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# Instrumentation and Controls Division

## Biennial Progress Report

FOR PERIOD SEPTEMBER 1, 1974, TO SEPTEMBER 1, 1976

Non-LMFBR Programs

MASTER

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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# INSTRUMENTATION AND CONTROLS DIVISION
# BIENNIAL PROGRESS REPORT
## For Period September 1, 1974, to September 1, 1976

**Non-LMFBR Programs**

C. J. Borkowski, Director
R. A. Dandl, Associate Director
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**Compiled by G. S. Sadowski**

**Date Published: November 1976**



OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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| ORNL-5032 | Period Ending September 1, 1974 |
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# Foreword

The role of the Instrumentation and Controls Division in the activities of the Laboratory is one of wide diversification and covers many technical disciplines. A major effort of the Division is to provide professional service for the design, development, procurement, fabrication, installation, testing, and repair of many kinds of instruments. Another effort of the Division deals with instrumentation systems that protect or control complex processes such as chemical plants and nuclear reactors, which requires an understanding of the kinetic behavior of the processes during both normal and abnormal conditions. Thus, part of the work of the Division is directed toward the analysis and evaluation of the dynamic behavior of large plants and facilities. It is only natural that the Division is participating in the preparation of standards and criteria for instrumentation systems for the control and protection of nuclear reactors.

It is our purpose in this report to tell what work we did – not how we did it. Since instrument services are provided for almost all Laboratory divisions, we describe the scope of the work and its range of complexity from very simple components to complex, sophisticated systems. We hope that from this information our scientific readers at the Laboratory will have a better understanding of the technological level and capability of this Division and perhaps will obtain some ideas on how some application described herein might be beneficially applied to other experimental work. Another purpose of this report is to announce new or improved designs of instruments, new methods of measurement, accessories, etc., which represent a lower cost or improved performance over an existing unit or are noteworthy for some other reason, such as extending the range of application.

Most topics are reported briefly, only one or two paragraphs. If a report or a journal article has been published or submitted for publication or if a paper has been given or proposed, the abstract is included here. We hope that interested readers desiring more information on any topic will call or write any of the persons whose names are listed with each topic.

**NOTICE**

# 1. Basic Electronics Developments

## 1.1 DERIVATION OF THE POINT SPREAD FUNCTION FOR ZERO-CROSSING-DEMODULATED POSITION-SENSITIVE DETECTORS[1]

C. H. Nowlin

A high-quality approximation to the point spread function for position-sensitive detectors (PSDs) that use pulse-shape modulation and crossover-time demodulation was mathematically derived. The approximation was determined as a general function of the input signals to the crossover detectors to enable later determination of optimum position-decoding filters for PSDs. This work is precisely applicable to PSDs that use either RC or LC transmission line encoders. The effects of random variables, such as charge-collection time, in the encoding process are included. In addition, derivation of this function presents a new, rigorous method for the determination of upper and lower bounds for conditional crossover-time distribution functions (closely related to first-passage-time distribution functions) for arbitrary signals and arbitrary noise covariance functions.

1. Abstract of ORNL-5081 (to be published).

## 1.2 POINT SPREAD FUNCTIONS AND OPTIMUM FILTERS FOR POSITION-SENSITIVE DETECTORS THAT USE PULSE-SHAPE MODULATION AND ZERO-CROSSING DEMODULATION[1]

C. H. Nowlin

To enable the later determination of nearly optimum, realizable position-decoding filters for position-sensitive detectors (PSDs) and to enable valid comparisons of various PSDs, a productive, high-quality approximation to the point spread function for PSDs that use pulse-shape modulation and crossover-time demodulation is introduced in this work. This approximation is the result of a theoretical calculation and was determined as a general function of the input signal and rms noise at the input to each of the two crossover detectors. It is precisely applicable to PSDs that use any type of transmission line encoding. The effects of random variables, such as charge-collection time, are included in the calculation, but the effects of correlated noise in the two channels are not included. For the broad class of PSDs for which electronic and thermal noise is the dominant cause of position uncertainty, general equations, based on the approximate point spread function, are given for the optimum filter impulse responses, for the optimum pulse shapes at the inputs to the crossover detectors, and for the associated minimum positional full width at half maximum (FWHM). General equations are also given for the positional FWHM of electronic-noise-limited detectors that use nonoptimum filters. Finally, for electronic-noise-limited detectors that use an RC transmission line encoder that is terminated into its characteristic impedance, a plot is given of the optimum pulse shape at the input to the crossover detectors.

1. Abstract of paper to be published in the *Review of Scientific Instruments.*

## 1.3 DESIGN AND PROPERTIES OF POSITION-SENSITIVE PROPORTIONAL COUNTERS USING RESISTANCE-CAPACITANCE POSITION ENCODING[1]

C. J. Borkowski M. K. Kopp

The construction and signal processing methods of several experimental, gas-filled position-sensitive proportional counters using RC position encoding are described, and guidelines for the design and operation of these counters are given.

Using these guidelines, the spatial resolution was improved, and the signal processing time was shortened; for example, the intrinsic spatial uncertainty in the position measurement was reduced to 28 $\mu$ FWHM for alpha particles and 100 $\mu$ FWHM for low-energy x rays (2 to 6 keV). Also, the signal processing time was reduced to 0.6 $\mu$sec without seriously degrading the spatial resolution.

These results have widened the field of application of the RC position-encoding method for position measurements of low-energy photons, neutrons, and charged particles in a wide variety of nuclear physics experiments; in nuclear medicine imaging; and in low-dose, medium-resolution radiography.

1. Abstract of published paper: *Rev. Sci. Instrum.* **46**(8), 951 (1975).

## 1.4 DEVELOPMENT OF A LOW-NOISE, HIGH COMMON-MODE, REJECTION INSTRUMENTATION AMPLIFIER[1]

K. Rush

Several previously used instrumentation amplifier circuits were examined in order to determine limitations and possibilities for improvement. One general configuration was then analyzed in detail, and methods for improvement are enumerated.

An improved amplifier circuit is described and analyzed relative to common-mode rejection and noise. Experimental data are presented that show good agreement between calculated and measured common-mode rejection ratios and equivalent noise resistance.

The new amplifier was shown to be capable of common-mode rejection in excess of 140 dB for a trimmed circuit at frequencies below 100 Hz and for equivalent white noise below 3.0 $nV/\sqrt{Hz}$ above 1000 Hz.

1. Summary of thesis submitted to the Graduate Council of the University of Tennessee in partial fulfillment of the requirements for the degree of Master of Science.

## 1.5 POLE-ZERO CANCELLATION IN THE FEEDBACK CIRCUIT OF WIDE-BAND PREAMPLIFIERS TO IMPROVE THE BASELINE STABILITY FOR HIGH COUNT RATES OR LARGE SIGNALS[1]

M. K. Kopp

Pole-zero cancellation was applied to the feedback circuit of wide-band preamplifiers to improve the baseline stability and reduce the saturation of the output for high count rates ($10^6$ counts/sec) or large output signals (>1 V), without compromising the bias point stabilization.

1. Abstract of published paper: *Rev. Sci. Instrum.* **46**(8), 1120 (1975).

## 1.6 PULSE-SHAPE DISCRIMINATION AMPLIFIER DEVELOPMENT

K. Rush

Development was begun of an instrument for pulse-shape discrimination of neutron and gamma pulses produced by a fast scintillator-photomultiplier system. A filter circuit that has a better timing resolution than either the RC-$(RC)^n$ or the double delay-line filters was devised. This circuit has only one delay line and is compensated to restore the signal lost due to skin effects in the cable delay line. A hybrid microcircuit, wide-band, linear differential amplifier, with high current-drive capability, is also being developed for use in the instrument.

## 1.7 POWER SUPPLY CONTROLLED BY PROM FUNCTION GENERATOR FOR CORE FLOW TEST LOOP

M. J. Roberts

To simulate power transients during a loss-of-coolant accident (LOCA), the core flow test loop requires a power supply that precisely and rapidly changes the power applied to the fuel pin simulators. A new power supply was designed for this purpose. The power is varied, through amplitude modulation of the applied voltage, by an arrangement of isolated transformer secondary voltages that are switched in different combinations by zero-fired SCRs. The result is a fast, precise, digitally controlled, power supply without the high-frequency noise of phase-fired SCR supplies.

This power supply (or any other supply that may ultimately be chosen) will be controlled by another new device, a PROM function generator (PFG), which generates control signals by reading out the contents of a programmable read-only memory (PROM). The PFG can generate analog or digital signals, under manual or automatic control, independently or in response to an external analog signal, with the inherent stability and accuracy of a digital machine. The PFG will find use in many applications beyond the scope of the core flow test loop.

## 1.8 HYBRID MICROCIRCUIT ACTIVITIES

J. T. De Lorenzo R. A. Todd E. J. Kennedy[1]
V. C. Miller C. A. Tucker H. N. Wilson

A contract between the Instrumentation and Controls Division and the Electrical Engineering Department of the University of Tennessee at Knoxville (UTK) was continued in order to study the properties of thick-film inks and to develop fabrication techniques for hybrid, thick-film microcircuits, including exchange of technical assistance and information between the two institutions ORNL personnel were allowed to use the UTK thick-film laboratory to evaluate thick-film techniques and to fabricate prototypic representative circuits A UTK graduate student worked 16 hr/week in the laboratory and received supervising assistance from the Electrical Engineering Department staff during 4 hr/week

Evaluation of both conductive and resistive thick-film inks was continued, and platinum-based conductive inks were evaluated as substitutes for inks formulated from palladium-based alloys, because platinum inks give better ultrasonic bonds Several commercially available resistive inks in a range from 1 to 10 kΩ per square were tested to determine the low-frequency excess noise properties and the effects of abrasive trimming on these properties

The UTK personnel partially transferred their assistance from the study phase in order to construct prototypic thick-film circuits (including artwork and mask fabrication) Several circuits, with all required resistor trimming, were constructed (Final assembly, which includes chip attachment, bonding, and packaging, was performed at ORNL.) These circuits included a fast current-pulse amplifier, an eight-channel, thermister temperature multiplexer, a charge-sensitive preamplifier, an overload clamp for a charge-sensitive preamplifier, a voltage-sensitive preamplifier, an electrometer, and a wide-band, linear, differential pulse amplifier with a high output-drive capability Active resistor trimming with the airbrasive trimmer was not successful because of abrasive overspray. Further work will be done to correct this problem

1 Consultant, Electrical Engineering Dept , University of Tennessee, Knoxville

## 1.9 HYBRID, THICK-FILM, TEMPERATURE MULTIPLEXER

R. A. Todd E. J. Kennedy[1] J M Rochelle

A hybrid, thick-film microcircuit was designed and fabricated to telemeter rotor temperatures from a high-speed centrifuge. The circuits operate with a centrifugal force of 30,000 *g* at 65°C After development at ORNL, the circuit was commercially fabricated and is in use at the Oak Ridge Gaseous Diffusion Plant

1 Consultant, Electrical Engineering Dept , University of Tennessee, Knoxville

## 1.10 HYBRID, THICK-FILM, VOLTAGE-SENSITIVE PREAMPLIFIER

R. A. Todd E. J. Kennedy[1] M. K. Kopp

A hybrid, thick-film, voltage-sensitive preamplifier was developed for use with position-sensitive proportional counters. The preamplifier stage configuration consists of a JFET input, a current-gain section, a high-current drive output, and a feedback that incorporates pole-zero cancellation.[2] Input devices were selected for high transconductance, and the bias current of the output transistors was stabilized by close thermal tracking of the base-spreading diodes. The circuit performance and especially the rise time of this preamplifier was better than that of a discrete model. As with other microcircuits, the performance from unit to unit was uniform.

