2.10.4 ARTIFICIAL INTELLIGENCE ACTIVITIES IN THE INSTRUMENTATION AND CONTROLS DIVISION

R. L. Anderson

Since the last progress report, the I&C Division has shifted from interested observation to active involvement in AI. Two years ago, one or two staff members were actively involved in AI; today approximately 20 I&C staff members are working part- or full-time on various aspects of AI applications in instrumentation and control areas. As AI tools and personal computers become more generally available, it is expected that more persons will begin to use them on a routine basis. It is not far-fetched to predict another order-of-magnitude increase in the use of AI systems and tools during the next reporting period.

Reports of specific AI projects are scattered throughout this volume; in many respects, AI is simply the next step in measurement and control system development. Existing control systems, especially large ones, represent static, unchanging intelligence of design. Such systems have a limited ability to accommodate off-normal behavior and have essentially no adaptive capability to respond to equipment degradation or failure.

The I&C Reactor Systems Section has made much progress in developing AI tools for process control, including an AI interface to the simulation of the HIFR control system running on the hybrid computer. This work is now receiving additional support through additional manpower, through acquisition of a Lambda LISP Machine, and through additional financial support for FY 1985.

Several projects are under way in MACES: an "OPS engine" is being developed to directly execute rule-based expert systems written in OPS-5; a parallel effort has implemented OPS-5 in FORTH on a Hewlett-Packard 9836 desktop computer, and a more generic version is being prepared for other 68000-based machines; an expert system for organic synthesis is being developed jointly with the ORNL Chemistry Division; two expert systems are under development to serve as operator advisors on high-voltage electron microscopes for a group at ORGDP; and an expert diagnostic program is being developed to detect and analyze failures in multi-degree-of-freedom servomanipulators.

2.10.5 AN EXPERT SYSTEM FOR ORGANIC CHEMICAL SYNTHESIS

J. D. Allen, Jr.* W. E. Thiessen†

This program is the product of a collaboration between members of the ORNL I&C and Chemistry divisions. The ultimate goal of this effort is incorporation into an expert system of a substantial fraction of the chemical knowledge possessed by the practicing organic chemical synthesist. Most work to date has been devoted to developing a control structure in terms of which this chemical knowledge can conveniently be expressed. This control structure, now largely complete, embodies most of the tools the chemist utilizes to perform a synthesis. These tools comprise, in part, knowledge about the structural alterations implied by the various kinds of chemical reactions the chemist may employ. They also incorporate "bookkeeping" knowledge so that the program can keep track of its progress in the synthetic process. Still to be added is a body of knowledge about relative reaction rates for the reaction types now encoded in the program. This last body of knowledge is what distinguishes the gifted human synthesist from the mere combinatorial manipulator.

*Consultant.
†Chemistry Division.

2.10.6 EXPERT SYSTEMS FOR ELECTRON MICROSCOPY

J. D. Allen, Jr.*
J. H. Marable* T. A. Nolan†

Two expert systems are now being written for electron microscopic applications. The first (and simpler) of these is intended as an interactive expert advisor for microscope users who need to produce high-quality images that now can take several years to learn to produce on a high-voltage device. The program, interacting with the user in relatively free syntax English and with the microscope via a computer interface, will be capable of deducing from these two interactions the nature of problems the user is experiencing and of providing advice about potential solutions.

The second expert system is being constructed as a flaw analyzer. When complete, it will possess a considerable store of knowledge about flaw types (e.g. physical and chemical processes that lead to flaw production). It will interact with both the microscope user and the microscope scanning controls so that it can focus on those parts of the flaw image that continuing analysis suggests may be of importance.

The first goal is to encode enough human expert knowledge about flaws and enough pattern recognition capability to make the program capable of making accurate deductions about the nature of the flaws to which its attention is directed. Ultimately, the program must be able to find and analyze flaws for itself.

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*Consultant.
†ORGDP Process Support Division.

2.10.7 AN EXPERT-SYSTEMS LANGUAGE FOR CONTROL OF INSTRUMENTATION AND PROCESSES

W. B. Dress

Constraints of speed, real-time control, and multitasking capabilities preclude the use of the currently available expert-systems languages for controlling physical processes as opposed to simulations. Furthermore, current sensor development requires interpreting of multivariate outputs as well as correlating the reading of multiple sensors. This wealth of information concerning a process must be analyzed in real time or faster than real time in order to make a class of predictions before a controller response is required. The interpretation of data and the search for an appropriate response to developing situations dictate the use of AI methods, but the delays inherent in traditional hardware and software (even in state-of-the-art AI machines claiming to give real-time response) foil any hope of attaining the goal of intelligent machine process control.

The first step in developing a control-oriented expert system language for the I&C Division was to rewrite Carnegie Mellon's highly successful OPS-5 expert-system language in a multitasking version of FORTH for the HP 9836 desktop computer. The HP 9836 is a high-throughput machine supporting the IEEE488 instrument bus which meets the requirement for fast hardware with easy access to instrumentation-based data. The FORTH language has the benefits of a high to very high level language, gives easy access to the underlying hardware, and results in high programmer productivity. For several months, this new implementation of OPS-5 has been undergoing testing for efficiency and extensibility.

The program for creating the new control language includes plans for optimizing the current version, extending its pattern-recognition features, implementing the multitasking capability, and creating a user interface to overcome some of the obscure features of the original language. This phase is estimated to take approximately 9 to 18 months and result in a highly versatile process control language.

The development of an online expert diagnostician for the advanced servomanipulator currently uses the initial version of the new control language. Later versions will allow extension of the diagnostician to the role of autonomous expert, acquiring its own data and requesting and performing its own tests during normal functioning of the manipulator. Failure prediction is also to be included in this mode of functioning.

2.10.8 THE BEGINNING OF ASTM STANDARDS FOR NUCLEAR INSTRUMENTATION

D. D. McCue

(Abstract of *ASTM Standardization News*, 27–29, March 1983)

One result of post-accident studies of the Three Mile Island incident was a recommendation by the President's Commission on the Accident at Three Mile Island to "consider the need for additional instrumentation to aid in the understanding of plant status." In their report, "TMI-Related Requirements for New Operating Licenses" (NUREG-0694), the NRC recommended installation of additional instrumentation to "provide unambiguous, easy-to-interpret indications of inadequate core cooling."

In 1980, ASTM Committee C-26 on Nuclear Fuel Cycle responded to this need by creating Subcommittee C26.10 on Instrumentation. The mission of the subcommittee is "to develop standard practices and definitions and to promote knowledge of instrumentation and control relating to the entire nuclear fuel cycle, including exploration, processing, enrichment, fuel fabrication, conversion, and reprocessing." The specific interest of the committee is with in-line instrumentation. The accomplishments and intentions of the subcommittee are reported.

Section 3

REACTOR SYSTEMS

3.0. Section Overview

3.1. Detectors

3.: Dosimetrics and Electromagnetic Pulse Protection

3.3. Diagnostics

3.4. Systems Analysis

3.5. Reviews and Assessments

3.6. Thermometry

3.7. Reactor Maintenance

3.8. Special Projects

3. REACTOR SYSTEMS

3.0 SECTION OVERVIEW

L. C. Oakes

The Reactor Systems Section (RSS)* is committed to the development of advanced measurement and surveillance systems and to the development of instruments, components, systems, and techniques for the control and protection of nuclear reactors. Past efforts have included the design and installation of control and protection systems for all research reactors constructed at ORNL and substantial contributions to the design and fabrication of systems for a number of other research and test reactors throughout the country. The designs were confirmed by total plant simulations and preoperational testing in our laboratories and at other ORNL reactor facilities. The Section has retained the responsibility for maintaining the control and protection systems for ORNL reactors and for upgrading them as components and techniques have improved.

Extensive experience has been acquired by the RSS staff in the design of measurement, control, and protection systems for virtually all reactor types. In the last decade, however, emphasis has shifted from design and installation of reactor instrumentation to development engineering in support of LWR, HTGR, and ABR systems. These activities include simulation and analysis of a wide spectrum of dynamic systems, design analysis, review, and confirmatory research for the NRC, as well as the development of standards. The Section has likewise become more involved with basic research, development of surveillance and diagnostic systems, sensor systems, subcriticality measurement methods, and special projects in support of FEMA and the U.S. Navy's undersea acoustics program.

The Reactor Systems Section has the responsibility for I&C management of fission reactor instrumentation and control systems for LWR and LMRs. The Section has also had responsibility for management of ORNL NRC programs for the Office of Nuclear Reactor Regulation.

ACCOMPLISHMENT HIGHLIGHTS

- Installation and verification of a complete engineering simulation of the Oconee Nuclear Plant on the RSS hybrid computer
- Development of a TV-based, computer-controlled data collection system which provides a thousandfold gain in sensitivity compared to film methods previously used
- Development and demonstration of improved methods for measuring subcriticality in nuclear fuel storage facilities and reprocessing plants
- Demonstration of an automated reactor noise signature acquisition system at a commercial nuclear plant.

FUTURE TRENDS

- Design of special instrumentation, automated data acquisition and analysis equipment, and database management systems in support of the U.S. Navy's undersea acoustics program
- Design and analysis of advanced control and protection systems for future nuclear power plants and fuel reprocessing facilities

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*The acronym list at the end of this report may be folded out for reference.

- Application of artificial intelligence and expert system technology to aid operation of nuclear plants under both normal and off-normal conditions
- Support of NRC in the evaluation of methods potentially useful for detecting component aging in nuclear plants prior to the onset of degraded performance.

SECTION ORGANIZATION

The RSS technical staff consists of electronic and electrical engineers, physicists, nuclear engineers, mechanical engineers, and engineering technologists. Their activities are described below by functional group.

Dynamic Analysis Group

This group conducts computer analyses of engineered and/or natural systems whose behavior is of concern to development or evaluation projects. Analytical studies are made of system dynamic behavior, instrumentation and control systems designs, and overall plant or process stability. Current research activities include simulations of gas-cooled power reactor systems, boiling water reactor stability, and PWR plant systems to evaluate in-depth the control system impact on safety. There is also a pilot program on the application of artificial intelligence techniques. A powerful hybrid computer facility available to this group is a unique tool for performing some of its system simulations.

Surveillance and Diagnostic Methods Group

The activities of this group are directed toward the development and demonstration of new or improved surveillance and diagnostic measurement methods for improving the safety, reliability, and operability of nuclear power plants.

Research activities of the group include investigations leading to the development of advanced methods for the extraction of information from process and acoustic noise signals. The group also assesses research and consults for the NRC and the David W. Taylor Naval Ship Research and Development Center. The principal consultation areas are loose-part monitoring, neutron and process signal noise analysis, core internals vibration monitoring, and acoustic noise measurement and analysis. The research tasks include PWR internals vibration monitoring, BWR stability monitoring, modeling of stochastic processes, and developing and testing methods for performing automated surveillance and diagnostics. The group is also involved in the demonstration of prototypic automated noise surveillance and diagnostic systems at a commercial BWR and at the Fast Flux Test Facility (a liquid-metal-cooled test reactor).

Design and Evaluation Group

The technical activities of this group encompass three major areas: (a) advanced control and protection system design, (b) design assistance for ORNL reactors and experimental facilities, and (c) technical assistance to the NRC. The work performed in these three areas is amplified in the following paragraphs.

a. A program is under way to develop a methodology for control of modular nuclear plants employing light water, liquid metal, or gas reactor coolants. A modular plant requires a configuration, functionality, and control system communications different from that of conventional reactor plants. Integrated, intelligent, flexible supervisory control is needed to provide central coordinated control of the modular plant under both normal and off-normal plant conditions. The program will result in a guide to help plant designers use the best, most applicable advanced techniques and equipment for designing control systems.

In a separate but related task, the current state of automation and advanced control technology of commercial U.S. nuclear power plants will be compared to control technology worldwide. The applicability of available advanced techniques from both nuclear and other industries will then be assessed and subsequent developmental needs will be identified to further improve the reliability and availability of nuclear power plants.

Another task evaluates the effect on reliability of potential interactions between control systems and protection systems, and seeks to identify both philosophical and hardware techniques for minimizing adverse interactions to improve both features.

b. Design assistance is provided to ORNL research reactors and experimental facilities. In addition to performing the original control and protection system designs, replacements for aging and obsolete components and systems are provided as needed.

c. Technical assistance to the NRC is provided in a variety of areas including reviews for adequacy and reliability, assessment, technique development, and recommendations for regulatory policies and guides. An example of such assistance is the study of unresolved safety issues of nuclear power plants, including station blackouts (dealing with the reliability of emergency ac power systems) and inadequate core cooling (dealing with special instrumentation for measuring in-vessel coolant level).

Detectors Group

This group is engaged in the development of advanced detectors and detector systems. Particular emphasis is placed on detector application in reactor systems and auxiliary experiments.

High-temperature, high-sensitivity fission chambers and associated electronics are currently under study for LMR applications. Position-sensitive gamma and neutron counting systems are also a specialty. A recently developed curved detector for neutrons has proved useful for solid state diffraction research. An improved model is now being completed.

Proportional counters and new counter gases are under study for application to wide-range counting channels and portable rate meters for FEMA. Solid state detectors and ion chambers are also within this group's area of expertise. In addition, autofluorographic electrophoretic data collection for biological application is a current project. This TV-based, computer-controlled data collection system supplants film methods with a thousandfold gain in sensitivity.

Facilities Support Group

This group maintains the control and protection systems of operating ORNL reactors and associated experiments, modifies these systems when needed or requested, maintains up-to-date system drawings, initiates and maintains test procedures, and keeps records of the failure rates and other historical maintenance data on system components.

Other activities of this group have included (1) an in-depth review of the coil protection system in use at the Large Coil Test Facility, (2) a review he TREAT Upgrade reactor scram system reliability analysis, and (3) a review of the CRBRP instrumentation and electrical drawings for internal consistency and conformance to the system design descriptions and applicable codes and standards.

Process Instrument Development Group

Activities of this group include the development and qualification of thermometers thermocouples, resistance thermometers, and the Johnson noise thermometer for use in nuclear reactor plants and test facilities. The group's responsibilities also include development of other process instruments. Current projects include developing fiber optic thermometers, demonstrating the use of Johnson noise thermometry for in situ calibration of the resistance thermometers widely used in nuclear power plants, and developing flow measurements in support of the U.S. Navy advanced propulsors program. Major interests of the group are the development of methods for in situ calibration and response-time testing of thermometers and other process sensors.

Special Assignments Group

The research, development, and support activities of this group cover a broad range of subjects that include instrumentation for biological systems; measurement of particulate suspensions; radiation survey instrumentation; evaluation of electromagnetic pulse effects; subcriticality measurements for fission reactor startup, spent-fuel storage facilities, and reprocessing plants; nondestructive assay for total fissile mass of spent reactor fuel; plasma diagnostics; and fusion energy engineering.

3.1.1 SCINTILLATION NEUTRON DETECTORS

J. B. Davidson

(Summary of invited paper presented at the Workshop on Instrumentation for the Advanced High-Flux Reactor, Oak Ridge National Laboratory, May 30, 1984)

Two basic types of scintillation neutron area detectors are reviewed. The first is the prompt detector, which uses photomultipliers to convert the neutron scintillations to electrical pulses. These signals are combined in weighting or encoding circuits to give event location. Then the number in the corresponding address in a computer memory is incremented. Both timing and amplitude information are available. Timing is necessary for energy measurements by time-of-flight when using pulsed sources. The amplitude information is useful for background discrimination. Several embodiments of the weighted and coded scintillator approach are mentioned. For a fuller description of these and other neutron area detectors, an excellent recent book by Convert and Forsyth[1] should be consulted. Much of the following brief information has been taken from this source, which contains many references.

The second type of scintillation detector is based on television techniques and has a delayed readout. It will be discussed in more detail because it is the approach I have taken and also it seems to be the one type not fully discussed in ref. 1.

Three TV-based detectors are discussed.[2,3] One system is a fiber opticoupled counting camera sensitive to single events. Its detector diameter of 150 mm has a resolution of ≈2 mm. It is based on a commercial X-ray system and is used in an analog mode. Approximately 10 neutrons/mm^2/s are detectable. The third camera is an inexpensive, lens-coupled, 150-mm unit for real-time sample alignment and orientation.

The several applications described include in situ crystal growth, section topography, phase transition studies, observation of charge density waves, and diffuse scattering patterns. "Tabletop" small-angle scattering experiments were performed using ~0.5- to 1.0-m collimator-to-sample and sample-to-detector distances. Real-time video recordings of many of the applications were shown.

1. *Position-Sensitive Detection of Thermal Neutrons*, P. Convert and J. B. Forsyth, Eds., Academic Press, New York, 1983.

2. "Flys Eye: A Counting Camera for Thermal Neutrons," J. B. Davidson, *J. App. Cryst.* 7, 356–65 (1974).

3. "TV-Based Neutron Detectors and Applications," J. B. Davidson and H. G. Smith, in *Use and Development of Low and Medium-Flux Research Reactors*, proceedings of an International Symposium, Cambridge, Mass., October 17–19, 1983. Supplement to Vol. 44. Atomenergie-Kerntechnik Karl Thiemig, Munich (1984).

3.1.2 TV-BASED NEUTRON DETECTORS AND APPLICATIONS

J. B. Davidson H. G. Smith*

(Abstract of paper presented at International Symposium on the Use and Development of Low and Medium Flux Research Reactors, Cambridge, Massachusetts, October 16–19, 1983)

Three TV-based wide-area thermal neutron detectors at Oak Ridge National Laboratory are described. Included are fiber-optic and lens-coupled systems using ^{6}LiF-ZnS scintillation screens having diameters of 150 mm and 300 mm, respectively, permitting a wide-angle viewing area of 140° (2 Θ). One system is a counting camera sensitive to single events with a resolution of ~0.3 mm; it can also be used in an integrating mode for rapid inspection of scattering patterns. The second is an integrating 300-mm camera based on a commercial medical X-ray system. The third is an inexpensive camera for rapid sample alignment and qualitative examination of strong reflections, which virtually eliminates film methods for these purposes.

Application to a number of areas of neutron research are described, many applicable in low- and medium-flux reactors. Among these are in situ crystal growth, section topography of directionally solidified alloys, phase transition studies, observation of charge density waves, and diffuse scattering patterns. "Table-top" small-angle scattering using ~1-m collimator-to-sample and sample-to-detector distances is also described.

*Solid State Division.

3.1.3 RECENT DEVELOPMENTS IN POSITION-SENSITIVE NEUTRON COUNTING

K. H. Valentine G. C. Guerrant
M. K. Kopp J. A. Harter

(Abstract of paper presented at Workshop on Position-Sensitive Detection of Thermal Neutrons, Grenoble, France, October 11-12, 1982)

Continuing research on advanced methods of thermal neutron detection and position sensing with gas-filled counters was aimed at improving their performance and extending the limits of their applicability. High electron drift velocities obtained from measurements on gas mixtures containing CF_4 motivated us to evaluate the properties of ^3He-CF_4 and Ar-CF_4 mixtures to show that these gases have the potential of improving the count rate capability, spatial resolution, and photon discrimination of neutron PSPCs (position-sensitive proportional counters) and fission counters. In support of the U.S. National Small-Angle Neutron Scattering (SANS) Facility, we developed a large-area (65-cm × 65-cm) PSPC camera. RC position encoding was chosen for simplicity of construction, but since previous experience with this encoding method had been limited to smaller PSPCs (area < 25 cm × 25 cm), the main objective of this development was to show that RC encoding parameters and construction methods could be scaled up for larger area PSPCs. The use of the new counter gas mixtures enabled the development of position-sensitive transmission line fission counters (TLFCs) for neutron flux monitoring and a one-dimensional, curved PSPC for large-angle (130°) neutron diffraction experiments. The main objective of these developments was to extend the capabilities of the LC-encoding method by mitigating the effects of interelectrode capacitance, and thereby increase the count rate capability.

3.1.3.1 POSITION-SENSITIVE FISSION COUNTER FOR IN-CORE FLUX-PROFILE MONITORING

M. K. Kopp G. C. Guerrant
K. H. Valentine J. A. Harter

[Abstract of paper presented at 1983 Nuclear Science Symposium, San Francisco, 733 37 October 19 21, 1983]

A prototype model of a position-sensitive fission counter (PSFC) was developed for power-range flux profile monitoring in light water reactor cores. The flux profile is measured by delay-line position encoding and time-interval decoding of individual fission pulses from 11 small fission counters incorporated along a coaxial transmission line. Significant improvements over currently used flux profile monitors are the 33-cm spatial resolution of the 3.5-m-long PSFC and the requirement for only one cable penetration into the reactor pressure vessel.

3.1.4 NEW METHOD OF PROPORTIONAL COUNTER FEEDBACK BIASING FOR WIDE-RANGE RADIATION DOSE-RATE MONITOR

M. K. Kopp G. C. Guerrant
K. H. Valentine F. W. Manning

(Abstract of paper presented at 1984 Nuclear Science Symposium, Orlando, Florida, October 31-November 2, 1984)

A prototypic wide-range radiation dose-rate monitor for civil defense applications was developed and tested. The specified dose-rate range (0–100 R/h) was covered on a single readout scale by using feedback controlled bias of a proportional counter. This new method is based on controlling the avalanche multiplication factor (gas gain) of the counter by varying its bias voltage in response to its measured output current (i.e., detected dose rate). The counter output current varies between 0 and 1.5 nA in a quasi-logarithmic response to the detected dose rate in the range from 0 to 100 R/h. The corresponding values of gas gain and bias range from 1 to 300 and 200 to 1900 V, respectively.

3.1.5 PARALLELING OF PREAMPLIFIER INPUT STAGES FOR A LOW-NOISE WIDEBAND TERMINATION OF LOW-IMPEDANCE TRANSMISSION LINES

M. K. Kopp K. H. Valentine

(Abstract of paper presented at 1984 Nuclear Science Symposium, Orlando, Florida, October 31 November 2, 1984)

A new concept of paralleling input stages was developed to meet the requirements for a low-noise, wideband preamplifier that matches the transmission-line impedance of ultrahigh-sensitivity fission counters. The prototypic preamplifier consists of four dual-feedback-path amplifiers and a summing amplifier. It has an 18-pA/$\sqrt{Hz}$ equivalent input noise current density, a 60-MHz bandwidth, a 25-Ω input impedance, and a 5-kΩ transimpedance.

3.1.6 RADIATION STABILITY OF COUNTING GAS MIXTURES CONTAINING CF_4

K. H. Valentine **G. C. Guerrant**
M. K. Kopp **J. A. Harter**

[Abstract of paper presented at 1983 Nuclear Science Symposium, San Francisco, October 19–21, 1983; IEEE *Trans. Nucl. Sci.* NS 31(1) 264–68 (February 1984)]

Several noble gas mixtures containing CF_4 were irradiated at high neutron and gamma dose rates to determine their radiation stability for neutron flux monitoring applications where the total radiation dose can be large. Five test detectors (ionization and proportional counters employing either ^3He or ^{235}U as the sensitizing material) containing CF_4 gas mixtures were irradiated in a neutron flux of $\sim 10^{11}$ n·cm^{-2}·s^{-1} and a gamma field of $\sim 2 \times 10^8$ R/h. All detectors exhibited moderate to total degradation of pulse response at fluences from 10^{15} to 10^{16} n·cm^{-2}, with more rapid degradation occurring in the fission detectors. The pulse height degradation was probably caused by electron attachment on irradiation products such as C_2F_6, C_3F_8, and CF_3OF, which were detected at 100- to 6000-ppm levels in subsequent mass spectrometric analyses.

3.1.7 AN ULTRAHIGH-SENSITIVITY THRESHOLD NEUTRON DETECTOR FOR PLASMA DIAGNOSTICS

K. H. Valentine
M. K. Kopp **W. T. Clay**
G. W. Allin **V. C. Miller**

(Abstract of paper presented at 1984 IEEE Nuclear Science Symposium, Orlando, Florida, October 31–November 2, 1984)

An ultrahigh-sensitivity fast fission counter was developed to selectively detect high energy neutrons (E_n>1 MeV) produced by D-D and D-T fusion reactions in thermonuclear plasmas. Discrimination against slow and epithermal neutrons produced by scattering or electrodissociation of deuterium was achieved by sensitizing the detector with 100 g of highly depleted $^{238}UO_2$ which has a fission threshold for neutron energies E_n>1 MeV. Capacitive signal loading effects of the detector's large electrode area (5 m^2) were mitigated by using a transmission line electrode configuration. Wideband, low-noise preamplifiers were developed to match the 25-Ω characteristic impedance of the transmission line. Initial laboratory testing of the detector showed that its neutron sensitivity is 0.07 counts·s^{-1}·[neutron/(cm^2·s)]$^{-1}$ for E_n>2 MeV.

3.1.8 INSTRUMENTAL MEASUREMENT OF THE TOTAL PARTICULATE MATTER OF CIGARETTE SMOKE

R. A. Jenkins* **T. M. Gayle**

(Invited paper presented at the 36th Tobacco Chemists' Research Conference, Raleigh, North Carolina, October 24–27, 1982)

A cigarette smoke monitor (CSM) for the instrumental measurement of cigarette smoke total particulate matter (TPM) has been developed. The cigarette holder consists of a hollow tube containing a small orifice. Upstream of the orifice is an optical smoke sensor. Between the cigarette and the cigarette holder is a short length of tubing containing two small mixing orifices and chambers. A device developed by Arthur D. Little, Inc., measures pressure drop across the orifice and outputs a signal which is directly proportional to the flow rate through the cigarette holder. The smoke concentration signal from the sensor in the cigarette holder is fed into an electronic signal processor. The processor multiplies the smoke concentration by the flow rate. The product is integrated, and the integral is indicative of the amount of smoke particulate matter passing through the cigarette holder. Evaluation of the CSM was performed by smoking cigarettes under varying puff conditions. TPM deliveries were compared with the CSM response. The response of the smoke monitor was directly proportional to the amount of TPM collected on filter pads downstream of the cigarette holder over a range of 0.5 mg TPM per cigarette to 35 mg per cigarette. Comparison of predicted TPM deliveries with those actually observed indicated that the monitor is accurate to within 1 mg TPM or 20% of the actual TPM generated, whichever is larger.

*Analytical Chemistry Division.

3.1.8.1 DEPOSITION AND DISTRIBUTION OF THE TOTAL PARTICULATE MATTER OF CIGARETTE SMOKE IN MICE IN A LARGE-CAPACITY SMOKE EXPOSURE SYSTEM

C. J. Henry et al.*† T. M. Gayle

[Abstract of *Toxicol. Appl. Pharmacol.* 58(3), 399–409 (1981)]‡

A newly developed automatic smoke exposure machine (SEM II) was used to generate [^{14}C]dotriacontane, labeled University of Kentucky reference 2A1 or 2R1 cigarette smoke. The SEM II is a large-capacity (480 mice) dynamic smoke exposure system in which smoke is routed through the animal containment system as a continuously flowing stream. Mice are restrained about the neck in stock like holders for "nose-only" exposure. Using standard smoke exposure conditions, the deposition and internal distribution of the total particulate matter (TPM) from cigarette smoke was determined in BC3Fl/Cum male and female mice. Results show: (a) smoke exposure conditions can be varied so that deposition from 30 to 200 μg TPM/lung can be obtained, (b) 80 to 90% of the TPM deposition was found in the respiratory tissues, (c) the mouse-to-mouse variation for TPM deposition in pulmonary tissue was ~20%, (d) similar deposition and distribution of TPM was observed in male and female mice, and (e) deposition and distribution of TPM was not altered in mice exposed to smoke on a daily basis over a 6-month period of time.

*Microbiological Associates.

†Because of the large number of coauthors, only the principal author and coauthors from the Instrumentation and Controls Division are listed here.

‡Omitted from 1982 progress report.

3.1.9 A VARIABLE PUFF PARAMETER SMOKING MACHINE FOR SMOKE COMPOSITION STUDIES

R. A Jenkins*
R. W. Holmberg* G. W. Allin
T. M. Gayle S. K. Holliday*

(Invited paper presented at the 38th Tobacco Chemists' Research Conference, Atlanta, November 5 8, 1984)

In order to study changes in smoke composition as a function of puff shape and other parameters, a minicomputer-controlled smoking machine has been developed. The machine is essentially a low dead-volume piston-cylinder unit incorporating a stepping motor, which in turn operates the piston through a ball bearing lead screw drive system. The stepping motor is driven by a translator unit which receives its command pulses from a minicomputer. The speed and displacement of the piston is thus controlled by the rate and total number of pulses sent by the computer. Depending on the parameters entered by the operator (including puff volume, duration, shape, frequency, and number), the program automatically adjusts the number of pulses and delay time to give the proper generation purging, and delay time. Puff volume can be specified to the nearest milliliter, and the puff shape can be adjusted continuously.

When programmed appropriately, the puff shapes obtained are essentially identical to those obtained from analytical smoking machines. Not surprisingly, tar, nicotine, CO, and CO_2 deliveries of Kentucky Reference 2R1 and 1R4F cigarettes were the same as those obtained on a 20-port analytical smoking machine. The effects of puff shape and other parameters on the relative composition of smoke particulate matter is discussed.

*Analytical Chemistry Division.

3.1.10 AN INSTRUMENTAL INHALED SMOKE DOSIMETER FOR THE QUANTITATIVE CHARACTERIZATION OF AEROSOL EXPOSURES

R. A. Jenkins* T. M. Gayle

(Abstract of "Pulmonary Toxicology of Respirable Materials," 19th Annual Hanford Life Sciences Symposium, December 1980; Ed. Charles L. Sanders et al. (NTIS CONF-791002)]†

A model being used by the National Cancer Institute for tobacco-smoke inhalation bioassay involves passive, intermittent exposure of male beagle dogs to 100% cigarette smoke Whole smoke is deposited into the head of a stand tube located downstream of an inspiration valve. The animal withdraws smoke from the tube via a cuffed tracheal cannula. Such systems are potentially applicable for exposure to a wide variety of concentrated aerosols. As part of our tobacco-smoke dosimetry studies, we have been developing instrumental approaches to the determination of the quantity of smoke particulates inhaled and/or retained by the exposed animal.

The instrumentation package uses a smoke-concentration sensor and a laminar-flow meter. The light-emitting-diode—phototransistor aerosol sensor is mounted at the entrance to the animal's tracheal cannula and relates backscattered infrared light to smoke concentration in the cannula. Response of the sensor is linear over a wide range of aerosol concentrations (10 μg/liter to 100 mg/liter). Inhaled flow is measured at the inspiration valve of the smoke-exposure system. This configuration permits visualization and quantitation of animal breathing patterns during smoke exposure. Amplified signals are multiplied electronically so that smoke registers as being inhaled only when it is drawn into the cannula. The integral of the product of smoke concentration and instantaneous flow rate is directly related to the inhaled-smoke dose.

Evaluation of the system under a wide range of inspiratory flows and simulated breathing patterns indicates that the relative standard deviation of the integrated response per unit of particulate matter is about 4% for the smoke of a standard experimental blend cigarette. Observations made during field tests with beagle dogs indicate that animals seldom overrange the linear range of the flow system and that fogging of the sensor by exhaled breath is not a significant problem. Animals were observed to inhale 23 to 100% of the tobacco smoke made available for inhalation, with most animals averaging 90%.

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*Analytical Chemistry Division.
†Omitted from 1982 progress report.

3.1.10.1 AN INSTRUMENTAL SMOKE MONITOR DESIGNED FOR DIRECT MEASUREMENT OF SMOKE PARTICULATE MATTER GENERATED IN HUMAN SMOKE STUDIES

R. A. Jenkins* T. M. Gayle

[Abstract of *Phychonom. Soc. Am.* **16**(3), 263–67, (1984)]

An instrumental cigarette smoke monitor (CSM) system designed for human smoking studies has been developed and validated using a smoking machine as a human surrogate. The cigarette holder contains both smoke-mixing and flow-measurement orifices and a smoke-concentration sensor. Smoke flow through the holder and smoke concentration in the holder are determined simultaneously. The two signals are multiplied electronically and the product signal integrated. The integrated response is directly proportional to the amount of particulate matter collected immediately downstream of the holder, regardless of cigarette type or the particular way in which the cigarette is smoked. The CSM is sufficiently sensitive to quantitatively determine the amount of smoke TPM generated from cigarettes in the 1-mg Federal Trade Commission tar-delivery category.

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*Analytical Chemistry Division.

3.1.11 THE SAMPLING AND CHEMICAL CHARACTERIZATION OF CONCENTRATED SMOKES

R. A. Jenkins* J. S. Wike*
T. M. Gayle D. L. Manning*

(Invited paper presented at the ASTM 1981 Conference on Sampling and Analysis of Toxic Materials in the Atmosphere, Boulder, Colorado, August 2–5, 1981)†

Because of rapid change in both their chemical and physical properties, concentrated (0.5 to 100 g/m^3) aerosols, such as a diesel fuel-based military obscurant and tobacco smoke, represent a unique challenge to the analytical chemist. Sampling procedures must minimize the alteration of phase concentrations of particular constituents. For example, collection of tobacco smoke particulate matter on glass fiber filters is limited to linear velocities of ~100 cm/min to prevent the evaporation of nicotine. Trapping of reactive constituents must be performed rapidly so as to prevent loss through side reactions with other smoke constituents.

Chemical characterization studies are directed at comparing laboratory-generated test aerosols with those existing under field or "real world" conditions. For the diesel fuel aerosol, a tiered analytical scheme, high-performance liquid chromatographic (HPLC) fractionation followed by high-resolution gas chromatography, has proved useful for the determination of major constituents. Limited comparisons have suggested that observed differences result from differences in fuel composition and sampling conditions, rather than generation procedures. For tobacco smoke, comparisons are made between the compositions of smokes generated under standard conditions by smoking machines and that of smokes to which animals are actually exposed. In some cases, exposure smokes have been found to be depleted in particulate matter, relative to the vapor phase. However, gross changes in the composition of the particulate matter do not occur.

Online instrumental monitoring of smoke concentrations provides an important adjunct to chemical measurements. An optical particle monitor measures back-scattered, infrared radiation as being proportional to smoke concentration. Systems employing the particle sensor are being used now to quantitatively determine particle concentrations in tobacco smoke and diesel fuel aerosol inhalation toxicology studies.

*Analytical Chemistry Division.
†Omitted from 1982 progress report.

3.1.11.1 CHEMICAL CHARACTERIZATION AND TOXOLOGICAL EVALUATION OF AIRBORNE MIXTURES: GENERATING, MONITORING, AND CONTROLLING PETROLEUM AEROSOLS FOR INHALATION CHAMBER STUDIES

R. W. Holmberg*
J. H. Moneyhun* T. M. Gayle

(Abstract of ORNL/TM-8903, October 1983)

A system has been designed and built for generating, monitoring and controlling concentrated petroleum aerosols for an inhalation toxicology study of diesel fuel aerosol such as is produced in the military vehicle engine exhaust smoke system (VEESS). The generator, an online light-scattering particle monitor, and a spent aerosol clean up system are discussed. An addition to the exposure chambers to laminarize the flow to ensure a homogeneous exposure atmosphere is also discussed. The design parameters are based on experience gained in the laboratory and in the course of a large-scale inhalation toxicology experiment for the past two years. Aerosol concentrations from 0.25 to 20 mg/L (routinely to 6 mg/L) have been developed for periods up to 6 h. The generators, the monitoring system, and the spent aerosol removal system have also been found effective for less volatile petroleum-based obscurants such as fog oil. This report emphasizes the hardware and electronic control system; the characterization of the aerosol with respect to both its physical and chemical properties and a discussion of the toxicology have been presented elsewhere.

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3.2 Dosimetrics and Electromagnetic Pulse Protection

3.2.0 OVERVIEW

F. W. Manning

Cooperation between FEMA and its predecessor agencies and the I&C Division has existed since 1961. Several radiological instrumentation developments in the I&C Division have been incorporated into this program, and continuing involvement has resulted in the creation of a cadre of experts at ORNL in the radiological field. Included are experts in instrument packaging, solid state electronic instrument design, human engineering of instrumentation systems, development of detectors for penetrating radiation, establishment of a procurement and manufacturing base, technology transfer to industry, and allied efforts.

I&C work for FEMA falls into four categories:

1. Instrumentation and assistance for defense against nuclear attack.
2. Instrumentation for peacetime emergency preparedness.
3. Engineering assistance for developing and maintaining mobilization base and/or production capabilities in support of FEMA instrumentation.
4. Technical assistance in the protection of Emergency Operating Centers (EOC), emergency broadcast stations (EBS), and other resources against the electromagnetic pulse (EMP) resulting from a nuclear detonation.