1 Consultant, Electrical Engineering Dept , University of Tennessee, Knoxville
2 M K Kopp, *Rev Sci Instrum* **46**(8), 1120 (1975)

## 1.11 CHARGE-SENSITIVE PREAMPLIFIER WITH HYBRID, THICK-FILM, MICROCIRCUIT CONSTRUCTION

J. T. De Lorenzo E. J. Kennedy[1] N. W. Hill
V. C. Miller J. H. Todd R. A. Todd

For neutron experiments at the Oak Ridge Electron Linear Accelerator and at the Tower Shielding Facility, a small, charge-sensitive preamplifier was developed which can be mounted in photomultiplier tube bases and close to proportional counters. This close-coupled operation simplifies the cabling and overall instrumentation and eliminates an input connector. The reduction of input capacitance (∿3 pF) derived from the chip form of the input FET microcircuit construction and absence of an input connector significantly decreased the noise for the proportional counter application. The close-coupled arrangement also increased the effectiveness of an overload protective clamp (also constructed in a hybrid microcircuit form).

Several units were constructed, and only a few failed to operate and required minor reworking. The performance of all units equalled or was superior to that of a unit constructed from discrete components.

1 Consultant, Electrical Engineering Dept , University of Tennessee, Knoxville

## 1.12 HYBRID, THICK-FILM, ELECTROMETER AMPLIFIER

E. J. Kennedy[1] J. T. De Lorenzo
V. C. Miller R. A. Todd

A hybrid, thick-film, integrated circuit (IC) electrometer amplifier was developed for use in portable radiation-monitoring circuits and in other applications that require dc amplifiers with very low input bias currents. The circuit operates from power supplies that have output voltages within a range from ±6 to ±8 V. It is designed to operate with a total quiescent current of 150 $\mu$A with a ±10-V power supply, although the operating current is externally programmable to allow an increase in frequency bandwidth and slew rate. The open-loop gain is adjustable from 200 to 50,000.

This circuit is an improved version of the hybrid, thin-film, IC electrometer reported in 1974.[2]

1 Consultant, Electrical Engineering Dept , University of Tennessee, Knoxville
2 1974 Government Micro-Circuits Applications Conference (GOMAC), Boulder, Colorado, June 25–27, 1974

## 1.13 HYBRID, THICK-FILM, CURRENT-PULSE AMPLIFIER WITH POSITIVE INTERNAL FEEDBACK

R. A. Todd N. W. Hill

The principles of positive internal feedback were applied to current-pulse preamplifiers. Positive feedback has previously been used to stabilize the charge gain of charge-sensitive amplifiers for a change in detector capacitance. One of the authors (N. W. Hill) proposed that the beneficial attributes of positive feedback in charge-sensitive amplifiers, that is, gain stabilization and decrease in rise time with little degradation in the noise performance, might likewise improve the characteristics of a current-pulse preamplifier. The application required an input impedance of 10 Ω, a rise time <1 nsec, a current gain of 10, and an equivalent noise current less than the alpha-particle background from the fission chamber.

To satisfy both the input impedance and noise requirements, a common base configuration was used for the first stage. A common emitter input with 10 Ω shunted to ground to achieve the input impedance was a factor of 4 too noisy; however, the common base stage with a 10-Ω input resistor and a 40-pF detector had stability problems. Positive feedback increased the stability against oscillation by increasing the phase margin at the closed-loop crossover frequency, but the gain stability of the amplifier was inferior to the usual 50-Ω systems, due to the low loop transmission.

### 1.14 HYBRID, THICK-FILM, CURRENT-PULSE PREAMPLIFIER

J. T. De Lorenzo  E. J. Kennedy[1]
V. C. Miller  R. A. Todd

A hybrid, thick-film, current-pulse preamplifier was developed for use with fission chambers. Hybridization of this circuit resulted in a significant size reduction and an improvement in performance. The circuit (fabricated on a ½ X ½ in. ceramic substrate) contains four high-frequency transistors, ceramic chip capacitors, and seven thick-film resistors. Lead lengths and parasitic capacitances were kept to a minimum, which accounted for the reduction in rise time from 2.5 to 1.0 nsec. A comparison of several units showed a high uniformity of performance, as well as gain stability and linearity comparable to a discrete-component counterpart.

1. Consultant, Electrical Engineering Dept., University of Tennessee, Knoxville.

### 1.15 HYBRID, THICK-FILM, CURRENT-PULSE PREAMPLIFIER FOR USE WITH PROPORTIONAL COUNTERS IN HIGH GAMMA BACKGROUNDS

J. T. De Lorenzo  M. M. Chiles  V. C. Miller

The neutron assay of fuel sticks for the High-Temperature Gas-Cooled Reactor program has developed interest in processing the current pulse of proportional counters in order to reduce the pileup of a large gamma background. A current-pulse preamplifier with a current gain of 100 was constructed from two hybrid, thick-film microcircuit modules for this application. The circuit design of the module is similar to that used in the discrete version, ORNL model Q-3125.[1,2]

The rise time is more than a factor of 2 superior to the discrete version, but the input noise is ~1.4 times higher. The second transistor and the thick-film resistors are believed to be the sources of the excess noise.

1. J. T. De Lorenzo, *Instrumentation and Controls Div. Annu. Prog. Rep. Sept. 1, 1970,* ORNL-4620.
2. J. T. De Lorenzo, "Low Noise, Wide-Band, Current-Pulse Preamplifiers for Neutron Counters," *IEEE Trans. Nucl. Sci.* **18**(2), 114–16 (April 1971).

### 1.16 OVERLOADING CLAMP PREAMPLIFIER WITH HYBRID, THICK-FILM CONSTRUCTION

J. T. De Lorenzo  N. W. Hill
V. C. Miller  R. A. Todd

Particle detectors using photomultiplier tubes and charge-sensitive preamplifiers at the Oak Ridge Electron Linear Accelerator are plagued with the large transients created by the gamma flash generated at the beam target. Overloading circuits have been designed (N. W. Hill) to reduce the transient created in charge-sensitive preamplifiers. A hybridized, thick-film version of a successful discrete design was created with the expectation of obtaining improved performance, particularly if coupled to a hybridized version of a charge-sensitive preamplifier. Although the performance of the all-hybrid circuits did not show any improvement over an all-discrete design, the microcircuit devices were more compact and easily assembled, and their performance was reproducible.

# 2. Instrument Development

## POSITION-SENSITIVE DETECTION SYSTEMS

### 2.1 LINE-SCANNING PROPORTIONAL-COUNTER PHOTON CAMERA[1]

C. J. Borkowski M. K. Kopp J. A. Harter

A new method was developed for imaging spatial distributions of photons, charged particles, or neutrons over large areas by a line-scanning camera. This camera uses a linear position-sensitive proportional counter (PSPC) based on RC position encoding.

Applications of this camera include low-dose, medium-resolution radiography of large objects (>2 X 2 m); and, in nuclear medicine, low-dose, whole-body radionuclide imaging and radiography with low-energy photons (<150 keV).

A prototypic camera was built and tested to scan an area of 60 X 100 cm. The spatial resolution is 1 X 1 mm FWHM for radiography with 60-keV photons and 3 X 3 mm FWHM for radionuclide imaging with 50-keV photons (limited by collimator resolution).

Compared with point-by-point scanning, the line-scanning method reduces the mechanical complexity of the camera and eliminates problems encountered in construction of large-area, high-pressure PSPCs. This method is superior to the area PSPC for imaging objects >60 X 60 cm.

1. Abstract of published paper: *IEEE Trans. Nucl. Sci.* **NS-22**(2), 896 (1975).

### 2.2 LARGE-AREA PROPORTIONAL-COUNTER PHOTON CAMERA

C. J. Borkowski M. K. Kopp V. A. McKay

A large-area, proportional-counter photon camera was designed for imaging low-energy (<150 keV) radionuclide distributions, as well as for low-dose, medium-resolution radiography of the human torso. The camera consists of a channel collimator, a two-dimensional position-sensitive proportional counter, and an electronic data-acquisition and display unit.[1]

The counter dimensions are 54 X 95 X 25 cm high, and its sensitive area is 44 X 79 cm. Electronic depth discrimination permits selection of counter depths of 44, 77, 117, 171, or 224 mm and enables selection of the most favorable resolution, the most favorable sensitivity, the optimum of the two, and all of the preceding if needed. Components for the counter were fabricated, and tests of subassemblies were completed.

The area of the channel collimator is 45.7 X 80.47 cm. It has 107,445 apertures that have a 1.36-mm effective diameter, septa of ¼-mm lead thickness, and a 30-mm height. The optimum aperture parameters were determined by using a recently developed probabilistic point spread function calculation program.[2] Test results from measurements with small-area collimators were in good agreement with the program.

1 C J Borkowski and M K Kopp, *Rev Sci Instrum* 46(8), 951 (1975)
2 J L Blankenship, unpublished program

## 2.3 FLY'S EYE, A COUNTING CAMERA FOR THERMAL NEUTRONS SOME APPLICATIONS PROBLEMS AND PROSPECTS[1]

J B. Davidson

An area detector for thermal neutrons based on image intensification techniques is described Some capabilities and limitations of the detection system are discussed Among the former are high spatial resolution, high instantaneous counting rate, electronic zoom, time-gating, and integration The detector is limited in that the maximum counting rate for a resolution element is 60 regularly spaced counts per second Also, the nonuniformity of response over the detector limits the useful size and requires point-by-point calibration. In addition, a higher efficiency for neutron detection would be desirable Some typical applications of the system are crystal inspection, neutron magnetic diffraction topography, and searches for temperature-induced changes in diffraction patterns The future applications of solid-state television sensors and microchannel plate intensifiers to improve the system are briefly mentioned

1 Summary of invited paper presented to the Brookhaven Symposium in Biology No 27, "Neutron Scattering for the Determination of Biological Structure," June 2–6, 1975

## 2.4 APPLICATIONS OF THE FLY'S EYE NEUTRON CAMERA: DIFFRACTION TOMOGRAPHY AND PHASE TRANSITIONS[1]

J. B. Davidson A L. Case

The Fly's Eye Neutron Camera[2] is a detector consisting of a 150-mm-diam image-intensifier tube that is fiber optically coupled to an SEC-TV camera tube A neutron-sensitive phosphor layer contacts the input fiber optic faceplate of the image-intensifier tube Neutron-induced scintillations in the phosphor are intensified and then stored on the target of the camera tube until scanned by its electron beam As the scanning detects and the beam erases the spots, the coordinates of the scintillations are derived from the beam deflection timing and are stored in a 200- by 100-channel magnetic core memory.

Development was started on electronic techniques to improve the vertical spatial resolution, and tests to improve the detector nonuniformity were continued. The application of the new solid-state TV detectors was pursued because of their inherent geometric fidelity and digital readout

Neutron diffraction topographs and tomographs including magnetic diffraction were made to illustrate the submillimeter resolution capability of the system. The system was applied to the observation of phase changes in crystals.

1 Abstract of paper presented at the International Conference on Neutron Scattering, Gatlinburg, Tenn , June 6–10, 1976
2 J B Davidson, *J Appl Crystallogr* 7(3), 356 (1974)

## 2.5 APPLICATION OF SEC-TV DETECTOR TO NEUTRON DIFFRACTION[1]

J. B. Davidson

A TV-based neutron detector and counting system is described. The detector consists of a 6-in.-diam image intensifier coupled to an SEC-TV camera tube. A neutron-sensitive phosphor on the input fiber optic produces scintillations that are stored temporarily as single events on the target of the camera tube. As the tube is scanned, the coordinates of the events are determined with a pair of time-to-amplitude converters. The coordinate pulses address the memory of a 20 K channel, two-parameter, pulse-height analyzer, and the events are stored in the magnetic core memory. After the neutron image is accumulated, it can be displayed in isometric, contour, and elevation views and recorded on magnetic tape for computer processing. Applications to neutron diffraction, crystal topography, and radiography will be illustrated. Extension of the techniques to low-level x-ray and light-photon counting will be briefly discussed.

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1. Abstract of invited paper presented at the Eighteenth Conference on Analytical Chemistry in Nuclear Technology, Gatlinburg, Tenn., Oct. 22–24, 1974.

## 2.6 CLINICAL TESTING, LINE-SCANNING PROPORTIONAL COUNTER CAMERAS

C. J. Borkowski J. A. Harter

Two prototypic line scanners were tested at the Oak Ridge Associated Universities (ORAU) Medical Division. These tests included detector system evaluation and optimization; thyroid, lung, and liver phantom studies; and clinical scans of 100 thyroid outpatients.

Detector energy and spatial resolutions were improved, and background was reduced by using pulse rise time and energy discrimination. The line-focus collimator response pattern was measured as a function of source distance. Artifacts due to transport and display system nonlinearities were eliminated, and gray-scale improvement was effected in video and photographic recordings.

Phantom simulations of point, line, matrix, and area radioactivity concentrations – and of voids in such regions – were measured for several low-energy (10–100 keV) radionuclides.

Iodine-125 diagnostic scans of human thyroid patients showed good correlation between in vivo and in vitro scans; detected anomalies (cold nodules, hot spots, ectopic tissue, lobe distortion by tumors) were confirmed by pathological examination. Comparison with images from conventional rectilinear scanners demonstrated the improved image definition obtained by the line scanner (better spatial resolution and contrast ratio). Scans were made in support of ORAU animal experiments (in vivo imaging of dog and white-rat radioactivity distributions and radiation-damage circulatory impairment).

Additional measurements were made with the two-dimensional position-sensitive proportional counter in support of ORNL and the University of Tennessee biologists' request for x-ray microscope localization of precancerous cells. Proof-of-principle experiments resolved microcurie-level $^{125}$I-tagged resin beads of $<200\ \mu$ in diameter.

## 2.7 POSITION-SENSITIVE PROPORTIONAL COUNTERS

A. C. Morris, Jr. M. K. Kopp

A facility is being set up to give postconstruction tests and field support for the various position-sensitive proportional counter (PSPC) installations in this area. When completed, the facility will include instrumentation to conduct position-resolution, energy resolution, sensitivity, noise, efficiency, rise-time, and gas-amplification tests of these counters Technical personnel are being taught the operating characteristics of these PSPC devices for future repair and assistance The facility will be capable of testing and repairing the following types of counters one- and two-dimensional, flow-through, single- and double-chamber, and high- and low-pressure devices to sense a variety of radiations including x rays, gamma rays, protons, neutrons, alpha rays, and heavy ions

Examples of the kinds of field support for these counters are as follows

1 A microcircuit version of a PSPC preamplifier was developed that performs better in field installations The pulse response is about five times faster (20 vs 100 nsec) than that of earlier printed-circuit models Ten new preamplifiers operated for a break-in period of seven days, with essentially no change in measured performances

2 Four PSPC preamplifiers were redesigned for the Oak Ridge Electron Linear Accelerator to operate under vacuum conditions These circuits were modified to operate from ±12 V, rather than the standard ±24 V, to help reduce gas discharge under low-pressure conditions

3 A one-dimensional PSPC was installed and calibrated at the Oak Ridge Research Reactor (ORR) for neutron-distribution experiments This new PSPC receives distribution data at much higher rates than was possible with the previous slit-type neutron detector, especially at low counting rates experienced in some neutron scattering experiments Data previously accumulated over weeks of counting time can now be accumulated in one 24-hr session

4 A two-dimensional PSPC was tested, calibrated, and installed at the Van de Graaff Laboratory This detector will be used as an imaging device for a high-power, x ray microscope for detection of void counts and sizes in reactor-irradiated metal samples The x-ray position accuracy of this detector is less than the specified 1 mm over the 20-cm-square area of the detector's front face

5 The Solid State Division is determining the scattering properties of neutrons dispersed by various crystal structures A two-dimensional PSPC was installed at the ORR for these studies Instrumentation for this detector includes an isometric oscilloscope display of counts obtained over the full area of the detector and computer storage and a tape-punched output of the data from each run

## PROPORTIONAL-COUNTER DEVELOPMENT

### 2 8 RESONANCE ION SPECTROSCOPY PROPORTIONAL COUNTER

G S Hurst[1] R E Zedler

A proportional counter designed for basic research by the Health Physics Division in resonance ion spectroscopy was fabricated The detector is equipped with a quartz window in each endplate, both windows being on the same longitudinal axis, to provide entrance apertures for two laser beams Solid samples to be studied are inserted through an entrance port on the side and center of the cathode directly below the laser beam axis A beryllium window may be easily substituted for the sample tube for counter performance calibration with x-ray sources The detector is operated in the gas flow mode with argon–10% methane and at a gas multiplication sufficient to detect pulses originating from only one electron

The sensitivity of the system, with this detector, is such that a single atom of lithium in $10^{19}/cm^3$ atoms plus molecules of a different type has been identified

A second proportional counter incorporating additional features to increase the versatility and research potential of the detector was built.

1. Health Physics Division.

# RESEARCH INSTRUMENTS

## 2.9 CONSTANT-POWER, HIGH-VOLTAGE SUPPLY

K. Rush

A constant-power, high-voltage (15-kV) dc supply was developed for coating quartz wires with pyrolytic carbon. A phase-fired, SCR regulator on the primary side of a high-voltage, step-up transformer regulates the high-voltage dc. Signals are fed to an integrated-circuit multiplier from a high-voltage attenuator and a current-shunt feed to obtain a feedback-control voltage proportional to the output power. The 50-W maximum output power is limited by the upper voltage limit of about 15 kJ and the upper current limit of about 10 mA.

## 2.10 ELECTROMETER-RATIOMETER

F. M. Glass

An electrometer-ratiometer was designed for measuring the ratio of two currents within a range from $10^{-13}$ to $10^{-10}$ A. This instrument was built for the Health Physics Division to be used as part of a reflectometer. Its function is to simultaneously measure the ion currents produced in a low-pressure gas by a pulsed photon beam, before and after the beam is reflected from a surface, and to read out the ratio of the two currents. This instrument was needed because of the poor stability of the pulsed photon source and the required high accuracy for ratio measurements. Some of the required features were low noise, short- and long-term stability, low leakage, low input bias current, and range switching and tracking capability of the two electrometer channels that would give an accurate and direct ratio readout regardless of the range being used.

The low-noise goals were achieved by employing ultralow bias current Varactor bridge operational amplifiers and the lowest noise input resistors available and by making the bandwidth narrow for both channels. Ratio tracking accuracy was achieved by means of excellent linearity, separate calibration trimmers for each range; a 0.1% linearity, ten-turn Helipot in the comparator circuit; and identical integrating time constants in the two channels.

The instrument was used successfully over a three-month period with a reproducibility that approached 0.1%.

## 2.11 MOLTEN-SALT RESISTANCE MONITOR

L. H. Thacker

An instrument was developed for continuously monitoring and recording the resistance of molten-salt mixtures during a series of engineering experiments in which it was necessary to maintain a layer of solid salt on the inside vessel walls. The resistance was determined by sampling the ac and voltage required to melt the salt by resistance heating, rectifying these signals, and computing the ratio with an analog divider module Abrupt changes in the resistance signaled a breakthrough in the solid salt layer, and the heating power was reduced until the hot spot solidified.

## 2.12 FLOW PHOTOMETERS FOR LIQUID CHROMATOGRAPHY

L. H. Thacker

A new series of single-channel, double-beam flow photometers was developed to inexpensively and efficiently fulfill a variety of research and process requirements with a single basic instrument. A variety of different ultraviolet and visible wavelengths may be selected by proper choice of light source, wavelength converting phosphors, filters, and photoconductor detectors. The various implementations of the system now in service operate at 254, 280, and 340 nm in the ultraviolet, and six systems are in operation.