During the past two years, significant assistance has been given to the FEMA Project Office. In particular, the Project Office has emphasized the following priority tasks for the FEMA effort in I&C:

1. Support of the pilot dosimeter plant at Rolla, North Dakota, particularly the William Langer Jewel Bearing Facility, which is operated for FEMA by the Bulova Watch Company.

2. Develop new ratemeter devices for operation in shelter conditions and capable of storage for 10 or more years without logistic support.
3. Provide engineering support of radiological instruments and subsidiary support devices including calibrators and repair parts which are located in shops, warehouses, and shelters throughout several states.

These tasks are discussed individually in the following articles. The current level of effort is approximately eight work years annually, and work is expected to continue at this level for some time.

3.2.1 ENGINEERING SUPPORT OF THE FEMA RADIAC INSTRUMENTATION INVENTORY

H. N. Wilson

For many years ORNL has supplied technical assistance to the Federal Emergency Management Agency in support of the U.S. Civil Defense Program. Most recently, ORNL conducted a review of the CD V-720, a high-range ion chamber instrument that is now more than 20 years old. Problem areas were determined, possible retrofit alternatives were identified, and recommendations were given. Another instrument (the CD V-700, which is a low-range G-M tube instrument operating in the normal pulse mode) also required review and recommendations. Additional scalers were needed by the various state shops as part of the civil defense instrument maintenance program. Specifications were written and 33 units were purchased.

Most of the instruments in the FEMA RADIAC inventory are quite old, and the shortage of spare parts is becoming critical. Three items in particular have required attention: the type 5886 electrometer tubes, the 50-μA round panel meters, and some 50-kΩ quad calibration pots on a single ceramic substrate. Studies have been made and are continuing on the aging and selection of electrometer tubes with the goal of maximizing the number of usable tubes and minimizing the replacement of usable instrument tubes. Many used meters in the inventory are still good, and these are being checked and sorted according to condition: open, sticky, or functional within specifications. Some of the calibration pots, which can no longer be obtained, have a hairline crack between the resistance element and the terminal. These pots, which have been removed from instruments, are being repaired by cleaning and then applying silver epoxy paint over the connecting metalization. Meter selection and cleaning and repair of the calibration pots are being carried out at the Michael Dunn Center under contract with ORNL.

3.2.2 DEVELOPMENT OF NEW SHELTER RATEMETERS

M. K. Kopp F. W. Manning
K. H. Valentine G. C. Guerrant

Several approaches have been investigated to solve the problem of updating shelter ratemeters for the FEMA Civil Defense Program in case of nuclear attack. The problem is caused primarily by the requirement to provide indication of gamma ray exposure rate from 0.1 R/h to 100 R/h. It is important that ratemeters be operable without servicing after a storage period of up to 20 years.

A new approach for such instrumentation was undertaken, and three designs seem feasible. Developmental models of them that may prove acceptable have been constructed.

1. A ratemeter employing a proportional counter detector with feedback control of the high-voltage power supply. Wide range monotonic response is obtained.
2. A digital instrument employing a silicon PIN diode as the gamma sensor. Lithium batteries are under consideration as the power source.
3. An ion chamber device in a dc bridge circuit employing a fiber dosimeter as a null indicator. The apparent current gain is determined as the ratio of capacitance being discharged by a current generator with that of the ion chamber. Current gains of 10^6 are practical with this arrangement. A hand- or spring-operated dynamo is being considered as a power source.

3.2.3 SUPPORT OF THE FEMA CARBON FIBER DOSIMETER PROGRAM

G. A. Holt
H. N. Wilson F. W. Manning

ORNL developed a detailed design, produced complete documentation, and procured the required equipment for the FEMA dosimeter calibration facility at Rolla, North Dakota.

The equipment supplied to Rolla were two dosimeter calibrator assemblies, two lead shielding door assemblies, and two sets of closed-circuit television assemblies for monitoring and controlling the source rooms. Also, miscellaneous jigs and fixtures were modified or designed and fabricated for dosimeter testing and assembly, and three IBM personal computers were purchased and programmed for assembly and test record keeping and communications.

The Rolla Facility is operated for FEMA by the Bulova Watch Company under a General Services Administration agreement. Its functional layout was designed by ORNL Engineering in cooperation with the I&C Division, which coordinated interaction among the owner and lessor, the architect-engineer, the State of North Dakota, GSA, and FEMA.

The pilot production research program to produce a low-cost indicating fiber electrometer type gamma dosimeter at Rolla is now established. An open house for industry and the military was scheduled for October 1984.

3.2.4 ELECTROMAGNETIC PULSE HARDENING OF EMERGENCY BROADCAST STATIONS AND EMERGENCY OPERATING CENTERS

M. E. Buchanan

The FEMA EMP Support Group currently has seven persons actively involved in the EMP protection of selected radio stations, emergency operating centers, and emergency communications systems. The group performs engineering surveys and designs EMP protection plans for the facilities. This group also purchases the protective devices and tests them, provides warehousing at ORNL, and distributes them to the facilities. In addition, the EMP Support Group performs research and development on new EMP protection devices and protection techniques, and teaches classes in the field on protection techniques.

FEMA requires that EMP protection and shielding techniques be tested and verified. Individual protection devices are tested on a high-voltage test stand capable of producing either a 0- to 600-V rms or a 0- to 60-kV dc transient signal. The individual devices are then installed, and the entire system is tested by exposing it to a simulated EMP field and measuring instantaneous and/or permanent changes in equipment performance and related characteristics. To approximate the EMP, the group is fabricating a parallel-plate simulator, a test apparatus which uses electromagnetic fields between the plates of a parallel-plate transmission line. The simulator will be driven by a Physics International 125-kV pulse generator. The ORNL Energy Division has expressed interest in the use of this test facility. It is also planned to fabricate a current-injection test set to produce a current similar to that produced by an EMP that can be directly injected onto the external wires leading into a shielded enclosure.

3.3 Diagnostics

3.3.1 THE ^{252}CF-SOURCE NEUTRON NOISE ANALYSIS METHOD OF MEASUREMENT OF SUBCRITICALITY: STATUS OF DEVELOPMENT AND FUTURE APPLICATIONS

J. T. Mihalczo
W. T. King   E. D. Blakeman

The ^{252}Cf-source-driven neutron noise analysis method[1-3] obtains the subcriticality from the ratio of spectral densities $G_{12}^{*}G_{13}/G_{11}G_{23}$ where * means complex conjugation and subscript 1 refers to an ionization chamber (the source) containing ^{252}Cf that is placed in or adjacent to the subcritical assembly and that provides source neutrons to initiate the fission chain multiplicative process. The subscripts 2 and 3 refer to a pair of detectors that is also located in or near the assembly and that detects neutrons from the fission chains. The main advantages of this method are (a) the subcriticality is obtained from measurements only at the subcritical state of interest, and thus a reference measurement near cirtical is not required and (b) the interpretation does not depend on relative or absolute value of the detection efficiency or the intensity of the inherent source. Thus, this method can be used in the initial fuel loading of systems where a determination of subcriticality dependent on absolute calibration near critical is not possible. It can also be used in determining the reactivity of assemblies where sufficient material to achieve criticality is not available or where loading to critical would be undesirable. Second, the interpretation of the measured data to obtain the subcriticality does not depend on knowledge of the inherent source strength or the detection efficiency. The advantages of the method allow its use in a variety of applications: (1) initial fuel loading in a wide variety of reactors, (2) refueling of illerors, (3) fuel preparation facilities, (4) fuel processing facilities, (5) fuel storage facilities, (6) zero-power testing of reactors, (7) post-accident situations, (8) shutdown reactivity of reactors, (9) quality control and assurance, and (10) verification of calculational methods for assemblies with $k < 1$. To date a variety of measurements have been performed which demonstrate the usefulness of the method. During this reporting period, measurements related to applications (1), (2), (3), (5), (8) and (9) have been performed. Some theoretical work to aid in the interpretation of experimental data has been completed.[4]

HFIR Fuel Elements. Measurements for determining the subcriticality[5] of HFIR fuel elements submerged in water[6] indicated that the first full elements manufactured by Babcox & Wilcox had a metal-to-water ratio different from previous and subsequent fuel elements. This was manifest in a 5% decrease in the neutron lifetime obtained from the noise analysis measurements. Increased pickling of the fuel elements by the manufacturer before shipment to Oak Ridge increased the water-to-metal ratio to that of previous elements, and this discrepancy was resolved. These measurements are part of a continuous program at ORNL of verifying the reactivity of HFIR fueld elements after manufacture and before use in the reactor.

Uranyl Nitrate Solutions. A type of criticality accident that has occurred in processing plants is a fuel concentration change in a fixed-volume process tank.[7] The subcriticality monitoring of this latter type of criticality accident was studied in the experiments performed in Oak Ridge.[8] For these experiments, a 75.2-cm-diam cylindrical tank was filled to a 75.2-cm height with an aqueous uranyl (93.17 wt% ^{235}U) nitrate solution, and then the fuel solution was diluted with water in steps while maintaining a fixed solution volume, thus, simulating in reverse in a stepwise manner an accident in which the fuel concentration increases. The ratio of spectral densities $G_{12}^*G_{13}/G_{11}G_{23}$, from which the subcriticality can be obtained, was measured as a function of fuel concentration for a variety of source-detector configurations. The neutron multiplication factors obtained from these measurements were compared with criticality calculations.

Then the sensitivity of the method to small changes was demonstrated in experiments with uranyl nitrate solution where the ^{235}U density was varied from 0.3 to 13.7 g/L.

These measurements (Fig. 3.3-1) demonstrate the ability of the method to detect the difference between plain water in the tank and a solution with approximately 200 g of ^{235}U in the entire tank. Thus, the method's sensitivity was high for this type of application.

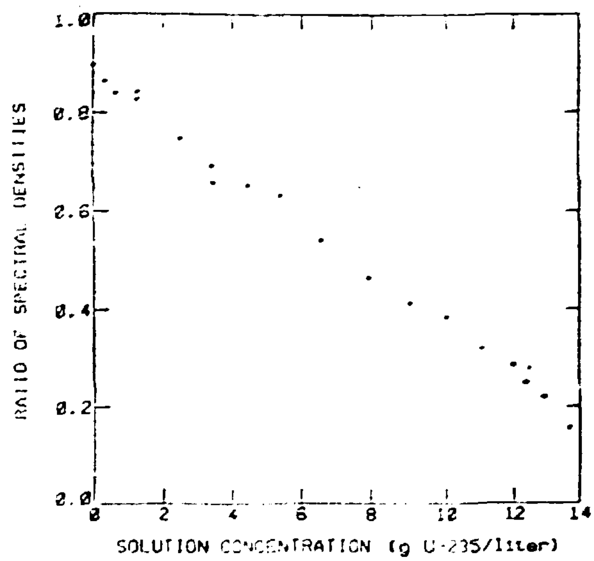

Fig. 3.3-1. Measured ratios of spectral densities versus solution concentration for a 30-in.-OD, 30-in.-high tank of uranyl nitrate.

Source and Detection Efficiency Independence. The measured ratio of spectral densities does not depend on ^{252}Cf source intensities as long as all ^{252}Cf fissions produce a pulse in detection channel 1. The independence of source size is shown by the measurements with uranium metal cylinders presented in Table 3.3-1. These measurements were performed in 1975 and again in 1984 with two ionization chambers containing different amounts of ^{252}Cf (0.07 μg and 0.20 μg). In both measurements the detectors were Li glass scintillators, but they had different detector efficiencies. These results demonstrated the method's reproducibility even though the sources and detectors were different.

Table 3.3-1. Measured ratios of spectral densities for uranium (93.15 wt% ^{235}U) metal cylinders showing that measurements are easily reproducible

Measurement Configuration	Date	Mass (g)	Ratio[a]	^{252}Cf Source Intensity (g)
4-in.-thick, 7-in.-diam ^{252}Cf source located in center of flat surface of Li glass scintillators adjacent to the radial surface at the midplane	4/1/75 9/11/84	47290 47020	0.069 0.067	0.20 0.07

[a] $G_{12}^{*}G_{13}/G_{11}G_{23}$.

LWR Fuel Pins. Calculations for an approximately 4-m-diam configuration of light water reactor (LWR) fuel elements likewise indicated the feasibility of measuring the subcriticality of large, loosely-coupled arrays by this method.[9,10] The analyses suggested application to the initial loading of both pressurized and boiling water reactors, zero-power testing of reactors (such as shutdown margin measurements after initial loading in BWRs), LWR refueling, and safe shipment and storage of LWR spent fuel. In the fuel storage application, direct measurement of subcriticality in the actual fuel storage facilities provides the parameter k that is directly related to criticality safety; through such measurements, proper credit for fuel burnup can be taken without depending on calculations for criticality safety.

An initial test of the method for these types of applications was provided by an experiment performed with an array of LWR fuel pins at the Babcock & Wilcox critical facility in Lynchburg, Virginia.[11] Six cylindrical configurations were assembled containing 4961, 3713, 2533, 1281, 749, and 333 pins with effective radii of 66.05, 56.26, 46.65, 33.06, 25.29, and 16.89 cm respectively. In these experiments the boron concentraion of the water reflector and moderator was 1510 ppm of natural boron. Measurements were made with the ^{252}Cf neutron source located at the center of the fuel pin configuration. The neutron detectors [^{3}He proportional counter, 76.2 cm long and 1.91 cm diam, with an efficiency of 70 cps per $(nv)_{th}$], could be located at radial increments approximately 15.24 cm outwards from the source along a diameter. The ratio of spectral densities $G_{12}^{*}G_{13}/G_{11}G_{23}$ for the detectors closest to the outer radial boundary of fuel pin configurations on opposite sides of the arrays is plotted as a function of number of fuel pins in the array in Fig. 3.3-2. These ratios were measured to 5% precision in 5 to 30 min. The k values obtained from the ratios of spectral densities using a point kinetics interpretation of the data are also plotted in Fig. 3.3-2 as a function of the number of fuel pins in the cylindrical configurations. The values agree within approximately 0.005 with those obtained from VENTURE calculations[11] using 27-group cross sections obtained from ENDF B-IV data (Fig. 3.3-2).

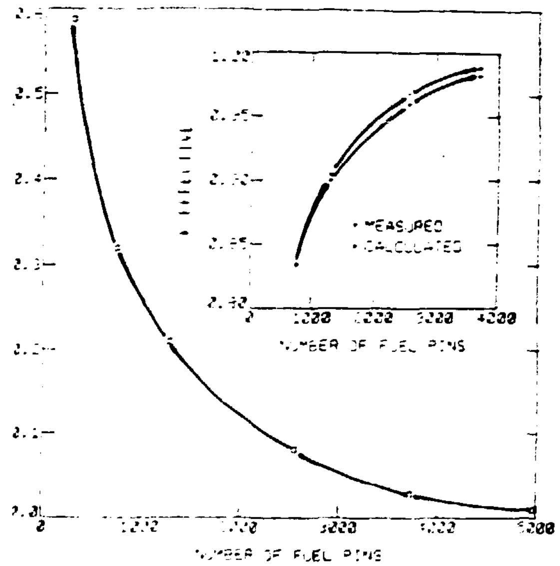

Fig. 3.3-2. Measured ratios of spectral densities and neutron multiplication factors for various size arrays of LWR fuel pins.

Summary. The experiments described here have demonstrated the insensitivity of this method to source intensity and detection efficiency. Thus, it can be implemented easily since it does not require calibrations of neutron source intensities or detector sensitivities. Measurements can be easily repeated over long periods of time using different sources and detectors and achieve the same measured results. The sensitivity of the method to even a small change in uranium concentration in fuel solutions makes it useful for fuel preparation and reprocessing facilities. The proof-of-principle experiments with LWR fuel pins showed that the subcriticality of arrays of LWR fuel pins can be measured by the ^{252}Cf-source-driven neutron noise analysis method, and thus it has promise for online monitoring of subcriticality in LWR fuel storage facilities. These experiments also demonstrated an ability to monitor the subcriticality of an array of LWR fuel pins as its size changes. The relatively short measurement times required illustrate the practicality of the method. The experiments were limited in that the size of the tank in which the pins were assembled was 152.4 cm diam. Before practical application of the method can be made to LWR fuel storage and initial loading of LWRs, further experiments should be performed for even larger arrays of LWR fuel.

The results of the experiments performed show that the ^{252}Cf-source-driven noise analysis method for measuring subcriticality has a variety of applications. Its implementation is simplified by the fact that it needs neither source nor detector calibrations to obtain reproducible, interpretable results.

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3.3.1.1 ABSOLUTE SUBCRITICALITY MEASUREMENT WITHOUT CALIBRATION AND DETECTION EFFICIENCY DEPENDENCE BY THE ^{252}Cf-SOURCE-DRIVEN NOISE METHOD

J. T. Mihalczo W. T. King

(Abstract of paper presented at 1984 Nuclear Science Symposium, Orlando, Florida, October 31–November 2, 1984)

The ^{252}Cf-source-driven noise analysis method determines the subcriticality of a system containing fissionable material from the ratio of cross power spectral densities between the detectors that detect particles from the fission process and between these detectors and an ionization chamber containing a spontaneously fissioning neutron source which provides neutons to induce fission in the system. This method has two advantages: (a) a calibration is not required and thus subcriticality can be determined from measurements only on the subcritical system of interest, and (b) the subcriticality is independent of the type of detector or its efficiency. These properties of this technique are illustrated by measurements.

3.3.1.2 TECHNIQUE FOR REDUCTION OF COHERENCE FUNCTION BIAS ERROR

W. T. King

(Abstract of paper presented at 1984 Nuclear Science Symposium, Orlando, Florida, October 31 November 2, 1984)

The bias error in the coherence function is found to arise from the calculation of the square magnitude of the cross power spectral density when the real and imaginary components are not converged. Therefore, the bias error of the coherence function can be decreased significantly without averaging more data blocks if the variance of the real and imaginary components are reduced by fitting the spectra of these separate components to an appropriate model.

3.3.1.3 SPATIAL EFFECT CORRECTIONS TO SUBCRITICALITY MEASUREMENTS BY THE ^{252}Cf-SOURCE-DRIVEN NEUTRON NOISE ANALYSIS METHOD

G. Verdú-Martín*
J. L. Muñoz-Cobos* W. T. King
J. T. Mihalczo E. D. Blakeman

For certain placements of the source and detectors in highly subcritical systems, the interpretation of the measured data using the point kinetic assumptions is not adequate and an interpretation that involves spatial kinetics effects is required. A spatial kinetics model may allow interpretation of measurements with $k_{eff} < 0.5$. This paper presents a method of accounting for spatial kinetics effects by use of a multiplicative factor, which can be obtained from calculations.[1] This type of correction can be implemented simply and may extend the applicability of the method and allow choices of more convenient and practical source-detector locations for in-plant situations. Since both the numerator and denominator of the ratio of spectral densities must be corrected separately for spatial kinetics effects, it may be possible to locate the source and detectors such that the correction to the product in the numerator $G^*_{12}G_{13}$ and that for the denominator G_{23} would be equal and thus cancel. In this case, the use of the measured ratio and a point kinetics interpretation would give the subcriticality. Previous evaluations of experimental data have not incorporated modal effect corrections and have to some extent limited the source-detector placements. The work reported here, which is the first treatment of spatial effects, should remove some of these limitations on source-detector locations.

A modal expansion using diffusion theory with three energy groups has been used to calculate the three cross power spectral densities $G_{12}(\omega)$, $G_{13}(\omega)$, and $G_{23}(\omega)$ as a function of frequency, ω, for cylindrical, homogeneous geometry systems. The formulation includes the detectors as part of the system and also includes distributed sources that might result from inherent source fission. These inherent source neutron-initiated fission chains contribute to G_{23} and must be incorporated for systems with neutron sources other than ^{252}Cf. The spectra are calculated with sufficient terms in the expansion to assure that additional terms will not significantly affect the result. The ratio of spectral densities is also calculated with only the fundamental mode term in the expansions. The calculated ratio of spectral densities with many terms in the expansion to that with the fundamental mode only, M_c, is then used with the measured ratio of spectral densities, which includes all modal effects and which can be used to obtain a measured value associated with the fundamental mode.

To investigate the applicability of this spatial correction method, calculations were performed for an aqueous solution of uranyl fluoride in which ^{252}Cf-source-driven noise analysis measurements for subcriticality determination were performed.[2-5] An unreflected 56-cm-diam cylindrical tank was partially filled (height of solution varied) with a solution of 4.95 wt% ^{235}U enriched uranium. The ^{252}Cf was located in a central tube on the cylinder axis at approximately half the height of the solution, and the detectors were located outside the radial surface at the midplane. The modal correction factors for $G_{12}(M_{12})$, for $G_{23}(M_{23})$, and for the ratio (M_c) were constant at low frequencies. These calculations show that for these solution heights, the modal corrections to the reactivity obtained by this method are ~5%, although the modal corrections in the numerator and denominator of the ratio are as much as 27%.

These calculations show that the ^{252}Cf-source-driven noise analysis technique for subcriticality measurement is less sensitive to modal effects than other methods because of the cancellation effects. This calculational method is a useful tool for planning and analyzing the results of this type of measurement. It extends the applicability of this method to lower values of k_{eff} since this model incorporates spatial and energy modal effects.

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3.3.2 DEVELOPMENT OF AN AUTOMATED DIAGNOSTICS SYSTEM FOR BOILING WATER REACTOR STABILITY MEASUREMENTS

J. March-Leuba* **C. M. Smith**

[Abstract of paper presented at Fourth Specialists' Meeting on Reactor Noise (SMORN-IV), Dijon, France, October 15–19, 1984; also *Trans. Am. Nucl Soc.* **47**, 420–21 (1984)]

This paper presents an automated algorithm for online boiling water reactor stability estimation based on neutron noise measurements. The concepts of asymptotic and apparent decay ratios are presented. Several methods to estimate stability are discussed and applied to both BWR data and computer-generated data for difficult pole-zero configurations. Finally, the importance of using long enough records of data is emphasized with some examples.

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3.3.2.1 CALCULATION OF LIMIT CYCLE AMPLITUDES IN COMMERCIAL BOILING WATER REACTORS

J. March-Leuba*
R. B. Perez **D. G. Cacuci**[†]

[Abstract of *Trans. Am. Nucl. Soc.* **46**, 749 50 (1984)]

Recent stability tests have shown that boiling water reactors (BWRs) can be linearly unstable when operated at low flow and high power. It was observed that under these conditions the amplitude of the resulting power oscillations was limited to about ±10% of the operating power by the appearance of a limit cycle caused by reactor nonlinearities. The existence of a limit cycle corresponds to an oscillation of fixed amplitude and period.

This paper describes an investigation of the dynamic behavior of a BWR in the nonlinear region corresponding to linearly unstable conditions. For this purpose, a nonlinear model of a typical BWR was developed. The equations underlying this model represent: (a) a one-dimensional void reactivity feedback (described by a 12-node axial expansion of the energy, continuity, and momentum equations for the average channel), (b) point kinetics with a single delayed-neutron group, (c) fuel behavior (obtained by using a two-node representation of pellet and cladding behavior), and (d) recirculation loop dynamics (described by a single-node integral momentum equation).

Important conclusions of the research described in this work are: (a) the nonlinear model developed successfully predicts the appearance of the experimentally observed limit cycles, (b) the amplitude of the power oscillations in the nonlinear region is very sensitive to changes in the operating conditions, and (c) limit cycles of large amplitude, but not so large as to cause an automatic scram, are a possible scenario for BWR plant operation.

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3.3.3 LOCAL STABILITY TESTS IN DRESDEN 2 BOILING WATER REACTOR

J. March-Leuba* **M. E. Buchanan**
D. N. Fry **C. O. McNew**

[Abstract of ORNL/TM-9054, April 1984; see also *Trans. Am. Nucl. Soc.* **46**, 746 47 (1984)]

This report presents the results of a local stability test performed at the Dresden Unit 2 boiling water reactor (BWR) in May 1983 to determine the effect of a new fuel element design on local channel stability. This test was performed because the diameter of the new fuel rods increases the heat transfer coefficient, making the reactor more responsive and, thus, more susceptible to instabilities.

After four of the new fuel elements with a 9 × 9 array of fuel rods were loaded into Dresden 2, the test was performed by inserting an adjacent control rod all the way in and then withdrawing it to its original position at maximum speed. At the moment of the test, reactor conditions were 52.7% power and 38.9% flow.

Both the new 9 × 9 fuel elements and the standard 8 × 8 ones proved to be locally stable when operating at minimum pump speed at the beginning of cycle in Dresden 2, and no significant difference was found between the behavior of the two fuel types. Finally, Dresden 2 showed a high degree of stability during control rod and normal noise type perturbations.

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3.3.4 USE OF NEUTRON NOISE FOR DIAGNOSIS OF IN-VESSEL ANOMALIES IN LIGHT-WATER REACTORS

D. N. Fry
J. March-Leuba* F. J. Sweeney

(Abstract of NUREG/CR-3303, ORNL/TM-8774, January 1984)

The value of neutron noise analysis for diagnosis of in-vessel anomalies in light-water reactors (LWRs) was assessed by: (1) analyzing ex-core neutron noise from seven pressurized water reactors (PWRs) to determine the degree of similarity in the noise signatures and the sources of ex-core neutron noise; (2) measuring changes in ex-core neutron noise over an entire fuel cycle at a commercial PWR; (3) applying PWR neutron noise analysis to diagnose a loose core barrel, to infer in-core coolant velocity, and to infer fuel assembly motion; and (4) applying BWR neutron noise analysis to diagnose in-core instrument tube vibrations and bypass coolant boiling, to infer in-core two-phase flow velocity and void fraction, and to infer stability associated with reactivity feedback.

This report summarizes these assessments and provides guidance for the acquisition and analysis of neutron noise in LWRs.

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3.3.4.1 REPORT OF THE FIRST UNITED STATES CONFERENCE ON UTILITY EXPERIENCE WITH NEUTRON NOISE ANALYSIS

D. N. Fry
G. P. Horne* C. W. Mayo[†]

[Abstract of paper presented at Fourth Specialists' Meeting on Reactor Noise (SMORN-IV), Dijon, France, October 15-19, 1984]

An informal meeting was held in Washington, D.C. on April 3 and 4, 1984, to discuss the current state of the art and experiences with neutron noise analysis in U.S. pressurized water reactors (PWRs). The meeting was attended by 33 persons representing 11 utilities and 3 PWR reactor vendors as well as consultants, universities, and research laboratories. Presentations at the meeting covered several applications of neutron noise for diagnosing such things as vibrations induced by baffle jetting, detection of mechanical degradation of thermal shield supports, and electrical degradation of nuclear instrumentation channels.

Twenty-one responses were obtained from a questionnaire circulated to all participants requesting their viewpoints and experiences regarding neutron noise analysis.

The meeting participants concluded that a working group on neutron noise analysis should be formed to (1) establish a baseline library of neutron noise data, (2) provide a forum for communicating experiences with neutron noise surveillance, and (3) develop good practices and quality assurance procedures for neutron noise measurement and interpretation.

*Duke Power Company.
[†]Science Applications, Inc.

3.3.5 SENSITIVITY OF DETECTING IN-CORE VIBRATIONS AND BOILING IN PRESSURIZED WATER REACTORS USING EX-CORE NEUTRON DETECTORS

Frank J. Sweeney John-Paul A. Renier*

(Abstract of NUREG/CR-2996, ORNL/TM-8549, July 1984; see also *Trans. Am. Nucl. Soc.* **43**, 699-701 (1982), and **44**, 549-50 (1983))

Neutron transport and diffusion theory space- and energy-dependent reactor kinetics calculations were performed in the frequency domain to determine the sensitivity of an ex-core neutron detector to in-core vibrations and coolant boiling in a pressurized water reactor (PWR). The results of these calculations indicate that the ex-core detectors are sensitive to neutron sources, to vibrations, and to boiling occurring over large regions of the core.

Calculations were also performed to determine the effects of fuel burnup, boron concentration, and xenon poisoning on the spatial sensitivity of the ex-core detector. These calculated results show that fuel assembly vibrations would be expected to produce ~60% greater ex-core detector response at the end of the first fuel cycle at Sequoyah-1 compared to the beginning of the fuel cycle for a constant amplitude of vibration.

The results were compared with experimental ex-core neutron noise data obtained from Sequoyah-1 during the first fuel cycle. The predicted increase in ex-core neutron noise was

experimentally observed in the 2.5- to 4.0-Hz frequency range (the range of frequencies associated with fuel assembly vibration), indicating that the vibrational amplitude of the fuel assemblies did not increase significantly during the first fuel cycle.

*Computing and Telecommunications Division.

3.3.5.1 SENSITIVITY OF EX-CORE NEUTRON DETECTORS TO VIBRATION OF PWR FUEL ASSEMBLIES

F. J. Sweeney J. P. Renier*

(Abstract of paper presented at Seventh International Conference on Structural Mechanics in Reactor Technology, Chicago, August 22–26, 1984)

The response of an ex-core neutron detector to fuel assembly vibrations in an 1150-MW(e) Westinghouse pressurized water reactor (PWR) was determined by performing space-dependent reactor kinetics calculations. The effect on the detector response of reducing the soluble boron concentration in the coolant and fuel burnup over the first fuel cycle was also determined.

The results of the calculations indicate that the ex-core neutron detectors are sensitive to fuel assembly vibrations occurring over large spatial regions of the core, and that the detector response increases with fuel burnup and decreasing soluble boron concentration. The predicted increases in the detector responses to fuel assembly vibrations have been observed experimentally in several commercial PWRs.

*Computing and Telecommunications Division.

3.3.5.2 CONTRIBUTION OF FUEL VIBRATIONS TO EX-CORE NEUTRON NOISE DURING THE FIRST AND SECOND FUEL CYCLES OF THE SEQUOYAH-1 PRESSURIZED WATER REACTOR

F. J. Sweeney
J. March-Leuba* C. M. Smith

[Abstract of paper presented at Fourth Specialists' Meeting on Reactor Noise (SMORN-IV), Dijon, France, October 15–19, 1984; see also *Trans. Am. Nucl. Soc.* **46**, 734–35 and 735–36 (1984)]

Noise measurements were performed during the first and second fuel cycles of the Sequoyah-1 pressurized water reactor (PWR) to observe long-term changes in the ex-core neutron signatures. Increases in the ex-core neutron noise amplitude were observed throughout the 0.1- to 50.0-Hz range. In-core noise measurements indicate that fuel assembly vibrations contribute significantly to the ex-core neutron noise at nearly all frequencies in this range, probably due to mechanical or acoustic coupling with other vibrating internal structures. Space-dependent kinetics calculations show that ex-core neutron noise induced by fixed-amplitude fuel assembly vibrations will increase over a fuel cycle because of soluble boron and fuel concentration changes associated with burnup. These reactivity effects can also lead to 180° phase shifts between cross-core detectors.

We concluded that it may be difficult to separate the changes in neutron noise due to attenuation (shielding) effects of structural vibrations from changes due to reactivity effects of fuel assembly motion on the basis of neutron noise amplitude or phase information. Amplitudes of core support barrel vibrations inferred from ex-core neutron noise measurements using calculated scale factors are likely to have a high degree of uncertainty, since these scale factors usually do not account for neutron noise generated by fuel assembly vibrations. Modifications in fuel management or design may also lead to altered neutron noise signature behavior over a fuel cycle.

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3.3.6 PRESSURE NOISE UTILIZATION FOR REACTOR ANOMALY MONITORING

J. A. Thie* J. A. Mullens

(Abstract of paper presented at IAEA Specialists' Meeting on Early Diagnosis of Failures in Primary System Components of Nuclear Power Plants, Prague, Czechoslovakia, June 21–25, 1982)

A unique opportunity for exploring the potential for obtaining surveillance information from pressure sensors appeared in tests recently conducted at the Loss-of-Fluid Test (LOFT) PWR. A special noise analysis program on this highly instrumented reactor was sponsored by the NRC Office of Regulatory Research. Data, mostly from pressure sensors, were collected under steady-state and severe transient conditions.

Pressure noise phenomena investigated were (1) pump shaft and impeller vane-passing frequency

fine structure, (2) sonic standing waves, (3) hydrodynamic oscillations in the 1- to 4-Hz range, (4) boiling-induced pressure noise, and (5) anomalous transducer behavior. Spectra and cross-spectra from sensors in various locations gave insights into these phenomena. Among the conditions investigated was boiling after a shutdown and pump trip.

Interpretation shows LOFT data to be representative of pressure noise data from commercial PWRs. A theoretical tool, shown to have attractive interpretive capabilities, is the lumped acoustic impedance model. Also, a transfer function model, constructed from both theoretical and experimental foundations, permits the use of neutron detectors as sensors of in-core pressure phenomena.

Many specific surveillance applications are suggested by this work. Hence, it is concluded that pressure noise can be an important tool for monitoring reactor performance.

*Analysis and Measurement Sevices, Inc.

3.3.6.1 THE USE OF PRESSURE NOISE IN PWR DIAGNOSTICS

J. A. Mullens J. A. Thie*

(Abstract of paper presented at Eleventh Water Reactor Safety Research Information Meeting, National Bureau of Standards, Gaithersburg, Maryland, October 24–28, 1983)

The term "pressure noise" refers to the natural fluctuations of pressure which occur in a pressurized water reactor (PWR). These fluctuations carry information about the state of the PWR primary coolant system. For example, a change in noise signals from a differential pressure sensor at the Loss-of-Fluid Test Facility (LOFT) coincides with a gamma densitometer indication of steam voids appearing in the hot leg of the primary coolant loop.

The analyses described in this paper use "noise analysis" techniques which are very similar to the neutron noise analysis techniques that have been successfully used in the past to diagnose such problems as excessive core barrel motion and instrument tube vibrations. The analyses presented in this paper use "spectral analysis," a very common technique in noise analysis. Briefly stated, signals are transformed from the time domain to the frequency domain via the Fourier transformation. The resulting spectra indicate how the signal behaves at different frequencies.

*Analysis and Measurement Services, Inc.

3.3.6.2 MODELING AND DIAGNOSTIC TECHNIQUES APPLICABLE TO THE ANALYSIS OF PRESSURE NOISE IN PRESSURIZED WATER REACTORS AND PRESSURE-SENSING SYSTEMS

J. A. Mullens J. A. Thie*

[Abstract of paper presented at Fourth Specialists' Meeting on Reactor Noise (SMORN-IV), Dijon, France, October 15-19, 1984]

Pressure noise data from a PWR are interpreted by means of a computer-implemented model. The model's parameters, namely hydraulic impedances and noise sources, are either calculated or deduced from fits to data. Its accuracy is encouraging and raises the possibility of diagnostic assistance for nuclear plant monitoring. A number of specific applications of pressure noise in the primary system of a PWR and in a pressure sensing system are suggested.

*Analysis and Measurement Services, Inc.

3.3.7 IN-CORE COOLANT FLOW MONITORING OF PRESSURIZED WATER REACTORS USING TEMPERATURE AND NEUTRON NOISE

F. J. Sweeney
B. R. Upadhyaya* D. J. Shieh*

[Abstract of paper presented at Fourth Specialists' Meeting on Reactor Noise (SMORN-IV), Dijon, France, October 15-19, 1984; see also *Trans. Am. Nucl. Soc.* 43, 789–90 and 795–97 (1982) and 46, 847–49 (1984)]

Noise measurements were performed at the Loss-of-Fluid Test (LOFT) and Sequoyah-1 pressurized water reactors (PWRs) in order to investigate the possibility of inferring in-core coolant velocities from cross-power spectral density (CPSD) phases of core-exit thermocouple and in-core neutron detector signals. These noise measurements were used to investigate the effects of inlet coolant temperature, core flow, reactor power, and random heat transfer fluctuations on the noise-inferred coolant velocities. The effect on the inferred velocities of varying in-core neutron detector and core-exit thermocouple locations was also investigated. Theoretical models of temperature noise were developed, and the results were used to interpret the experimental measurements.

Results of these studies indicate that the neutron detector/thermocouple phase is useful for monitoring core flow in PWRs. Our results show that the

interpretation of the phase between these signals depends on the source of temperature noise, the response time and locations of the sensors, and the neutron dynamics of the reactor. At Sequoyah-1 we found that the in-core neutron detector/core-exit thermocouple phase can be used to infer in-core coolant velocities, provided that the measurements are corrected for the thermocouple response time.