## 2.13 FISH TAG DATA ACQUISITION SYSTEM

K. Rush

A system (Q-5270) was developed to monitor, record, and play back data from an ultrasonic temperature-sensitive fish tag.[1] This system has the latest low-power CMOS circuitry and an incremental cassette tape recorder to achieve light weight, long battery life, and good noise immunity over extremes of time, temperature, and battery voltage The data recording and the power capacities are sufficient that the system can be used for months in a remote location without service. An internal electronic circuit keeps track of the time and initiates sampling of data at a programmable rate. Modular construction allows for expansion to 13 data channels in a portable, weatherproof package

The bench-top tape playback unit converts recorded data to a format compatible with a time-share computer terminal for printout or analysis This two-unit system enables data storage and retrieval without removing the recorder from the field. Data can also be printed on a digital panel printer in the playback unit if a computer terminal is not available.

1 J M Rochelle, *Instrumentation and Controls Division Annu Prog Rep Sept 1, 1971* ORNL-4734, p 10

## 2.14 FISH TAG IMPROVEMENTS

J. M. Rochelle  C C. Coutant[1]

Reliability and performance of the Q-5099 fish tags were improved by changes in the circuit and packaging design The original six-transistor, integrated-circuit chip was replaced with a three-transistor circuit fabricated by using discrete devices mounted on conventional printed-circuit boards. The new circuit works well with any battery voltage between 3.0 and 6.0 V, which gives the option of trading battery life for transmitter power, or vice versa. If long life is preferred, a battery of two silver oxide cells (3.0 V) is installed, if long transmitting range is preferred, four cells (6.0 V) are installed If longer range is needed, the output pulse width can be increased from 500 to 1000 μsec by adjusting the value of one resistor.

With a 1-MΩ (at 25°C) thermistor, the pulse interval varies from 250 msec at 35°C to 1450 msec at 0°C. With a two-cell battery, the life is about four months at 35°C or about 12 months at 0°C Changing from two to four cells quadruples the output power and halves the battery life.

An encapsulated two-cell tag is 15 mm OD and 36 mm long, a four-cell tag is 15 mm OD and 47 mm long.

To improve reliability, the thermistors are purchased with extra long leads, which do not require splicing during tag fabrication, and the thermistors in the new tags are packaged in tubing having lower moisture premeability Bench tests with the new assembly immersed in 0 9% saline solution at 25°C for nine months show less than 0 1% change in thermistor resistance when checked at 0°C (4 47 MΩ thermistor resistance).

1 Environmental Sciences Division

## 2.15 PEAK INTEGRATOR FOR GAS MASS SPECTROMETER

W. L. Bryan

A peak integrator for a gas mass spectrometer was developed for hydrogen isotope separation experiments. This instrument provides an experimenter with a digital display of the quantitative isotope concentrations for comparison of experimental spectra, without laborious graphic integration of a mass spectrometer output

## 2.16 NEUTRON DAMAGE SIMULATION CHAMBER

G. W. Allin R. C. Muller

A new chamber for exposing metal specimens to a beam of heavy ions from the 5.5-MeV Van de Graaff accelerator to simulate neutron damage effects in nuclear reactor materials was developed for the Metals and Ceramics Division The objectives were to improve the use of accelerator time and control of specimen temperatures. The chamber operates at a vacuum of $8 \times 10^{-8}$ torr and houses a six-position, remotely operated positioner, which sequentially positions six specimen holders into the beam Since each holder contains an array of nine specimens, a total of 54 specimens can be exposed to the beam before reloading Each specimen array is individually heated with an electron beam, using a commercially available cathode and grid assembly from a planar triode device Thermocouples measure and control the temperature of the specimens up to 800 ± 5°C through feedback to the electron-gun grids. A separate preheat control allows one specimen array to be preheated while another specimen array is undergoing bombardment in the beam.

This equipment, in the preliminary checkout stage, is performing satisfactorily A significant improvement in the use of accelerator time was accomplished, and a threefold improvement in temperature control was demonstrated.

## 2.17 ELECTROSTATIC AUTOPILOT

W. R. Miller

A radio-controlled model aircraft to gather atmospheric data is planned. An electrostatic autopilot was designed and built to keep the aircraft flying a constant electrostatic voltage gradient through the atmosphere. This type of guidance results in a more level flight path than guidance by barometric-type sensing.

Small alpha sources mounted on the wingtips and the tail feed a pair of differential voltmeter circuits. Outputs from these voltmeters provide correction signals to the roll and pitch servomotors.

The autopilot is brought into operation by an auxiliary channel command circuit when the desired altitude for automatic flight is reached.

## 2.18 HIGH-SPEED, HIGH-TEMPERATURE, STRESS-STRAIN MEASUREMENTS

R. C. Muller

A testing device (Fig. 2.18.1) was constructed in order to determine the stress-strain properties of stainless steel specimens at 1400°C and high strain rates. To make a test, a projectile strikes an anvil and rapidly strains a specimen. Infrared photocells and an interval timer measure the projectile's speed. When the anvil is struck, anvil motion (specimen strain) is detected by a potentiometer wire. Strain gages mounted on the molybdenum bars, away from the high temperature, detect the stress shock wave as it is generated by the strained specimen High-gain amplifiers feed the signals thus generated to transient recorders. The frequency response of the system is about 3 MHz.

ORNL-DWG 76-17285

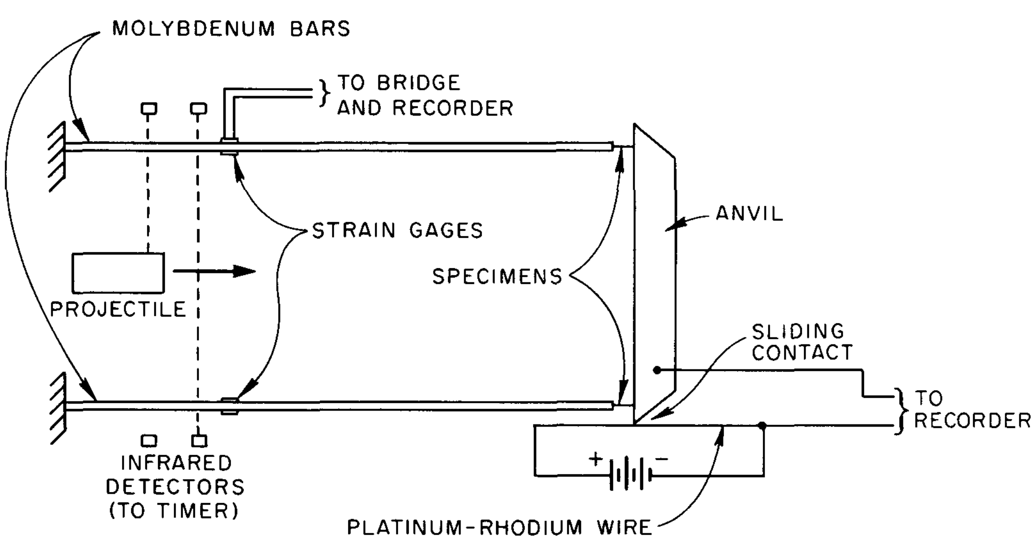


**Fig. 2.18.1. Device for high-speed, high-temperature, stress-strain measurements.**

## 2.19 POTENTIOSTATIC COULOMETER

D. W. McDonald

An inexpensive potentiostatic coulometer was developed in order to verify the claim that a university research team had achieved 100% electrolytic efficiency with a tubular platinum electrode If the efficiency of the electrode can be verified, the electrode would be used in the coulometric determination of the electroactive species in the effluent from a liquid chromatograph.

## 2.20 CONTROL SYSTEM FOR AN X-RAY GENERATOR

G. K. Schulze

A control system (Fig. 2.20.1) for an x-ray generator was designed and placed in operation. The system enables safe operation of the generator at precisely controlled dose rates and total dose for spectrometry and dosimetry experiments in medical diagnostic radiology. This research is being conducted by the Health Physics Division. The equipment has been in service since the fall of 1975. This system is the only known working unit controlled in this way and consistently gives reproducible dose rates and total dose.

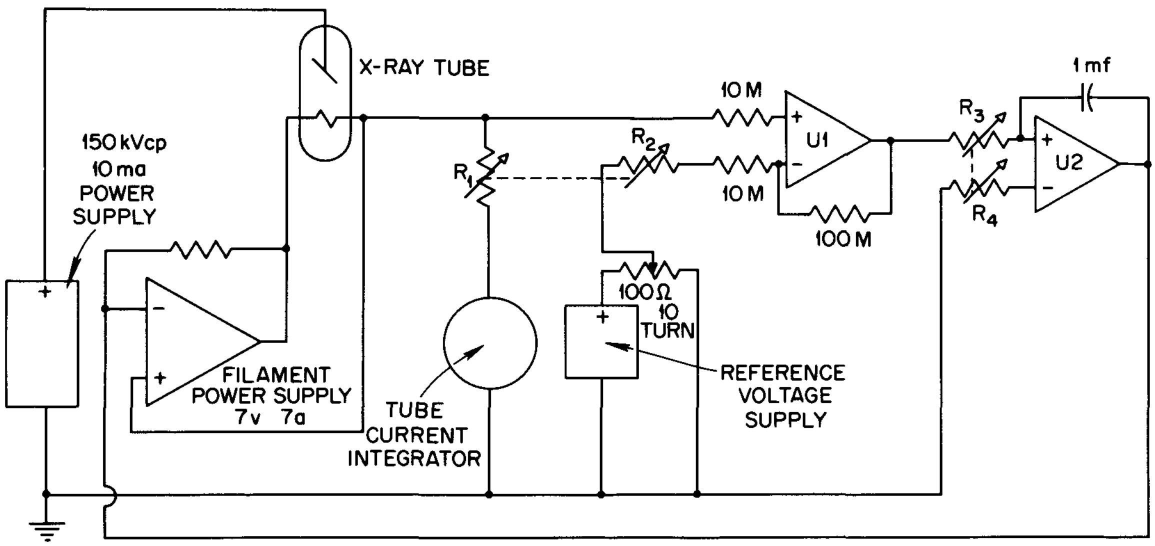


**Fig. 2.20.1. Control system for an x-ray generator.**

The dose rate is regulated by one ORNL-designed instrument. It senses the emission current of the x-ray tube, which has the cathode at ground potential, and compares the current to a precise reference; then it regulates the current from 1 $\mu$A to 20 mA by controlling a programmable power supply that supplies power to the x-ray tube filament. The total dose is controlled by integrating the emission current with a second instrument and terminating the emission when a preset value of total charge is accumulated.

The system includes an interlock to ensure that the door switches, radiation monitors, and cooling-oil systems (and the oil pressure, temperature, and level) are all operational before power can be supplied to the system.

## 2.21 IN-LINE SMOKE ANALYZER

T. M. Gayle C. E. Higgins[1] J. R. Stokely[1]

A multicomponent, continuous, smoke-monitoring system was designed, fabricated, and tested for the Analytical Chemistry Division. This system is used to study tobacco-smoke chemistry and to monitor cigarette smoke output from large continuous-exposure (smoking) machines. The unit records, integrates, and indicates limit alarms (for animal safety) based on measurements of the following:

1. total particulate matter, which is detected by an optical backscatter sensor for smoke (aerosol) concentration;[2]
2. carbon monoxide, which is sensed by a medium-speed nondispersive infrared analyzer;
3. hydrogen, which is detected by a thermal conductivity cell after the sample is first passed through a chemical trap to remove $CO_2$ and moisture.

Based on the successful use of this unit, a more compact prototype is being designed and built.

1. Analytical Chemistry Division.
2. Developed by the Instrumentation and Controls Division.

## 2.22 SMOKE-CONCENTRATION SENSOR

T. M. Gayle  C. E. Higgins[1]

A miniature optical sensor for the measurement of smoke and aerosol concentrations was developed for the Analytical Chemistry Division. The sensor functions as a backscatter measuring system, using a light-emitter diode for the emission of 900-nm energy and a high-gain phototransistor to measure the reflected energy. The unit is used to study tobacco smoke in concentrations from 1 to 100%.

The volume of the sensor is about 0.125 $cm^3$. Several sensors were built into the walls of small sections of pipe and tubing, for in-line or flow-through measurement, and mounted on long, thin probes, for insertion into large chambers. The external circuit used with the sensor normally consists of a power supply, a dc amplifier, and an integrator. Over the 100% smoke range, the output is linear within ±5%.

Since the unit responds within milliseconds, it has been employed to evaluate commercially available cigarette smoking machines, to quantify the dose rate to test animals, and to integrate the total dose.

The unit has also been used by the Chemical Technology Division to study $U_3O_8$ aerosols.

1 Analytical Chemistry Division

## 2.23 IMPROVED CARBON AND OXYGEN ANALYZERS FOR THE ANALYTICAL CHEMISTRY DIVISION

A. C. Morris, Jr.

Development was started to improve four analyzers used by the Analytical Chemistry Division for determining the amount of carbon and oxygen present in metallic samples. Three analyzers are complete and operating. We replaced the mechanical integrators and obsolete electronics components that are no longer available with currently available components, electronic integrators, and digital readouts. These modifications will extend the life of these analyzers and avoid the expense of replacement of these units at this time.

## 2.24 SIMPLIFIED CYCLIC VOLTAMMETER

G. K. Schulze

A cycle voltammeter (Q-5251) was developed for the Metals and Ceramics Division for corrosion studies. Two of these instruments were built and the design was proved.

This cyclic voltammeter is a simplified version of an earlier design. It is basically a potentiostat that can be preset to a specific potential by a digital-to-analog converter controlled by a four-digit binary coded decimal thumb-wheel switch. It can then be swept from one preset limit to another in a half-, full-, or continuous-cycle mode. The sweep rate is selectable from 1.0 to 1000 mV/sec, in a 1, 2, 5 sequence. The current can be metered from microamperes to amperes. A hybrid, low-pass filter module, which is designed to compute the derivative of the current, gives a $dI/dT$ output  Output jacks on the front panel enable readout of the values of potential, currents, and sweep.

### 2.25 CRYSTAL-CONTROLLED TIMER CIRCUIT FOR REMOTE FIELD EXPERIMENTATION

G. K. Schulze

A crystal-controlled clock-timer device was designed and put into operation in order to study water utilization by a tulip poplar tree by the Environmental Sciences Division. The device allows precise timing and control of standard equipment where 60-Hz power is not available.

A low-frequency crystal and digitally programmable integrated circuit timer comprise a precision clock. CMOS dividers generate a 15-min *on* period every 2 hr. During the *on* time, a relay energizes a dc-to-ac inverter which provides power to the recording instrument. This arrangement gives precise timing and enables standard equipment to operate on battery power, with low average current consumption and, therefore, fewer charges of batteries.

## BIOMEDICAL INSTRUMENTS

### 2.26 OPTICAL ROTATORY DISPERSION MONITOR

L. H. Thacker

An instrument was developed for detecting optically active components in liquid chromatograph eluates. The instrument is unique in that it integrates light source, wavelength selection, sample flow cell, prism polarizer and analyzer, and two photomultiplier tubes in a 3 × 3 × 6 in. block. It is a practical monitor that replaces a large assembly of laboratory equipment formerly required for such measurements. Results from preliminary tests of the prototype are encouraging.

### 2.27 AUTOMATED PLASMA, RED BLOOD CELL, AND HEMOLYSATE PREPARATION

W. F. Johnson    M. L. Bauer    D. G. Lakomy

The automated whole-blood-sample preparation system developed for genetic monitoring was modified. The sample handling capabilities of the system were improved by increasing the capacity of the rotor from 16 to 24 samples, and the mixing attained in this rotor was enhanced by adding a clutch-brake rotor drive to rapidly accelerate and brake the rotor. An automated rotor washing station and a sample transfer unit were added to the system, which is being evaluated at the University of Michigan.

### 2.28 FAST ANALYZER SYSTEMS

W. F. Johnson    M. L. Bauer    D. G. Lakomy

Additional miniature fast analyzer systems were constructed and are being evaluated at the National Center for Toxological Research, Jefferson, Arkansas; the National Institutes of Health, Bethesda, Maryland; the University of Michigan; and the ORNL Chemical Technology Division.

Another continuing development in this program is a portable fast analyzer. This unit, 11 × 18 × 12 in. high, contains its own microprocessor for data acquisition, data reduction, analyzer control, and analyzer monitoring. The analyzer, which contains its own alphanumeric printer, can operate from an internal battery supply. The analyzer also contains a new rotor drive mechanism that accelerates the rotor to its 3500-rpm analysis speed in 150 msec, thus allowing reactions in the rotor to be monitored after the first 60 msec of the reaction vs a delay of 7 sec in the miniature fast analyzer.

# 3. Radiation Monitoring

## 3.1 ENGINEERING ACTIVITIES CONCERNING RADIATION MONITORING

C. C. Hall   A C Morris, Jr.

### Facility Radiation and Contamination Alarm System

Radiation monitoring instruments were installed in a new storage vault (Building 3127). The system consists of a constant alpha air monitor, a criticality monitor, an evacuation horn, and rotating magenta beacons. The criticality monitor, evacuation horn, and rotating beacons were integrated into the facility radiation and alarm system for Buildings 3012, 3027, and 3044.

A procedure was prepared to annually test all neutron monitors at ORNL that alarm in a neutron-burst mode. All such monitors were tested in accordance with this procedure at the ORNL DOSAR facility, and all indicated a satisfactory burst-mode alarm (some needed minor repairs and were retested for proper operation). These results were reported. Hereafter, burst-mode tests will be made annually at the DOSAR facility.

A reset circuit was designed and constructed that enables personnel at Guard Headquarters to silence alarms in certain buildings subsequent to a criticality incident. Since a burst of radiation from a criticality incident will cause alarms to sound in many nearby buildings, this circuit will help to determine the burst location, because only monitors in the building where the excursion actually occurred would continue to send an alarm subsequent to a general remote reset. The reset circuit was demonstrated to operate satisfactorily between Buildings 2500 and 3525, but further installation of these circuits is being withheld until future plans for them can be ascertained.

The Special Electronics Group continued to maintain and upgrade the facility radiation and contamination alarm systems and the process waste disposal monitoring and alarm systems Since most of these systems are equipped with vacuum-tube instruments designed 15 to 20 years ago, they need to be replaced with modern instruments containing more reliable solid-state and integrated-circuit electronics.

### Effluent Monitoring

A monitor was installed to measure the alpha particles in gaseous effluents in an exhaust duct from environmental growth chambers in Building 3508. Alarms from the duct monitor were installed at the facility radiation and contamination alarm panel for the building

Alpha and beta-gamma monitors were installed in an exhaust duct from hot cells in Building 4501 Alarms from these monitors were telemetered to a central alarm panel in the building.

Beta-gamma water monitors were installed to check a steam-condensate drain line and a resin-column drain line in the new process waste treatment plant (Building 3544).

The circuits of most of the local air monitors were modified to help reduce damage to telephone changeover switches from lightning discharges. However, since the telephone features of this installation were superseded by the use of portable radios, the telephone circuits were bypassed in such a way that they can be restored if necessary.

### Radiation Safety Interlock Systems

Safety interlock systems were designed and installed at x-ray facilities in Buildings 2000, 2008, 4501, and 4500S.

Design of a controlled-access, safety interlock system to be installed in the Hollifield Heavy-Ion Research Facility was started. Installation is scheduled for 1978.

Safety interlock systems were designed for and installed on several x-ray diffraction machines.

### Emergency Public Address System

The emergency public address system in the Building-4500 complex was modified and updated.

## 3.2 GAMMA MONITRON

F. M. Glass W. T. Clay R. A. Maples

An ionization chamber, electrometer-type gamma monitron was designed to replace the Q-1154 monitron, which is a 25-year-old design. One reason for replacement is that some of the components in the Q-1154 monitron are no longer available. Since many of these instruments are used at ORNL, a replacement was required that would perform the same functions and would be as dependable as the old monitron. No commercially available instrument could be used as a replacement without extensive modifications or creation of interface equipment to make it compatible with ORNL systems. Therefore, this Mark II monitron was designed.

The new monitron is functionally similar to the old instrument, including the spectral response of the chamber and the relay logic of the auxiliary alarm circuits. Since the chassis connectors are the same as those on the older instrument, they can be plugged in existing systems without connector changes or the use of adaptors. The new instrument is inherently stable. It is much smaller and costs less to produce than its predecessor. An experimental model was tested for more than a year, with satisfactory results. The prototype was completed and documentation is near completion.

## 3.3 WATER MONITOR

F. E. Gillespie C. C. Hall

A new water monitor (Q-1907-31) was developed to monitor beta and gamma emitters in low-pressure, liquid-waste lines at ORNL. A thin-walled (type 106C) G-M tube inside a plastic centrifuge tube and a steel spring can withstand the line pressure and still monitor beta emitters. A prototype was tested to 20 psi. Two units are in service.