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3.3.7.1 RELATIONSHIP OF CORE-EXIT TEMPERATURE NOISE TO THERMAL-HYDRAULIC CONDITIONS IN PWRs

F. J. Sweeney B. R. Upadhyaya*

(Abstract of paper presented at Second International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Santa Barbara, California, January 11-14, 1983)

Core-exit thermocouple temperature noise and neutron detector noise measurements were performed at the Loss of Fluid Test Facility (LOFT) reactor and a Westinghouse 1148-MW(e) PWR to relate temperature noise to core thermal-hydraulic conditions. The noise analysis results show that the rms of the temperature noise increases linearly with increasing core ΔT at LOFT and the commercial PWR. Out-of-core test loop temperature noise has shown similar behavior.

The phase angle between core-exit temperature noise and in-core or ex-core neutron noise is directly related to the core coolant flow velocity. However, if the thermocouple response time is slow, compared to the coolant transit time between the sensors, velocities inferred from the phase angle are lower than measured coolant flow velocities.

Our results indicate that core-exit temperature noise is a potentially valuable tool for the detection of thermal-hydraulic anomalies such as flow blockages or boiling.

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3.3.7.2 THEORETICAL AND EXPERIMENTAL STOCHASTIC MODELING ANALYSIS OF PWR CORE HEAT TRANSFER

B. R. Upadhyaya* F. J. Sweeney

(Abstract of paper presented at Fifth Power Plant Dynamics, Control and Testing Symposium, Knoxville, Tennessee, March 21-23, 1983)

A multi-nodal stochastic heat transfer model has been developed to study the fuel-to-coolant heat transfer and the effects of various heat flux perturbations on the core-exit coolant temperature in a pressurized water reactor (PWR). These perturbations can be associated with the fuel or the coolant. We have studied the effects of these on the dynamic responses, which are considered to be random processes. The analysis showed that the effect on the core-exit coolant temperature of perturbations of the heat deposited in the fuel was most influential in the frequency range 0–1 Hz. This analysis is made by transforming the dynamic model to the frequency domain and estimating the contribution to the power spectrum of the core-exit temperature from various perturbations. Further studies showed that the perturbations in the coolant flow rate were more dominant on the core-exit temperature than the perturbations in the inlet coolant temperature. The analysis of operational data from a commercial PWR showed high coherence between the neutron signal and the core-exit temperature signal, also in the 0- to 1-Hz frequency range. This observation, together with a multivariate time-series modeling of the signals, demonstrated the existence of unidirectional flow dynamics between the neutron and the temperature signals. Investigations of this type are useful in understanding the mechanism of coolant temperature "noise" behavior, the factors influencing inadequate core cooling (that is, deviation from normal heat transfer), and the sources of perturbations that affect the temperature signals. Also, diagnostic information such as coolant flow monitoring and sensor fault monitoring can be obtained using dynamic modeling and operational data.

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3.3.8 ON-LINE NOISE MONITORING AT THE FAST FLUX TEST FACILITY

J. A. Mullens
J. A. Thie* L. R. Campbell†

[Abstract of paper presented at Fourth Specialists' Meeting on Reactor Noise (SMORN-IV), Dijon, France, October 15–19, 1984]

An automated noise surveillance and diagnostics system (ANSDS) is being demonstrated at the Fast Flux Test Facility (FFTF). Three low-level, in-vessel fission chambers (LLFMs), three ex-vessel compensated ion chambers (CICs), and two accelerometers on the mechanism of one advanced absorber (ADVAB) control rod were monitored with an automated noise surveillance and diagnostic system (ANSDS) in late 1983.

*Analysis and Measurement Services, Inc.
†Westinghouse-Hanford.

3.3.9 LONG-TERM AUTOMATED SURVEILLANCE OF A COMMERCIAL NUCLEAR POWER PLANT

C. M. Smith R. C. Gonzalez*

[Abstract of paper presented at Fourth Specialists' Meeting on Reactor Noise (SMORN-IV), Dijon, France, October 15–19, 1984]

A pattern recognition system for monitoring nuclear reactor signals is presented. The system is based on detecting deviations from baseline signatures learned automatically during the normal plant operation. The capabilities and limitations of the recognition approach were investigated during a 2 1/2-year, continuous, online series of experiments at the Sequoyah-1 nuclear power plant.

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3.3.9.1 A DESCRIPTION OF THE HARDWARE AND SOFTWARE OF THE POWER SPECTRAL DENSITY RECOGNITION (PSDREC) CONTINUOUS ON-LINE REACTOR SURVEILLANCE SYSTEM (CALIFORNIA DISTRIBUTION)

C. M. Smith

(Abstract of NUREG/CR-3439, Vols. 1 and 2, ORNL/TM-8862/V1 and V2, December 1983)

This report documents the Power Spectral Density Recognition (PSDREC) Continuous On-Line Reactor Surveillance Program. Volume I of this manual is a description of the major concepts and philosophy of the PSDREC surveillance system. Volume I is of interest to readers who desire to understand how the system operates. Volume II is the appendices which contain detailed information useful only to a reader involved with the computer implementation of this system. Volume I has been given a general distribution. Volume II is available from the author upon request.

3.3.9.2 NUCLEAR POWER PLANT SURVEILLANCE BY HEURISTIC LEARNING PARAMETER IDENTIFICATION

E. L. Machado* R. B. Perez

[Abstract of *Trans. Am. Nucl. Soc.* **44**, 550–51 (1983)]

Continuous surveillance of large dynamic systems such as nuclear power plants can improve system availability by early detection of incipient failure and by avoiding unnecessary periodic maintenance. Noise analysis has been used for surveillance because it does not interfere with plant operation and has been proven effective for the detection of several types of anomalies. When models for the measured noise descriptors are available, the identification of plant parameters can improve the assessment of the plant operational condition. For fast anomaly detection, the parameter identification must be repeated very often, in which case automatic, efficient, and reliable parameter identification methods are necessary.

Parameter identification typically involves finding the set of parameters that minimizes a functional of the residuals between a set of measured descriptors and the corresponding model-calculated values. In the past, this minimization has been solved by either iterative-analytical techniques, (e.g., the Gauss-Newton least-squares method) or by direct search algorithms such as the pattern search method. In practice, these methods are not well suited for automatic identification. Experience and "rules of thumb" (heuristics) are necessary for choosing the starting points for the parameters, which makes the algorithm converge to solutions that appropriately fit the relevant "features" of the descriptors such as areas, peaks, break frequencies, and other pecularities.

The purpose of this paper is to present a new identification method, based on some ideas of heuristic learning control, that (a) incorporates previous knowledge in reactor diagnostics and (b) is able to learn from past experience, with the ultimate goal of performing automated, online parameter identification for nuclear reactor surveillance and diagnostics. The heuristic learning parameter identification method can use past experience to improve future identifications, making it an efficient methodology in situations where the same class of identifications must be repeated several times, as in the case of continuous surveillance of nuclear power plants.

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3.3.10 NUCLEAR ENGINEERING LABORATORY SELF-REGULATED POWER OSCILLATION EXPERIMENTS AT THE HEALTH PHYSICS RESEARCH REACTOR

L. F. Miller*
J. T. Mihalczo N. D. Woody*
E. G. Bailiff[†] G. D. Gardner*

[Abstract of *Trans. Am. Nucl. Soc.* 44, 38-39 (1983)]

For several years, self-regulated power oscillation experiments with a variety of initial conditions have been performed at the ORNL HPRR by undergraduate nuclear engineering students from the University of Tennessee. These experiments demonstrate the coupling between reactor kinetics and heat transfer and show how the temperature coefficient of reactivity affects reactor behavior. A model that consists of several coupled first-order nonlinear differential equations is used to calculate the temperature of the core center and surface and the power as a function of time, which is then compared with the experimental data. The model is also used to study the effects of various model parameters and initial conditions on the amplitude, frequency, and damping of the power and temperature oscillations. This paper presents the results of experiments for

1. the initial power fixed at 9 kW with central core temperatures of 300 and 500°F
2. the initial central core temperature fixed at 500°F with initial powers of 6 and 8 kW.

The data from the HPRR power oscillation experiments with various initial conditions illustrate to the students some interesting characteristics of a coupled reactor kinetics and heat transfer system.

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3.3.11 EXPERIMENTAL RESULTS ON FINITE BETA LIMITS AND TRANSPORT IN THE ISX-B TOKAMAK

A. J. Wootton et al*[†] V. K. Paré

(Abstract of ORNL/TM-8750, October 1983)

A summary of experimental results pertaining to plasma energy and particle transport in the Impurity Study Experiment (ISX-B) Tokamak is presented. Emphasis is placed on results with neutral beam heating, usually in the "co-" direction (aligned with the plasma current), and the relative roles of various energy loss mechanisms are discussed. The derived electron thermal diffusivity and the predictions of various models have been compared. The measured values are within a factor of 2 of the values expected to result from resistive pressure-driven modes. Evidence for the presence of these modes is discussed.

Values of ion thermal diffusivity are compared with the predictions of neoclassical theory. Anomaly factors (the ratio of experimental value to theoretical value) between 1 and 5 are found. Comparisons between experimental results and theoretical predictions are also made for cases with increased toroidal field ripple, produced by using only 9 of the 18 toroidal field coils.

Convection is shown to play a small role in energy transport, except at the plasma periphery. The behavior of both plasma and impurity particles is discussed and shown to be strongly dependent on the direction of the plasma current relative to the neutral beam (coinjection and counterinjection). Results obtained for impurities are in qualitative agreement with the expectations of models that include the effects of toroidal mass rotation and direct momentum transfer.

Beta limits are discussed. The maximum values obtained for both β_I (~2) and $<\beta>$ (~2.5%) are not thought to be limited except by the restricted power available for heating.

*Fusion Energy Division.
[†]Because of the large number of coauthors, only the principal author and coauthors from the Instrumentation and Controls Division are listed here. See the List of Publications for a complete listing of authors.

3.3.11.1 MHD ACTIVITY IN THE ISX-B TOKAMAK: EXPERIMENTAL RESULTS AND THEORETICAL INTERPRETATION

B. A. Carreras et al.*† V. K. Paré

(Abstract of ORNL/TM-8648, June 1983; also paper presented at IAEA Ninth International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Baltimore, September 1–8, 1984)

The observed spectrum of magnetohydrodynamic (MHD) fluctuations in the Impurity Study Experiment (ISX-B) Tokamak is clearly dominated by the $n = 1$ mode when the $q = 1$ surface is in the plasma. This fact agrees well with theoretical predictions based on three-dimensional (3-D) resistive MHD calculations. They show that the $(m = 1; n = 1)$ mode is the dominant instability. It drives other $n = 1$ modes through toroidal coupling and $n > 1$ modes through nonlinear couplings. These theoretically predicted mode structures have been compared in detail with the experimentally measured wave forms (using arrays of soft X-ray detectors). The agreement is excellent. More detailed comparisons between theory and experiment have required careful reconstructions of the ISX-B equilibria. The equilibria so constructed have permitted a precise evaluation of the ideal MHD stability properties of ISX-B. The present results indicate that the high-beta ISX-B equilibria are marginally stable to finite-n ideal MHD modes. The resistive MHD calculations also show that at finite beta there are unstable resistive pressure-driven modes. For low-β_p equilibria these modes saturate at very low level and their evolution has little effect on the dominant $(m = 1; n = 1)$ mode. However, with increasing β_p they become more important. Their n spectrum is concentrated at low mode number and is broad. Analytic calculations indicate that their saturated kinetic energy scales like $(\epsilon\beta_p)^{5/3}\eta^{4/3}$. These scalings have been confirmed by numerical results. The resistive ballooning modes are good candidates for the explanation of the confinement deterioration at high β_p in ISX-B. The transport effects induced by them are estimated from the theory and are found to be mainly thermal electron conduction losses. An expression for χ_e is derived, and it yields values that agree well with those from the experiment.

*Fusion Energy Division.

†Because of the large number of coauthors, only the principal author and coauthors from the Instrumentation and Controls Division are listed here. See the List of Publications for a complete listing of authors.

3.4 Systems Analysis

3.4.1 INSTRUMENTATION AND CONTROLS EVALUATION FOR SPACE NUCLEAR POWER SYSTEMS

J. L. Anderson L. C. Oakes

(Abstract of paper presented at First Symposium on Space Nuclear Power Systems, Albuquerque, New Mexico, January 11–13, 1984)

Design of control and protection systems should be coordinated with the design of the neutronic, thermal hydraulic, and mechanical aspects of the core and plant at the earliest possible stage of concept development. An integrated systematic design approach is necessary to prevent uncoordinated choices in one technology area from imposing impractical or impossible requirements in another.

Significant development and qualification will be required for virtually every aspect of reactor control and instrumentation. In-core instrumentation widely used in commercial light water reactors will not likely be usable in the higher temperatures of a space power plant. Thermocouples for temperature measurement and gamma thermometers for flux measurement appear to be the only viable candidates. Recent developments in ex-core neutron detectors may provide achievable alternatives to in-core measurements. Reliable electronic equipment and high-temperature actuators will require major development efforts.

3.4.2 HTGR SAFETY STUDIES FOR THE NRC DIVISION OF ACCIDENT EVALUATION

S. J. Ball R. M. Harrington

Research on systems and safety analysis of high temperature gas-cooled reactors (HTGRs) includes dynamic model development for component and system codes, analysis of postulated accidents and other transients, partial verification of codes using experimental data, and analytical and experimental studies of HTGR fuel failure mechanisms and fission product release and transport for postulated severe accidents. The program goals are to provide independent verification of analyses required for safety analysis reports and licensing questions, and to improve the definitions of design safety margins and overall risks.

The work is divided into three main task areas. Task 1 includes development and documentation of HTGR component and system dynamic models and computer codes for large monolithic plants, for small modular plants, and for Fort St. Vrain (FSV). Task 2 covers the analysis of postulated FSV reactor accidents, on-call support for FSV licensing problems, experiments relating to verification of important models and parameters, and support of risk assessment and siting criteria development for large and modular HTGRs. Task 3 includes reviews and analysis of HTGR fuel failure, fission product transport and chemistry, and construction and operation of small-scale experiments as required.

In a cooperative effort with three other national laboratories, a preliminary evaluation[1] was made of postulated severe accident fission product releases or "source terms" for a DOE-sponsored design of a 2240-MW(t) HTGR, which was the leading candidate for introduction of a large HTGR to the U.S. commercial market. Detailed thermal-hydraulic analyses were performed for core heatup accident scenarios, including a number of parameter sensitivity studies to show the effects of uncertainties.

Because the small [250-MW(t)] modular HTGR design claim "inherent" safety and improved licensability, dynamic simulations of several of the current designs have been developed and used for accident analyses. These include codes for primary system transients and for long-term heatup accidents involving heat loss to the surrounding earth (for below-grade siting).

A continuing effort of support for the FSV reactor includes development of severe accident analytical tools and on-call technical assistance to NRC for licensing questions. A series of test plans for large-scale code verification experiments has also been developed.

Quarterly reports[2,3] detail work performed under this program.

The fission product transport work on this program is done primarily in the ORNL Chemical Technology Division.

1. H. J. Reilly et al., EG&G Idaho, Inc., Report EGG-REP-6565, April 1984.

2. S. J. Ball et al., NUREG/CR 2874, ORNL/TM-8443, Vols. 1-4 (1982-1983).

3. S. J. Ball et al., NUREG/CR 3492, ORNL/TM-8912, Vols. 1-4 (1983-1984).

3.4.2.1 PRELIMINARY EVALUATION OF HTGR SEVERE ACCIDENT SOURCE TERMS

H. J. Reilly* P. G. Kroeger‡
C. A. Anderson† C. A. Sastre‡
S. J. Ball K. R. Stroh†

(Abstract of EG&G Idaho, Inc. Report EGG-REP-6565, April 1984)

A study of the 2240-MW(t) high temperature gas-cooled reactor (HTGR) being developed by GA Technologies under DOE sponsorship was conducted for the purpose of estimating possible radiological source terms that might result from severe HTGR accidents. Fault- and event-tree analyses were conducted, and a literature review was performed to identify the severe accidents possible for the HTGR. Accidents leading to core heatup were identified as the most important for study. Independent analysis of core heatup accidents was conducted, and the estimated releases from such accidents were used, along with estimated releases for less severe accidents (from the literature), to provide five source terms spanning the range of possible releases. It was concluded that severe HTGR accidents will not produce early containment failure; only the rare event of prolonged total loss of all cooling systems, including the liner cooling system, can cause containment failure 5 to 10 days or more after onset of the accident. None of the more probable accidents can produce containment failure. The estimated source terms can be compared with those estimated by others for the HTGR and other reactor types.

*Idaho National Engineering Laboratory.
†Los Alamos National Laboratory.
‡Brookhaven National Laboratory.

3.4.3 A COMPARISON OF BWR STABILITY MEASUREMENTS WITH CALCULATIONS USING THE CODE LAPUR-IV

J. March-Leuba P. J. Otaduy

(Abstract of NUREG/CR-2998, ORNL/TM-8546, January 1983)

A parametric study of stability characteristics in boiling water reactors (BWRs) was performed using the frequency domain code LAPUR-IV. Two different reactors, Peach Bottom Unit 2 and Vermont Yankee, were considered in a total of 17 different operating conditions that corresponded to three series of low-flow stability tests performed in these two reactors. Stability margins, in terms of decay ratio and natural frequency of the closed-loop reactivity-to-power transfer function (T.F.) were calculated and then compared with the experimental results.

In addition, a sensitivity analysis was performed to determine the changes in calculated results to be expected in response to alterations in the density reactivity coefficient (DRC), the recirculation loop pressure-to-flow T.F. parameters, and the fuel-to-cladding-gap heat conductance. This allows assessment of the effect of input data uncertainty on the calculated results.

Satisfactory agreement was found between the stability margins calculated using LAPUR-IV and the experimental results. The sensitivity analysis shows that the DRC is the most critical of the parameters investigated for accurate stability calculations.

3.4.4 POSSIBLE MODES OF STEAM GENERATOR OVERFILL RESULTING FROM CONTROL SYSTEM MALFUNCTIONS AT THE OCONEE-1 NUCLEAR PLANT

F. H. Clark
N. E. Clapp R. Broadwater*

(Abstract of NUREG/CR-3692, ORNL/TM-9061, July 1984)

A study has been made of control system failures which might lead to overfill of the steam generator in Babcock & Wilcox nuclear plants. The steam generator and its control system are described. Only one sequence has been found in which a single failure would proceed rather slowly. Because of high-level protective features, all other failure sequences we have examined require at least two failures to produce overfill beyond the point of high-level protection. Several sequences are described in which high-level protection features can be placed in an undetected failed state by a control system failure; a subsequent additional failure, occuring prior to the detection and correction of the first failure, could then produce system overfill. Mechanical damage is identified which might be consequent upon steam generator overfill and water entry into the main steam line. Several ways of reducing the probability of steam generator overfill are suggested. No assessment has been made of the probability of occurence of any of the sequences.

*Tennessee Technological University, Cookville.

3.4.5 A METHODOLOGY FOR ALLOCATING NUCLEAR POWER PLANT CONTROL FUNCTIONS TO HUMAN OR AUTOMATIC CONTROL

R. Pulliam*
H. E. Price* C. R. Sawyer*
J. Bongarra* R. A. Kisner

(Abstract of NUREG/CR-3331, ORNL/TM-8781, August 1983)

This report describes a general method for allocating control functions to man or machine during nuclear power plant (NPP) design, or for evaluating their allocation in an existing design.

The research examined some important characteristics of the systems design process, and the results make it clear that allocation of control functions is an intractable problem, one which increases in severity with the increasing complexity of systems. The method is reported in terms of specific steps which should be taken during the early stages of a new system design, and which will lead to an optimal allocation at the functional design level of detail.

The procedures described are not expected to provide an ultimate solution to the allocation-of-functions problem. However, these procedures can at least assure that allocation of control functions is considered during design in an orderly and rational way. They should substantially advance the general understanding of this problem and the ability of the design community to allocate control functions to humans or automation in complex systems.

*BioTechnology, Inc.

3.4.5.1 AN APPROACH TO MODELING SUPERVISORY CONTOL OF A NUCLEAR POWER PLANT

S. Baron*
C. Feehrer* R. Pew*
R. Muralidharan* P. Horwitz*

(Abstract of NUREG/CR-2988, ORNL/Sub/81-70523/1, November 1982)†

This report describes the results of a study aimed at determining the feasibility of applying a supervisory control modeling technology to the study of critical operator-machine problems in the operation of a nuclear power plant. The report includes brief overviews of various alternative approaches to the modeling of human performance, and different perspectives on the roles of operators in process control activities such as those represented in a power plant.

The result of the study is a conceptual model that incorporates the major elements of the operator and of the plant to be controlled. The operator portion of the model is developed at a block diagram level and includes several algorithms that are considered suitable for use with various model components. The plant portion of the model is developed from literature available on plant dynamics and is of the "first-principles" type. Both models are presented in detail sufficient for demonstrating the feasibility of developing a quantitative supervisory control model, for outlining the requirements for data to build and operate such a model, and for discussing its potential applications.

*Bolt Beranek and Newman, Inc.
†Work performed under subcontract to ORNL (R. A. Kisner, project leader).

3.4.5.2 A NOTE ON EVALUATION OF COMPLEX MAN-MACHINE SYSTEMS

W. B. Rouse* Sandra H. Rouse*

[Abstract in *IEEE Trans. Sys., Man, Cybernet.* SMC-14(4), 633-36 (July-August 1984)]†

Almost 200 documents reporting results of evaluative studies of complex man-machine systems were reviewed. These documents were classified in terms of domain of study, method, approach to measurement, type of data, data collection methods, measures assessed, and nature of results. An analysis of the degree to which definitive evaluative results were produced as a function of a study's classification is discussed. The results are used to suggest several guidelines for design of evaluation efforts.

*Search Technology, Inc.
†Work performed under subcontract to ORNL (R. A. Kisner, project leader).

3.4.5.3 COMPUTING AND COGNITION IN FUTURE POWER PLANT OPERATIONS

R. A. Kisner T. B. Sheridan*

(Abstract of paper presented at Fifth Power Plant Dynamics, Control and Testing Symposium, Knoxville, Tennessee, March 21-23, 1983)

The intent of this paper is to speculate on the nature of future interactions between people and computers in the operation of power plants. In particular, the authors offer a taxonomy for examining the differing functions of operators in interacting with the plant and its computers and the differing functions of the computers in interacting with the plant and its operators.

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3.4.5.4 WORKSHOP ON COGNITIVE MODELING OF NUCLEAR PLANT CONTROL ROOM OPERATORS

T. B. Sheridan* R. A. Kisner
J. P. Jenkins† L. S. Abbott‡

(Abstract of paper presented at Workshop on Cognitive Modeling of Nuclear Plant Control Room Operators, Dedham, Massachusettes, August 15-18, 1982)

This document presents 11 invited papers and the deliberations of four working groups at a Workshop on Cognitive Modeling of Nuclear Plant Control Room Operators that was held in Dedham, Massachusetts, under the sponsorship of the U.S. Nuclear Regulatory Commission. The purpose of the workshop was to review the status of "cognitive modeling" and to recommend to the NRC whether it should support research directed toward the development of a cognitive model of a reactor operator that could be useful by itself or as a part of a larger model of the human-machine system. It was the consensus of the invited papers and the working groups that some cognitive models developed for other types of systems can be adapted to the reactor operator under limited and precisely defined conditions (and, indeed, some already are being used). However, the development of a comprehensive model for the reactor operator should be preceded by an improved understanding of the task. In the meantime, the need for further applied research in operator cognition is apparent, as is the need for supporting data collection. Work in these areas could begin immediately.

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†U.S. Nuclear Regulatory Commission.
‡Engineering Physics and Mathematics Division.

3.4.6 REVIEW OF OPERATIONAL AIDS FOR NUCLEAR PLANT OPERATORS

R. A. Kisner

(Abstract of paper presented at Tenth Water Reactor Safety Research Information Meeting, National Bureau of Standards, Gaithersburg, Maryland, October 12–15, 1982)

Many approaches are being explored to improve the safety of nuclear plant operations. One approach is to supply high-quality, relevant information by means of computer-based diagnostic systems to assist plant operators in performing their operational and safety-related roles. Privately and federally funded research has resulted in the development of operational aid concepts* to improve plant monitoring, diagnostic and corrective capabilities, and operator-process communication. Many of these concepts have passed from the idea state to the point of testing.

The evaluation of operational aids to ensure safe plant operations is a necessary function of NRC. However, such evaluation is made difficult by the lack of reliable quantitative performance measures and function analysis data. This lack exists because the nuclear power industry has not uniformly adopted a rigorous systems approach as characterized by the aerospace/aircraft industry. As a result, to obtain these data for design use requires post-engineering synthesis; that is, reconstruction of the original design process.

Furthermore, a situation the reverse of the systems approach has evolved: many operational aid systems are being developed without adequate analysis of the operator's role, system function, and operator tasks. This is analogous to having solutions in search of problems. Analysis would help point to specific functions and tasks for which the operator may require assistance, especially those in the areas of information processing and problem solving.

This ORNL project has two purposes: to collect limited data on a diversity of operational aids, and to provide a method for evaluating the safety implications of the functions of proposed operational aids. This report will discuss the methods for aid evaluation now under study and will outline data collection to date.

*Operational aids for the purposes of this study are limited to computer-based systems that transcend the fundamental monitoring and control instrumentation of the control room. Such aids allow the operator to offload such tasks or functions as (1) supervision of plant operations, (2) maintenance of equipment, and (3) coordination of support activities.

3.4.6.1 A METHOD FOR ANALYTICAL EVALUATION OF COMPUTER-BASED DECISION AIDS

W. B. Rouse* S. H. Rouse*
P. R. Frey* R. A. Kisner

(Abstract of NUREG/CR-3655, ORNL/TM-9068, July 1984)

This report presents a proposed methodology that involves a two-stage process of classification and analytical evaluation of decision aids for nuclear power plant operators. The classification scheme relates any particular aid to one or more general decision-making tasks. Evaluation proceeds using a normative top-down design process based on the classification scheme and involves determining how various design issues associated with this process were resolved by the designer. The result is an assessment of the "understandability" of the aid as well as the identification of training and display requirements necessary to ensure understandability. The methodology is illustrated by applying it to the evaluation of an aid designed to support operators in recovery of critical safety functions at a pressurized water reactor.

Two appendices are included. Appendix A contains information collected from manufacturers, developers, and users of operational aid systems. Appendix B is a review of NRC documents and guidelines that might apply to operational aids.

*Search Technology, Inc.

3.4.6.2 REVIEW OF HUMAN FACTORS IN OPERATOR AIDS DEVELOPMENT AT OAK RIDGE NATIONAL LABORATORY

W. H. Sides, Jr.

(Abstract of paper presented at Eleventh Biennial Conference on Reactor Operating Experience "Plant Startup and Operations in the '80s," Scottsdale, Arizona, August 1–3, 1983)

Oak Ridge National Laboratory (ORNL) currently is involved in projects related to several areas of human factors research, including human performance evaluation, testing and training, human engineering, and management and organizational structure interface. In this paper, three human engineering projects related to human factors in diagnostic aids will be described. One is sponsored by the Electric Power Research Institute (EPRI) and two by the Office of Research of the U.S. Nuclear Regulatory Commission (NRC).

3.4.6.3 COMPUTER-GENERATED DISPLAY SYSTEM GUIDELINES—VOLUME 1: DISPLAY DESIGN

P. R. Frey* R. M. Hunt*
W. H. Sides, Jr. W. B. Rouse*

(Abstract of Electric Power Research Institute Report EPRI NP-3701, Vol. 1, September 1984)

The method of communicating process information to the operator in a nuclear power plant control room is presently in a state of transition; the hardwired instruments currently in use are slowly being supplemented and may eventually be replaced by information presented by computer-generated display systems.

The primary objective of this document is to provide guidance to utilities in the design of displays and the selection and retrofit of a computer-generated display system to the control room of an operating nuclear power plant. The information contained in this guide is closely linked to the *process* of retrofitting a computer-generated display system. Guidance is offered regarding important human engineering considerations that should be addressed during the retrofit process. These human engineering considerations are linked to the hardware, software, and implementation decisions which must be made.

*Search Technology, Inc.

3.4.6.4 COMPUTER-GENERATED DISPLAY SYSTEM GUIDELINES—VOLUME 2: DEVELOPING AN EVALUATION PLAN

W. B. Rouse* W. H. Sides, Jr.

(Abstract of Electric Power Research Institute Report EPRI NP-3701, Vol. 2, September 1984)

Volume 1 of this report provides guidance to utilities on the design of displays and the selection and retrofit of a computer-generated display system in the control room of an operating nuclear power plant. Volume 2 provides guidance on planning and managing empirical evaluation of computer-generated display systems, particularly when these displays are primary elements of computer-based operator aids. The guidance provided is in terms of a multilevel evaluation methodology that enables sequential consideration of three primary issues: (1) compatibility, (2) understandability, and (3) effectiveness. The evaluation process approaches these three issues with a "top-down" review of system objectives, functions, tasks, and information requirements. The process then moves "bottom-up" from lower-level to higher-level issues, employing different evaluation methods at each level in order to maximize the efficiency and effectiveness of the evaluation process.

*Search Technology, Inc.

3.4.7 CAN MODELING IMPROVE CROPPING EFFICIENCY?

O. L. Smith

(Abstract of paper presented at NIFTAL Conference on Nitrogen Cycling in the Tropics, Emmaus, Pennsylvania, July 13–15, 1983)

In the developing nations of Africa, Asia, and Latin America, where agricultural resources are at a premium, the establishment of efficient cropping practices may significantly reduce the unit cost of output. Quantity and quality of product are affected by a range of field variables which may be partially or wholly manipulated for optimization. Because the array of such factors is large, it is often costly and time consuming to investigate them in the field. Is it possible to replace slow and expensive field experiments with faster and cheaper computer experiments? A model with appropriate resolution and accuracy may answer important questions. Can such a model be constructed for legume cropping in the tropics? In principle the answer may be "yes," but in practice it is "maybe."

Model construction may itself be costly and time consuming. To be useful, the simulation must have predictive capability beyond what would be learned in the construction process.

The key to success in any modeling effort and one that is consistently underemphasized, is the generation of specific experimental data for parameterization and model testing. There appear to be insufficient data on tropical legumes; it is therefore necessary to determine whether adequate research can be undertaken.

How much new modeling is desirable? Except for N fixation and possibly other selected processes, it may be more cost effective to adapt existing methodology to present needs.

3.4.8 MODEL OF THE SOLAR POWER SUPPLY SYSTEM OF THE MISSISSIPPI COUNTY COMMUNITY COLLEGE

J. A. Mullens

(Abstract of ORNL/TM-8262, October 1982)

A digital computer program has been written to model the performance of the solar power system of the Mississippi County Community College campus in Arkansas. One year of operation was simulated in order to assess the capabilities of the power supply system. The model predicts that the system will be able to supply electricity as intended but may have difficulty delivering heat at the design temperatures.

3.5 Reviews and Assessments

3.5.1 ASSESSMENT OF SAFETY IMPLICATIONS OF NUCLEAR PLANT CONTROL SYSTEMS

R. S. Stone

This program is intended to assess the safety implications of nuclear power plant control systems by examining the consequences of control system failures and actions, both planned and unplanned. Criteria will be developed for establishing the relative importance of control systems to overall safety; design and operation criteria will then be recommended for these systems based on their relative importance to safety.

In performing these tasks, a major objective is to assist in the resolution of Unresolved Safety Issue (USI) A-47, Safety Implications of Control Systems. The task action plan for that USI states that its objective "is to perform an in-depth evaluation of the control systems that are typically used during normal plant operation and to verify the adequacy of current licensing design requirements or propose additional guidelines and criteria to assure that nuclear power plants do not pose an unacceptable risk due to inadvertent nonsafety-grade control system failures."

This study embodies all objectives of USI A-47. It goes beyond the objectives of A-47, however, and addresses operator errors, sabotage, and harsh environments to a degree not included in the guidelines for A-47. It is intended that this work be done in a plant-specific fashion, and the first task provides a careful examination of reactor transients in one specific plant of Babcock & Wilcox (B&W) design, Oconee-1. Future work will address the Calvert Cliffs-1 Plant, an installation of Combustion Engineering design.

A failure mode and effects analysis (FMEA) is the standard method used for a systematic, qualitative search for significant failures and their consequences. It has commonly been applied to elements of the reactor protection system, and we are extending this same formalism to failures in control systems. Upon completion of the broad FMEA process, there remains a residuum of system failures with potential safety consequences. These are addressed through computer simulations in an activity referred to as "augmented FMEA."

The plant systems that make up the Oconee Nuclear Station have been identified and evaluated to assess potential impacts of system failures on three plant failure modes: steam generator overfilling, reactor coolant system overcooling, and insufficient core cooling. In parallel with the FMEA activity, a simulation program for the Oconee-1 system was developed on the ORNL hybrid computer. A number of transients have been simulated, and the results have been applied to a study in which failures of the targeted types have been identified.

Several suggestions have been offered which could make the plant less susceptible to unacceptable control system failures. The most important of these would make the high-level trip of the main feedwater pump less apt to fail. Other suggestions include greater use of the plant computer to identify inconsistent sensor readings, and classification of emergency procedures to call upon the operator explicitly to consult backup instrumentation in certain situations.

3.5.2 FAILURE MODE AND EFFECTS ANALYSIS (FMEA) OF THE ICS/NNI ELECTRIC POWER DISTRIBUTION CIRCUITRY AT THE OCONEE-1 NUCLEAR PLANT

A. F. McBride*
C. W. Mayc* R. E. Battle

(Abstract of draft report NUREG/CR-3991, ORNL/TM-9383)

The effects of nonnuclear instrumentation (NNI) and integrated control system (ICS) electric power supply failures have been analyzed for the Oconee Unit 1 nuclear plant. The instrument and control system power distribution circuits were analyzed to define a comprehensive set of 19 single-point failure modes. For each power supply failure, the failed and operating control system signal inputs were propagated through the partially energized control system circuits as well as the energized and deenergized output control devices to evaluate the initial plant response. In addition, the effects of the power supply failures on the principal control room parameter displays were combined with the initial plant response to the automatic control circuits to evaluate possible control room operator responses. Plant responses to the defined power supply failures are described in detail.

The automatic responses of the plant to the instrument and control system power supply failures were not found to be severe. This was due in part to post Three Mile Island modifications. Possible operator responses to spurious control room displays generally did not result in significant transients. Improved automatic transfer of control system input circuits to operable power supplies, automatic trip of feedwater pumps on loss of certain power supply branch circuits, and suppression of spurious alarms have been identified as possible ways to further limit the effects of transients induced by instrument power supply failures. A status review of the power supply failure alarms and applicable operating procedures was recommended to corroborate the adequacy of the information available to the control room operator following any power supply failure.

*Science Applications, Inc.

3.5.3 RELIABILITY OF EMERGENCY AC POWER SYSTEMS AT NUCLEAR POWER PLANTS

R. E. Battle D. J. Campbell*

(Abstract of NUREG/CR-2989, ORNL/TM-8545, July 1983; also paper presented at IEEE Power Conference, Los Angeles, May 18–22, 1983)

Reliability of emergency on-site ac power systems at nuclear power plants has been questioned within the Nuclear Regulatory Commission (NRC) because of the number of diesel generator failures reported by nuclear plant licensees and the reactor core damage that could result from diesel failure during an emergency. Because of these considerations, the NRC classified the loss of all ac power (station blackout) at a nuclear plant an unresolved safety issue. The NRC requested Oak Ridge National Laboratory (ORNL) to develop a technical basis to help resolve this issue. This report contains the results of a reliability analysis of the on-site ac power system, and it uses the results of a separate analysis of off-site power systems to calculate the expected frequency of station blackout.

Included is a design and operating experience review. Eighteen plants representative of typical on-site ac power systems and ten generic designs were selected to be modeled by fault trees. Operating experience data were collected from the NRC files and from nuclear plant licensee responses to a questionnaire sent out for this project. A total of 1526 events are categorized by failure type for 120 diesel generators, along with data on the number of starts, scheduled maintenance, and repair times for 86 diesel generators.