## 3.4 MONITORING OF ION EXCHANGE COLUMNS FOR LOW-LEVEL WASTE TREATMENT PLANT

F. E. Gillespie T. F. Sliski

In the low-level waste treatment plant operated at ORNL, process water flows through ion exchange resin columns in order to remove the radioactivity in the water. As radioactivity is collected, a detector on the outside of a column monitors the resin so that, before the resin becomes saturated with radioactivity and breakthrough occurs, the flow of process water is switched to another column. The monitor has two 106C G-M tubes inside a lead collimator, which are raised up 20 ft outside the column.

## 3.5 OFF-GAS TRITIUM MONITOR

R. L. Shipp, Jr.

Development of a monitor for tritiated water vapor in fuel reprocessing off-gas was begun for the Chemical Technology Division in order to indicate the quantity and time of a tritium release, if one should occur. However, $^{85}Kr$, which is also in the off-gas, interferes. A method developed by Osborne[1] for measuring tritium vapor in the presence of noble radioactive gases was tried. Tritiated water vapor in a sample of off-gas is collected in water in an exchange column filled with glass beads. A portion of the water effluent from the column is mixed with liquid scintillator and transferred to a flow-through liquid scintillation counter for measurement of the tritium content.

The performance of the system is not satisfactory, because its response time is too slow and separation of tritium from $^{85}Kr$ in the exchange column is insufficient. Members of the Chemical Technology Division are continuing with the chemical engineering aspects of improving the response time and separating $^{85}Kr$ from the tritiated water vapor.

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1 R V Osborne, *Development of a Monitor for Tritiated Water Vapor in the Presence of Noble Gases,* AECL-4303 (September 1972)

## 3.6 SAMPLING THE BUILDING 3039 STACK FOR IODINE-131

W. T. Clay

A study was made of the $^{131}I$ sampling equipment installed on the Building 3039 stack for the Operations Division. The system consists of two sampling lines that contain activated-charcoal adsorbers and filter papers for iodine and particulate matter respectively. The goal of this study was to suggest changes that would lead to a reliable calculation of the quantity of $^{131}I$ being discharged from the stack.

After a study of 180 pieces of data, which were collected over a nine-month period, a day-by-day correlation of the data from the two channels could not be determined Several recommendations were made to improve the sampling and, thus, the quality of the data from the two channels. Five major changes were suggested to improve the system design and the data acquisition and analysis system. These changes should provide more reliable effluent data.

The Operations Division assigned a staff member to be in charge of the sampling program, and some of the suggested system modifications were made with apparent success

## 3.7 GAMMA SPECTROMETER FOR THE IODOX EXPERIMENT

M M Chiles C. R Mitchell B. A Hannaford[1] W. S. Groenier[1]

A gamma-ray spectrometer was installed in Building 4505 to supply pulse-amplitude data for determining the amount of $^{131}I$ at different locations in the chemical process for Iodox experiments A well-type, NaI(Tl) scintillation detector (7.62 cm in diameter and 7 62 cm long) was installed inside a copper-cadmium-lined lead shield (Q-2001) to minimize background contribution. Liquid samples are pumped through 0.125-in.-OD tubing into a 3.3-cc Zircaloy capsule, which is inserted into the well of the scintillation detector. A liquid dispenser pump transfers the liquid samples into and out of the capsule. A multiposition valve sequentially selects a sample from 17 different locations inside the cell each hour.

A multichannel analyzer accumulates an energy spectrum from each sample for a preset period of time. When the time period ends, the analyzer sends a signal to the liquid-dispensing mechanism to flush out the previous sample and collect the next sample while the data are being printed out. At the end of the printout cycle, the analyzer receives a signal from the automatic dispensing controller that indicates that the next sample is ready to be analyzed. The energy spectrum from the next sample is accumulated

The analyzer was altered to print out only the channels of interest where the 364-keV gamma peak from $^{131}I$ occurs, so that the time cycle for each sample would be reduced.

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1 Chemical Technology Division

## 3.8 PERSONAL RADIATION MONITOR DEVELOPMENT

R. A. Todd F. M Glass

The original design objectives for the personal radiation monitor (PRM) replacement were reduction in size and weight and improved packaging to facilitate maintenance. Since size reduction often makes repair more difficult, the incidence of component failures and possible solutions were determined. Another design objective was to maintain a more constant sound level as the battery voltage decreases with use.

A developmental model PRM was built Its idling current is 40 $\mu$A, compared with 100 $\mu$A for the old design. This reduction in battery drain made it possible to reduce the battery weight from 1.4 to 0.9 oz. Battery life in low radiation levels is limited by the shelf life of the battery

The average sound level 4 in. from the older PRM is 105 dB, using a new battery, and from 85 to 90 dB at the end-point voltage of the battery. An intensity of 90 dB is inaudible in high background noises. The sound level of the new model is 115 dB, with a new battery, and 105 dB at the battery end-point voltage. This greater audio output was accomplished with about one-third the power consumption of previous models. A new RC oscillator, which functions independently of the blocking oscillator high-voltage power supply, maintains an almost constant frequency over the range of battery voltages. This constant frequency ensures constant acoustical coupling by the quarter-wave coupler on the hearing-aid transducer and should result in a more constant audio output over the life of the battery and, therefore, in fewer transducer failures.

With a separate tone generator the blocking oscillator transformer is not required to operate at the audio frequency. The keyed frequency can be as low as 900 Hz, which results in lower power consumption.

Due to the number of large components used, such as the G-M tube, sound column, high-voltage capacitors, transformer, and battery, the size of the pencil model will not be appreciably changed, even if hybrid, thick-film fabrication techniques are used.

## 3.9 BATTERY-POWERED PERSONNEL GAMMA-RAY DIGITAL DOSIMETER AND DIGITAL DOSE-RATE METER

H. R. Brashear F. M. Glass

A laboratory model of a gamma-ray digital dosimeter and digital dose-rate meter was designed and fabricated for the U.S. Army Electronics Command. The dosimeter detector is an ionization chamber filled with xenon to 10 atm abs. A solid-state microcircuit is sealed in the chamber to quantize the ionization charge at 0.5-mR equivalent increments. All electrical leads to the chamber are in low-impedance circuits The meter is dual range, with automatic range switching. The dosimeter detector is used for the high range of the dose-rate meter (1–999 R/hr), and a small G-M tube is used for the low range (0.1–999.9 mR/hr) of the dose-rate meter.

Complementary metal-oxide silicon field-effect transistor, medium-scale integration circuit packages are used extensively throughout the counting circuitry to conserve power. Dose and dose-rate measurements are displayed on a five-digit light-emitting diode array via push-to-read switches. An audible alarm, powered by a separate battery, is energized each time 10 mR of radiation is accumulated, and the alarm is terminated when an additional 1 mR is accumulated or when the alarm reset switch is depressed The dosimeter and dose-rate-meter batteries are rechargeable.

## 3.10 POWER SUPPLY AND REGULATOR CARD CHECKER

F. M. Glass

A test instrument was designed and fabricated for the RADEF Instrumentation Test Facility under contract to the Defense Civil Preparedness Agency. This instrument enables rapid and simultaneous checking of the regulation and efficiency of power supply cards used to upgrade the CD V-700 beta-gamma survey instruments. The tester simulates operating conditions of a survey instrument the current drains on the power supply cards are the same, and the terminal voltage and internal impedance of the primary power source are similar to the values of an average, commercial-grade D cell. The tester simulates the condition of a new D cell and the terminal voltage end point (0.8 V)

This instrument has been tested and will be ready for use when the cards are received from the vendor.

## 3.11 CIVIL PREPAREDNESS TRAINING INSTRUMENT

K. Rush

A simulated CD V-715 survey instrument was developed for the Defense Civil Preparedness Agency to train local civil preparedness personnel. This instrument gives vocal instructions and simulates radiation measurements (without requiring a radioactive source). A commercial, miniature audio cassette recorder was mounted in the instrument case along with electronic components to convert recorded tones into meter readings.

## 3.12 MODIFIED CD V-715a SURVEY INSTRUMENT

R. A. Todd

A CD V-715 survey instrument was modified for civil defense training programs. Students can practice taking readings with this instrument, or it can be used in field exercises. The circuit consists of an electronic counter, timing circuitry, a nonvolatile memory, low-power CMOS data storage, a four-decade digital-to-analog converter, and a meter drive circuit.

### 3.13 DCPA TRAINING SYSTEM

R. A. Todd

A training system consisting of an instructor console that transmits information to remote student monitors was designed for use in training programs of the Defense Civil Preparedness Agency. The instructor console includes power supplies, timer circuits, a nonvolatile memory, a parallel-to-serial data converter, a keyed transmitter, and a meter readout of the data sent. Information can be sent by rf transmission in either an automatic or a manual mode. In the automatic mode, information recorded in the memory is sequentially transmitted at regular time intervals. In the manual mode, information and receiver numbers can be selected by setting toggle switches on the front panel and keying the transmitter.

The monitor is battery operated and includes a 27-MHz receiver, a serial-to-parallel converter, and a meter-drive circuit, all housed in a modified CD V-720 plastic case.

# 4. Pulse Counting and Analysis

## 4.1 IMPROVED, ADJUSTABLE-DELAY MODULE FOR TIMING CONTROL

J. T. De Lorenzo T. A. Love[1]

An adjustable delay of logic pulses ranging from a few nsec to a few μsec with minimum dead time and good stability of delay is an important requirement in many physics experiments at ORNL. Earlier designs, Q-3073A (100 nsec to 1.2 μsec in 18 steps) and Q-3084A (15 to 125 nsec in 18 steps), were improved with the use of an MECL III fast-comparator MC1650L integrated circuit. The delay module will now respond to input fast NIM logic (negative 0.7 V) with widths as small as 5 nsec. (The previous design had a 20-nsec limit on the width of the input pulse.) The new design is easier to adjust, and no major adjustments are required after any of the semiconductor components are replaced. The new designs are now designated Q-3074B and Q-3084B.

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1. Neutron Physics Division.

## 4.2 HIGH-SPEED DISCRIMINATOR FOR AN AUTOMATED DATA ACQUISITION SYSTEM

J. T. De Lorenzo

The development of a high-sensitivity fission counter by the Controls Department of the Instrumentation and Controls Division created a need for a linear and stable high-speed discriminator (>50 MHz) with a remotely adjusted trigger-threshold level. No remotely adjustable discriminator of this type is commercially available. A modified commercial unit lacked both linearity and stability. The discriminator designed for this purpose has an integral nonlinearity of <0.25% for either rectangular pulses (20-nsec width, 1-nsec rise time) or tail-type pulses (50-μsec tail, 2-nsec rise time) for amplitudes ranging from 50 mV to 1.0 V. The temperature coefficient for a temperature range from 25 to 55°C is $<-50\ \mu V/°C$.