Important contributors to on-site power system reliability vary from plant to plant, but among the important contributors are the following:

1. diesel generator failure probability, for which the industry average is 2.5×10^{2} and the range is 8×10^{3} to 1×10^{-1},
2. human error and hardware failure common-cause failure, for which the unavailabilities range from 1×10^{-4} to 4.2×10^{-3},
3. scheduled maintenance unavailability during reactor operation for which the industry average is 6×10^{-3} and the range is 0 to 3.7×10^{-2},
4. diesel repair time, for which the average is 20 h and the range is 4 to 92 h,
5. plant service-water system unavailability, for which the independent failure probability is 2×10^{-3}, the common-cause failure probability is 8×10^{-5}, and the unavailability for scheduled maintenance is 2×10^{-3}.

For the 18 plants modeled, the median probabilities that the on-site power system will fail on demand vary from 2.2×10^{-4} to 4.8×10^{-2}. Sensitivity of the on-site system unreliability to contributors 1–3 listed above is analyzed, and costs of decreasing the probabilities of failure for those contributors are estimated. The important factors affecting on-site ac power system reliability are dependent upon plant-specific features. These features may be independent diesel failure, scheduled diesel downtime, service water unavailability, or common-cause failure of the diesels.

Independent failure of diesel generators is an important contributor to the probability of failure of an on-site ac power system, but significantly reducing the industry-average probability of independent diesel failure will be difficult because there is no single subsystem that dominates the failure probability. Common-cause failure probability may be reduced inexpensively by improving operating and maintenance procedures and eliminating some design features which have a common-cause failure potential. Plants which have two reactors and which require two-of-three diesels to cool both reactors after a loss of off-site power have the least reliable diesel configuration. By adding a diesel, such a plant could improve the on-site ac system reliability by a factor of 5 to 10. However, the approximate cost to add a 3000-kW diesel is \$20–\$30 million. The costs and reliability improvement for other, less expensive modifications are also included in this report.

*JBF Associates, Inc.

3.5.3.1 COLLECTION AND EVALUATION OF COMPLETE AND PARTIAL LOSSES OF OFF-SITE POWER AT NUCLEAR POWER PLANTS

R. E. Battle

(Executive Summary of NUREG/CR-3992, ORNL/TM-9384, in press)

The purpose of this report is to provide an accurate database for use by the NRC in the resolution of USI A-44—"Station Blackout." Events involving loss of off-site power that have occurred at nuclear power plants through 1983 are described and categorized as complete or partial losses. The events were studied in detail to understand their significance for further statistical analyses by the NRC staff.

Design features were evaluated to determine those that may be important factors affecting off-site power system reliability. The off-site power failures were identified as plant-centered or grid-related failures. Design features that would affect the frequency and duration of grid-related losses of off-site power (including severe weather) are the number of transmission lines and rights-of-way to the plant switchyard and the availability of generators such as hydro, gas turbines, or fossil units near the nuclear plant. Design features that may be important for plant-centered losses of off-site power are the independence of the sources of off-site power (electrically separate sources), the number of off-site sources, and the relay scheme for transferring between off-site sources. These design features were tabulated for most of the operating nuclear power plants. The tabulated information was provided to NRC for a statistical analysis to determine the importance of these design features for plant-centered losses of off-site power.

In addition, the causes of the failures were classified as weather, human error, design error, or hardware failure. The plant-centered failures were usually of shorter duration than the weather-related grid failures. For this reason, the weather-related events were reviewed in detail.

Tornados have caused the most extensive damage to off-site power systems, but they have caused only one complete loss of off-site power. Hurricanes have not caused extensive damage near a nuclear power plant that resulted in a complete loss of off-site power. Winter storms have caused losses of off-site power, but these storms have not caused extensive damage that resulted in extended duration of loss of off-site power. Wind-blown salt spray has contaminated switchyard insulators with salt and caused arcing across the insulators. The arcing caused some switchyard equipment to fail and made the off-site power intermittent. However, for these events, the off-site power did not fail completely, and it may have been usable in an emergency.

The frequency of losses of off-site power versus duration were estimated for three time periods. The frequency of loss of off-site power was estimated to be 0.09/reactor-year based on industry-wide data for the years 1959 through 1983.

3.5.4 INTEGRATED ASSESSMENT OF PRESSURIZED THERMAL SHOCK

R. C. Kryter

(Abstract of paper presented at Tenth Water Reactor Safety Research Information Meeting, Gaithersburg, Maryland, October 12–15, 1982)

The objectives of this research program are to (1) develop appropriate methodologies for assessing the likelihood of reactor pressure vessel failure as a result of sudden, inadvertent vessel overcooling in combination with high internal pressure (this combination of circumstances has been termed "pressurized thermal shock," abbreviated as PTS) and then (2) apply the resulting methodologies to three representative U.S. PWRs (manufactured by B&W, W, and CE) so as to obtain a balanced assessment, independent of similar studies performed by the NRC staff and industry owners' groups, of the total probability of vessel failure posed by a combination of all conceivable pathways leading to PTS in the plants selected for study.

In performing this work, we were directed by NRC to address, as a minimum, the following:

- specific initiating and subsequent causative events (overcooling accident scenarios), both operator- and equipment-induced
- likelihoods of occurrence for these postulated scenarios
- resulting consequences to the reactor vessel
- sensitivity of the results to key analysis assumptions, systems and operator performance, vessel material properties, and related data
- effectiveness of postulated corrective measures which might reduce the frequency of challenge to the vessel and/or increase its ability to withstand severe overcooling transients—including possible hardware and control systems modifications, additional operator training, and operator aids.

3.5.4.1 PRESSURIZED THERMAL SHOCK EVALUATION OF THE OCONEE-1 NUCLEAR POWER PLANT

T. J. Burns*
R. D. Cheverton† D. G. Ball‡
G. F. Flanagan* L. B. Lamonica**
J. D. White R. Olson‡

(Abstract of draft report NUREG/CR-3770, ORNL/TM-9176; also paper presented at ASME Pressure Vessel and Piping Conference, San Antonio, June 17–21, 1984)

An evaluation of the risk to the Oconee-1 nuclear plant due to pressurized thermal shock (PTS) has been completed by Oak Ridge National Laboratory (ORNL). This evaluation was part of a Nuclear Regulatory Commission (NRC) program designed to study the PTS risk to three nuclear plants: Oconee-1, a Babcock & Wilcox reactor plant owned and operated by Duke Power Company; Calvert Cliffs-1, a Combustion Engineering reactor plant owned and operated by Baltimore Gas and Electric Company; and H. B. Robinson-2, a Westinghouse reactor plant owned and operated by Carolina Power and Light Company. Studies of Calvert Cliffs-1 and H. B. Robinson-2 are still underway.

The specific objectives of the Oconee-1 study were to (1) provide a best estimate of the probability of a crack propagating through-the-wall (TWC) of the reactor pressure vessel due to PTS; (2) determine dominant accident sequences, plant features, operator and control actions, and uncertainty in the PTS risk; and (3) evaluate effectiveness of potential corrective measures. To perform the studies, ORNL constructed millions of hypothetical overcooling events using computer-generated event trees and then quantified the branch points. A screening frequency of 10^{-6} per reactor year was used to screen out those event tree branches (scenarios) whose frequencies were below that value. All of the remaining scenarios were considered explicitly. The scenarios which were screened out were included into a residual; their probability contributions were included in the study. Thermal-hydraulic analyses were performed on a few of the scenarios by Los Alamos National

Laboratory and Idaho National Engineering Laboratory and were reviewed by Brookhaven National Laboratory. For some transients, mixing calculations were performed by Professor T. Theofanous of Purdue University. Thermal-hydraulic consequences of all remaining transients (including as one group all those in the residual) were estimated by Science Applications, Inc. For all transients, probabilistic fracture mechanics calculations were performed by ORNL. The results of all these analyses were integrated by ORNL to predict the probability of TWC for Oconee-1.

The best estimate of the frequency of TWC at Oconee-1 due to PTS is 4.5×10^{-6}/reactor year. An uncertainty analysis performed by ORNL indicates that a factor of about 100 is an appropriate 95% confidence interval, assuming a log-normal uncertainty distribution. Steamline breaks were the most significant contributors to the risk of the types of sequences considered. Uncertainty in downcomer temperatures was the most important contributor to the overall uncertainty in the risk. The most important plant features which reduce PTS risk at Oconee-1 are (1) vent valves and (2) feedwater pump trips on high steam generator level. The most important operator action for negating PTS is isolating a steam generator during a steamline break.

Minimal systems interactions were considered in this study and no external events (fire, floods, seismic events) were considered.

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**Science Applications, Inc.

3.5.4.2 A STUDY OF PRESSURIZED THERMAL SHOCK BASED ON THREE OPERATING PWRs

J. D. White
T. J. Burns* G. F. Flanagan*
P. D. Cheverton† B. Lamonica‡

The U.S. Nuclear Regulatory Commission (NRC) instituted a program at ORNL in 1981 to deal with the subject of pressurized thermal shock (PTS). This action was brought about by the renewed interest of the nuclear community in the failure probability of a reactor pressure vessel (RPV) during overcooling transients. Radiation-induced reductions in the fracture toughness of RPV material containing high concentrations of copper and nickel make the RPV more susceptible to brittle fracture caused by high tensile stresses generated at the inner surface of the RPV during rapid cooling of the water in the reactor downcomer. These overcooling transients could be caused by several hypothetical transients such as uncontrolled main feedwater flow rates, overfill of steam generators, small-break loss-of-coolant accidents (LOCAs), or secondary-side depressurizations.

The possibility of vessel failure due to overcooling transients generated enough concern that the NRC designated the PTS problem an Unresolved Safety Issue, A-49. In December 1982, the NRC directed its staff to develop a notice of proposed rule making. Furthermore, the staff was to prepare guidance for plant-specific analyses and was to continue analytical and experimental programs to resolve A-49 on a high-priority basis. The ORNL PTS program was initiated to provide input to the NRC staff for their use in preparation of the proposed rulemaking.

The overall objectives of the PTS studies at ORNL are (1) to provide a best estimate of the probability of a crack propagating through the wall of a RPV due to pressurized thermal shock; (2) to determine the dominant accident sequences, plant features, operator and control actions, and the uncertainty in PTS risk; and (3) to evaluate the effectiveness of potential corrective measures. These PTS studies were to be plant specific. The plants studied are Oconee-1, a Babcock & Wilcox design owned and operated by Duke Power Company; Calvert Cliffs-1, a Combustion Engineering design owned and operated by Baltimore Gas & Electric Company; and H. B. Robinson-2, a Westinghouse design owned and operated by Carolina Power and Light Company.

Analysis of Oconee-1 is complete and the draft report has been issued for comment and is discussed here (see 3.5.4.1). Analyses of the other plants are nearing completion. The analyses consisted of

1. gathering plant data
2. building event-tree models and thermal-hydraulic models
3. quantifying frequencies of event-tree end states
4. predicting thermal-hydraulic responses of the plant to events
5. calculating through-the-wall-crack (TWC) probabilities of the events
6. integrating Steps 3 and 5 to produce an estimate of overall TWC frequency at Oconee-1 due to all events considered

7. performing sensitivity and uncertainty analyses on the results
8. evaluating potential corrective measures.

Several organizations participated in these studies in support of the ORNL work. Duke Power Company provided copies of Oconee-1 plant drawings, plant data, and operating procedures. Thermal-hydraulic models were built by Science Applications, Inc. (SAI), Idaho National Engineering Laboratory (INEL), Los Alamos National Laboratory (LANL), and Purdue University.

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*Engineering Physics and Mathematics Division.
†Engineering Technology Division.
‡Science Applications, Inc.

3.5.5 EVALUATION OF EVENTS INVOLVING UNPLANNED BORON DILUTIONS IN NUCLEAR POWER PLANTS

E. W. Hagen

(Abstract of NUREG/CR-2798, ORNL/NSIC-208, July 1982)

This report reviews and evaluates events concerned with the inadvertent dilution of boron concentrations to the reactor coolant system for pressurized-water-cooled thermal reactors in commercial service. The safety concern is the unplanned addition of reactivity. The information was collected from operating experiences, licensee event reports, system designs in safety analysis reports, and regulatory documents. The results are collated and analyzed for significance and impact on power plant safety performance.

Several operating experience events were selected for analysis because they meet the criteria for safety significance. However, no boron dilution incidents resulted in a reactivity excursion or transient that scrammed a unit, nor was a reactor protection system challenged by any of the events. The most common cause for unplanned boron dilutions was human error, of which one was a common-mode/common-cause failure. For each recorded event, the operator had sufficient time to diagnose and correct the cause of the inadvertent dilution before the shutdown safety margin was lost or seriously challenged.

3.5.6 COMPRESSED-AIR AND BACKUP NITROGEN SYSTEMS IN NUCLEAR POWER PLANTS

E. W. Hagen

(Abstract of NUREG/CR-2796, ORNL/NSIC-206, July 1982)

This report reviews and evaluates the performance of the compressed-air and pressurized-nitrogen gas systems in commercial nuclear power units. The information was collected from readily available operating procedures will not only result in substantial improvement in the performance and availability of the compressed-air (and backup nitrogen) systems but in improved overall plant performance.

Under certain circumstances, the "fail-safe" philosophy for a piece of equipment or subsystem of the compressed-air systems initiated a series of actions culminating in reactor transient or unit scram. However, based on this study of prevailing operating experiences, reclassifying the compressed gas systems to a higher safety level will neither prevent (nor mitigate) the recurrences of such happenings nor alleviate nuclear power plant problems caused by inadequate maintenance, operating procedures, and/or practices. Conversely, because most of the problems were derived from the sources listed previously, upgrading of both maintenance and operating procedures will not only result in substantial improvement in the performance and availability of the compressed-air (and backup nitrogen) systems but in improved overall plant performance.

3.5.7 EVALUATION OF INSTRUMENTATION FOR DETECTION OF INADEQUATE CORE COOLING IN BOILING WATER REACTORS

J. Lewin

(Abstract of NUREG/CR-3652, ORNL/TM-9029, April 1984)

Since the TMI-2 incident of March 1979, the attention of the U.S. Nuclear Regulatory Commission (NRC) and of the power reactor industry has been focused on the prevention of gradual and protracted overheating of reactor fuel cladding that

may be signaled ambiguously to the plant operators, thereby resulting in improper responses that may compound the seriousness of the event. The total issue has come to be known as "Approach to Inadequate Core Cooling," or simply "Inadequate Core Cooling" (ICC).

This report is a review of the ICC detection issue relative to boiling water reactors (BWRs) as it has been addressed by the NRC and the Boiling Water Reactor Owners Group (BWROG) and, in particular, the instrumentation that can be used to indicate an approach to ICC.

3.5.7.1 LOSS OF DHR AT BROWNS FERRY UNIT ONE—ACCIDENT SEQUENCE ANALYSIS

D. H. Cook* R. M. Harrington
S. R. Greene† S. A. Hodge†

(Abstract of NUREG/CR-2973, ORNL/TM-8532, May 1983; also paper presented at International Meeting on Light-Water Reactor Severe Accident Evaluation, Cambridge, Massachusetts, September 1, 1983)

This study describes the predicted response of Unit One at the Browns Ferry Nuclear Plant to a postulated loss of decay heat removal (DHR) capability following scram from full power with the power conversion system unavailable. In accident sequences without DHR capability, the residual heat removal (RHR) system functions of pressure suppression pool cooling and reactor vessel shutdown cooling are unavailable. Consequently, all decay heat energy is stored in the pressure suppression pool with a concomitant increase in pool temperature and primary containment pressure. With the assumption that DHR capability is not regained during the lengthy course of this accident sequence, the containment ultimately fails by overpressurization. Although unlikely, this catastrophic failure might lead to loss of the ability to inject cooling water into the reactor vessel, causing subsequent core uncovery and meltdown. The timing of these events and the effective mitigating actions that might be taken by the operator are discussed in this report.

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3.5.8 THE EFFECT OF SMALL-CAPACITY, HIGH-PRESSURE INJECTION SYSTEMS ON TQUV SEQUENCES AT BROWNS FERRY UNIT ONE

R. M. Harrington L. J. Ott*

(Abstract of NUREG/CR-3179, ORNL/TM-8635, September 1983)

The TQUV accident sequence [Transient-induced scram, Power Conversion System Unavailable, High Pressure (HPCI, RCIC) and Low Pressure (RHR, Core Spray) injection systems unavailable] has been shown to be among the dominant accident sequences in almost all BWR Probabilistic Risk Assessments (PRAs). This report provides an analysis of the ability of the Control Rod Drive (CRD) hydraulic system and the Standby Liquid Control (SLC) system, utilized singly or in combination, to adequately cool the reactor core during this accident sequence. The class of shutdowns considered consists of those initiated by a transient or a loss of off-site power in which there is a successful reactor scram and there is no pipe break. Various combinations of flow delivery capability and operator action are considered and an optimum procedure is recommended. A special version of the MARCH computer code is used to calculate core temperatures and estimate fuel damage for cases involving partial or full core uncovery. The results show that fuel damage can be avoided by appropriate operator action.

*Engineering Technology Division.

3.5.9 A REVIEW OF THE TREAT UPGRADE REACTOR SCRAM SYSTEM RELIABILITY ANALYSIS

D. F. Montague* H. E. Knee†
J. B. Fussell* J. J. Manning†
P. A. Krois† P. M. Haas†
T. C. Morelock K. W. West

(Abstract of ORNL/TM-9367, October 1984)

This review was conducted to assess the adequacy and accuracy of the TREAT upgrade reactor scram system (RSS) reliability analysis, identify potential problem areas, and make recommendations for resolving the potential problems. The review was divided into seven areas: reactor trip system (RTS)

design, data analysis, failure mode and effects analysis, (FMEA), independent failure analysis, common-cause failures (CCF) analysis, human reliability analysis (HRA), and dedicated microprocessor tester (DMT) reliability.

No major flaws in the RTS design were found; that is, it was concluded that the RTS is capable of performing its design function. Data used in the analysis are conservative and were taken from recognized and accepted sources. The study concurs with the Argonne National Laboratory (ANL) FMEA finding that no single-component failure will cause a RSS failure. Three additional potential CCF initiators were identified: grit, corrosion, and contaminants in the air and in the hydraulic systems. Assuming that ANL will analyze these initiators, the CCRA and IFA are acceptable. The information reported on the HRAs is limited, and the analysis incomplete. Provided ANL performs periodic independent testing of the DMT, the DMT is reliability acceptable. We believe the reliability of the RSS to be as high as can be reasonably achieved.

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3.5.10 LOOSE-PART MONITORING PROGRAMS AND RECENT OPERATIONAL EXPERIENCE IN SELECTED U.S. AND WESTERN EUROPEAN COMMERCIAL NUCLEAR POWER STATIONS

R. C. Kryter

(Abstract of NUREG/CR-3687, ORNL/TM-9107, April 1984)

Technical personnel at thirteen nuclear power stations (ten in the United States and three in Western Europe) were interviewed during the summer of 1983 to ascertain their collective experience with acoustic-based loose-part monitoring systems (LPMSs). Subjects receiving special attention were the number and location of sensors (accelerometers) required to reliably detect and locate loose parts in both pressurized and boiling water reactors; detection sensitivity to loose objects in both primary and secondary coolant loops; false alarm experience; calibration procedures; day-to-day monitoring system operation; premature failure of in-containment components of the LPMS caused by hostile environments; and overall success to date in detecting the presence of potentially damaging loose parts and in assessing their operational and safety implications. The individual utilities' responses to questions addressing these and other issues are provided, along with the author's summary and interpretation of what the information gathered means in a collective sense, that is, a viewpoint of the present state of application of loose-part monitoring technology in this selected set of commercial nuclear plants.

It is concluded that the technology of loose-part detection and assessment is moving slowly toward increased acceptance by the utility industry but, at the same time, the full potential benefits of loose-part monitoring systems are not presently being realized and, furthermore, probably will not be unless actions are taken in four recommended areas.

3.5.11 ENGINEERING REVIEW OF THE CRBRP

H. A. Bishop C. L. Rose
T. C. Morelock K. W. West

Our engineering review of the instrumentation and controls for the Clinch River Breeder Reactor Project ended in October 1983. During the preceding 24 months, the review group received 5,755 instruments and controls and electrical drawings covering 14 balance-of-plant systems and 17 nuclear island systems. The engineering drawings, composed of process and instrument diagrams, control logic diagrams, and elementary diagrams, were reviewed to ascertain that (1) the correct information, logic, and data were consistantly contained throughout all the drawings, and (2) the engineered systems could be expected to function as intended in the System Design Descriptions. In executing this review, all appropriate codes, standards, and regulations were applied.

More than 400 pages of comments contained in 26 documents were transmitted to the CRBR Project Office. A total of 1632 drawings were identified as showing some clerical error, design deficiency, lack of adequate information, or some questionable area requiring further clarification. The drawing correction turaround time with the architect-engineer and the vendors was about four months.

A database management system was established to record transactions occurring on the drawings. This database and associated program is stored on magnetic tape in I&C along with the system design descriptions, instrument specifications, and regulations.

3.6 Thermometry

3.6.1 FIBER OPTIC THERMOMETER FOR HIGH-VOLTAGE APPLICATIONS

R. J. Fox J. A. Williams

Optical fibers are inherently immune to electric and magnetic fields and can be designed to have large temperature coefficients. It appeared feasible, therefore, to produce a distributed line hot-spot sensor for possible use in electric power generation equipment.

A fiber consisting of, for example, silica cladding and a liquid #702 silicone core, forms an efficient light guide and has the required negative temperature coefficient. This temperature dependence is due primarily to the large thermal expansion coefficient of the silicone core material, which determines its thermal coefficient of refraction, dn/dt. As a result, the maximum acceptance angle of the fiber is significantly reduced at elevated temperatures.

Hot-spot sensing is achieved by launching a narrow laser beam into the end of the fiber at a controlled angle to the fiber axis. If the launch angle is small, the light is completely confined to the core by total internal reflections, and none of it propagates in the silica cladding. However, if the launch angle is increased beyond the maximum acceptance angle of the fiber, guidance is lost and light escapes to the cladding where it is readily detected. Such loss of guidance occurs first at the hottest point along the fiber where the refractive index of the core is at its minimum. Thus, measurement of the launch angle corresponding to the onset of cladding light permits the determination of the peak fiber temperature.

The optical response of a 1-mm-diam fiber sensor 80 cm long was compared at several temperatures with a calibrated type K thermocouple in intimate contact with the fiber. At each temperature, the corresponding refractive index of the core, n_c was determined from[1]

$$n_c = (1.457^2 + \sin^2\theta_0)^{½}$$

where θ_0 is the launch angle at the onset of cladding light. Then, using a six-parameter fit of n_c versus T, the fiber temperature was calculated.

Measurements were made at 14 temperatures between ambient and 167°C. The standard deviation of the errors in fiber temperature was 0.23°C, with a maximum error of 0.3°C.

The foregoing measurements used a hermetically sealed fiber sensor with self-contained optically flat entrance and exit windows, an entrance aperture stop, an expansion diaphragm and a protective teflon jacket.

1. R. J. Fox, *Applied Optics* 22 (7), 967–69 (1983).

3.6.1.1 MEASUREMENT OF PEAK TEMPERATURE ALONG AN OPTICAL FIBER

Richard J. Fox

[Abstract of *Applied Optics* 22(7), 967–69 (1983)]

The inherent immunity of optical fibers to interference from electric and magnetic fields has spurred the investigation of fiber-optic sensors to aid in monitoring the operating parameters of electric-power-generation equipment. Fibers are particularly attractive for the measurement of discrete hot spots in large high-voltage transformers, where high electric fields preclude the use of metallic lead wires to join remote readout equipment to thermocouples or thermistor sensors. There is the further possibility of determining remotely the maximum temperature attained at any point along the fiber's length [i.e., a distributed (line) sensor]. Realization of such a device could significantly reduce the required number of sensors and transformer containment penetrations.

Several possible configurations for line sensors have been discussed by Gottlieb et al.[1] A common limitation of the proposed designs is an inability to distinguish between a long warm region and a short hot spot. The following concept addresses this problem.

1. M. Gottlieb, G. B. Brandt, and J. Butler, *ISA Trans.* 19(4), 55 (1980).

3.6.2 QUALIFICATION OF INCONEL-SHEATHED TYPE K THERMOCOUPLES

R. M. Carroll   R. L. Shepard

Inconel-sheathed type K thermocouples were requested by the Westinghouse Steam Generator Division for the Clinch River Breeder Reactor Plant (CRBRP) and by United Nuclear Company for the Hanford N Reactor to avoid the sheath cracking from stress corrosion experienced with stainless steel Type 304 sheaths. Anderson et al., reported[1] that the high-temperature drift rate for Inconel-600-sheathed Type K thermocouples was 1/3 to 1/5 that of stainless steel Type 304-sheathed thermocouples. Inconel-sheathed thermocouples are not specified by either NE(RDT) standard C7-6T nor ASTM standard E-235, nor are they procured under the ORNL program for large-scale procurement of temperature sensors (LSPTS).

Several manufacturers had sufficient Inconel-600-sheathed thermocouples in their inventory to meet the needs of the requestors. The thermocouple material was made to commercial standards, and we were asked (1) to evaluate the existing material and recommend which, if any, manufacturer's stock would meet the requirements; (2) to examine the standards used for evaluation and judge whether they were pertinant or sufficient; and (3) to evaluate the manufacturers with the aim of incorporating Inconel-600-sheathed thermocouple material into the LSPTS Program.

Commercial Inconel-600-sheathed stock 1.6 and 3.2 mm in diameter from four different manufacturers was evaluated using standards RDT C7-6T and ASTM E-235 as guides. We also applied some additional tests (indicated by *) to further evaluate the material and to support the eventual incorporation of the tests in the standards.

1. *Sheath Defects Test:* Liquid penetrant measurements were used. One manufacturer's material was disqualified. We found that cold-lap defects not detected by liquid penetrant could be detected by a sheath tensile test (4).

2. *Sheath Diameter Test:* All materials met the requirements.

3. *Sheath Wall Thickness Test:* Two lots did not meet RDT C7-C6 standards, but all passed ASTM E-235.

4. *Sheath Tensile Test:** This test evaluates sheath ductility and strength. Specifications for Inconel 600 allow a range of composition which affects properties. For example, six different thermocouple lots from the same manufacturer were tested, one of which had a 50% lower ductility and ruptured with 21% less stress than the other five lots.

5. *Sheath Grain Size Test:* One manufacturer's sheath material had significantly smaller gains than the others, a desirable characteristic.

6. *Insulation Purity Test:** MgO insulation extracted from the finished thermocouple stock was analyzed for carbon and sulfur content. Two manufacturers had five times more carbon and two to three times more sulfur in the insulation than the others.

7. *Insulation Resistance, Room Temperature Test:* One vendor's material failed, apparently because faulty sheath closures allowed moisture to penetrate the sheath.

8. *Insulation Resistance, 1000°C Test:* None of the vendors passed this test. It is our opinion that this test is ill-defined. We found that material purchased to LSPTS standards also could not pass the test.

9. *Wire Size Test:* One manufacturer had smaller wires than required by existing thermocouple standards.

10. *Wire Uniformity Test:** Wire uniformity was evaluated by measuring thermocouple loop resistance during sheath tensile tests. No vendor materials showed neckdown before at least 12% sheath elongation.

11. *Wire Grain Size Test:** Material from one manufacturer had significantly larger grains in the wires than material from the other manufacturers, an undesirable characteristic.

12. *Temperature Calibration Test:* Only one vendor met the calibration requirements up to 870°C.

13. *Short-term Drift Test:* This test required that thermocouples not drift more than 1.5°C in 2 h at 1000°C; all thermocouples passed.

From these tests we concluded that none of the available commercial Inconel-600-sheathed stock met all standards for nuclear-grade material. However, for the limited temperature range in which the thermocouples would be used, one vendor's was suitable.

We recommend that the Inconel-600-sheathed thermocouple material be included in the LSPTS program. Any of the four manufacturers could produce Inconel-600-sheathed Type K thermocouple material if these test requirements were imposed and they produced the material with the same care they employ in manufacture of stainless-steel sheathed thermocouples to meet the NE(RDT) standard.

1. R. L. Anderson, J. D. Lyons, T. G. Kollie, W. H. Christie, L. R. Eby, "Decalibration of Sheathed Thermocouples," *Temperature*, Vol. 5, Part 2, pp. 977–1007, American Institute of Physics (1982).

3.6.3 IN SITU CALIBRATION OF NUCLEAR PLANT PLATINUM RESISTANCE THERMOMETERS USING JOHNSON NOISE

T. V. Blalock
M. J. Roberts R. L. Shepard

Johnson noise power measuring techniques have been used to calibrate platinum resistance thermometers (PRTs) installed in an operating nuclear plant, achieving agreement with the dc calibration of more than 0.1% or 0.5°F at the normal operating temperature of 585°F. In this application, PRTs with an ice-point resistance of 200 Ω were connected to a test station with four-wire cables approximately 100 ft long. Methods were developed for in situ cable characterization and quantitative measurement of and correction for nonthermal induced noise.

Problem Statement. Operating light water reactor nuclear plants require an accuracy of 0.2 to 0.65% in the temperature measurements made by wide-range PRTs installed at the inlets and outlets of the vessel or the steam generator. After several years operation, these PRTs may drift by as much as 1%. Removal and recalibration of the PRTs in the laboratory is undesirable, since their reinstallation may adversely affect their response time or lead to wiring errors. An in situ method for calibration of PRTs that does not assume isothermal conditions, does provide an absolute temperature standard, does not require any modification of the sensor or its cabling, and would significantly improve the operation of existing nuclear reactor plants.

Measurement Method. The Johnson noise power thermometer developed at ORNL can be used to determine independently the absolute temperature and the electrical resistance of any resistor (including a PRT) from measurements of the noise voltage and noise current at the accessible terminals of the device. These measurements are made at microvolt and nanoamp levels in a passband centered at 47 kHz. Major problems in implementing this method under field conditions are (1) determining the effects of long cables connecting the PRT to accessible terminals and (2) distinguishing between thermal (Nyquist) noise and nonthermal (EMI) noise picked up in the cables and sensor. Methods were developed for (1) determining the cable transfer function from impedance measurements made at the input of the extension cables and for (2) quantitative measurement of the induced EMI using the Johnson noise measurement apparatus connected between the sensor leads and the cable shield. Additional measurements, using noise, were required to determine the noise contributed by the amplifiers, the effects of long cables and varying resistive loads on the amplifier noise, and the gain of the amplifiers. The gain was determined using a high-level noise source developed at ORNL.

Plant Tests Previously Performed. Field calibrations of resistance thermometers installed in the Diablo Canyon Nuclear plant under hot-functional conditions were conducted in 1979 under EPRI Contract RP 1440-1. These tests made on PRTs with short (20-ft) cables provided closer than 0.3% agreement between noise temperatures and dc calibrations. Noise measurements were made in three different passbands to differentiate between thermal and nonthermal noise. Microphonics were detected in one type of PRT, and a difference between dc resistance and noise resistance of about 5% was observed and attributed to skin effect or inductance. Attempts to calibrate PRTs with extension cables longer than about 30 ft were unsuccessful, and this was felt at that time to be an insurmountable practical constraint.

Noise Transfer Characteristics of Long Cables. The present contract focused on methods for determining the transfer characteristics of long (greater than 30-ft) extension cables connecting the PRT to a remote junction box by measurements made only at the accessible terminals. Two methods were developed. One, the similitude method, required a measurement of the effective length of the installed cable, using dc resistance, time domain reflectometry, or input capacitance, and relating the characteristics of the installed cable to characteristics of similar cables of various lengths measured in the laboratory. This approach has the virtue of measuring cable properties at the signal levels and in the frequency passband used in the calibration of the PRTs; it has the limitation imposed by the assumption that the installed cable properties are identical to the archive cable characteristics. The second method used input impedance measurements (phase and magnitude) made directly on the installed cable which were related to a two- or three-wire model of the transmission line to calculate the transmission function for the cable. Measurements were made at many frequencies covering the passband used in the noise measurements. This method requires no assumptions about the similarity between installed and archive cable.

Measurements of cable transfer characteristics made in the laboratory and used in the plant showed that, for PRTs with an ice-point resistance of 200 Ω (which increased to more than 400 Ω at plant operating temperatures) and four-wire, shielded cables of about 70 pF/ft capacitance, cable transfer functions could be obtained for cables of about 100 ft in length with an accuracy of about 0.1%. For longer cable lengths which could be characterized by this method, the noise signals to the input of the noise-measuring amplifiers would be attenuated so much that at 150 ft, the input signals were comparable to the amplifier noise and the calibration uncertainty would exceed several percent.

Measurement Uncertainties. The uncertainty in the Johnson noise calibration of installed PRTs is determined by the stochastic uncertainty in the noise measurements of the sensor signal and the amplifier noise and gain, the characterization of the cable transfer function, and the detection of nonthermal noise in the amplifier output. The stochastic uncertainty is given by the Rice equation: $\epsilon S/S = (4BW \cdot t_i)^{-1/2}$, where BW is the band width of the amplifiers and t_i is the integration time. For the bandwidth used in these measurements (about 62 kHz) and 100 s integration time, the limiting stochastic uncertainty is 0.020% for each measurement. Since several measurements are made to determine the noise temperature, the limiting uncertainty in noise temperature for a zero-length cable is 0.028% assuming that the amplifier gain is known, or 0.040% if the amplifier gain is measured each time. For a 100-ft cable terminated by a PRT of 400 Ω at 270°C (520°F), an uncertainty in cable length of 1% introduces a temperature uncertainty of 0.83% in the similitude method. The cable length uncertainty effect is reduced to 0.12% uncertainty in temperature if the length is reduced to 75 ft and the sensor resistance is halved. Nonthermal EMI was quantitatively determined, at a level of less than 1% of the thermal noise from the PRT by measuring the noise between the sensor circuit and the cable shield and using the measured values to correct the amplifier output signal.

Plant Tests under the Present Contract. Three field tests of these methods were conducted at the Connecticut Yankee Haddam Neck Nuclear Plant (CYAP): two at shutdown in February 1983 and July 1984, and one at full power in December 1983. CYAP provided an accessible terminal box connected to five PRTs in Loop 4 by extension cables about 100 ft long, archive cables of various lengths, several spare PRTs, dc calibrations for the plant PRTs, and technical support for the field tests. The plant temperatures were held steady to within 1°F during the tests. Three of the PRTs were equipped with padder and trimmer resistors and could not be calibrated by these methods; two were four-wire PRTs without padders and trimmers. Lengths of the installed cables were measured by several electrical methods but are uncertain by 0.5 ft. Using the similitude method of determining cable transfer function, the resulting best agreement between noise temperatures and dc calibration temperatures was 0.72% (7.5°F) uncorrected for EMI and 0.45% (4.7°F) corrected for EMI at the operating temperature (585°F) and 0.1% at shutdown (113°F). The uncertainty in the similitude method is 0.4%. Using direct impedance measurements to characterize the installed cable and then to correct the amplifier input signal for the actual noise generated by the PRT, the best agreement between noise and temperatures was 0.04% or 0.43°F at a normal operating temperature of 585°F, and 0.16% or 0.94°F at shutdown. These results are well within the calculated overall measurement uncertainty of 0.2% rms, using direct measurement of the cable transfer function.

Conclusion and Assessment. Methods have been demonstrated in operating nuclear plants for the in situ calibration of resistance thermometers, with agreement between measured noise temperatures and dc calibration temperatures well within these required by the plant. The methods use Johnson noise measurements and provide an absolute calibration independent of the prior dc calibration. The methods include techniques for characterization of the installed extension cables and the quantitative determination of induced EMI and its effect on the calibration. The techniques are applicable to ordinary four-wire platinum resistance thermometers operating over their entire design temperature range and to extension cables of about 100 ft length. Careful attention needs to be paid to the choice of cables, location of terminal boxes, and grounding and shielding practices in the plant installation to achieve comparable results.