## 4.3 DECADE-TO-BINARY CONVERTER

R. W. Ingle

The time resolution obtained from a fission chamber used in neutron time-of-flight experiments at the Oak Ridge Electron Linear Accelerator is determined not only by the accelerator pulse characteristics, but by the ratio of the neutron flight path distance to the total spacing of the isotope within the fission chamber. The total spacing of the multisection fission chambers used by the Neutron Physics Division may be as much as 6 cm; therefore, it is necessary to separate time-of-flight data by sections to obtain optimum time resolution. A decade-to-binary converter that would perform this function was designed, fabricated, and used in a fission cross-section experiment with a ten-section $^{238}U$ fission chamber.

This circuit, which was housed in a double-wide NIM module, accepts the fast-NIM logic pulses from each of ten fission chamber amplifier-discriminator modules and converts those pulses to a four-bit binary number. The output also consists of an "All" output, which is present when there is any input signal. This binary number is presented to the "tag" inputs of a time digitizer, and the All signal is used as the time-of-flight "stop" event. The data acquisition computer software stores this time-of-flight data in ten separate regions, depending on the binary value of these tags. Only wide-bandwidth integrated circuits are used in the converter.

## 4.4 HIGH-SPEED, DIGITAL BUFFER MEMORY

R. W. Ingle

Neutron multiplicity experiments require data processing instrumentation with high count-rate capabilities. The measurement of $\bar{\nu}$, the number of neutrons per fission of a fissile isotope, requires knowledge of the time of fission and the times of capture of fission neutrons in the liquid scintillator.

To store multiple time-of-flight events following a single start with minimum dead time, a fast, 12-bit by 16-word buffer memory was fabricated and installed in a 12-bit, 20-nsec, digital, time-interval counter. Time-of-flight events are recorded as binary numbers and are transferred into the buffer memory with a dead time of 200 nsec. A maximum of 16 such events can be stored following a single fission. This unit can be used with a nuclear data analyzer or as an integral part of the multiparameter data acquisition system at the Oak Ridge Electron Linear Accelerator, which is used by the Neutron Physics Division for $\bar{\nu}$-experiments.

This buffer has TTL first-in, first-out memory-integrated circuits, which are capable of a 14-MHz data rate. Our goal is to reduce the dead time of the system in order to handle this data rate.

## 4.5 800-kHz, ANALOG-TO-DIGITAL CONVERTER

J. H. Todd

A ten-bit, analog-to-digital converter (ADC) with a conversion rate of 800 kHz was developed. Its total dead time is 1.25 μsec, and it accepts input pulses with rise times up to 20 μsec. Differential nonlinearity is determined by the ±½ of the least significant bit generated by the successive-approximation technique.

The ADC will truncate the ten bits to 9, 8, 7, 6, or 5 bits.

# 5. Electronic Engineering Support for Research Facilities

## ORMAK

### 5.1 A 140-GHz DIGITAL MICROWAVE INTERFEROMETER FOR ELECTRON DENSITY MEASUREMENTS IN ORMAK[1]

D. D. Bates R. Dyer[2] W. R Wing[2]

A digital microwave interferometer has been developed and placed in operation on the ORMAK (Oak Ridge Tokamak) experiment. The 140-GHz interferometer provides time-resolved electron density measurements of the plasma for line densities up to $4 \times 10^{13}$ $cm^{-3}$ The interferometer uses trilevel modulation of the Klystron, which provides both the sin $\theta$ and cos $\theta$ signals and a reference signal that eliminates the need for wide-band amplifiers and, in particular, eliminates low-frequency noise from the plasma in the frequency band corresponding to the time rate of change of the density Positive and negative zero crossings of both the sin $\theta$ and cos $\theta$ signals are routed through digital logic and counted to provide $\pi/2$ (equivalent to quarter fringe of the familiar zebra-stripe interferometer) resolution of the increasing or decreasing density. A digital-to-analog decoder converts the time-varying density information from the up-down counter to an analog signal that is compatible with any further recording or display medium.

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1 Abstract of paper presented at the meeting of the American Physical Society, Division of Plasma Physics, Albuquerque, N M , Oct 28–31, 1974

2 Thermonuclear Division

### 5.2 A 120-kA PULSED DC POWER SYSTEM WITH COMPUTERIZED THYRISTOR TRIGGERING[1]

S. W. Moski[2] D. D. Bates R. R Bigelow[2]
E. K. Cottongim[2] E. W. Pipes[2] K. Sueker[3]

A pulsed dc power system provides 120-kA excitation current for the ORMAK toroidal field coils. A drive potential of 1000 V brings the coils to full current in about 0.5 sec. Constant current is maintained for 0.25 sec, then approximately $20 \times 10^6$ J of stored energy is dumped into a free-wheeling diode and resistance network. The power system contains eight 30-kA, 500-V, thyristor-controlled, dc power modules in a series-parallel combination. A control computer generates thyristor trigger pulses in a programmed sequence as required for the desired duty cycle. A feedback network including current sensing and computer software permits trigger timing adjustments as necessary for constant current operation

1 Abstract of paper presented at 6th Symposium on Engineering Problems of Fusion Research, San Diego, Calif , Nov 18–21, 1975
2 Thermonuclear Division
3 Robicon Corp , Pittsburgh, Pa

## 5.3 SUPPORT FOR THE THERMONUCLEAR DIVISION

J. L Anderson R. J Colchin[1] R B. Easter[2]

The Thermonuclear Division was assisted in technical feasibility studies and preparation of a reference design for a fusion experimental power reactor, in the area of electrical energy storage and switching concepts to supply and control the magnetic fields produced by the ohmic heating windings of the reactor

The feedback controller, which maintains plasma equilibrium in the ORMAK experiment, was completed and is in routine operation. The controller reduces the plasma shift for well-behaved discharges to less than 2 mm, where position changes, of up to 2 cm without feedback, are not uncommon

A similar plasma-position controller is being designed for the impurity studies experiment (ISX), which is under construction. This controller will differ significantly in that the ISX will not use a stabilizing conductive shell as is used in the ORMAK This will be more demanding of controller performance but, at the same time, will eliminate a problem of delaying time constants due to eddy currents in the shell.

1 Thermonuclear Division
2 UCC-ND Engineering Division

## 5.4 SOFTWARE FOR FOURIER ANALYSIS OF PLASMA OSCILLATIONS IN THE ORMAK

V K. Paré

In the ORMAK operated by the Thermonuclear Division, magnetohydrodynamic oscillations of the plasma can be detected by magnetic pickup coils near the periphery and by semiconductor detectors that respond to x rays emitted from the interior of the plasma The frequency range of the oscillations is from 1 to 15 kHz. Measurements of the frequencies and wave numbers of these oscillations should make it possible to identify the instabilities that drive them. Such identification would provide guidance in selecting plasma conditions for more stable operation.

Software was developed for processing these signals by a digital Fourier analyzer. The software system differs from those used for fission reactor noise analysis, because the plasma signals have very short duration (<0.1 sec) and are highly nonstationary, thus, signal averaging is not possible. Fortunately, the signal-to-noise ratio is usually high. Because a digitizing rate of $\sim$100 kHz is needed and because the condensation inherent in signal averaging is not available, the quantity of data obtained in 0.1 sec is too great for storage in the analyzer. Thus, the signals are recorded by a tape recorder and played back into the Fourier analyzer at $^1/_{64}$ the recording speed.

The speed reduction makes possible storage of the data, as it is digitized, on the Fourier analyzer disk. The software system facilitates disk-storage allocation and data identification, generates auto- and cross-power spectral densities from data channels selected by the operator, and automatically generates plots with data and scale-factor identification.

### 5.5 SUPERCONDUCTING MAGNET PROTECTION SYSTEM RELIABILITY

Paul Rubel

The superconducting magnets being developed for fusion machines will store amounts of energy that must be dissipated externally whenever a coil quenches (loses superconducting property), in order to avoid coil damage. We assisted the magnet designers of the magnet development program in matters of imparting reliability to such a protection system.

## ELMO BUMPY TORUS EXPERIMENT

### 5.6 HELIUM-3 FAST-NEUTRON SPECTROMETER

C J. Borkowski M. K. Kopp

An $^3$He fast-neutron spectrometer was developed. Related experience from our work with position-sensitive proportional counters was applied to achieve good resolution of energy, discrimination of background counts, and elimination of wall effects.

The spectrometer was tested with neutrons from the *(d,d)* reaction in a Cockroft-Walton accelerator that was emitting ~$10^5$ neutrons/sec. The line width for the 2.2-MeV neutrons was 200 keV (FWHM) The discriminator was set to accept ~50% of all detected neutrons from the *(d,d)* reaction With this discriminator setting, the background count rate from thermal neutrons and helium recoils was reduced by a factor of 50.

The spectrometer is being used by the Thermonuclear Division to measure fast-neutron spectra in the ELMO Bumpy Torus experiment

### 5.7 DATA ACQUISITION SYSTEM FOR THE ELMO BUMPY TORUS EXPERIMENT

J. W. Reynolds

The data acquisition program for this experiment was modified as a result of test runs in November 1974. The data acquisition loop timing was improved, and the required amount of core was decreased. Occasional errors due to a conflict between transfers from core memory to the disk and transfers to core memory from the analog-to-digital converter system were eliminated, and an overlay of 1024 words of core memory was provided in order to allow future expansion of the system commands by addition of four control words per command to the resident monitor. An overlay may contain a maximum of eight commands.

The data format was changed from 14 frames per record (72 data points per frame) to 12 frames per record (81 data points per frame), with an additional 36 data points recorded at the beginning of each record. The nine miscellaneous frame data points and the three data points per sector on each of the 24 sectors of the torus are displayed as data are acquired.

Programming for transferring data files over the communication link between the PDP-12 and the PDP-11/45 remote access terminal was completed In addition, listing files from both the PDP-8/E and the PDP-12 can be transferred and listed on the line printer at the remote access terminal Data transfers to or from the PDP-8/E from or to the PDP-12 will be added when required by the experiments.

A visible and an ultraviolet grazing incidence spectrometer requiring both hardware and software interfaces for the PDP-8/E were added. The uv spectrometer has two DEC modules (an M730 bus interface module and an M734 I/0 bus input multiplexer module) to control the speed of scanning, the initial and final scan positions, and to record a histogram of pulse count from the scattered-light signal as a function of position. The visible spectrometer uses one channel of a DEC AM8-EA, 8-channel analog multiplexer, an AD8-EA analog-to-digital converter system, and a DR8-EA 12-channel buffered digital I/0 module to record the spectrometer mirror position and the scattered signal-pulse count histogram.