3.6.3.1 APPLICATION OF JOHNSON NOISE THERMOMETRY TO THE CALIBRATION OF PLATINUM RESISTANCE THERMOMETERS IN NUCLEAR POWER PLANTS

T. V. Blalock

(Abstract of paper presented at WATTec Energy Conference, Knoxville, February 21–24, 1984)

A Johnson noise power thermometer (JNPT) has been developed and applied to the in situ calibration of platinum resistance thermometers in nuclear power plants. The JNPT measured the open-circuit noise voltage and the short-circuit noise current from a sensing resistor. These data were used to calculate the absolute temperature and the resistance of the resistor. The measurement uncertainty in temperature and resistance is less than ±0.5% (99% confidence) for sensing resistors from 50 to 300 Ω over a temperature range from 273 to 1000 K, using signal cables as long as 18 m. Work is continuing using signal cables up to about 50 m in length. The errors due to signal cable parameters were corrected by employing computer algorithms based on either lumped-element or distributed-parameter models.

3.6.3.2 IN SITU CALIBRATION OF NUCLEAR PLANT PLATINUM RESISTANCE THERMOMETERS USING JOHNSON NOISE METHODS

T. V. Blalock **D. C. Agouridis**
R. L. Shepard **J. L. Horton**

(Abstract of Electric Power Research Institute Report EPRI NP-3113, June 1983)

Methods for in situ calibration of reactor plant platinum resistance thermometers using Johnson noise measurements were tested in the laboratory and in two operating reactors: Diablo Canyon and Sequoyah. The Johnson noise methods provide an absolute measurement of the thermometer temperature and can be compared with the dc calibration of the thermometers to confirm their calibration without removing the thermometers from the plant coolant loops. Inaccuracies of less than 0.1% were obtained with these methods for ideal situations where the noise measuring equipment could be connected directly to the installed thermometer terminals. For measurements made at the ends of long extension cables, inaccuracies were 0.5–1%, at best. Extension cables must be optimized and well characterized electrically to achieve such accuracies. Other factors that affect the accuracy of these methods were evaluated: electromagnetic interference induced in thermometers and cables, microphonic noise induced in the sensor by flow or mechanically induced vibration, and increased sensor resistance at high frequencies due to skin effects. Measurement methods and thermometer designs to minimize these effects were investigated. Calculational algorithms for noise thermometers with long cables were derived.

3.6.4 THE EFFECTS OF TEMPERATURE ON THE RESPONSE TIME OF THERMOCOUPLES AND RESISTANCE THERMOMETERS

R. M. Carroll **R. L. Shepard**

The response times of sheathed thermocouples and platinum resistance thermometers, both bare and in thermowells, were measured at temperatures up to 650°C using plunge tests and an in situ loop-current step-response (LCSR) measurement technique.[1,2] Both methods of measurement agreed over a wide range of sensor sizes and response times, verifying the LCSR method. The response times were temperature dependent. The magnitude and direction of the temperature dependence of response time varies from sensor to sensor. The response time of a sensor is defined as the time required to respond 63.2% of a step change of temperature imposed on the sensor's outer surface.

It is well known that many factors, including installation, fluid type, temperature, and velocity will have a drastic effect on the response time of the sensor by affecting the surface heat transfer. It is not so often recognized that process temperature will affect sensor response time because the sensor itself has temperature-dependent heat transfer properties.

Thermocouple Temperature Dependence. Loop-current step-response (LCSR) tests[1] were made on thermocouples in a circulating sodium loop at various temperatures. An increasing temperature made the response longer. Typical results are shown in Fig. 3.6-1.

A plot of response time versus temperature is shown in Fig. 3.6-2. The upper curve shows the

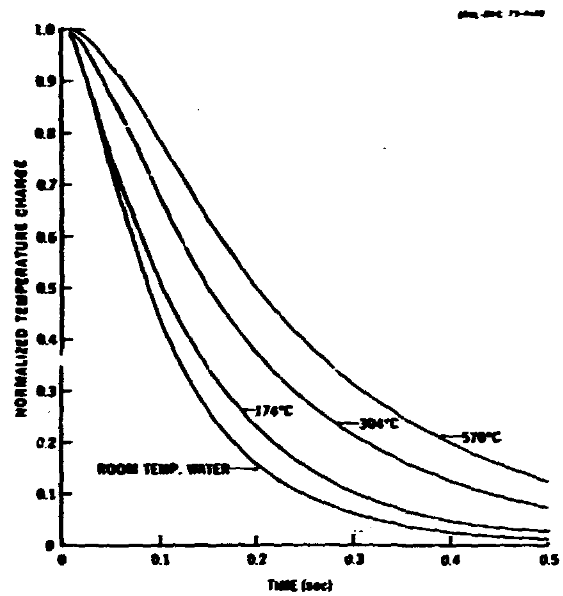

Fig. 3.6-1. The response to a step change of temperature from LCSR tests for different temperatures in sodium. The response in stirred water at room temperature is given for comparison.

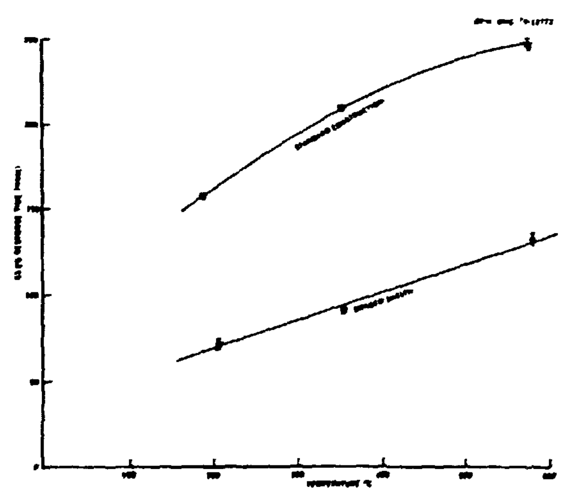

Fig. 3.6-2. The response time of a stainless-steel-sheathed, MgO-insulated type K thermocouple becomes longer as temperature increases both before and after the sheath diameter was reduced by swaging from 1.6 mm to 1.48 mm.

typical increased response time at higher temperatures. The thermocouple was removed from the sodium loop, and the sheath was swaged to a smaller diameter at the junction region. The swaging made the response time shorter, as shown in the lower curve of Fig. 3.6-2, but did not much affect the temperature dependence of the response.

Thermocouples in Thermowells. When a thermocouple is installed in a thermowell, the added heat capacity and longer thermal conduction path make the response time longer. A schematic drawing of a thermocouple in a thermowell is shown in Fig. 3.6-3. The overall heat conduction between the thermocouple wire and the coolant is greatly affected by the loose contact between the thermocouple sheath and the thermowell wall and material that fills the annulus.

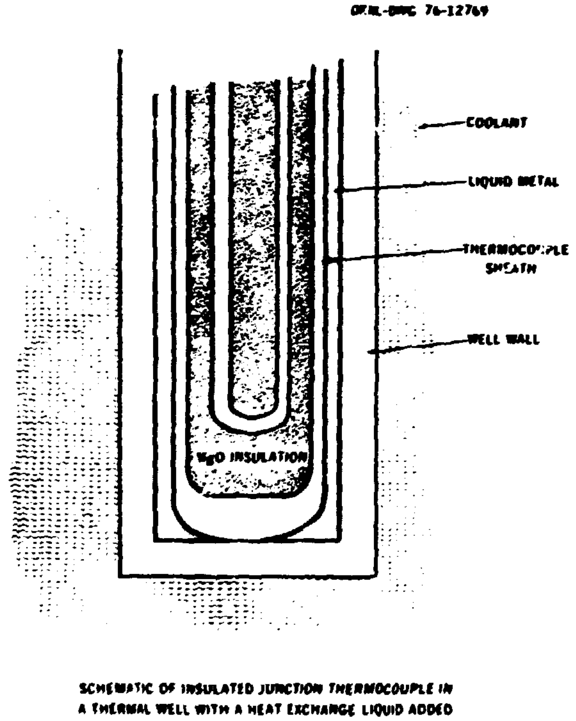

Fig. 3.6-3. Schematic diagram of insulated junction thermocouple in a thermowell with a heat exchange liquid added.

A test was performed in sodium with a thermowell containing a thermocouple fitted so that different gases could be used to fill the annulus. Figure 3.6-4 shows the effects of temperature and annulus fill material on the measured response time of the thermocouple-thermowell assembly. The response time became shorter with increasing temperature for the gas fills due to the increased thermal conductivity of gases at higher temperatures. With liquid metal (GIT—62.5% gallium + 21.5% indium + 16% tin) in the annulus, the response time increased slightly as the temperature increased, as shown in Fig. 3.6-4.

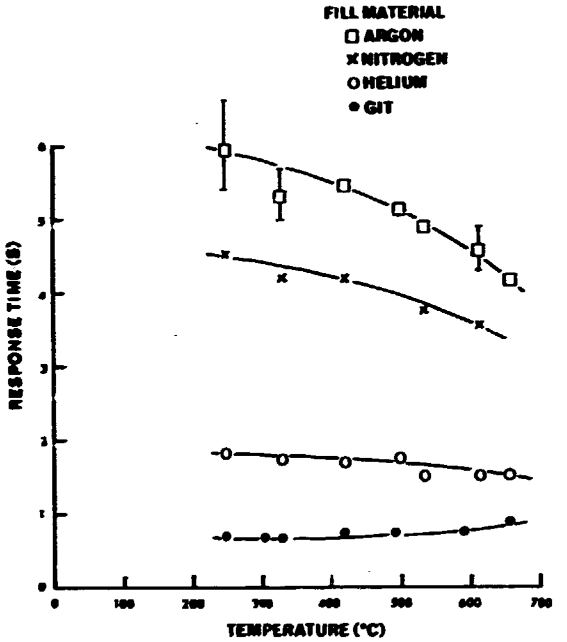

Fig. 3.6-4. The response time of a thermocouple in a thermowell depends somewhat on the temperature but mainly on the annulus fill material.

Platinum Resistance Thermometer Response-Time Temperature Dependence. The response time of a platinum resistance thermometer (PRT) in a thermowell was measured with air and Never-Seez* in the annulus, and the response times are shown in Fig. 3.6-5. The erratic changes of response time with air in the annulus illustrate the strong effects of variable contact between the PRT and the thermowell. When the annulus was filled with Never-

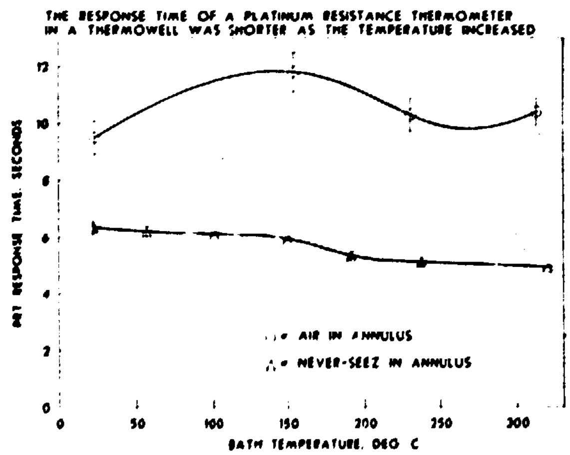

Fig. 3.6-5. Decrease in response time of a platinum resistance thermometer as temperature increases.

Seez to act as a heat transfer medium, the irregular contact problem was solved and the response time was a predictable function of temperature.

Conclusions. The response times of both thermocouples and platinum resistance thermometers depend on temperature. The changes in time constant, τ, with temperature range from about a factor of 2 (for sheathed thermocouples directly immersed in liquid metal over a 600°C temperature range) to about 10% (for PTRs in thermowells over a 300°C temperature range).

*Trademark name of Never-Seez Compound Corporation.

1. R. M. Carroll and R. L. Shepard, "Measurement of the Transient Response of Thermocouples and Resistance Thermometers Using an In-Situ Method," ORNL/TM-4573, June 1977.

2. T. W. Kerlin et al., "In-Situ Response Time Testing of Platinum Resistance Thermocouples," *ISA Trans.* 17(4), 71 (1978).

3.6.5 ESTIMATION OF TEMPERATURE SENSOR RESPONSE USING TESTS IN FLOWING WATER

T. W. Kerlin*
R. K. Chohan*   R. L. Shepard

Tests were performed at the University of Tennessee[1] to evaluate methods for predicting the time response of temperature sensors in various fluids flowing at various velocities from laboratory measurements of response time measured in flowing water and from fluid hydraulic properties of the various liquids. Tests were performed on five thermometers (both resistance thermometers and thermocouples) with outer sheath diameters ranging from 3.05 to 6.35 mm in five fluids—water, heptane, ethylene glycol, carbon tetrachloride, and engine oil. Measurements of thermometer response time were made in both a closed-loop pumped system and a rotating tub.

Results of response time testing were used to evaluate the constants in the general equation:

$$\tau = C_1 + C_2/h \qquad (1)$$

where the time constant τ is related to the surface heat transfer coefficient h for a particular fluid by two constants: C_1, the internal component of the thermometer's response time, and C_2, the external surface component. The surface heat transfer constant, h, is determined by the properties of a given fluid and its flow velocity, U, by the relationship:

$$h = bU^a \quad (2)$$

where a is a constant with a value of 0.5–0.6.

Equation (1) may then be rewritten as

$$\tau = C_1 + C_3 U^{-0.6} \quad (3)$$

Equation (3) predicts that the time constants of a given thermometer measured in different fluids at various velocities will show linear relationships with $U^{-0.6}$, intercept the ordinate at a single value C_1 that is determined only by the sensor construction and properties, and vary from fluid to fluid by changes in C_3, which may be calculated from known physical properties of the fluids. If this relationship (Eq. 3) is verified, time response measurements may be made on a sensor in water flowing at several different velocities and the response time in other liquids may then be calculated.

The five liquids were chosen to provide a range of fluid factors, F, which is a function of the fluid density, specific heat, thermal conductivity, and viscosity, ranging from 41 for engine oil to 1121 for water. Discrepancies were observed between measurements made in the pumped loop and the rotating tub at low flow velocities. While the results show a characteristicly linear behavior with U^{-a}, the values for the intercepts (C_1) vary for a given sensor by from 8 to 36%, with the data for engine oil departing more than the data for the other fluids. The general methodology appears to be valid, but questions about its application to sensors that do not show first-order response times, the validity of the fluid correlations for obtaining appropriate values for a and h, and the flow conditions in the loop and the tub have not been resolved. Additional experiments are planned for measuring the time response of thermometers in flowing air and steam.

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*The University of Tennessee, Knoxville.

†Conducted by the University of Tennessee, Knoxville, under subcontract to Martin Marietta Energy Systems, Inc.

3.6.5.1 SURFACE HEAT TRANSFER IN A STIRRED BOILING WATER BATH

R. M. Carroll R. L. Shepard

(Abstract of ORNL/TM-8522, November 1982)

A platinum resistance thermometer element was used to measure both temperature and heat transfer conditions in a stirred boiling water bath. The average heat transfer rate was affected strongly by stirring but only slightly by the boiling rate. For both room temperature stirred baths and stirred boiling baths, there were fluctuations about the mean heat transfer rate. The magnitude of the fluctuations increased with stirring rate and the fluctuations had periods of 1 to 2 s. It is concluded that stirred water baths, whether boiling or room temperature, are not reproducible heat transfer systems and thus measurements of the thermal response time of temperature sensors in the baths will contain errors unless the heat transfer rate of the bath is measured during the response tests.

3.7 Reactor Maintenance

3.7.1 MAINTENANCE ACTIVITIES OF THE I&C FACILITIES SUPPORT GROUP

K. W. West
D. S. Asquith J. A. Ray
J. M. Farmer J. N. Smith

The Facilities Support Group provided engineering and technical support to the Instrumentation and Controls Division technicians in maintaining six operating reactors, their associated experiments, and the Critical Experiments Facility. A computer database was established and appropriate programs were developed for maintaining current status and historical data on some 1500 reactor controls drawings and some 460 design changes. This group also provided instructions and training for the qualification of reactor controls instrument technicians. Maintenance activities carried out at the reactor facilities are described in the following paragraphs.

Maintenance of the Bulk Shielding Reactor and the Pool Critical Assembly. During this reporting period, the BSR operated on a very limited basis for the irradiation of research samples, design measurements for future use as a National Low-Temperature Neutron Irradiation Facility, and for limited training of ORNL Operations Division personnel and nuclear engineering students. The PCA was also operated for similar types of training. Both reactors were inoperative for an extended period for cleaning and application of a fiberglass coating to the pool walls and bottoms.

Reactor instrument surveillance testing and calibration was performed on a regular schedule when the facility was available for operation. Unscheduled maintenance activities centered on the counting, servo, and log-N channels.

Four Reactor Design Change memoranda were implemented for these reactors during this reporting period.

Maintenance of the Oak Ridge Research Reactor. The ORR was available for operation 84% of the time during this reporting period. Although ten unscheduled instrument failures caused shutdowns, they accounted for only a small fraction of total downtime.

The ORNL-designed dual ionization chambers in the ORR have been in use for many years and are beginning to fail. A program was therefore begun to convert to commercially available ionization chambers for safety and control channels. It has been necessary to redesign the ionization chamber mounting and positioning mechanisms due to the geometry of the commercial ionization chambers.

Reactor instrument surveillance testing and calibration has been performed on a regular schedule. Programmed maintenance activities were performed as scheduled by the computerized I&C Maintenance Information System (MAINS).

Reactor nuclear and process instrument maintenance procedures have been revised and updated. These procedures and associated check sheets have been approved and are now in use.

Six Reactor Design Change Memoranda were implemented during the period covered by this report. These changes have provided for improved reactor operation and upgraded reactor instrumentation.

Maintenance of the High-Flux Isotope Reactor. Maintenance activities at the HFIR have continued essentially as during the previous reporting period. Approximately 90% of the programmed maintenance was performed online while the reactor was operating. The 10% of maintenance requiring reactor shutdown generally involved single-channel systems essential for reactor operation or instruments in areas of high radiation.

The more critical instruments were reviewed for possible component obsolescence. As a result, the wide-range counting channel preamplifier was redesigned, and an improved integrated circuit multiplier for use in the neutron flux signal conditioner was approved as a replacement. Use of a newer, internally trimmed multiplier integrated circuit (IC) eliminated the need for seven circuit resistors, which in the past had to be individually selected for each of the original ICs. (This reduced replacement time for this component from several hours to a few minutes.)

During the past two years, unscheduled reactor shutdowns occurred nine times during routine online testing of the safety channels when the second of three channels in the two-of-three coincidence was tripped, apparently caused by induced electrical noise in the second safety channel. These instrument-related shutdowns accounted for 56.2 h of a total of 399.6 h of unscheduled reactor shutdowns from all causes.

Three Reactor Design Change Memoranda were processed during this period. These changes reflected removal of unused circuits and wiring, replacement of obsolete components, and revision of a portion of the primary coolant conductivity control system.

Maintenance of the Health Physics Research Reactor. The instrumentation and controls system for the HPRR performed satisfactorily. During this reporting period, no reactor shutdowns were attributed to instrument failure. Routine maintenance was performed on various instruments and systems as needed, and reactor instrument surveillance testing and calibration has been performed on a regular schedule.

One Reactor Design Change Memorandum was implemented during the period covered by this report. This change has resulted in the upgrading of the reactor startup channels.

Maintenance of the Tower Shield Reactor. Performance of the TSR-II reactor instrumentation and control systems has been satisfactory during this reporting period. The reactor has been operated on a limited basis for radiation-shielding studies and for instrumentation integrity tests. Continued assistance was provided to maintain instrumentation for various experiments.

Instrumentation and Controls Division personnel provided considerable assistance to Operations Division personnel during the removal of the No.5 shim safety plate, the installation of a blank aluminum plate in this position, and the checkout of the completed modification. The necessary instrumentation changes were implemented to reflect the modification. Routine maintenance was performed on various instruments and systems as needed, and reactor surveillance testing and calibration has been performed on a regular schedule.

The Tower Shielding Facility has been utilized for the Cask Drop Testing Program, which rendered the reactor inoperable for periods of time. Two Reactor Design Change Memorada were implemented during the periods covered by this report. These changes have provided for improved reactor operation and upgraded reactor instrumentation.

Maintenance of the Critical Experiments Facility. The Facilities Support Group assumed responsibility for routine maintenance of the CEF during this reporting period. Activities thus far have consisted primarily of training in the instrumentation and control systems of the facility, followed by participation in two system checkouts prior to operation.

3.8 Special Projects

3.8.1 DEMONSTRATION OF EXPERT SYSTEMS IN AUTOMATED MONITORING

P. J. Otaduy J. D. Allen, Jr.

The Reactor Systems Section of the I&C Division has been developing expertise in the application of artificial intelligence tools and techniques to control complex systems. A list of areas of interest for new techniques relevant to nuclear reactor operations is shown in Table 3.8-1. A summary of hardware and software now available at the I&C Division for the development of AI applications is shown in Table 3.8-2.

One of the applications developed demonstrates the capabilities of a rule-based expert system to monitor a nuclear reactor. A unique hybrid computing facility consisting of two AD-4 analog computers and a DEC-10 digital computer has been used to develop this application. In this hybrid facility, MacLisp primitives developed at I&C permit full interaction between two simultaneously occurring processes; for example, an expert system running in the digital computer can interact with the environment that uses its expertise simulated in the analog computer.

Table 3.8-1. Areas of interest for the application of artificial intelligence to reactor operations

- Capture of human expertise and its embodiment in control structures
- Interpretation and validation of signals
- Dynamic management of signal and alarm flow to the human operator
- Timely recognition of disturbances
- Dynamic allocation of priorities
- Automatic surveillance of equipment performance and aging
- Procedural assistance to operator during normal and abnormal situations
- Evaluation of control actions prior to initiation
- Verification of engineered safety functions
- System realignment to mitigate the effects of plausible disturbances
- Natural language interfacing with explanatory capabilities for recommended courses of action

Figure 3.8-1 shows the hybrid facility configuration particular to this demonstration. The reactor expert system, which was implemented using the expert production system OPS-5 customized with MacLisp, interacts with a realistic analog model of the 100-MW(th) HFIR. Figure 3.8-2 shows the functional blocks of the HFIR analog model. The implementation permits operation of the reactor simulation from either the analog computer console or from a remotely located CRT by means of a reactor console simulation interface.

The operation of the analog simulation is independent from that of the expert system running in the digital computer. The expert system can be brought online at any time to monitor the operation of the reactor and provide expert advice to the reactor operator as needed. The expert system operates by applying the first-principles engineering knowledge it embodies to data extracted from twelve of the reactor's process signals. These signals are generated in parallel by the analog model running concurrently in the AD-4 computer.

Based on the experience acquired with this demonstration, a two-year program has just been initiated for the development and implementation of an intelligent monitoring adviser to the operators of the actual HFIR Facility. The intelligent monitoring system will act as an alert and cooperative expert to relieve the operators of routine tasks, request their attention when abnormalities are

Table 3.8-2. Summary of hardware and software available in the I&C Division for the development of AI applications

Hardware

1. DEC-10/Dual AD-4 Hybrid Computer
   DEC-10 characteristics
   - 1 Mbyte of memory
   - 150 Mbytes of disk storage
   - 1/2 in. tapes

   AD-4 consists of two consoles with a total of
   - 80 integrator/summers,
   - 50 summers,
   - 28 solid-state multipliers,
   - 112 DCUs (15-bit unipolar digital coefficients),
   - 36 DCAs (14-bit bipolar digital coefficients),
   - 124 servo coefficients,
   - 20 hand-set coefficients,
   - 40 comparators,
   - 16 dual electronic switches
   - 8 function generators
2. Lambda Lisp Machine
   - 2 Mbytes memory,
   - 474 Mbytes disk storage
   - 1/2-in. tape drive
3. VAX-11/780
   - 4.5 Mbytes memory
   - 800 Mbytes disk storage
   - floating-point accelerator
   - two 1/2-in. tape drives
4. PDP-11/44
   - 1.2 Mbytes memory
   - 150 Mbytes disk storage
   - 1/2-in. tape drive
   - 32-channel custom signal acquisition system

Software

1. Zlisp—MIT's programming environment for artificial intelligence (2)*
2. MacLisp—MIT's language for AI—predecessor to and subset of Zlisp (1)
3. NIL—MIT's version of Zlisp for the VAX computer under VMS (3)
4. OPS-5—Carnegie Mellon's expert production language: (1,2,3,4)
5. I&C Advanced Data Processing Environment—FORTRAN based (4)
6. Automated Reasoning System ITP—ANL's reasoning system built on the PASCAL-based logic machine architecture software package. (3)

*Numbers in parentheses denote the hardware on which the software is functional.

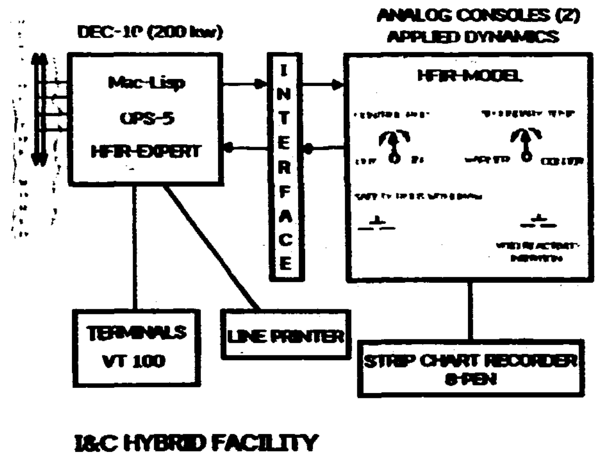

Fig. 3.8-1. Block diagram of the HFIR demonstration on the I&C hybrid computer facility.

detected, and provide them with interactive diagnostic aid and project action/effects information as needed or on demand.

3.8.2 ONLINE SURVEILLANCE TECHNIQUE FOR MONITORING COMPRESSORS IN THE ORGDP CASCADE

C. M. Smith

The I&C Surveillance and Diagnostic Methods Group has been taking measurements to determine the applicability of an online surveillance technique for monitoring compressors in the gaseous diffusion cascade at the ORGDP. The findings to date on the ability to monitor size 000 compressors are reported here.

Data were obtained from a size 000 compressor operating in the K-633 test facility by recording vibration signals from accelerometers installed on the motor-driven end and the thrust-bearing end of the compressor. These recorded vibration signals were analyzed to determine if the surveillance algorithm called PSDREC (Power Spectral Density Recognition) could determine a baseline signature for each vibration signal and detect specific changes

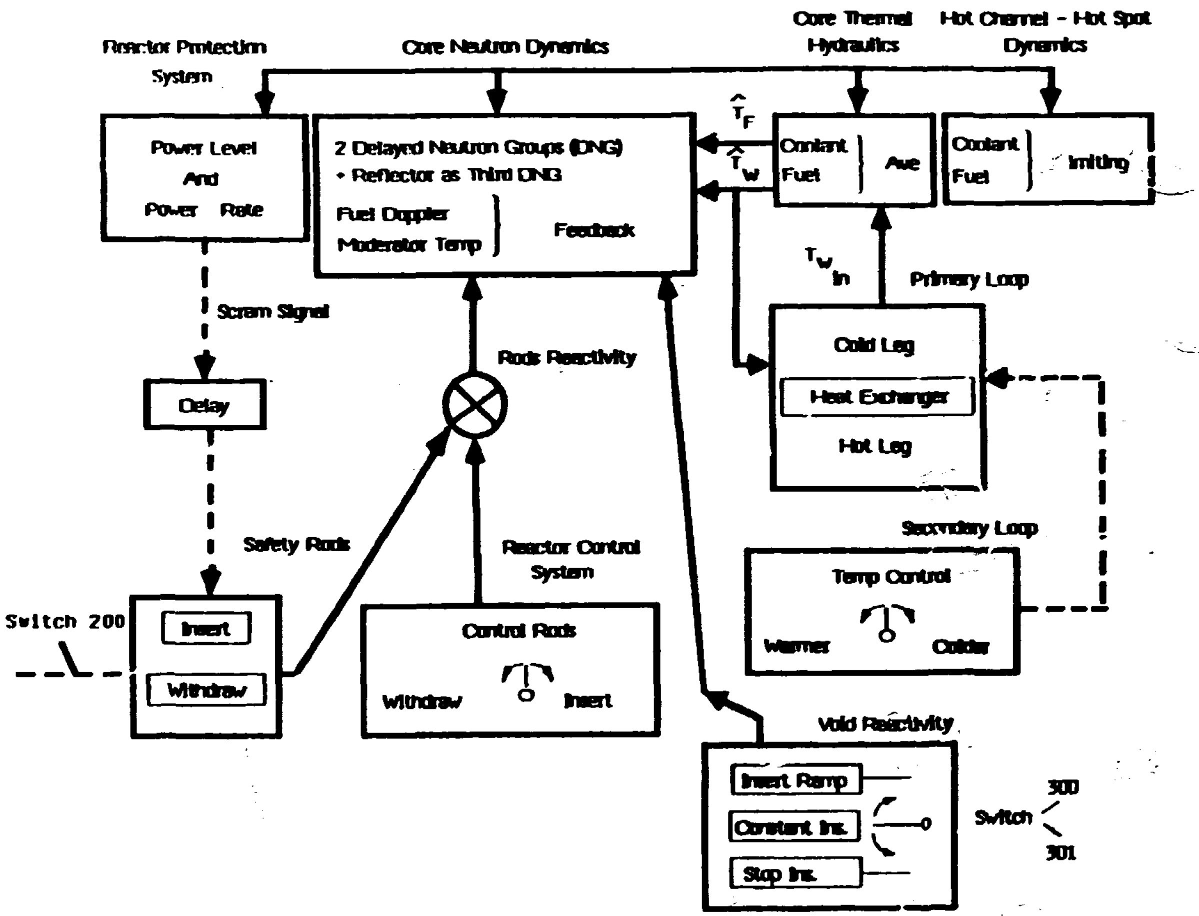

Fig. 3.8-2. Analog model of the High-Flux Isotope Reactor.

in this signature as the compressor was operated at nine different operating conditions around the baseline operating state as shown in Table 3.8-3.

The surveillance algorithm did establish a consistent baseline signature for each of the two vibration signals. In addition, the algorithm was able to give a quantitative indication of the compressor operating state. The PSDREC surveillance algorithm uses eight discriminants to identify changes from the baseline signature. Each discriminant is sensitive to a different type of spectral feature change (i.e., overall level, shift of resonances, appearance or disappearance of resonances, etc.). The value of these discriminants and the combinations of discriminants whose values changed gave the quantitative indication of the compressor operating state. Figure 3.8-3 presents the discriminant values of one discriminant for the baseline and test operating states. It can be seen that the discriminant value differs with operating states, even though each operating state does not have a statistically unique value. However, by observing similar data for the entire discriminant set (eight discriminants), it is found that certain combinations of discriminants have characteristic discriminant

Table 3.8-3. Operating conditions for compressor monitoring tests

Operating state	Inflow ratio	Outlet/Inlet pressure ratio
Baseline	1.0	1.13
1	0.8	1.25
2	0.8	min
3	0.8	1.45
4	1.0	1.33
5	1.0	1.31
6	1.0	min
7	1.2	min
8	1.2	1.2
9	1.2	1.27

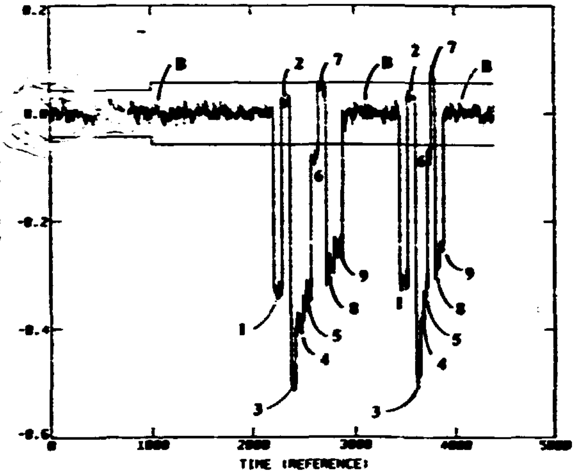

Fig. 3.8-3. Values for PSDREC discriminant D_1 during baseline and nine test operating states from size 000 compressor vibration signals.

values for each operating state and which, as a set, are unique identifiers for each of the nine off-normal operating states.

Since these conclusions are drawn for only one set of data, they may not be universally conclusive. However, they are encouraging because these results indicate that the surveillance algorithm may be able to determine the compressor operating state by monitoring the vibration signals from the compressor. The Surveillance and Diagnostic Methods Group believes it would be useful to continue the feasibility study. We therefore installed the PSDREC surveillance system on one cell of 000 compressors in the ORGDP cascade. This will allow compressor-to-compressor variations to be evaluated, and also will determine whether the baseline and off-baseline signatures for compressors in the cascade are stable enough to allow such a sensitive analysis of the discriminant values. This analysis is currently under way.

3.8.3 ELECTRONIC AUTOFLUOROGRAPHY: PRINCIPLES, PROBLEMS, AND PROSPECTS

J. B. Davidson

(Abstract of paper presented at Fourth International Meeting of the Electrophoresis Society, Gottingen, W. Germany, August 27–31, 1984)

Detection principles of electronic autofluorography are described. A comparison with film is presented, which indicates the gain in sensitivity and linearity of response obtainable by electronic means. Analog integration is compared with counting of individual particles, and the compatibility of the secondary electron conduction (SEC) camera tube with both modes is shown. Lens coupling and fiber optic coupling of the scintillator light to the intensifier are discussed, along with the desirability of the former in order to remove the gel size limitations of the available image intensifier with fiber optic inputs. In an experimental system, images from ^{3}H and ^{32}P were recorded in a digital memory by both direct contact and lens coupling. In a 2-min exposure 60 dpm/mm^2 of ^{3}H were measured using direct contact to a 150-mm-diam intensifier. The spatial resolution was 0.5 mm. Individual betas were registered using ^{32}P and an intensifying screen in direct contact. Using lens coupling to the same intensifier and a format of 200 × 250 mm an exposure of 5 min was required for visibility of 2 dpm/mm^2 of ^{32}P. A resolution of 2.0 mm was obtained. Exposures of 1 h are possible, with a proportional lowering of the minimum detector activity. It is concluded that the method is applicable to low- and high-energy betas as well as X rays and, compared to film, can increase the speed of acquiring data from a gel by a factor of 100 to 1000. The possible application of the same camera to fluorescence from 2-D gels is briefly described. The future of the method appears promising.

Section 4

MAINTENANCE MANAGEMENT DEPARTMENT

4.0. Department Overview

4.1. Maintenance Management Department Job Management System and Customer Appraisal Program

4.2. Technical Training for Instrumentation and Controls Division Maintenance Personnel

4.3. Operational Safety Requirements Program

4.4. Report on Shops

4.5. Local Area Networks: Applications in the Instrumentation and Controls Division at Oak Ridge National Laboratory

4.6. X-Ray-Generating Devices

4.7. Special Projects

MAINTENANCE MANAGEMENT DEPARTMENT

4.0 DEPARTMENT OVERVIEW

P. W. Hill

It is the purpose of the I&C Maintenance Management Department to support the goals of ORNL by providing an effective maintenance program. A well-managed maintenance organization is critical to the success of both the Division and the Laboratory in fulfilling their respective missions.

The intent of the I&C maintenance program is to ensure planned and systematic performance with the highest regard for safety, quality, reliability, and cost effectiveness in the areas of maintenance, fabrication, modification, installation, calibration, testing, and operation of instrumentation and controls used in support of research and development efforts. A degree of flexibility is maintained in the maintenance program to allow the unique needs of our customers to be met in a timely manner.

The Maintenance Management Department Computer Center was established as a central location for the integration of two computerized tools, the Maintenance Information System (MAINS) and the Job Management System (JMS). MAINS is a computerized maintenance information system utilized to provide historical data, preventive maintenance scheduling, backlog summaries, service documents, and other information related to instrumentation maintenance. JMS is a management tool designed to bring about the uniform collection of data, assignment of work, and control of manpower and materials.

Maintenance Management Department manpower consists of 20 management and staff personnel, 19 technical support personnel, and 93 instrument technicians. The Department operates 40 shops with staffs of 1 to 20 technicians, strategically located throughout ORNL. The Department currently expends more than $5 million annually for maintenance and fabrication, providing service for approximately 45,000 documented instruments with a total value in excess of $51 million.

Recognizing that involved workers are the key to high productivity, a results-oriented management program has been initiated to establish objectives and achieve goals within a reasonable time and allow supervisors and technicians to work together more effectively.

Improving maintenance management is a continuous process requiring progressive attitudes and constant attention. A documented maintenance management plan, along with the computerized job control system and maintenance information system, makes it possible to recognize and implement needed changes in direction in a planned and systematic manner.

4.1 MAINTENANCE MANAGEMENT DEPARTMENT JOB MANAGEMENT SYSTEM AND CUSTOMER APPRAISAL PROGRAM

D. G. Prater
A. D. Summey C. C. Barringer

The interactive job management system (JMS) was developed to handle the uniform collection of data, assignment of work, and control of manpower and materials. It is a management tool that will aid in the planning and documentation of tasks, scheduling, cost estimation and collection, and equipment history. It also provides information on backlog, job status, and work performance.

The JMS is built around the 1022 database management program maintained in the main DEC PDP-10 at ORNL, and it may be accessed from each supervisor's terminal through a local area network (LAN). The I&C Maintenance Work Request Form is used to collect information for JMS. The Maintenance Information System (MAINS), which is used with JMS, provides the maintenance history of instruments in the inventory and may be transferred from the IBM batch card system to the 1022 database. Scheduled recall for preventive maintenance and calibration is handled by the MAINS.

The JMS offers such features as unique job identification; accrual of current material and labor costs; verification of work orders, a hard copy of labor and material estimates; and exception reporting of backlog, job scheduling, and estimated overruns. A spare parts inventory is maintained, indicating both the availability and location of spare parts.

Using the JMS, a customer appraisal program was initiated to improve customer relations and provide I&C Division Maintenance Management Department staff with feedback regarding delivery of maintenance services. The program utilizes information from the JMS to randomly select work requests and query the customer regarding evaluation of the work performed. The customer is asked to evaluate the quality of various aspects of the job as either very good, satisfactory, or unsatisfactory. The attributes considered are quality of workmanship, response time, downtime, and functioning of equipment after the work is performed. In addition to the attributes mentioned above, the customer is given an opportunity to supply additional comments that will assist in assessing and improving the quality of service provided.

Customer appraisal information is solicited on a weekly basis. The information received is entered into a local computer database for the purpose of developing statistical data to enable the maintenance management staff to note and monitor trends in maintenance service. Customer appraisals are also returned to the maintenance supervisor for review. The supervisor is required to interact with the technician and/or the customer to resolve problems and find ways to improve the delivery of maintenance service. The outcome of this interaction is documented in the customer appraisal and added to the database. Corrective actions are reviewed by the maintenance management staff to ensure that appropriate corrective actions have been taken. Documenting corrective actions also provides a means of reviewing what action was taken to improve the quality of service. Performance is measured and controlled by use of the Demming statistical control technique, and statistical control information is reviewed with the maintenance staff on a regular basis. Examples of this information are depicted in Figs. 4.1-1 and 4.1-2.

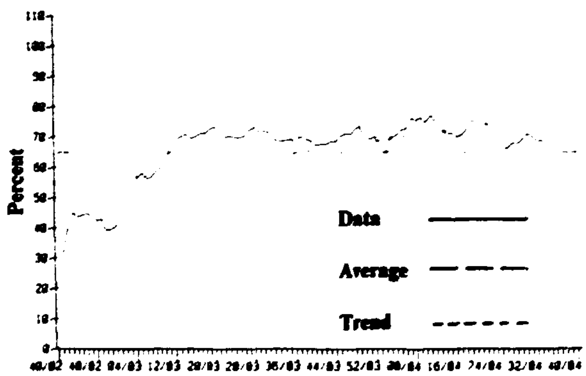

Fig. 4.1-1. Percentage of jobs completed on or before due date.

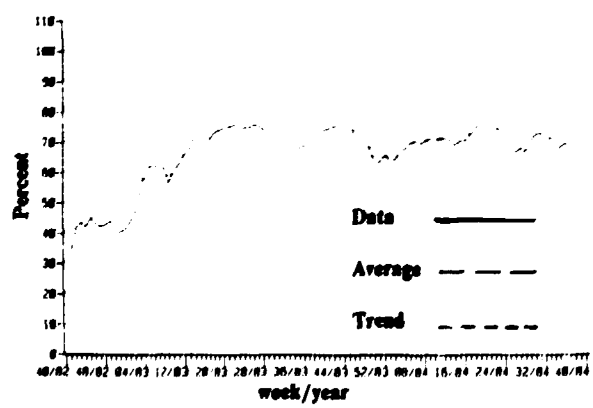

Fig. 4.1-2. Percentage of jobs completed at or below estimated cost.

*The acronym list at the end of this report may be folded out for reference.

4.2 TECHNICAL TRAINING FOR INSTRUMENTATION AND CONTROLS DIVISION MAINTENANCE PERSONNEL

C. T. Stansberry

The objective of the I&C Maintenance Management Department Training Program is to provide Department personnel with the training necessary to keep abreast of technical, administrative, and managerial skills.

During this reporting period, specific training needs were identified to improve the expertise of technical personnel. A fundamentals training program was established based on existing programs in quality assurance and workmanship standards together with new courses in solid state devices, digital logic, and microprocessors. Existing programs were updated as needed, and the new courses were offered on a quarterly basis. Supervisors were consulted and priorities were established before new courses were offered.

Since the introduction of the fundamentals program, 96% of all maintenance personnel have been through a quality assurance orientation and 96% have completed the four-hour course on Workmanship Standards. In addition, courses have been completed by the following numbers of persons: Digital Troubleshooting or Logic Fundamentals, 53; Solid State Devices, 15; and Introduction to Microprocessors, 28. The courses in logic and solid state devices have almost satisfied the need in these areas; however, additional microprocessor courses will continue on a quarterly basis for several more quarters.

Advanced training needs were met through special courses within the Department and the Laboratory and in other plant areas. In addition, technical personnel have participated in factory training courses. Keeping abreast of advancing technology requires a constant search for new courses.

A documentation program has been established to systematically record maintenance personnel training activities. Records of each individual's accomplishments are broken down into three major catagories: special training, training aids (mostly videotapes), and advanced education. Documentation is managed by a 1022 menu-driven interactive program consisting of a database with four data sets designed to minimize memory requirements. The database contains 7089 training records, an inventory of more than 400 training aids, a discriptive list of 200 special training courses, and a data set of personnel in the Maintenance Department that is useful in manpower and location logistics.

To augment the training of maintenance personnel, a new video viewing room has been established with more than 400 videotape items. Maintenance staff as well as other Division personnel make use of the new facility on a flexible schedule at their own pace, thus reducing formal classroom scheduling and the need to find qualified instructors.

For this reporting period, a total of 6192 training hours have been documented, including 263 hours of training aids and 5920 hours of special training (of which 1216 hours were factory training). Although not documented, on-the-job training is also very important to the total training effort.

In addition to technical training, members of the Maintenance Management Department have been responsible for training the I&C Emergency Squad in cardiopulmonary resuscitation (CPR), and 76 members of the Division staff are now CPR certified. The supervisors have also taken part in training to achieve better management skills leading to increased productivity.

4.3 OPERATIONAL SAFETY REQUIREMENTS PROGRAM

C. T. Stansberry

A program has been established to comply with new DOE and ORNL safety requirements relating to instrument maintenance in identified nonreactor nuclear facilities where failure or shutdown could create or increase health hazards or cause damage to the facility.

After operating safety requirements for a facility have been reviewed and approved by DOE, the Department provides maintenance services upon request of the facility's operating division through the Office of Operational Safety of the Industrial Safety and Applied Health Physics Division.

The primary functions of the I&C Maintenance Management Department are to ascertain that its personnel are properly trained in maintenance procedures relating to the facility, to mark with safety-item stickers each critical instrument, to make sure that spare parts are on hand, to specify special maintenance or calibration procedures, and to provide programmed maintenance of safety-related items.

These special review procedures have been completed and documented in six facilities, another three are in progress, and seven more have been identified in draft form and are awaiting DOE approval. Within the next two years a total of 32 facilities will require Operational Safety Requirements documentation packages containing training records, descriptive lists of instrumentation, and a sign-off list. Each facility program requires yearly review.

4.4 REPORT ON SHOPS

Measurement and Controls Group. This group comprises four supervisors who, with the assistance of five engineering technologists, direct and assist the activities of 34 instrument technicians located in 13 separate shops. These shops maintain process instrumentation, radiation and environmental monitoring equipment, leak detectors, and a variety of other instrumentation.

This reporting period has seen the upgrade and introduction of new technology in many areas that have required additional training for personnel. A newly created role for I&C Maintenance in managing small instrument projects for ORNL Engineering has proven advantageous to all personnel. *(J. H. Day)*

Process Instrument Group. This group—a supervisor, 3 engineering technologists, and 15 instrument technicians—is responsible for providing instrument maintenance to facilities throughout the ORNL complex. Other efforts of this group include providing calibrations for quality control, fabricating instruments, inspecting store stock items, and maintaining leak detectors as well as the fabrication, testing, and inspection of thermocouple parts and assemblies.

This group recently obtained expertise in providing maintenance support for the Bristol, Modicon, and Acurex Autodata Ten/10 digital process control systems. In order to provide efficient service, the six remote shops within this group are scattered geographically throughout the plant area. These shops are responsible for providing instrument maintenance support for instrumentation in the Transuranium Processing Plant, the Radiochemical Processing Pilot Plant, the Steam Plant, the Panel/Valve Shop, the Consolidated Fuel Reprocessing Plant, and the Thorium-Uranium Recycle Facility (TURF). Major maintenance efforts are being carried out at the Thorium Uranium Recycle Facility to prepare the exhaust and ventilation systems to accommodate the Californium Source Fabrication Facility, which will replace the existing facility at the Savannah River Laboratory. *(J. H. Day, C. G. Allen, A. J. Beal, J. W. McNeillie, R. A. Vines)*

Panelboard Fabrication Facility. This facility provides fabricated control room and transmitter panels for the Consolidated Edison Uranium Solidification Program (CEUSP) and the differential pressure Measurement and Purge Block Assemblies for the Advanced Instrumentation for Reflood Studies (AIRS) Program. This facility also performs all panel and rack fabrication to support the Maintenance Engineering Services Group. In addition, it is responsible for the routine repair and testing of control valves for ORNL and other plant facilities. *(C. G. Allen, A. J. Beal)*

Consolidated Fuel Reprocessing Facility. Maintenance continued in the areas of fabrication, installation, calibration, and testing of instruments associated with the various systems and experiments, with particular emphasis on CFRP Integrated Process Demonstration (IPD) Facility activities. Three technicians are responsible for maintenance of a broad range of instrumentation such as microprocessor-controlled digital pressure sources, pneumatic instruments, analytical instruments, and microprocessor-based control systems for chemical processes. *(C. G. Allen, J. W. McNeillie)*

Maintenance Engineering Services Group Projects. In 1983 key individuals in this group provided ORNL Engineering with a new in-house service by coordinating the field installation of engineering projects. These projects are presented to I&C Maintenance in the form of approved drawings, and Maintenance has the responsibility to procure and/or provide parts and materials, submit cost estimates, assure proper assignment of work to respective crafts, coordinate, fabricate, calibrate, install, and check out systems in a timely and orderly manner. The scope of these projects requires close coordination of both I&C and Plant and Equipment Division services. A completed project gives the user a fully functioning system and identifies instrumentation that is entered into the computer-based Maintenance Information System (MAINS) to ensure ongoing programmed calibrations and maintenance services.

Since fall 1983, this group has managed several important projects which involved monitoring of ORNL's major streams and tributaries, and low-level waste treatment. These projects were carried out for the ORNL Operations Division and the Environmental Management Department of the Industrial Safety and Applied Health Physics Division.

The first three field installations were new monitoring stations at White Oak Creek, Melton Branch, and the new White Oak Dam. Later projects were Ish Creek Water Quality Monitoring Station (a self-contained, battery-operated system) and the Coal Yard Runoff Monitoring System, which provides water quality data on the rainwater runoff from the ORNL Steam Plan Coal Yard. Current projects include upgrading the data acquisition systems for White Oak Creek, Melton Branch, and White Oak Dam; new instrumentation and controls systems for the new Hydrofracture Facility; and the upgrade of instrumentation and controls for TURF air compressor systems.

The past year's experience with ORNL Engineering and the Plant and Equipment Division as well as with other persons has afforded this group valuable insights into the vital areas of new installation and extensive upgrading and modifying of existing facilities. Our goal is to become even more involved in this area of maintenance service to satisfy both the Engineering needs and those of the end user.

In this group, engineering technologists are teamed with instrument technicians to support facilities with complex and varied types of equipment. *(C. G. Allen, A. J. Beal)*

Monitoring Systems Group. The Monitoring Systems Group of I&C Maintenance Management consists of a supervisor, one engineering technologist, and ten instrument technicians. This group provides maintenance and other support for portable survey and fixed station radiation and other monitoring equipment for the ORNL Environmental and Occupational Safety Division and the Liquid and Gaseous Waste Disposal section of the Operations Division.

In addition to servicing all ORNL personal radiation monitors and portable survey instrumentation, two technicians in Building 2007 also service portable units for the Radiological Survey Activities (RASA) Group of the ORNL Health and Safety Division and all ORDGP portable survey instruments. The shop in Building 3026C, operated by four technicians, has maintenance responsibilities for stationary radiation monitoring instrumentation, local air monitoring, perimeter air monitoring, fallout monitoring, and liquid and gaseous monitoring systems. Periodic checks are performed to ensure proper operation of these systems. Personal radiation monitors are also serviced by this group.

Four technicians assigned to Building 3130 provide service to the Liquid and Gaseous Waste Disposal Section of the Operations Division. In addition to normal maintenance and routine checks of systems, this group has provided support in the shakedown and successful operation of the new Hydrofracture Facility, the Gunite project, and the installation of seven data concentrators associated with the radiation waste data acquisition system in Building 3130. *(J. H. Day, J. D. Blanton, J. L. Basler)*

Reactor Controls Group. This group, which includes only technicians certified for reactor controls work, provides instrument maintenance to all operating reactors at ORNL. Additional efforts have been devoted to testing and installing new instrumentation in the BSR, the PCA, the ORR, the TSR-II, and the HPRR. This group will also continue its support of the ORR instrument upgrade program. *(J. H. Day, J. M. Farmer)*

Instrument Maintenance for the ORNL Metals and Ceramics Division. This group consists of a supervisor, one engineering technologist, and six instrument technicians who provide maintenance and small-scale design support to the Metals and Ceramics Division. The primary work of this group is to maintain instrumented fatigue test machines which operate at high, controlled temperatures for long periods of time and which have integrated fail-safe devices to protect tests from line transients and power outages.

Some of the small-scale design projects by the group, particularly D. L. Thomas, are a 16-bit I/O logic circuit for MTS machines, a digitally controlled function generator, an impact machine position control, an ac load cell conditioner, and a frequency response test set. *(J. H. Day, R. L. McKinney, D. L. Thomas)*

Research Instrument Maintenance Group. The activities of this group include maintenance of computers, data terminals and other data communications equipment, analytical chemical instrumentation, two-way communications, test equipment, pulse height analyzers, video equipment (including broadband and CATV systems), security systems, and site support as detailed below.

Providing training and keeping replacement parts available on-site in order to minimize customer downtime and operating expense continue to be the major goals of this group. Documentation of bench stock replacement parts and preservation of maintenance documentation through microfilming is carried out for each new acquisition. *(J. A. Keathley)*

4500 Area Maintenance Group. This group is primarily responsible for chemical analysis instrumentation and also services medical, research, and operational instruments utilized in the 4500 Area complex. The Building 4500 North and South I&C shops have been combined administratively to reduce costs and better serve this research area by sharing expertise, personnel, and materials. Eleven persons make up this group, which also provides instrumentation support to Building 5500.

Significant recent accomplishments include maintenance of chemical analyzers at a savings of 60% over a previous service contract, while at the same time showing less equipment downtime. *(C. W. Kunselman, B. L. Carpenter, T. E. Chambers, R. S. Thomas)*

6000 Area Maintenance Group. This group of seven persons provides service in support of work primarily related to the use of the accelerators in the 6000 Area which are operated by the Physics and Engineering Physics and Mathematics divisions. Support includes service of the power supplies and instrumentation used in the control of these accelerators as well as research instrumentation. Service is routinely provided on a 16-h basis five days a week.

Significant accomplishments include assumption of maintenance service on the Holifield Tandem Accelerator and the implementation of Operating Safety Requirements for that facility. *(J. A. Keathley, R. H. Brown)*

Computer Maintenance Group. Maintenance of four major computer manufacturers' midsize and minicomputer systems is the responsibility of this service group, which is composed of twelve persons. The group places strong emphasis (as do the field service groups of the computer manufacturers) on training, adequate replacement parts, a rigid preventive maintenance program, and service contracts which ensure factory backup service. Innovation and vendor support permit this group to perform the required services in a cost-effective and timely manner. *(C. W. Kunselman, R. P. Rosenbaum, C. R. Cinnamon, K. H. Pate, C. W. Tompkins)*

Electronic Instrument Fabrication Group. Prototyping, major instrument modifications, and production of electronic instruments is performed by this group of eleven persons. Prototypes are constructed by technicians working with the Division's engineering staff, and production instruments are fabricated for the Product Engineering Group, I&C Engineering, and the ORNL research staff. Printed wiring boards are produced in small quantities in the group's PC Board Production Facility from drawings generated by the Product Design Group and are used in prototypes and small production jobs. Photometal work for panels, decals, plaques, and name plates is also performed in this facility.

Significant accomplishments during this reporting period include the fabrication of 200 modules for the AIRS Program and assistance in their installation at ORNL and in Japan and West Germany; fabrication of badge readers, Health Physics Survey Instrumentation prototypes, remote pipetting instrumentation for the ORNL Analytical Chemistry Division, and drop test instrumentation; and the upgrade of Oak Ridge Research Reactor (ORR) instrumentation.

The major equipment improvement is the installation of a numerically controlled drill to aid in the production of printed wiring boards, which is expected to reduce by one-half the cost of producing a PC board. *(J. A. Keathley, B. A. Denning, H. L. Brant)*

Special Electronics Maintenance Group. This group was created in 1983 by combining the maintenance functions for pulse height analyzers, test equipment and oscilloscopes, and phototypesetting equipment with the field shops for the Solid State, Inspection Engineering, and Environmental Sciences divisions. The group was formed to more effectively utilize personnel and expertise during peak workload situations and is quartered in Building 3001, where it is staffed by twelve persons.

A total of 201 analyzer systems (both hardwired and computer based) are now being serviced, an increase of 27 systems during this reporting period. The oscilloscopes and pieces of test equipment being maintained and calibrated number 2,270.

The major equipment improvement for this group has been calibration systems, which have resulted in workmanship improvements, cost reductions, and reportability in the oscilloscope and test equipment calibration program. *(J. A. Keathley, A. J. Millet, K. L. Allison, R. P. Effler, E. G. Price)*

Communications and Security Maintenance Group. The twelve persons in this group have responsibility for the maintenance of two-way radios, the security CATV network and other security systems, teletype equipment, building sound systems, and video equipment. They also provide audiovisual services for meetings at ORNL.

The major accomplishments of this group during this reporting period include the upgrade of ORNL radio systems under the DOE Master Radio Plan and the completion of the security CATV network. The Master Radio Plan required the relocation and/or replacement, installation, and change of frequency for 502 two-way radios used for security, operations, and management functions. The security CATV network includes 27 miles of cable along with the cameras and other equipment required for this function. *(J. A. Keathley, A. J. Millet, H. C. Ford, J. A. Goan, C. A. Smith)*

Personal Computer and Terminal Maintenance. The rapid growth in the number of personal computers at ORNL has resulted in the establishment of a Personal Computer and Terminal Maintenance Group. Terminal maintenance, remote job entry (RJE) station maintenance, and support for Computing and Telecommunication Division communication and plotting equipment was transferred from the Computer Maintenance Group and combined with PC maintenance. Fifteen persons are involved in the activities of this group.

The group's support for the ORNL central computing facility has increased to more than 2.5 work years during this reporting period because of the increase in the number of communications multiplexors. Terminal support for the more than 2700 units represented by 60 different manufacturers requires 4.5 work years, with an average service call of 2.5 h.

The number of PCs at ORNL has grown to approximately 700, representing 37 manufacturers. Service, including acceptance testing, warranty, and breakdown maintenance, is accomplished by five persons. This group has been designated as a Technical Support Center by two major suppliers of PCs to ORNL; this arrangement permits the Group to purchase parts from the local service centers and to return defective parts for exchange under warranty.

Shop facilities in Building 3500 have been expanded to meet growing maintenance requirements. A major supply of replacement parts is being stocked to expedite repairs and keep downtime at a minimum.

The PCs are repaired at the board or module level because of the low replacement cost of many components. A major accomplishment for this shop was the checkout and preparation of 26 PC systems for the Inspectors General of the U.S. Department of Energy. These units were set up for training and then packed for shipment throughout the United States. *(C. W. Kunselman, B. A. Tye, R. J. Bradford, R. M. Childs)*

4.5 LOCAL AREA NETWORKS: APPLICATIONS IN THE INSTRUMENTATION AND CONTROLS DIVISION AT OAK RIDGE NATIONAL LABORATORY

D. G. Prater

(Abstract of paper presented at the 13th Midyear Meeting of the American Society for Information Science, Indiana University, Bloomington, May 20–23, 1984)

The use of a local area network requires some knowledge of how computers are connected together and an understanding of computer terminology, standards, equipment, and strengths and weaknesses. This paper provides a brief background regarding these subjects and describes specific application of local area networks in the Instrumentation and Controls Division at Oak Ridge National Laboratory (ORNL).

4.6 X-RAY-GENERATING DEVICE

4.6.1 PERSONNEL SAFETY UPGRADE OF X-RAY-GENERATING DEVICES AT ORNL

R. P. Effler

More than 90 X-ray-generating devices of many types are used in research at ORNL. In accordance with ORNL safety policy and philosophy, personnel safety standards for these devices have been formulated. These standards are based on engineering standards developed at the Y-12 Plant and adapted to meet the specific requirements of ORNL, including specified personnel safety features. Following development and documentation of the ORNL standards, a plan was prepared for inspecting and evaluating all X-ray-generating devices for compliance with these standards and for upgrading the units which did not comply.

Existing documentation for each device is checked and corrected as necessary. Each device and its environment are examined by an I&C staff member and a representative of the Industrial Safety and Applied Health Physics Division. Areas of safety feature noncompliance are recorded, and the I&C staff member then makes detailed design modification recommendations and cost estimates. Upon acceptance of the recommendations and estimates, new technical documents are prepared which reflect the modifications. The I&C staff member then implements the modifications using the appropriate personnel.

After the completion of the safety feature upgrade, each device is tested to verify proper function. Up-to-date test, operation, and maintenance procedures are maintained for each research X-ray device at ORNL.

4.6.2 STANDARDS FOR PERSONNEL SAFETY FEATURES ON X-RAY FACILITIES

D. G. Prater

(Abstract of Engineering Standards Manual, September 1983)

This manual documents ORNL personnel safety standards for X-ray-producing equipment and the general philosophy and approach to use of these standards. Use of a matrix (type of installation versus radiation safety feature) to facilitate equipment classification and personnel safety feature requirements is described. Included is a set of standards showing formats, matrices, and the detailed standards for each safety feature.

4.7 SPECIAL PROJECTS

4.7.1 DESIGN OF AN ALPHA/BETA-GAMMA PULSE-SHAPE DISCRIMINATOR

D. G. Prater W. J. McDowell*

Drawings were prepared for the construction of a pulse-shape discrimination circuit for the separation of alpha-produced pulses from beta- and gamma-produced pulses in certain liquid scintillation alpha spectrometry systems. Included were circuit diagrams, a metalphoto panel, and etched wiring board drawings. The circuit operates by converting the incoming signal to a square wave, the width of which carries the pulse time length information. A standard negative square wave pulse is then subtracted from this pulse, leaving a pulse in which the ~30-ns difference between the beta-gamma (shorter) and alpha (longer) pulses represents a larger fractional difference. The time width of the pulse is then converted to a voltage by stopping and starting a voltage ramp. The resulting voltage analog of time shows a peak representing the alpha-produced pulses and a group of peaks representing the beta-gamma-produced pulses. An internal single-channel analyzer (discriminator) can be adjusted so that the unit outputs a logic signal for only the alpha-produced pulses. This logic signal can be used to gate a multichannel analyzer so that only alpha-produced pulses are recorded in an energy spectrum from an alpha liquid scintillation detector. Detectors, electronics, and scintillators designed for alpha liquid scintillation must be used. The device cannot be applied to the output pulses of a beta liquid scintillation spectrometer.

*Chemical Technology Division.

4.7.2 DEVELOPMENT OF AN ALPHA LIQUID SCINTILLATION DETECTOR (PERALS DETECTOR)

D. G. Prater W. J. McDowell*

A liquid scintillation detector for photon-electron rejecting alpha liquid scintillation (PERALS) spectrometry was developed and fabricated. The use of this detector with properly prepared samples in an all-organic scintillator allows collection of pulse information from which may be obtained: (1) an energy spectrum of 200 to 300 keV resolution FWHM, and (2) pulse-shape (time) information sufficient to quantitatively separate alpha from beta and gamma pulses. The detector is a single phototube device using a 2-in. bi- or trialkali phototube. A high-efficiency reflector is sealed to the face of the phototube, and the sample, in a 10 × 75-mm Pyrex culture tube, is placed between the reflector and the phototube face. The phototube reflector assembly is enclosed in a box 8.5 in. long × 5 in.

high × 3.5 in. wide. Access for sample changing is through a light-tight door that opens the front three-fourths of the box. The door is fitted with a switch that interlocks via a relay with the phototube high-voltage supply. The access door is held down by a spring-loaded latch whose handle activates an additional switch in the same high-voltage control circuit.

*Chemical Technology Division.

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—1984

Max J. Kopp, President, Validyne Engineering, Inc., 8626 Wilber Avenue, Northridge, CA 91324

Peter F. McCrea, Vice President and Director of Corporate Research, The Foxboro Company, Foxboro, MA 02035

Paul W. Murrill, Board Chairman and Chief Executive Officer, Gulf States Utilities Company, Post Office Box 2951, Beaumont, TX 77704

Henry M. Paynter, 2714 Nueces Street, Apt. 205, Austin, TX 78712

Herbert E. Trammell, Director, Engineering Technology Division, Oak Ridge National Laboratory, Post Office Box Y, Oak Ridge, TN 37831

Division Consultants

J. D. Allen
R. P. Broadwater
J. B. Byer
J. P. Cook
H. E. Cochran
E. P. Epler
C. S. Hollander
G. V. S. Raju
R. F. Saxe
M. A. Schultz
G. E. Shafer

Co-op Students

D. S. Chavis
C. Cornils
M. S. Cosson
A. P. Frissora
G. W. Herron
T. E. Julian
B. I. Leinart
J. C. Moyers, Jr.
T. J. Preston
M. N. Smith
M. W. Wendel
K. M. Whitely

Oak Ridge Associated Universities Trainee

J. S. Wright

SCIENTIFIC AND PROFESSIONAL ACTIVITIES, ACHIEVEMENTS, AND AWARDS

July 1, 1982–July 1, 1984

Note: The numbers in parentheses following invited papers and theses refer to items in this report.

R. K. Adams

Fellow, Instrument Society of America

Member, Martin Marietta Energy Systems Personal Computer Planning Committee

Registered Professional Engineer

D. C. Agouridis

Member, Institute of Electrical and Electronics Engineers

Member, Gamma Alpha

Member, Eta Kappa Nu

U.S. Patent No. 4,394,676, *Improved CdTe Photovoltaic Radiation Detector,* D. C. Agouridis, July 1983

G. O. Allgood

Member, Institute of Electrical and Electronics Engineers

Member, Instrument Society of America

Member, IEEE Control Systems Society

Member, Eta Kappa Nu

Member, Tau Beta Pi

Listing in *The International Who's Who in Engineering*

M.S. Thesis, "A Probabilistic Model of Annular-Dispersed Flow in a Reactor Subchannel as Seen by Cylindrical Geometry Impedance Probes," the University of Tennessee, Knoxville, March 1983 (2.8.18)

Registered Professional Engineer

G. W. Allin

Invited paper: "A Variable Puff Parameter Smoking Machine for Smoke Composition Studies," R. A. Jenkins, R. W. Holmberg, T. M. Gayle, G. W. Allin, and S. K. Holliday, presented at Thirty-Eighth Tobacco Chemists' Research Conference, Atlanta, November 5–8, 1984 (3.1.9)

A. H. Anderson, Jr.

Member, Instrument Society of America

Member, Institute of Electrical and Electronics Engineers

Member, Tau Beta Pi; Secretary, Great Smoky Mountain Alumnus Chapter

Member, Eta Kappa Nu

Registered Professional Engineer

J. L. Anderson

Member, American Nuclear Society; Member, Standards Committee Subcommittee ANS-4, Reactor Dynamics and Control

Member, ORNL Engineering Physics and Mathematics Division Safety Review Committee

Member, Eta Kappa Nu

Member, Tau Beta Pi

Registered Professional Engineer

R. L. Anderson

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, Sigma Xi

Metric Coordinator, Instrumentation and Controls Division

ORNL Delegate, National Conference of Standards Laboratories

W. H. Andrews, Jr.

Senior Member, Instrument Society of America

Patent application filed: *Differential Capacitance Measurement Circuit*, W. H. Andrews, Jr., June 1984

S. M. Babcock

Member, Robotics International; Treasurer, Knoxville Chapter

Member, American Society of Mechanical Engineers

Member, American Association for Artificial Intelligence

S. P. Baker

Senior Member, Instrument Society of America

Registered Professional Engineer

Invited paper: "Wide-Range Vortex Shedding Flowmeter for High Temperature Helium Gas," S. P. Baker, P. G. Herndon, and R. M. Ennis, Jr., presented at Instrument Society of America International Conference/Exhibit, Houston, October 10–13, 1983; *Proceedings* **38**(2), 1401–32, 1983 (1982)

S. J. Ball

Member, Society for Computer Simulation

Member, Sigma Xi

Chairman, ORNL Reactor Operations Review Committee (RORC)

T. R. Barclay

Member, ORNL Director's Laser Safety Review Committee

Registered Professional Engineer

D. D. Bates

Member, Fusion Energy Division Major Electrical Review Committee

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 Safety Review Committee for ISX-B Gyrotron Power System

Chairman, Fusion Energy Division Committee to review OSSPS Substation problems that resulted in total power outage at the Y-12 Plant

R. E. Battle

Member, Institute of Electrical and Electronics Engineers; Vice Chairman, Oak Ridge Section; Member, Working Group 4.3, "Station Blackout"

Registered Professional Engineer

M. L. Bauer

Member, American Vacuum Society

Invited paper: "A New In-Line Fiber Optic Spectrometer for Remote Analysis and Process Control," D. T. Bostick, J. E. Strain, D. D. McCue, M. L. Bauer, and R. E. Harper, *Trends Anal. Chem.* 2(9), XII–XIII, 1983. (2.8.8)

W. F. Bethmann, Jr.

Member, Instrument Society of America

E. D. Blakeman

Member, Institute of Electrical and Electronics Engineers

T. V. Blalock

Member, Transducers Committee of the Industrial Electronics and Control Instrumentation Society of the IEEE

Haliburton Engineering Professorship, the University of Tennessee, 1982–1984

J. L. Blankenship

Member, American Physical Society

Member, Local Organizing Committee for the Conference on Instrumentation for Heavy Ion Nuclear Research, October 22–24, 1984; Chairman, Technical Exhibits Committee

R. S. Booth

Member, ORNL Wigner Fellowship Selection Committee

W. L. Bryan

Chairman, Local Arrangements Committee for Hardened Electronics and Radiation Technology Second Annual Conference, Oak Ridge, 1983

Member, Local Arrangements Committee, IEEE Nuclear and Space Radiation Effects Twentieth Annual Conference, Gatlinburg, Tennessee, 1983

O. W. Burke

Member, American Nuclear Society

P. L. Butler

Member, Institute of Electrical and Electronics Engineers

K. R. Carr

Member, Instrument Society of America

Patent application filed: *Magnetically-Coupled Rotational Viscometer*, K. R. Carr, June 1983

R. M. Carroll

Member, American Nuclear Society

Member, American Society for Testing and Materials

Invited paper: "The Effects of Temperature on the Response Time of Thermocouples and Resistance Thermometers," R. M. Carroll and R. L. Shepard, Industrial Temperature Measurement Symposium, the University of Tennessee, Knoxville, September 10–12, 1984 (3.6.4)

N. E. Clapp, Jr.

Senior Member, Instrument Society of America

D. A. Clayton

Member, Institute of Electrical and Electronics Engineers

M. S. Thesis, "An ac Analysis of a Large Superconducting Coil System," Tennessee Technological University, Cookville, December 1983

G. A. Colman

M. S. Thesis, "Systems Study for an Advanced Tritium Detector," the University of Tennessee, Knoxville, June 1984

R. I. Crutcher

Registered Professional Engineer

J. B. Davidson

Member, Sigma Xi

U.S. Patent No. 4,389,670, *Electron Method for Autofluorography of Macromolecules on Two-D Matrices*, A. L. Case and J. B. Davidson, June 1983

Invited paper: "Electronic Autofluorography: Principles, Problems, and Prospects," Fourth International Meeting of the Electrophoresis Society, Gottingen, Federal Republic of Germany, August 27–31, 1984 (3.8.3)

Invited paper: "Scintillation Neutron Detectors," Workshop on Instrumentation for the Advanced High-Flux Reactor, Oak Ridge, Tennessee, May 30, 1984; *Proceedings*, pp. 21–27 (3.1.1)

J. H. Day

Senior Member, Instrument Society of America

Member, I&C Division Maintenance Information System Committee

W. B. Dress

Member, American Physical Society

Member, American Association for Artificial Intelligence

Member, Canadian Society for Computational Studies of Intelligence

Member, FORTH Interest Group

B. G. Eads

Member, Instrument Society of America

Member, Institute of Electrical and Electronics Engineers

M. S. Emery

Member, Institute of Electrical and Electronics Engineers

P. D. Ewing

Union Carbide Corporation Community Service Award, 1983

R. J. Fox

Member, Institute of Electrical and Electronics Engineers

U.S. Patent No. 4,415,237, *Solid State Radiation Detector Circuit*, R. J. Fox, November 1983

Patent application filed: *Optical Fiber Distributed Line Peak Temperature Detector*, R. J. Fox, July 1982

D. N. Fry

Member, American Nuclear Society

B. H. Fulcher

Member, Institute of Electrical and Electronics Engineers

T. M. Gayle

Registered Professional Engineer

Invited paper: "The Sampling and Chemical Characterization of Concentrated Smokes," R. A. Jenkins, T. M. Gayle, J. S. Wike, and D. L. Manning, presented at ASTM 1981 Conference on Sampling and Analysis of Toxic Materials in the Atmosphere, Boulder, Colorado, August 2–5, 1981 (3.1.11)

Invited paper: "Instrumental Measurement of the Total Particulate Matter of Cigarette Smoke," R. A. Jenkins and T. M. Gayle, presented at Thirty-Sixth Tobacco Chemists' Research Conference, Raleigh, North Carolina, October 24–27, 1982 (3.1.8)

Invited paper: "A Variable Puff Parameter Smoking Machine for Smoke Composition Studies," R. A. Jenkins, R. W. Holmberg, T. M. Gayle, G. W. Allin, and S. K. Holliday, presented at Thirty-Eighth Tobacco Chemists' Research Conference, Atlanta, November 5–8, 1984 (3.1.9)

F. E. Gillispie

Member, American Physical Society

G. C. Guerrant

Member, Iota Lambda Sigma

E. W. Hagen

Fellow, Instrument Society of America; Managing Editor, Oak Ridge Section *Oak Ridge Recorder*; Control and Instrumentation Section Editor, *Nuclear Safety Journal*

Member, Institute of Electrical and Electronics Engineers; Secretary, Nuclear Power Engineering Committee Subcommittee 7—Human Factors; Newsletter Editor

Member, International Electrotechnical Commission Subcommittee 45A. Reactor Instrumentation

Registered Professional Engineer

G. N. Hamby

Member, National Laboratory Electronic Services Committee

W. R. Hamel

Member, American Society of Mechanical Engineeers; Member, Oak Ridge Section College Affairs Committee

Member, Institute of Electrical and Electronics Engineers

Member, Robotics International; Chairman, Subchapter 5157

Member, Sigma Xi

Member, Tau Beta Pi

Member, Phi Kappa Phi

Advisory Review Committee, NASA Langley Research Center, Robotics and Intelligent Systems Programs

Reviewer, ASME Journal of Dynamic Systems, Measurements, and Controls

Patent application filed: *A Cantilever Coriolis Mass Flowmeter*, W. R. Hamel, October 1982

Invited paper: "Robotics-Related Technology in the Nuclear Industry," W. R. Hamel and H. L. Martin, Society of Photo-Optical Instrumentation Engineers' Technical Symposium, San Diego, August 21–26, 1983; *Proceedings* **442**, pp. 97–107 (2.7.2)

Invited paper: "Advanced Teleoperation in Nuclear Applications," W. R. Hamel, M. Feldman, and H. L. Martin, 1984 ASME International Computers in Engineering Conference, Las Vegas, August 1984; *Proceedings* **1**, pp. 302–5 (2.7.4)

R. M. Harrington

Member, ORNL Reactor Operations Review Committee

Invited paper: "Analysis of Loss of Decay Heat Removal Sequences at Browns Ferry Unit One," R. M. Harrington and S. A. Hodge, ANS/ENS International Meeting on Light-Water Reactor Severe Accident Evaluation, Cambridge, Massachusetts, August 28–September 1, 1983 (3.5.7.1)

J. A. Harter

Senior Member, Institute of Electrical and Electronics Engineers

R. W. Hayes

Member, Digital Equipment Corp. Users' Society; Chairman, East Tennessee Local Users' Group

T. W. Hayes

Member, Institute of Electrical and Electronics Engineers

K. M. Henry

Member, ORNL Burst Reactor Experiment Review Committee

P. G. Herndon

Member, Institute of Electrical and Electronics Engineers

Member, Three-Plant Standards Committee

Invited paper: "Wide Range Vortex Shedding Flowmeter for High Temperature Helium Gas," S. P. Baker, P. G. Herndon, and R. M. Ennis, Jr., presented at Instrument Society of America International Conference/Exhibit, Houston, October 10–13, 1983; *Proceedings* **38**(2), 1401–32, 1983 (1982)

M. B. Herskovitz

Fellow, Instrument Society of America

Senior Member, Institute of Electrical and Electronics Engineers

Member, American Society for Testing and Materials; Member, Committee E-20, Temperature Measurement; Chairman, Subcommittee E-20.04.03, Thermocouple Specifications

Chairman, ORNL Electrical Safety Committee

Registered Professional Engineer

M. S. Hileman

Member, Instrument Society of America

N. W. Hill

Member, U.S. NIM-CAMAC Committee

Member, Institute of Electrical and Electronics Engineers; Deputy Program Chairman, 1984 Nuclear Science Symposium

Exhibits Manager, Fifth International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, Knoxville, Tennessee, September 1984

P. W. Hill

Member, I&C Division Maintenance Information System Committee

J. H. Holladay

Member, Instrument Society of America

J. L. Horton

Senior Member, Instrument Society of America

Member, Institute of Electrical and Electronics Engineers

Registered Professional Engineer

J. O. Hylton

Member, Instrument Society of America

Member, Sigma Xi

R. W. Ingle

Registered Professional Engineer

J. M. Jansen, Jr.

Member, Institute of Electrical and Electronics Engineers

Member, IEEE Computer Society

Member, IEEE Subcommittee on Real-Time Systems

Manager, ORNL/Interplant Broadband Communications System

Member, Martin Marietta Energy Systems Broadband Network Committee

Chairman, Building and Division Coordinators for ORNL Broadband Communication System

Member, Martin Marietta Energy Systems Telecommunications Reorganization Committee

Member, Martin Marietta Energy Systems Minicomputer/Microcomputer Policy Task Force

W. B. Jatko

Member, Society of Motion Picture and Television Engineers

Patent application filed: *Precision Linear Ramp Function Generator,* W. B. Jatko, L. H. Thacker, and D. R. McNeilly, July 1984

E. B. Johnson

Fellow, American Nuclear Society; Member, Publications Steering Committee, 1982-85; Chair of Special Session, "Criticality Safety Audit Programs," ANS 1984 Annual Meeting; Ex Officio Member, Executive Committee, Nuclear Criticality Safety Division, 1982-83; Member, ANS Standards Committee; Member and Secretary, Standards Subcommittee 8, Fissionable Materials Outside Reactors

Member and Secretary, American National Standards Committee N16, Nuclear Criticality Safety

Member, New York Academy of Sciences

Member, American Physical Society

Member, ORNL Reactor Operations Review Committee

Member, NRC Atomic Safety and Licensing Board Panel

Member, NRC Atomic Safety and Licensing Board, Shoreham Low Power Monitor

Member, Sigma Xi

R. C. Juras

Member, Program Committee, IEEE Nuclear Science Symposium, Orlando, Florida, October 31–November 2, 1984

J. A. Keathley

Chairman, I&C Maintenance Information System Committee

S. M. Killough

M.E.E. Thesis, "Simplified Speech Recognition Techniques for Microcomputers," the University of Tennessee, Knoxville, December 1983

W. T. King

Member, American Nuclear Society

R. A. Kisner

Member, IEEE Nuclear Power Engineering Committee, Human Factors Working Group SC 7.1

Program Committee Chairman, Workshop on Large Plant Control Systems, Oak Ridge, Tennessee, February 14–15, 1983

Speaker, ORAU Traveling Lecture Program, "Man-Machine Interaction and the Design of Control Systems," University of Miami, April 8, 1983

Registered Professional Engineer

Invited paper: "Review of Decision Aids for Nuclear Plant Operators," presented at Workshop on Decision Processes in Operation Planning and Fault Diagnosis, San Diego, June 9–10, 1983 (3.4.6)

Invited paper: "Review of Operational Aids for Nuclear Plant Operators," presented at Tenth Water Reactor Safety Research Information Meeting, Gaithersburg, Maryland, October 12–15, 1982 (3.4.6)

Invited paper: "A Survey of Methods for Improving Operator Acceptance of Computerized Aids," presented at EEI Forum on Computer Applications in Power Plants, Denver, September 20–22, 1982 (1982)

M. K. Kopp

Member, Institute of Electrical and Electronics Engineers; Member, Program Committee for the IEEE Nuclear Science Symposium

Member, Sigma Xi

Registered Professional Engineer

U.S. Patent No. 4,390,786, *Neutron Detection Apparatus*, K. H. Valentine and M. K. Kopp, June 1983

U.S. Patent No. 4,404,164, *Neutron Flux Profile Monitor for Use in a Fission Reactor*, M. K. Kopp and K. H. Valentine, September 1983

R. C. Kryter

Member, American Nuclear Society

Member, ASME Standard-Preparation Subgroup on LWR Loose-Part Monitoring and Diagnostics

U.S. Representative, International Organizing Committee for SMORN-IV Conference

J. N. Lewin

Member, American Nuclear Society

Registered Professional Engineer

T. A. Lewis

Member, Institute of Electrical and Electronics Engineers

J. L. Lovvorn

Senior Member, Institute of Electrical and Electronics Engineers

Member, IEEE Computer Society

Member, I&C Division Maintenance Information System Committee

Member, DOE Subpanel on OP Model Video Teleconferencing

Member, Tau Beta Pi; Council Member, Smoky Mountain Alumnus Chapter

Member, Eta Kappa Nu

Member, Phi Kappa Phi

E. Madden

Member, ADP Equipment Maintenance Review Committee

W. W. Manges

Member, Institute of Electrical and Electronics Engineers

Member, IEEE Computer Society

M.S. Thesis, "Development of an Integrated Control and Measurement System," the University of Tennessee, Knoxville, January 1984 (2.1.27)

F. W. Manning

Life Member, Institute of Electrical and Electronics Engineers; Member, Committee for the 1984 IEEE Nuclear Science Symposium; Member, IEEE Nuclear and Plasma Science Society Standing Committee on Radiological Instrumentation

Member, American Nuclear Society

Member, American National Standards Institute; Member, Group N42, Nuclear Instrumentation

Registered Professional Engineer, Ohio and Tennessee

Registered Professional Land Surveyor

U.S. Patent No. 4,449,049, *Portable Battery-Free Charger for Radiation Dosimeters*, F. W. Manning, May 1984

U.S. Patent No. 4,430,559, *Pocket Radiation Dosimeter-Dosimeter Charger Assembly*, F. W. Manning, February 1984

R. A. Maples

Patent application filed: *Pistol-Grip Dosimeter Charger*, R. A. Maples, January 1983

C. D. Martin, Jr.

Member, Instrument Society of America

Member, Institute of Electrical and Electronics Engineers

Member, American Management Association

H. L. Martin

Member, Robotics International of the Society of Manufacturing Engineers; Founding Chairman, Knoxville/Oak Ridge Chapter (1983)

Member, American Society of Mechanical Engineers

Member, National Society of Professional Engineers

Registered Professional Engineer

U.S. Patent No. 4,390,841, *State of Charge Indication Method for Electric Vehicles*, H. L. Martin, 1982

Industrial Research 1984 I-R 100 Award, "Model M-2 Manipulator Control System," J. N. Herndon, H. L. Martin, and P. E. Satterlee, Jr. (2.7.9, 2.7.10)

Invited paper: "Robotics-Related Technology in the Nuclear Industry," W. R. Hamel and H. L. Martin, Society of Photo-Optical Instrumentation Engineers' Technical Symposium, San Diego, August 21–26, 1983; *Proceedings* **442**, pp. 97–107 (2.7.2)

Invited paper: "Teleoperated Manipulators," H. L. Martin, Robots in Design Session, Design Automation Conference, Miami, June 27–29, 1983

Invited paper: "Advanced Teleoperation in Nuclear Applications," W. R. Hamel, M. J. Feldman, and H. L. Martin, 1984 ASME International Computers in Engineering Conference, Las Vegas, August 1984; *Proceedings* **1**, pp. 302–05 (2.7.4)

D. D. McCue

Member, American Society for Testing and Materials; Member, Committee C.26, Nuclear Fuel Cycle; Chairman, Subcommittee C26.10, Instrumentation

Invited paper: "Remote Analyzer for Multicomponent Process Streams: RAMPS," D. T. Bostick, J. E. Strain, D. D. McCue, R. E. Harper, and R. D. Seals, Industrial Research Institute Conference, "Spotlight on Oak Ridge," Oak Ridge, Tennessee, May 22–24, 1984 (2.8.7)

Invited article: "A New In-Line Fiber Optic Spectrometer for Remote Analysis and Process Control," D. T. Bostick, J. E. Strain, D. D. McCue, M. L. Bauer, and R. E. Harper, *Trends Anal. Chem.* 2(9), XII–XIII, 1983 (2.8.8)

Invited article: "The Beginning of ASTM Standards for Nuclear Instrumentation," D. D. McCue, *ASTM Standardization News*, 27–29, March 1983 (2.10.8)

D. W. McDonald

Member, Institute of Electrical and Electronics Engineers

Member, Instrument Society of America

J. A. McEvers

Member, Institute of Electrical and Electronics Engineers

Member, IEEE Computer Society

Member, IEEE Automatic Controls Society

D. E. McMillan

Registered Professional Engineer

D. R. McNeilly

M.S. Thesis, "Development of a Wire Identifier and its Application to a Thermocouple Instrumentation System," the University of Tennessee, Knoxville, August 1984

Patent application filed: *Inexpensive Wide-Range Lock-in Amplifier*, D. R. McNeilly, December 1982

Patent application filed: *Light-Operated Proximity Detector with Linear Output*, D. R. McNeilly, December 1982

Patent application filed: *Noise Isolation System for High-Speed Circuits*, D. R. McNeilly, December 1983

Patent application filed: *Precision Linear Ramp Function Generator*, W. B. Jatko, L. H. Thacker, and D. R. McNeilly, July 1984

J. T. Mihalczo

Member, American Nuclear Society; Member, Committee on Engineering and Technology Accreditation/Registration and Professional Development

Chairman, ORNL Burst Reactor Experiment Review Committee

D. R. Miller

Senior Member, Instrument Society of America

Member, I&C Division Maintenance Information System Committee

U.S. Patent No. 4,432,232, *Device and Method for Measuring the Coefficient of Performance*, D. R. Miller and V. R. Brantley, February 1984

G. N. Miller

Member, Institute of Electrical and Electronics Engineers

Member, Instrument Society of America

Member, National Society of Professional Engineers

R. L. Moore

Member, Instrument Society of America

Member, Institute of Electrical and Electronics Engineers

Member, ORNL Reactor Experiment Review Committee

A. C. Morris, Jr.

Member, Institute of Electrical and Electronics Engineers

Registered Professional Engineer

C. A. Mossman

Member, Instrument Society of America

R. C. Muller

Member, Digital Equipment Corporation Users' Society

F. R. Mynatt

Fellow, American Nuclear Society

Member, ORNL Computer Steering Committee

Member, ORNL General Purpose Equipment Committee

Member, High Speed Communication Committee

Member, Industry Degraded Core Rulemaking Steering Group

M. W. Noakes

Member, Robotics International of the Society of Manufacturing Engineers; Secretary, Knoxville/Oak Ridge Chapter

C. H. Nowlin

Member, Institute of Electrical and Electronics Engineers

L. C. Oakes

Fellow, Institute of Electrical and Electronics Engineers: Secretary, Administrative Committee of the IEEE Nuclear and Plasma Society; Chairman, Awards Committee; Chairman, 1984 Nuclear Science Symposium

Member, American Nuclear Society

P. J. Otaduy

Member, American Nuclear Society

Member, American Association for Artificial Intelligence

Member, American Association for Computing Machinery

V. K. Paré

Member, American Nuclear Society

Member, Institute of Electrical and Electronics Engineers

Member, American Physical Society

D. R. Patek

Member, Digital Equipment Corporation Users' Group

D. G. Prater

Member, American Society for Quality Control

Member, Institute of Certification of Engineering Technicians

Member, Martin Marietta Energy Systems Maintenance Committee

Member, Association of Information Systems Professionals

Member, American National Standards Institute

J. A. Ray

Member, Institute of Electrical and Electronics Engineers

C. W. Ricker

Member, American Nuclear Society

Member, American Physical Society

Member, Phi Beta Kappa

Member, Sigma Pi Sigma

Interim U.S. Member representing ORNL on the Joint Standing Committee on Civil Nuclear Cooperation with the Republic of China (Taiwan)

M. J. Roberts

Senior Member, Institute of Electrical and Electronics Engineers

E. M. Robinson

Member, Health Physics Society

Member, American Society of Safety Engineers

S. C. Rogers

M.S. Thesis, "Invention of a Tunable Damper for Use with an Acoustic Waveguide in Hostile Environments," the University of Tennessee, Knoxville, December 1983 (2.8.20)

U.S. Patent No. 4,452,334, *Tunable Damper for an Acoustic Wave Guide,* S. C. Rogers, June 1984

Patent application filed: *Ultrasonic Probe Dampener*, S. C. Rogers, October 1982

E. R. Rohrer

Member, American Association for Advancement of Science

Member, American Physical Society, Southeastern Section

Member, Phi Beta Kappa

Member, Sigma Pi Sigma

Instrumentation and Controls Division Nuclear Energy Standards Coordinator

J. C. Rowe

Member, Tau Beta Pi

M.S. Thesis, "A Microcomputer-Based Flowmeter for Determining Average Liquid Phase Flow in a Two-Phase Fluid," the University of Tennessee, Knoxville, December 1982

F. R. Ruppel

Member, Instrument Society of America

Member, American Institute of Chemical Engineers

J. A. Russell

Member, American Society for Testing and Materials; Member, Committee F-12, Security Systems and Equipment; Chairman, Task Group F-12.40, Detection and Surveillance Systems and Devices

Member, Executive Committee, Carnahan Conference on Security Technology

Member, National Society of Professional Engineers

Member, Tennessee Society of Professional Engineers

Chairman, ORNL Accelerators and Radiation Sources Safety Review Committee

Registered Professional Engineer

P. E. Satterlee, Jr.

Member, Eta Kappa Nu

Industrial Research 1984 I·R 100 Award, "Model M-2 Manipulator Control System," J. N. Herndon, H. L. Martin, and P. E. Satterlee, Jr. (2.7.9, 2.7.10)

G. K. Schulze

Member, U.S. NIM-CAMAC Committee

Member, Eta Kappa Nu

Member, Phi Eta Sigma

Industrial Research 1984 I-R 100 Award, "Ultrasonically-Pulsed Neutron Time of Flight Spectrometer," H. A. Mook and G. K. Schulze

R. L. Shepard

1984 ASTM Award of Merit

Senior Member, Instrument Society of America; Lecturer on Thermometry (Short Courses); Editor, Sixth ISA Temperature Symposium

Member, American Society for Testing and Materials; Chairman, Committee E-20, Thermometry; Chairman, Subcommittee E-20.11, Sheathed Heaters

Member, Program Committee, Institute of Electrical and Electronics Engineers

Member, Sigma Xi

Invited paper: "The Effects of Temperature on the Response Time of Thermocouples and Resistance Thermometers," R. M. Carroll and R. L. Shepard, Industrial Temperature Measurement Symposium, the University of Tennessee, Knoxville, September 10–12, 1984 (3.6.4)

A. A. Shourbaji

Senior Member, Instrument Society of America

W. H. Sides

Member, American Nuclear Society

Associate Member, Sigma Xi

R. L. Simpson

Member, Digital Equipment Corporation Users' Society

Member, I&C Division Maintenance Information System Committee

D. E. Smith

Member, American Society of Clinical Pathologists

O. L. Smith

Member, Sigma Xi

C. T. Stansberry

Member, Instrument Society of America

R. S. Stone

Member, American Nuclear Society

Member, Society for Computer Simulation

Registered Professional Engineer

A. D. Summey

Member, Institute of Industrial Engineers

F. J. Sweeney

Member, American Nuclear Society

Lecturer on Surveillance and Diagnostics of Industrial Dynamic Systems, Tennessee Industries Week (TIW-18), the University of Tennessee, Knoxville, September 12–16, 1983

Invited paper: "Influence of Fuel Vibration on Ex-Core Neutron Noise at Sequoyah-1 PWR," F. J. Sweeney, First Conference on Utility Experience in Neutron Noise Analysis, Washington, D.C., April 3–4, 1984 (3.3.5)

Invited paper: "Ex-Core Neutron Detector Spatial Sensitivity to In-Core Noise Sources," Tennessee Industries Week (TIW-17), Short Course on Noise Analysis of Reactor Systems, The University of Tennessee, Knoxville, September 12, 1982

J. E. Swift

Member, Association of Information Systems Professionals

Member, American Business Women's Association

Career Planning Consultant

R. M. Tate

Member, Institute of Electrical and Electronics Engineers

Member, Eta Kappa Nu

Member, Tau Beta Pi

Member, Phi Kappa Phi

Registered Professional Engineer, Tennessee and Indiana

L. H. Thacker

Member, ORNL Laser Safety Committee

Member, ORNL Graduate Fellow Selection Panel

Member, Phi Beta Kappa

Patent application filed: *Precision Linear Ramp Function Generator,* W. B. Jatko, L. H. Thacker, and D. R. McNeilly, July 1984

H. A. Todd

Member, Engineering Physics and Mathematics Division Safety Review Committee

Registered Professional Engineer

J. H. Todd

Chairman, ORNL Stores Stock Advisory Committee

Registered Professional Engineer

R. A. Todd

Member, Institute of Electrical and Electronics Engineers

Member, NIM-GPIB Working Group

Registered Professional Engineer

K. H. Valentine

Member, American Nuclear Society

U.S. Patent No. 4,390,786, *Neutron Detection Apparatus,* K. H. Valentine and M. K. Kopp, June 1983

U.S. Patent No. 4,404,164, *Neutron Flux Profile Monitor for Use in a Fission Reactor,* M. K. Kopp and K. H. Valentine, September 1983

E. E. Waugh

Member, Institute of Electrical and Electronics Engineers

D. K. Wehe

ORNL Wigner Fellow, 1984

Member, American Nuclear Society

Member, American Association for Artificial Intelligence

Member, Tau Beta Pi

Member, Sigma Xi

Member, Alpha Nu Sigma

Ph.D. Dissertation: "Measurements of Neutron Spectra in HEU and LEU Fuels," the University of Michigan, May 1984

Invited paper: "Comparative Measurements of Neutron Spectra in HEU and LEU Fuels," D. Wehe, J. S. King, and J. C. Lee, 1984 International Meeting on Reduced Enrichment for Research and Test Reactors, Argonne National Laboratory, October 15–18, 1984

K. W. West

Member, Three Mile Island Instrumentation and E. E. Survivability Planning Group

Member, I&C Division Design and Drafting Standards Committee

Chairman, I&C Division Maintenance Information System Committee

G. R. Wetherington

M.S.E.E. Thesis, "Development of a Digitally Based Filter for Noise Reduction in Purged Dip-Tube Liquid Density Measurements," the University of Tennessee, Knoxville, August 1983 (2.8.19)

Patent application filed: *Beam Focusing Indicator for a Laser Cutting System,* B. S. Weil and G. R. Wetherington, Jr., December 1982

I. E. Williams

Member, Instrument Society of America; Vice-President/President Elect, Charleston, S. C., Section (1983); Member, Oak Ridge Section

W. L. Zabriskie

Senior Member, Instrument Society of America
Registered Professional Engineer

A. C. Zerby

Member, Beta Gamma Sigma

S. D. Zimmerman

Member, Institute of Electrical and Electronics Engineers
Member, Tau Beta Pi
Member, Eta Kappa Nu

W. D. Zuehsow

Member, Institute of Electrical and Electronics Engineers

PUBLICATIONS

Numbers shown in parentheses following titles refer to abstracts or articles in this report. The respective abstracts note the affiliation of those authors who are not members of the Instrumentation and Controls Division.

G. O. Allgood and M. J. Roberts, "A Probabilistic Model of Annular-Dispersed Flow in a Reactor Subchannel as seen by Cylindrical Geometry Impedance Probes," Thesis for the Master of Science Degree, the University of Tennessee, Knoxville, March 1983; also NUREG/CR-3622, ORNL/TM-8841, February 1984. (2.8.18)

R. L. Anderson and C. P. Cannon, "Thermocouple Tests: A Quick-Look Report on Failures During Loss-of-Fluid Tests L2-6 (Loft L2-6)," ORNL/TM-8852, March 1984. (2.8.13)

S. J. Ball, "Control of Two-Phase Evaporating Flows," ***Measurements and Control in Water Desalination***, Ed. Noam Lior, Elsevier Science Publications, Amsterdam (in press).

S. J. Ball, N. E. Clapp, Jr., J. C. Cleveland, J. C. Conklin, R. M. Harrington, A. D. Kelmers, and F. C. Kornegay, "High-Temperature Gas-Cooled Reactor Safety Studies for the Division of Accident Evaluation Quarterly Progress Report, April 1–June 30, 1982," NUREG/CR-2874 Vol. 2, ORNL/TM-8443/V2, January 1983. (3.4.2)

S. J. Ball, N. E. Clapp, Jr., J. C. Cleveland, J. C. Conklin, R. M. Harrington, A. D. Kelmers, T. B. Lindemer, and I. Siman-Tov, "High-Temperature Gas-Cooled Reactor Safety Studies for the Division of Accident Evaluation Quarterly Progress Report, July 1–September 30. 1982," NUREG/CR-2874 Vol. 3, ORNL/TM-8443/V3, May 1983. (3.4.2)

S. J. Ball, N. E. Clapp, Jr., J. C. Cleveland, J. C. Conklin, R. M. Harrington, T. B. Lindemer, and I. Siman-Tov, "High-Temperature Gas-Cooled Reactor Safety Studies for the Division of Accident Evaluation Quarterly Progress Report, October 1–December 31, 1982," NUREG/CR-2874 Vol. 4, ORNL/TM-8443/V4, August 1983. (3.4.2)

S. J. Ball, J. C. Cleveland, J. C. Conklin, R. M. Harrington, T. B. Lindemer, and I. Siman-Tov, "High-Temperature Gas-Cooled Reactor Safety Studies for the Division of Accident Evaluation Quarterly Progress Report, January 1–March 31, 1983," NUREG/CR-3492 Vol. 1, ORNL/TM-8921/V1, November 1983. (3.4.2)

S. J. Ball, J. C. Cleveland, R. M. Harrington, N. E. Clapp, Jr., J. C. Conklin, A. D. Kelmers, and F. C. Kornegay, "High-Temperature Gas-Cooled Reactor Safety Studies for the Division of Accident Evaluation Quarterly Progress Report, January 1–March 31, 1982," NUREG/CR-2874 Vol. 1, ORNL/TM-8443/V1, September 1982. (3.4.2)

S. J. Ball, J. C. Cleveland, R. M. Harrington, and T. B. Lindemer, "High-Temperature Gas-Cooled Reactor Safety Studies for the Division of Accident Evaluation Quarterly Progress Report,

July 1–September 30, 1983," NUREG/CR-3492 Vol. 3, ORNL/TM-8921/V3, March 1984. (3.4.2)

S. J. Ball, J. C. Cleveland, R. M. Harrington, T. B. Lindemer, and I. Siman-Tov, "High-Temperature Gas-Cooled Reactor Safety Studies for the Division of Accident Evaluation Quarterly Progress Report, April 1–June 30, 1983," NUREG/CR-3492 Vol. 2, ORNL/TM-8921/V2, January 1984. (3.4.2)

S. J. Ball, J. C. Cleveland, I. Siman-Tov, R. M. Harrington, and J. H. Wilson, "High-Temperature Gas-Cooled Reactor Safety Studies for the Division of Accident Evaluation Quarterly Progress Report, October 1–December 31, 1983," NUREG/CR-3492 Vol. 4, ORNL/TM-8921/V4, July 1984. (3.4.2)

S. Baron, C. Feehrer, R. Muralidharan, R. Pew, and P. Horwitz, "An Approach to Modeling Supervisory Control of a Nuclear Power Plant," NUREG/CR-2988, ORNL/Sub/81-70523/1, November 1982. (3.4.5.1)

R. E. Battle, "Collection and Evaluation of Complete and Partial Losses of Off-Site Power at Nuclear Power Plants," NUREG/CR-3992, ORNL/TM-9384, in press. (3.5.3.1)

R. E. Battle and D. J. Campbell, "Reliability of Emergency ac Power Systems at Nuclear Power Plants," NUREG/CR-2989, ORNL/TM-8545, July 1983. (3.5.3)

William F. Bethmann, Jr., "Correlation of the Analytical Solution with Experimental Data on the Electrolysis Potential Probe," NUREG/CR-3152, ORNL/TM-8650, June 1983. (2.8.17)

T. V. Blalock, R. L. Shepard, D. C. Agouridis, and J. L. Horton, "In Situ Calibration of Nuclear Plant Platinum Resistance Thermometers Using Johnson Noise Methods," EPRI NP-3113, June 1983. (3.6.3.2)

D. T. Bostick, J. E. Strain, D. D. McCue, M. L. Bauer, and R. E. Harper, "A New In-Line Fiber Optic Spectrometer for Remote Analysis and Process Control," *Trends Anal. Chem.* **2**(9), X11–XIII (1983). (2.8.8)

V. R. Brantley and D. R. Miller, "Efficiency of Heating System Measured Best by Heat Output Meters," *Ind. Res. Dev.* **25**(12), 78–81 (1983). (2.4.15)

T. J. Burns, R. D. Cheverton, G. F. Flanagan, J. D. White, D. G. Ball, L. B. Lamonica, and R. Olson, "Pressurized Thermal Shock Evaluation of the Oconee-1 Nuclear Power Plant," draft report NUREG/CR-3770, ORNL/TM-9176. (3.5.4.1)

C. E. Bush, S. C. Bates, J. L. Dunlap, E. A. Lazarus, M. Murakami, V. K. Paré, B. Thomas, Jr., C. E. Thomas, and R. M. Wieland, "Effects of Co- and Counter-Neutral Beam Injection Heating on Impurity Radiation from ISX-B Plasmas," *Nucl. Fusion* **23**, 67–73 (1983).

K. R. Carr, "Instrumentation Impulse Line Plugging in Coal Liquefaction Process Applications," ORNL/TM-8511, February 1983. (2.4.14)

B. A. Carreras, P. H. Diamond, M. Murakami, J. L. Dunlap, J. D. Bell, H. R. Hicks, J. A. Holmes, E. A. Lazarus, V. K. Paré, P. Similon, C. E. Thomas, and R. M. Wieland, "Transport Effects Induced by Resistive Ballooning Modes and Comparison with High Beta p ISX-B Tokamak Confinement," *Phys. Rev. Lett.* **50**, 503–06 (1983).

B. A. Carreras, J. L. Dunlap, W. A. Cooper, R. A. Dory, T. C. Hender, M. Murakami, V. K. Paré, A. J. Wootton, J. D. Bell, L. A. Charlton, H. R. Hicks, J. A. Holmes, V. E. Lynch, R. M. Wieland, P. H. Diamond, and P. L. Similon, "MHD Activity in the ISX-B Tokamak: Experimental Results and Theoretical Interpretation," ORNL/TM-8648, June 1983. (3.3.11.1)

R. M. Carroll and R. L. Shepard, "Surface Heat Transfer in a Stirred Boiling Water Bath," ORNL/TM-8522, November 1982. (3.6.5.1)

W. H. Christie, R. E. Eby, R. L. Anderson, and T. G. Kollie, "Investigation of Decalibrated Nicrosil Versus Nisil Thermocouples: Quantitative SIMS Analysis Using Indexed Sensitivity Factors and Oxygen Flooding," *Appl. Surf. Sci.* **18**, 287–98 (1984). (2.8.12)

F. H. Clark, N. E. Clapp, and R. Broadwater, "Possible Modes of Steam Generator Overfill Resulting from Control System Malfunctions at the Oconee-1 Nuclear Plant," NUREG/CR-3692, ORNL/TM-[illegible]061, July 1984. (3.4.4)

G. A. Colman, "Systems Study for an Advanced Tritium Detector," Thesis presented for the Master of Science Degree, the University of Tennessee, Knoxville, June 1984. (1.1.1)

G. A. Colman, J. T. DeLorenzo, J. E. Phelps, and G. W. Allin, "Development Report: A RADIAC System for Measuring Aqueous Tritium Concentration by the Liquid Scintillation Method," ORNL/TM-9290, October 1984. (1.1.4)

D. H. Cook, S. R. Greene, R. M. Harrington, and S. A. Hodge, "Loss of DHR at Browns Ferry Unit One—Accident Sequence Analysis," NUREG/CR-2973, ORNL/TM-8532, May 1983. (3.5.7.1)

J. T. DeLorenzo, "Fission Chamber Assembly and Matching Preamplifier," ORNL/TM-8212, December 1982. (1982)

P. F. Dittner, S. Datz, P. D. Miller, C. D. Moak, P. H. Stelson, C. Bottcher, W. B. Dress, G. D. Alton, N. Nešković, and C. M. Fou. "Cross Sections for Dielectronic Recombinations of B^{2+} and C^{3+} via $2s \Rightarrow 2p$ Excitation," *Phys. Rev. Lett.* **51**(1), 31–32 (July 4, 1983). (2.10.2)

W. B. Dress, "A Torsional Ultrasonic Technique for LWR Liquid Level Measurement," NUREG/CR-3113, ORNL/TM-8585, January 1983. (2.8.15)

W. B. Dress and G. N. Miller, "An Ultrasonic Level and Temperature Sensor for Power Reactor Applications," NUREG/CR-3856, ORNL/TM-9236, August 1984. (2.8.14)

D. K. Felde, R. L. Durall, S. S. Gould, G. S. Mailen, A. G. Sutton, D. J. Fraysier, E. C. Keith, L. J. Ott, and J. E. Wolfe, "Facility Description—THTF MOD 3 ORNL PWR BDHT Separate-Effects Program," NUREG/CR-2640, ORNL/TM-7842, September 1982. (2.3.10)

R. J. Fox, "Measurement of Peak Temperature Along an Optical Fiber," *Appl. Opt.* **22**(7), 967–69 (1983). (3.6.1.1)

P. R. Frey, W. H. Sides, Jr., R. M. Hunt, and W. B. Rouse, "Computer-Generated Display System Guidelines—Volume 1: Display Design," Electric Power Research Institute Report EPRI NP-3701, V1, September 1984. (3.4.6.3)

D. N. Fry, J. March-Leuba, and F. J. Sweeney, "Use of Neutron Noise for Diagnosis of In-Vessel Anomalies in Light Water Reactors," NUREG/CR-3303, ORNL/TM-8774, January 1984. (3.3.4)

R. Gwin, R. R. Spencer, R. W. Ingle, Jr., J. H. Todd, and S. W. Scoles, "Measurements of the Neutron Fission Cross Sections of ^{235}U (E_n = 0.01 eV to 30 keV) and ^{239}Pu (E_n = 0.01 to 60 eV)," *Nucl. Sci. Eng.* **88**(1), 37–55 (September 1984).

E. W. Hagen, "Compressed-Air and Backup Nitrogen Systems in Nuclear Power Plants," NUREG/CR-2796, ORNL/NSIC-206, July 1982. (3.5.6)

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C. M. Smith and F. J. Sweeney, "Demonstration of an Automated On-Line Surveillance System at a Commercial Nuclear Power Plant," pp. 46.01–46.20.

B. R. Upadhyaya and F. J. Sweeney, "Theoretical and Experimental Stochastic Modeling Analysis of PWR Core Heat Transfer," pp. 46.01–46.20. (3.3.7.2)

Sixth Tandem Conference, Chester, Great Britain, April 18–22, 1983

C. M. Jones, G. D. Alton, J. B. Ball, J. A. Benjamin, J. A. Biggerstaff, E. D. Hudson, R. C. Juras, P. K. Kloeppel, R. S. Lord, C. A. Ludemann, J. E. Mann, J. A. Martin, S. W. Mosko, E. G. Richardson, and N. F. **Ziegler**, "Status Report on the Holifield Heavy Ion Research Facility."

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G. O. Allgood and M. J. Roberts, "A Probabilistic Model of Annular-Dispersed Flow in a Reactor Subchannel as seen by Cylindrical Geometry Impedance Probes," pp. 1171–84. (2.8.18)

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R. E. Battle and D. J. Campbell, "Reliability of Emergency ac Power Systems at Nuclear Power Plants."

Contractors' Review Meeting, Dallas, June 8–10, 1983

S. L. Purucker and B. J. Bolfing, "IEDMS Acceptance Test Outline."

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R. A. Kisner, "Review of Decision Aids for Nuclear Plant Operators." (3.6.6)

1983 Annual Meeting of the American Nuclear Society, Detroit, June 12–17, 1983; Trans. Am. Nucl. Soc. 44

M. M. Clarke, J. V. Draper, and W. R. Hamel, "Human Factors in Remote Control Engineering Development Activities," pp. 564–65. (2.7.11)

W. T. King and J. T. Mihalczo, "Application of ^{252}Cf-Source-Driven Noise Analysis Measurements for Subcriticality of HFIR Fuel Elements," pp. 290–91.

E. L. Machado and R. B. Perez, "Nuclear Power Plant Surveillance by Heuristic Learning Parameter Identification," pp. 550–51. (3.3.9.2)

J. March-Leuba and R. B. Perez, "A Physical Model of Nonlinear Noise with Application to BWR Stability," pp. 523–25.

L. F. Miller, J. T. Mihalczo, E. G. Bailiff, N. D. Woody, and G. D. Gardner, "Nuclear Engineering Laboratory Self-Regulated Power Oscillation Experiments at the Health Physics Research Reactor," pp. 38–39. (3.3.10)

R. B. Perez, G. de Saussure, J. T. Yang, J. L. Munoz-Cobos, and J. H. Todd, "Comparison of Measured and Calculated ^{238}U Capture Self-Indication Ratios from 4 to 10 keV," pp. 537–38. (1.9.13)

J. P. Renier and F. J. Sweeney, "Calculation of Detector Spatial Sensitivities to Coolant Voiding in a Shutdown PWR," pp. 545–46.

F. J. Sweeney and J. P. Renier, "Fuel Assembly Vibration-Induced Neutron Noise in PWRs," pp. 549–50. (3.3.5)

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H. L. Martin, "Teleoperated Manipulators."

Nitrogen Fixation in Tropical Agricultural Legumes Conference on Nitrogen Cycling in the Tropics, Emmaus, Pennsylvania, July 13–15, 1983; Proceedings

O. L. Smith, "Can Modeling Improve Cropping Efficiency." (3.4.7)

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R. E. Battle and D. J. Campbell, "Loss of All ac Power in Nuclear Power Plants."

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P. Mioduszewski, L. C. Emerson, J. E. Simpkins, A. J. Wootton, C. E. Bush, A. Carnevali, J. L. Dunlap, P. H. Edmonds, W. L. Gardner, H. C. Howe, D. P. Hutchinson, R. C. Isler, R. R. Kindsfather, R. A. Langley, E. A. Lazarus, C. H. Ma, M. Murakami, G. H. Neilson, V. K. Paré, S. D. Scott, C. E. Thomas, J. B. Whitley, W. R. Wing, and K. Yokoyama, "Particle Removal with Pump Limiters in ISX-B."

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W. H. Sides, Jr., "Review of Human Factors in Operator Aids Development at Oak Ridge National Laboratory," pp. 104–5. (3.4.6.2)

Society of Photo-Optical Instrumentation Engineers' Technical Symposium, San Diego, August 21–26, 1983. Third in the SPIE Critical Reviews of Technology Series 442, Robotics and Remote Sensing Systems, 1983

W. R. Hamel and H. L. Martin, "Robotics-Related Technology in the Nuclear Industry," pp. 97–107. (Invited) (2.7.2)

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F. J. Sweeney and J. P. Renier, "Sensitivity of Ex-Core Neutron Detectors to Vibration of PWR Fuel Assemblies," pp. 341–48.

International Meeting on Light-Water Reactor Severe Accident Evaluation, Cambridge, Massachusetts, September 1, 1983; Proceedings

R. M. Harrington and S. A. Hodge, "Analysis of Loss of Decay Heat Removal Sequences at Browns Ferry Unit One." (3.5.7.1)

European Physics Society Eleventh European Conference on Plasma Physics and Controlled Nuclear Fusion, Aac'en, Federal Republic of Germany, September 5–9, 1983

S. D. Scott, S. C. Bates, J. D. Bell, C. E. Bush, A. Carnevali, B. A. Carreras, J. L. Dunlap, G. R. Dyer, P. H. Edmonds, O. C. Eldridge, A. C. England, W. L. Gardner, J. H. Harris, H. C. Howe, D. P. Hutchinson, R. C. Isler, T. C. Jernigan, R. R. Kindsfather, P. W. King, R. A. Langley, E. A. Lazarus, J. F. Lyon, C. H. Ma, P. K. Mioduszewski, M. Murakami, L. E. Murray, G. H. Neilson, V. K. Paré, M. J. Saltmarsh, D. J. Sigmar, J. E. Simpkins, K. A. Stewart, W. L. Stirling, C. E. Thomas, R. M. Wieland, J. B. Wilgen, W. R. King, and A. J. Wootton, "Neutral Injection Experiments in the ISX-B Tokamak."

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N. F. Ziegler, E. G. Richardson, J. E. Mann, P. K. Kloeppel, R. C. Juras, C. M. Jones, J. A. Biggerstaff, J. A. Benjamin, and G. D. Alton, "Status Report on the ORNL 25 URC Accelerator."

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J. B. Davidson and H. G. Smith, "TV-Based Neutron Detectors and Applications," pp. 767–75. (3.1.2)

Institute of Nuclear Materials Management Workshop: Integrating the Delay Element into Intrusion Detection and Entry Control Systems, Los Angeles, October 18–21, 1983

J. A. Russell, Jr., "ASTM Committee F-12 Activities on Security Systems and Equipment."

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M. K. Kopp, K. H. Valentine, G. C. Guerrant, and J. A. Harter, "Position-Sensitive Fission Counter for In-Core Flux-Profile Monitoring," pp. 733–37. (3.1.3.1)

K. H. Valentine, M. K. Kopp, G. C. Guerrant, and J. A. Harter, "Radiation Stability of Counting Gas Mixtures Containing CF_4," pp. 264–68. (3.1.6)

Eleventh Water Reactor Safety Research Information Meeting, National Bureau of Standards, Gaithersburg, Maryland, October 24–28, 1983; Trans. NUREG/CP-0047

W. B. Dress, "Torsional Ultrasonic Technique for Reactor Vessel Level Measurement," pp. 133–36. (2.8.15)

J. A. Mullens and J. A. Thie, "The Use of Pressure Noise in PWR Diagnostics," pp. 129–30. (3.3.6.1)

1983 Winter Meeting of the American Nuclear Society, San Francisco, October 30–November 4, 1983; Trans. Am. Nucl. Soc. 45

W. B. Dress and G. N. Miller, "An Ultrasonic Level and Temperature Sensor for Power Reactor Applications," pp. 866–67.

R. C. Kryter, "A Survey of the Status of Loose-Part Monitoring in the USA and Western Europe."

J. March-Leuba, D. G. Cacuci, and R. B. Perez, "Nonlinear Dynamics of Boiling Water Reactors," pp. 725–26.

J. T. Mihalczo, W. T. King, E. B. Johnson, and E. D. Blakeman, "Subcriticality Measurements for a Fuel Solution Tank with Changing Fuel Concentration Using ^{252}Cf-Source-Driven Neutron Noise Analysis," pp. 337–38.

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W. B. Dress, "A High Resolution Ultrasonic Densitomer," pp. 287–90. (2.8.16)

Twenty-Fifth Annual Meeting of the American Physics Society, Division of Plasma Physics, Los Angeles, November 7–11, 1983; Bull. Am. Phys. Soc. 28

J. L. Dunlap, V. K. Paré, J. D. Bell, and A. J. Wootton, "MHD Fluctuation Studies in ISX-B," p. 1112.

P. H. Edmonds, D. D. Bates, O. C. Cole, G. R. Dyer, W. L. Gardner, R. C. Isler, and E. A. Lazarus, "Opposed Neutral Beam Injection on ISX-B," p. 1111.

M. Murakami, J. D. Bell, C. E. Bush, A. Carnevali, J. L. Dunlap, W. L. Gardner, D. P. Hutchinson, R. R. Kindsfather, E. A. Lazarus, C. H. Ma, G. H. Neilson, V. K. Paré, S. D. Scott, C. E. Thomas, R. M. Wieland, and A. J. Wootton, "Transport Analysis of Beam-Heated Plasmas in ISX-B," p. 1112.

V. K. Paré, J. D. Bell, A. P. Navarro, J. L. Dunlap, and E. T. Blair, "MHD Mode Structure and Rotation as Shown by Soft X-Ray Imaging in ISX-B," p. 1254.

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J. E. Hardy and J. O. Hylton, "In-Core Two-Phase Flow Measurements in Experimental PWR Refill and Reflood Test Facilities."

Tenth Symposium on Fusion Engineering, Philadelphia, December 5–9, 1983; IEEE Trans. 1983 Tenth Symposium on Fusion Engineering, 1983

S. S. Gould, L. R. Layman, and D. L. Million, "Computer-Based Data Acquisition System in the Large Coil Test Facility," p. 905. (2.3.7.1)

First Symposium on Space Nuclear Power Systems, Albuquerque, New Mexico, January 11–13, 1984

J. L. Anderson and L. C. Oakes, "Instrumentation and Controls Evaluation for Space Nuclear Power Systems." (3.4.1)

Panel Discussion—Update: Loss of ac in Nuclear Power Stations, Dallas, January 29–February 3, 1984

R. E. Battle, "Reliability of Emergency ac Power Systems at Nuclear Power Plants."

Seventeenth Midyear Topical Meeting of the Health Physics Society, Pasco, Washington, February 5–9, 1984; Proceedings

B. A. Berven, M. S. Blair, C. A. Little, R. W. Doane, P. T. Perdue, "Application of Computers in a Radiological Survey Program." (1.7.8)

R. W. Doane, B. A. Berven, and M. S. Blair, "A Computer-Controlled System for Rapid Soil Analysis of Ra-226." (1.7.10)

C. A. Little, M. S. Blair, and T. R. Barclay, "Specific Uses of a Data Management System for Data Reduction and Tabulation." (1.7.9)

WATTec Energy Conference, Knoxville, Tennessee, February 21–24, 1984

T. V. Blalock, "Application of Johnson Noise Thermometry to the Calibration of Platinum Resistance Thermometers in Nuclear Power Plants." (3.6.3.1)

Advanced Instrumentation for Experiments in Engineering Mechanics Seminar/Workshop, Knoxville, Tennessee, March 7–8, 1984

J. E. Smith, D. R. McNeilly, and P. L. Butler, "A Transducer for Steam and Water Environment with Associated Electronics and Diagnostics."

Waste Management Symposium, Tucson, Arizona, March 11–15, 1984

M. J. Feldman and W. R. Hamel, "The Advancement of Remote Systems Technology: Past Perspectives and Future Plans." (2.7.5)

Fourth International Symposium on Heating in Toroidal Plasmas, Rome, March 21–28, 1984

A. J. Wootton, S. C. Bates, J. D. Bell, C. E. Bush, B. A. Carreras, W. A. Cooper, J. L. Dunlap, P. H. Edmonds, [illegible]. Eldridge, A. C. England, W. L. Gardner, J. T. Hogan, W. A. Houlberg, H. C. Howe, D. P. Hutchinson, R. C. Isler, T. C. Jernigan, R. R. Kindsfather, P. W. King, R. A. Langley, E. A. Lazarus, J. F. Lyon, C. H. Ma, P. K. Mioduszewski, M. Murakami, L. E. Murray, G. H. Neilson, V. K. Paré, M. J. Saltmarsh, S. D. Scott, J. Sheffied, D. J. Sigmar, J. E. Simpkins, K. A. Stewart, W. L. Stirling, C. E. Thomas, R. M. Wieland, J. B. Wilgen, and W. R. Wing, "Balanced Beam Experiments on ISX-B."

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F. J. Sweeney, "Influence of Fuel Vibration on Ex-Core Neutron Noise at Sequoyah-1 PWR."

Twentieth International Symposium, Advances in Chromatography, New York, April 16–19, 1984

R. S. Brazell and R. A. Todd, "A New Design for Helium Ionization Detection," pp. 257–68. (1.4.8)

ANS Topical Meeting on Robotics and Remote Handling in Hostile Environments, Gatlinburg, Tennessee, April 23–27, 1984; Proceedings

J. Barhen, S. M. Babcock, W. R. Hamel, E. M. Oblow, G. N. Saridis, G. de Saussure, A. D. Solomon, and C. R. Weisbin, "Basic Research on Intelligent Robotic Systems Operating in Hostile Environments: New Developments at ORNL," pp. 105–16. (2.7.16)

W. R. Hamel and M. J. Feldman, "The Advancement of Remote Systems Technology: Past Perspectives and Future Plans," pp. 11–24. (2.7.5)

J. N. Herndon and W. R. Hamel, "Analysis of the Options—Rationale for Servomanipulator Maintenance in Future Reprocessing Plants," pp. 439–42.

J. N. Herndon, D. G. Jelatis, C. E. Jennrich, H. L. Martin, and P. E. Satterlee, Jr., "The State-of-the Art Model M-2 Maintenance System," pp. 147–54. (2.7.10)

D. P. Kuban and H. L. Martin, "An Advanced Remotely Maintainable Force-Reflecting Servomanipulator Concept," pp. 407–15. (2.7.6)

H. L. Martin, W. R. Hamel, S. M. Killough, and R. F. Spille, "Control and Electronic Subsystems for the Advanced Servomanipulator," pp. 417–24. (2.7.8)

P. E. Satterlee, Jr., H. L. Martin, and J. N. Herndon, "Control Software Architecture and Operating Modes of the Model M-2 Maintenance System," pp. 355–66. (2.7.9)

R. S. Stoughton, H. L. Martin, and R. R. Bentz, "Automatic Camera Tracking for Remote Manipulators," pp. 383-93. (2.7.12)

Spring Meeting of the American Physical Society, Washington, D.C., April 23–26, 1984

C. H. Johnson, N. W. Hill, J. A. Harvey, and D. J. Horen, "Afterpulses at Several Microseconds for an RCA-8854 Multiplier."

Symposium on Applications of Radiation Thermometry, National Bureau of Standards, Gaithersburg, Maryland, May 8, 1984

R. L. Anderson, "Methods of Calibration at a National Laboratory." (2.9.9.1)

1984 Carnahan Conference on Security Technology, Lexington, Kentucky, May 16–18, 1984; Proceedings

J. A. Russell, Jr. and G. M. Fuller, Sr., "The Use of Multiple Cables Versus a Multichannel Cable for Television Signal Transmission," pp. 99–101. (1.6.6)

Thirteenth American Society Information Science Midyear Meeting, Bloomington, Indiana, May 20–23, 1984

D. R. Patek, J. M. Jansen, Jr., J. L. Redford, W. B. Ewbank, and J. S. Wright, "A Microcomputer-Mediated Electronic Bulletin Board." (2.5.1)

D. G. Prater, "Local Area Networks: Applications in the Instrumentation and Controls Division at Oak Ridge National Laboratory." (4.5)

Industrial Research Institute Conference, "Spotlight on Oak Ridge," Oak Ridge, Tennessee, May 22–24, 1984

D. T. Bostick, J. E. Strain, D. D. McCue, R. E. Harper, and R. D. Seals, "Remote Analyzer for Multicomponent Process Streams: RAMPS." (2.8.7)

Workshop on Instrumentation for the Advanced High-Flux Reactor, Oak Ridge, Tennessee, May 30, 1984; Proceedings

J. B. Davidson, "Scintillation Neutron Detectors," pp. 21–27. (Invited) (3.1.1)

1984 Annual Meeting of the American Nuclear Society, New Orleans, June 3–8, 1984; Trans. Am. Nucl. Soc. 46

J. March-Leuba, D. N. Fry, M. E. Buchanan, and C. O. McNew, "Evaluation of the Effect of a New 9 × 9 Fuel Design on Local Stability in Dresden 2," pp. 746–47. (3.3.3)

J. March-Leuba, R. B. Perez, and D. G. Cacuci, "Calculation of Limit Cycle Amplitudes in Commercial Boiling Water Reactors," pp. 749–50. (3.3.2.1)

J. T. Mihalczo, "Benchmarking Critical Safety Calculations with Subcritical Experiments," pp. 451–52.

D-J. Shieh and B. R. Upadhyaya, "Inference of Core Coolant Flow Parameters from Neutron-Coolant Temperature Noise Analysis in PWRs," pp. 847–49. (3.3.7)

F. J. Sweeney and J. March-Leuba, "Influence of Fuel Vibration on PWR Neutron Noise Associated with Core Barrel Motion," pp. 734–35. (3.3.5.2)

F. J. Sweeney, "In-Core Coolant Velocity Measurements in a Pressurized Water Reactor Using Temperature-Neutron Noise Cross Correlation," pp. 736 38. (3.3.5.2)

G. Verdú, J. L. Munoz-Cobo, J. T. Mihalczo, and W. T. King, "Spatial Effect Corrections to Subcriticality Measurements by the ^{252}Cf-Source-Driven Neutron Noise Analysis Method," pp. 452–53.

R. T. Wood, J. March-Leuba, R. B. Perez, and F. J. Sweeney, "A Stochastic Model to Monitor Mechanical Vibrations in Pressurized Water Reactors," pp. 735–36.

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S. M. Babcock and J. Barhen, "Real-Time Algorithms for Robotic Control of Teleoperators," pp. 19-72 through 19-78. (2.7.17)

H. L. Martin and W. R. Hamel, "Joining Teleoperation with Robotics for Advanced Manipulation in Hostile Environments," pp. 901–17. (2.7.3)

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T. J. Burns, R. D. Cheverton, G. F. Flanagan, J. D. White, D. G. Ball, L. B. Lamonica, and R. Olson, "Pressurized Thermal Shock Evaluation of the Oconee-1 Nuclear Power Plant." (3.5.4.1)

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W. R. Hamel, M. J. Feldman, and H. L. Martin, "Advanced Teleoperation in Nuclear Applications," pp. 302–5. (Invited) (2.7.4)

First World Conference on Robotics Research: The Next Five Years and Beyond, Lehigh University, Bethlehem, Pennsylvania, August 14–16, 1984; Proceedings

J. Barhen and S. M. Babcock, "Parallel Algorithms for Robotic Dynamics." (2.7.15)

Seventh International Conference on Structural Mechanics in Reactor Technology, Chicago, August 22–26, 1984

F. J. Sweeney and J. P. Renier, "Sensitivity of Ex-Core Neutron Detectors to Vibrations of PWR Fuel Assemblies." (3.3.5.1)

ANS Topical Meeting on Fuel Reprocessing and Waste Management, Jackson Hole, Wyoming, August 26–29, 1984

M. J. Feldman and W. R. Hamel, "The Advancement of Remote Systems Technology: Past Perspectives and Future Plans."

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J. B. Davidson, "Electronic Autofluorography: Principles, Problems, and Prospects," pp. 235–51. (Invited) (3.8.3)

IAEA Ninth International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Baltimore, September 1–8, 1984

B. A. Carreras, J. L. Dunlap, W. A. Cooper, R. A. Dory, T. C. Hender, M. Murakami, V. K. Paré, A. J. Wootton, J. D. Bell, L. A. Charlton, H. R. Hicks, J. A. Holmes, V. E. Lynch, R. M. Wieland, P. H. Diamond, and P. L. Similon, "MHD Activity in the ISX-B Tokamak: Experimental Results and Theoretical Interpretation." (3.3.11.1)

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R. M. Carroll and R. L. Shepard, "The Effects of Temperature on the Response Time of Thermocouples and Resistance Thermometers."

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R. C. Juras, J. A. Biggerstaff, K. A. Erb, P. A. Kloeppel, and R. O. Sayer, "The ORNL 25-MV Tandem Control System."

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IAEA/OECD Nuclear Energy Agency Seminar, Remote Handling Equipment for Nuclear Fuel Cycle Facilities, Harwell, Great Britain, October 2–5, 1984

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Fourth Specialists' Meeting on Reactor Noise (SMORN-IV), Dijon, France, October 15–19, 1984; Proceedings

D. N. Fry, G. P. Horne, and C. W. Mayo, "Report of the First United States Conference on Utility Experience with Neutron Noise Analysis." (3.3.4.1)

J. March-Leuba and C. M. Smith, "Development of an Automated Diagnostics System for Boiling Water Reactor Stability Measurements." (3.3.2)

J. A. Mullens, J. A. Thie, and L. R. Campbell, "On-Line Noise Monitoring at the Fast Flux Test Facility." (3.3.8)

J. A. Mullens and J. A. Thie, "Modeling and Diagnostic Techniques Applicable to the Analysis of Pressure Noise in Pressurized Water Reactors and Pressure-Sensing Systems." (3.3.6.2)

C. M. Smith and R. C. Gonzalez, "Long-Term Automated Surveillance of a Commercial Nuclear Power Plant." (3.3.9)

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Meeting of the American Physical Society, Nashville, Tennessee, October 18–20, 1984; Bull. Am. Phys. Soc. 29(7)

B. L. Burks, D. J. Horen, R. L. Auble, F. E. Bertrand, J. L. Blankenship, J. L. C. Ford, Jr., E. E. Grass, D. C. Hensley, R. O. Sayer, D. Shapira, and T. P. Sjoreen, "A Coupled-Channels Analysis of Elastic and Inelastic Scattering of ^{18}O from ^{28}Si," p.1026. (1.2.18)

IEEE 1984 Nuclear Science Symposium, Orlando, Florida, October 31–November 2, 1984; IEEE Trans. Nucl. Sci.

W. T. King, "Technique for Reduction of Coherence Function Bias Error." (3.3.1.2)

M. K. Kopp and K. H. Valentine, "Paralleling of Preamplifier Input Stages for Low-Noise Wideband Termination of Low-Impedance Transmission Lines." (3.1.5)

M. K. Kopp, K. H. Valentine, G. C. Guerrant, and F. W. Manning, "New Method of Proportional Counter Feedback Biasing for Wide-Range Radiation Dose-Rate Monitor." (3.1.4)

J. T. Mihalczo and W. T. King, "Absolute Subcriticality Measurement Without Calibration and Detection Efficiency Dependence by the ^{252}Cf-Source-Driven Noise Method." (3.3.1.1)

K. H. Valentine, M. K. Kopp, G. W. Allin, W. T. Clay, and V. C. Miller, "An Ultrahigh-Sensitivity Threshold Neutron Detector for Plasma Diagnostics." (3.1.7)

Thirty-Eighth Tobacco Chemicals Research Conference, Atlanta, November 5–8, 1984

R. A. Jenkins, R. W. Holmberg, T. M. Gayle, G. W. Allin, and S. K. Holliday, "A Variable Puff Parameter Smoking Machine for Smoke Composition Studies." (3.1.9)

1984 Winter Meeting of the American Nuclear Society, Washington, D.C., November 11–16, 1984; Trans. Am. Nucl. Soc. 47

W. T. King, J. T. Mihalczo, and E. D. Blakeman, "Preliminary Investigation of the ^{252}Cf-Source-Driven Noise Analysis Method of Subcriticality Measurement in LWR Fuel Storage and Initial Loading Applications," pp. 239–40.

J. March-Leuba, "The Pole-Zero Configuration of the Boiling Water Reactor Transfer Function," pp. 420–21. (3.3.2)

Symposium on New Technologies in Nuclear Reactor Power Plant Instrumentation and Control, Washington, D.C., November 28–30, 1984

D. N. Fry, M. E. Buchanan, E. L. Machado, J. A. Mullens, R. E. Pérez, C. M. Smith, F. J. Sweeney, J. A. Thie, B. R. Upadhyaya, and R. T. Wood, "Supplemental Plant Status Monitoring with an Automated Noise Surveillance and Diagnostic System."

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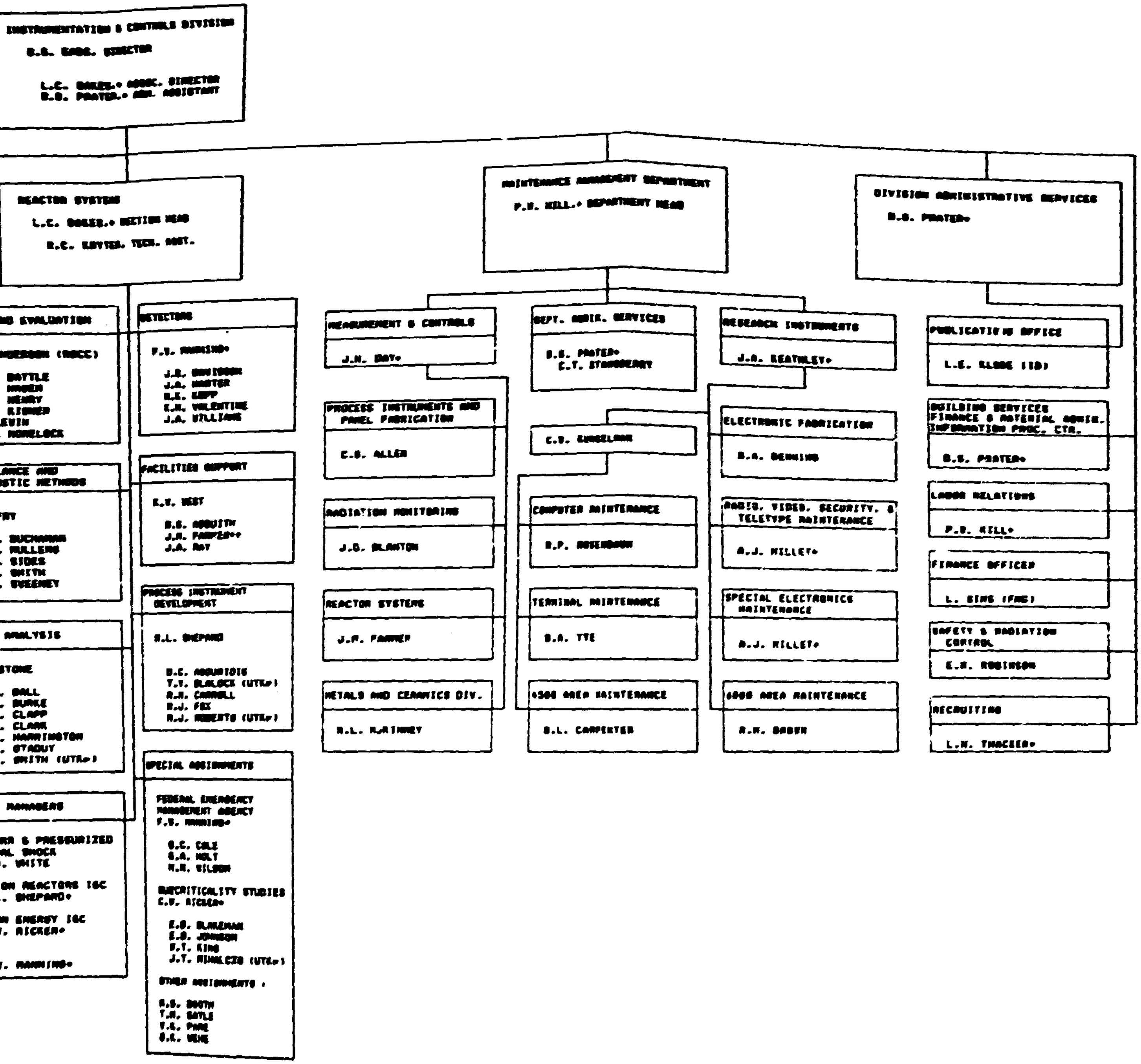
•	DUAL CAPACITY
••	MAINTENANCE DEPT.
(••)	PART-TIME EMPLOYEE
(UTK•)	UNIV. of TENN. PART-TIME
(•)	CONSULTANT or CONTRACTOR
(UTKs)	UNIV. of TENN. CONTRACT
(MSCC)	MOANE STATE COM. COL. ST[...]
(AVD!)	TEMP. ASSIGNMENT to AVLI[S]
(ID)	INFORMATION DIV.
(FRD)	FUEL REPROCESSING DIV. L[...]

B. G. Eads	JUNE 30, 1984
DIVISION DIRECTOR	



SYMBOL LEGEND

*	AL CAPACITY
**	MAINTENANCE DEPT.
(pt)	PART-TIME EMPLOYEE
(UTK*)	UNIV. of TENN. PART-TIME EMP.
(c)	CONSULTANT or CONTRACTOR
(UTKc)	UNIV. of TENN. CONTRACT
(ROCC)	ROANE STATE COM. COL. STAFF
(AVDT)	TEMP. ASSIGNMENT to ANLIS DIV.
(ID)	INFORMATION DIV.
(FRD)	FUEL REPROCESSING DIV. LOAN

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ACRONYMS

AACE Athens automation and control experiment
AACETS Athens automation and control experiment test system
ABR advanced breeder reactor
ACES annual cycle energy system
ACUREX monitoring equipment manufacturer
A/D analog-to-digital
ADC analog-digital converter
AGC Advanced Gas Centrifuge
AHPT Absorption Heat Pump Test
AIRS Advanced Instrumentation for Reflood Studies
AI artificial intelligence
ANL Argonne National Laboratory
APT programming language
ARCADES automatic RADIAC calibration and diagnostic equipment system
ASCII programming language
ASM advanced servomanipulator
ASSEMBLER programming language
ATE automatic testing equipment
AVLIS Atomic Vapor Laser Isotope Separation
AUB Athens Utilities Board

BASIC programming language
BIMOS bipolar/MOSFET process
BRS broad-range spectrometer
BSR *Bulk Shielding Reactor*
BTD breakthrough detector

CADAM programming language
CADRE computer-assisted detection and reporting enhancement
CAMAC computer-automated measurement and control
CATV cable television
CBCS carbon-bonded carbon fiber
CBM Commodore Business Machine
CCF common cause failure
CCTF Cylindrical Core Test Facility
CESAR Center for Engineering Systems Advanced Research
CEUSP Consolidated Edison Uranium Solidification Program
CFRP Consolidated Fuel Reprocessing Program
CFTL Component Flow Test Loop
CIM computer-integrated manufacturing
CMOS complementary metal-oxide semiconductor
CODAS computer-operated data acquisition system
COP coefficient of performance
CPU central processing unit
CRBR Clinch River Breeder Reactor
CRBRP Clinch River Breeder Reactor Project
CRT cathode ray tube
CSPT Core Support Performance Test
CTD Computing and Telecommunications Division

D/A digital-to-analog
DAC digital-to-analog converter
dc direct current
DCC data concentrater and controller
DEC Digital Equipment Corporation
DEM Department of Environmental Management
DLC dedicated loop controller
DMT dedicated microprocessor tester
DOE Department of Energy
DPMS differential pressure measurement system
DRC density reactivity coefficient

E-beam electron beam
EBIL Electron Beam Injector Laboratory
EBS Emergency Broadcast Station
EBT Elmo Bumpy Torus
EBT-S Elmo Bumpy Torus-scale
ECIP Energy Conservation Investment Program
ECL emitter control logic
EIS equipment interface system
emf electromotive force
EMI electromagnetic interference
EMP electromagnetic pulse
EOC Emergency Operating Center
E&OSD Environmental and Occupational Safety Division
EPRI Electric Power Research Institute
EPROM electronically programmable read-only memory
EROM electronically alterable read-only memory
ESP Enrichment Safeguards Program
EURI enriched uranium recovery improvements
EWB etched wiring board

FCTL Forced Convection Test Facility (loop)
FEMA Federal Emergency Management Agency
FESA Facilities Engineering Support Agency (U.S. Army)
FET field-effect transistor
FFT Fast Fourier Transform
FFTF Fast Flux Test Facility
FID field interface device
FMEA failure mode effects analysis
FORTH programming language
FORTRAN programming language
FRG Federal Republic of Germany

F.S.
FTE
FWH
GCEP
HFBR
HFIR
HHIR
HID
HPRR
HRA
HTGR
HTR
HV
IAEA
IBM F
LC
ICAM
ICS
IDB
IDL
IEDM
IEEE
INEL
INS
I/O
ISC
ISFM
ISTP
JAER
JFET
JMS
JPL
KWU
LAM
LAN
LANL
LC
LCB
LCD
LCR
LCTI
LD/I
LED
LET
LISP

ACRONYMS

Breeder Reactor Project
abe
Performance Test
ad Telecommunications

log
log converter

ater and controller
ment Corporation
f Environmental
nt
p controller
roprocessor tester
f Energy
essure measurement

vity coefficient

n Injector Laboratory
roadcast Station
Torus
Torus-scale
rvation Investment

ol logic
erface system
force
tic interference
tic pulse
perating Center
l and Occupational
sion
r Research Institute
programmable read-only

alterable read-only

afeguards Program
ium recovery
nts
board

ction Test Facility (loop)
gency Management Agency
ineering Support Agency
y)
ansistor
Transform
t Facility
device
effects analysis
language
language
blic of Germany

F.S.	full scale
FTE	full-time equivalent
FWHM	full width half maximum
GCEP	Gas Centrifuge Enrichment Project
HFBR	high-flux beam reactor
HFIR	High-Flux Isotope Reactor
HHIRF	Holifield Heavy Ion Research Facility
HID	helium ionization detector
HPRR	Health Physics Research Reactor
HRA	human reliability analysis
HTGR	High Temperature Gas-Cooled Reactor
HTR	high-temperature reactor
HV	high voltage
IAEA	International Atomic Energy Agency
IBM PC	International Business Machines
IC	inductance capacitance
ICAM	integrated control and measurement
ICS	integrated control system
IDB	instrument database
IDL	instrument development loop
IEDMS	integrated electrical distribution and management system
IEEE	Institute of Electrical and Electronics Engineers
INEL	Idaho National Engineering Laboratory
INS	Immigration and Naturalization Service
I/O	input/output
ISC	intelligent system computer
ISFMTF	International Fusion Superconducting Magnet Test Facility
ISTP	Integrated System Test Plan
JAERI	Japan Atomic Energy Research Institute
JFET	junction field effect transistor
JMS	Job Management System
JPL	Jet Propulsion Laboratories
KWU	Kraftwerk Union
LAM	look-at-me, local area monitor
LAN	local area network
LANL	Los Alamos National Laboratory
LC	inductance capacitance
LCBWS	load-cell-based weighing system
LCD	liquid crystal display
LCR	load control receiver
LCTF	Large Coil Test Facility
LD/DCC	laser diagnostic/data concentrater and controller
LED	light-emitting diode
LET	linear energy transfer
LISP	advanced programming language
LLFM	low-level flux monitor
LMFBR	liquid metal fast breeder reactor
LOCA	loss-of-coolant accident
LOFT	loss-of-fluid test
LPR	load profile recorder
LSPTS	large-scale procurement of temperature sensors
MAA	materials access area
MACES	Measurement and Controls Engineering Section
MAINS	Maintenance Information System
M&C	Metals & Ceramics Division
MCA	multichannel analyzer
MCC	module control computer
MDRL	Metrology Research and Development Laboratory
MHDM	Materials Handling Development Module
MECL	Motorola emitter coupled logic
MFE	magnetic fusion energy
MI	mineral-insulated
MIT	Massachusetts Institute of Technology
MOS	metal-oxide semiconductor
MOSFET	MOS field effect transistor
MPC	maximum permissible concentration
MSRE	Molten Salt Reactor Experiment
MTBF	mean time between failures
MWPD	multiwire proportional detector
NAF	number, address, function code
NBS	National Bureau of Standards
NBSR	National Bureau of Standards Reactor
NEC	National Electrical Code
NEMA	National Electrical Manufacturers' Association
NIM	nuclear instrument module
NNI	nonnuclear instrumentation
NRC	Nuclear Regulatory Commission
NSF	National Science Foundation
NSLS	national synchrotron light source
OPS	programming language
OPS-5	advanced programming language
ORELA	Oak Ridge Electron Linear Accelerator
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORIC	Oak Ridge Isochronous Cyclotron
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations
ORR	Oak Ridge Research Reactor
ORRDAC	ORR data acquisition system
OWR	Omega West Reactor
PAM	perimeter air monitor
PASCAL	programming language
PC	personal computer
PCA	Pool Critical Assembly

PEB	Process Evaluation Board
PEM	portable energy monitor
PERALS	photon-electron rejecting alpha liquid scintillation
PEV	process evaluator
PIG	particulate, iodine, and gas
PLC	programmable controller
PM	photomultiplier
PMT	photomultiplier tube
PPAC	parallel plate avalanche counter
PPAD	parallel plate avalanche detector
PROM	programmable read-only memory
PSD	power spectral density
PSDREC	computer program
PSPC	position-sensitive proportional counter
PTS	pressurized thermal shock
PTU	pole-top units
PWR	pressurized water reactor
QA	quality assurance
RADIAC	radiation detection, indication, and computation
RAM	random-access memory
RASA	remedial action and survey activities
RC	resistance capacitance
rf	radio frequency
RIS	Research Instruments Section
rms	root mean square
ROM	read-only memory
RPV	reactor pressure vessel
RSS	reactor scram system; Reactor Systems Section
RTD	resistive thermal device; resistance temperature detector; residence time distribution
RTG	radioisotope thermionic generator
RTRA	roof thermal research apparatus
RTS	reactor trip system
RTU	remote terminal unit
RVLIS	reactor vessel level indicating system
SAI	Science Applications, Inc.
SAM	security alarm monitoring system
SANS	small-angle neutron scattering
SAXS	small-angle X-ray scattering
SBLOCA	small-break LOCA
SCADA	supervisory control and data acquisition
SCR	silicon-controlled rectifier
SCTF	Slab Core Test Facility
SIMS	secondary ion mass spectrometry
SRC	solvent refined coal
SRL	structural return loss
STP	smart test panel
TC	thermocouple
TEC	Technology for Energy Corp.
TECH	Tennessee energy conservation in housing
Tempest	study of compromising emanations
THORS	Thermal Hydraulic Out-of-Reactor Safety
THTF	Thermal Hydraulic Test Facility
TLD	thermoluminescent dosimeter
TMI	Three Mile Island
TOF	time-of-flight
TPD	tons per day
TRUPACT-I	transuranic package transporter
TREAT	transient reactor test facility
TSF	Tower Shielding Facility
TSR	Tower Shield Reactor
TTL	transistor-transistor logic
TURF	Thorium-Uranium Recycle Facility
TWC	through-the-wall crack
UART	universal asynchronous receiver-transmitter
UHSFC	ultrahigh-sensitivity fission counter
UPTF	Upper Plenum Test Facility
USI	unresolved safety issue
VCR	video cassette recorder
VDC	vertical drift chamber
VMOS	vertical metal-oxide semiconductor
VPIS	videodisk personnel identification system
WAND	wide-angle neutron diffractometer
WIDD	workspace intrusion inspection device

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