## 5.8 FAST SERVO PRESSURE CONTROLLER

R. E. Wintenberg

An electronic servo controller was designed for pressure control ($10^{-5}$ torr) on the Thermonuclear Division's ELMO Bumpy Torus experiment. The controller was designed to exploit the speed of response of a piezoelectric valve and a fast-ion gage regulator.[1] The valve will open or close fully in less than 2 msec and has a throughput of 2.5 torr-liters/sec at a 1-atm pressure differential.

Pressure in the cavity containing the ion gage sensor and the control valve can be modulated with a small-signal sine wave to 80 Hz (−3 dB)

1 R E Wintenberg, *Instrumentation and Controls Div Annu Prog Rep Sept 1, 1972,* ORNL-4822, p 14

## 5.9 LOW-ENERGY, FLUORESCENT X-RAY PROPORTIONAL COUNTER

R. E. Zedler

A small, gas-flow proportional counter was designed and fabricated for the Thermonuclear Division to detect and identify characteristic fluorescent x rays in the 5- to 0.1-keV range produced by bremsstrahlung radiation from materials present during operation of the ELMO Bumpy Torus experiment.

The detector has a small, replaceable side window of polypropylene that is less than 1 $\mu$ thick and is supported by 92% open-area electromesh. The window can withstand a 1-atm pressure differential. A thin beryllium window, mounted on the counter side opposite the entrance window, allows the higher-energy x rays to pass through the detector without producing internal fluorescent x rays from the cathode. The entrance window assembly is designed so that the detector may be placed on or taken off the Bumpy Torus vacuum system.

# HOLIFIELD HEAVY-ION FACILITY

## 5.10 ELECTROMETER FOR THE HEAVY-ION FACILITY MONITORING SYSTEM

F. M. Glass

A highly specialized, single-range electrometer was designed for the Holifield Heavy-Ion Facility (HIF) monitoring system. Unlike other systems in use at ORNL, the HIF system will require standard logic signals for all alarm functions and a low-impedance voltage signal from an external meter output that will permit changing the number of meters on-line without affecting the calibration In addition to caution-level- and high-level radiation alarm signals, the HIF monitor must energize a green light when the radiation is below a predetermined safe level, so that experimenters are assured that the system is operating before they enter a hazardous work area. The panel meter and one of the external meters are calibrated in minutes, in order to indicate the time that the experimenter can safely stay in a work area.

This electrometer was bench tested for eight months The maximum drift observed at the output with a 5½-digit digital voltmeter was 0.04% of full scale. There was no perceptible change in calibration, and none of the alarm trip points drifted more than 2% from the original setting. The drift during the last six months was <1%.

# ORIC

## 5.11 OAK RIDGE ISOCHRONOUS CYCLOTRON MAGNET REGULATOR IMPROVEMENT PROGRAM

W E. Lingar

A new current-regulator system was designed as part of a program to upgrade the main field regulator and the AVF (trim and harmonic) regulators of the ORIC. The object was to replace the original regulating system with one that would be significantly more stable and more reliable and that would reduce the current ripple. The new main field regulator has operated successfully, and no maintenance has been required. The new regulator significantly reduces the current ripple and improves the long-term stability of the current of the trim coil. The new AVF regulator was installed in January–February 1976 on one of the ORIC trim coils. The regulator is in use, and circuit optimization is being performed during the scheduled downtime of the ORIC.

The design and fabrication of the regulating system included the following

1. A new transistor bank, containing 80 paralleled transistors, was designed using higher-frequency transistors and commercially available heat sinks.
2. Precision, water-cooled shunts were installed which had lower temperature coefficients and higher outputs than the original shunts.
3. Stud-mounted rectifiers and commercial heat sinks were installed to replace the original rectifier banks.
4. New power cables were installed to interconnect the shunt, transistor bank, and rectifier bank.
5. New electronics for the feedback regulator and control circuits were designed. The components required by these circuits were assembled on two chassis.
6. A control panel that contained circuitry compatible with both manual and computer operation of the regulator was designed for the control room.

# ORELA

## 5.12 OAK RIDGE ELECTRON LINEAR ACCELERATOR IMPROVEMENT PROGRAMS

T A. Lewis

The increased beam handling capability of the target when using the swept-beam mode of operation was proved for levels of about 60 kW. An additional heat exchanger was added to the target cooling-water circuit to allow the target to dissipate the heat from a 75-kW average power ORELA beam

The program for improving the performance of the accelerator in the short-pulse (3 to 5 nsec) region is progressing favorably. Calculations[1] with a one-dimensional approximation model are favorable Expansion of these calculations to more dimensions in order to better determine the magnetic field and gap field effects is being investigated Tests[2] of certain critical items of hardware are sufficiently far along to anticipate completion of all necessary prototype systems within the next year

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1 By R G Alsmiller, Jr , F S Alsmiller, and J Barrish, Neutron Physics Division
2 By D W Bible, T A Lewis, and J H Todd, Instrumentation and Controls Division

## 5.13 EXPERIMENTAL ACTIVITIES FOR THE NEUTRON PHYSICS DIVISION

R W. Ingle J H. Todd

The Neutron Physics Division fissile isotopes group was assisted in the following areas (1) maintaining the stability and reliability of the instrumentation and compiling documentation necessary for analysis of the data for nuclear cross-section experiments at the ORELA, (2) designing special circuits or modifying commercially available instruments, and (3) developing and improving radiation detectors, particularly fission chambers and scintillation detectors, and applying them to neutron time-of-flight measurements.

Updating and improving the experimental systems is a continuing process, with the goal of improving data accuracy. Modifications are under way to expand the neutron multiplicity system to measure multiple pulse height and multiple fission neutron time-of-flight parameters The CAMAC system of nuclear instrumentation is being used for these purposes

The 3000-liter liquid scintillator system used for capture measurements at the ORELA was disassembled, and the 32 photomultiplier tubes were replaced because they had failed owing to permeation of helium. This detector is used for $^{238}$U capture measurements

## 5.14 PROTON RECOIL DETECTOR SYSTEM

R. W. Ingle J. H. Todd H. Weaver[1]

The accurate determination of $\bar{\nu}$, the number of neutrons per fission of a fissile isotope, requires knowledge of the precise detection efficiency of the detector. A system was designed and fabricated for the Neutron Physics Division to measure the efficiency of the $\bar{\nu}$ detector vs energy over a range from 0.5 to 10 MeV. The proton-recoil detector consists of a ¼-in.-thick, 2-in.-diam Ne-213 liquid scintillator enclosure mounted on a 2-in.-diam flat-faced photomultiplier tube. The detector is at the center of the $\bar{\nu}$ tank. Beam neutrons are scattered by the Ne-213 liquid into the large, liquid, neutron scintillator The efficiency of the detector as a function of neutron energy is determined from the energy of the incident neutrons, the pulse-height spectra from the proton-recoil detector, and the ratio of the number of neutrons detected by both detectors to those detected by the recoil detector. Pulse shape discrimination is used to reject gamma rays from the recoil detector, and neutron energy is determined by the fast (anode) signal from this detector.

Investigations were started to improve the accuracy of this measurement system by reducing unwanted scattering of neutrons. In order to accomplish this goal, smaller-diameter photomultiplier tubes and a solid-state detector were purchased to be incorporated in the system.

1. Neutron Physics Division.

### 5.15 SUPERHEAVY ELEMENT DETECTION SYSTEM

J. H. Todd

Development of a neutron multiplicity detector was started. The original concept of the system, to detect the presence of superheavy elements by means of a predicted $\bar{\nu}$ (the number of neutrons per fission) of 8 to 10, was broadened, and the development was changed so that some experiments planned for the Hollifield Heavy-Ion Facility can make use of this system.

The system will consist of multiple (probably 12) fast-scintillation detectors in a dodecahedron. Nanosecond logic and data handling will detect and record the time distribution of events. The time distribution of multiple events will be sorted into 6-nsec increments. Special handling of different multiplicities will be possible. Detector efficiencies of 80% for single neutrons with energies down to 100 keV will be attempted.

### 5.16 SCINTILLATOR SYSTEMS

J. H. Todd  H. Weaver[1]

The improvement of scintillator-photomultiplier tube systems was continued.

Conflicting requirements (e.g., bubble-free containers and practical shape requirements, reflective surfaces that are stable both in color and bonding ability while in contact with hydrocarbons and fluorocarbons, and wide-band optical coupling requirements) eliminated the use of commercially available scintillator packages.

Procedures were developed for selecting the type of reflective coating and for treating the coating, based on factors such as type of container (whether or not the coating will be in contact with a hydrocarbon or a fluorocarbon) and the optical coupling requirements.

Packages were developed to have either pyrex or quartz optical windows. A directly coupled container was also developed.

Development of gas scintillation detectors was started, with emphasis on closed (noncirculating) systems.

1. Neutron Physics Division.

## 5.17 NEW LIQUID SCINTILLATOR SYSTEM

R. W. Ingle J. H. Todd H. Weaver[1]

Installation of a 210-gal, liquid scintillator detector was started at the ORELA 85-m flight station for the Neutron Physics Division for neutron multiplicity and capture gamma-ray experiments. This detector is similar to one previously used for these experiments, but it has been improved. Compared with the previous detectors, this one is also spherical in shape, but the center tube holding the fissile material is smaller, which results in greater neutron detection efficiency. Twelve 5-in.-diam photomultiplier tubes – vs eight in the original system – improve the detection efficiency, pulse-height resolution, long-term gain, and resolution stability and reduce noise and background effects by permitting coincidence operation between two or three groups of tubes. These characteristics are necessary for the precision required for this measurement.

The component parts of the total system are being assembled.

1. Neutron Physics Division.

## 5.18 GAS SCINTILLATION FISSION COUNTERS

J. H. Todd

Ionization chambers have been used for many years to measure fission cross sections of fissionable isotopes. However, as the need increased for cross-section measurements of isotopes with greater alpha activity, problems caused by pileup of pulses inside the chambers increased as well.

An investigation of gas scintillators was started in order to determine whether these detectors would not be so affected by pileup and whether these detectors would extend the range of isotopes for measurement of fission cross sections.

## 5.19 FISSION CHAMBERS FOR CROSS-SECTION STUDIES

F. E. Gillespie

A 20-plate fission chamber containing 40 mg of $^{240}$Pu was fabricated for the Neutron Physics Division's cross-section studies at the ORELA. The $^{240}$Pu was evaporated on 0.5-mil-thick aluminum foils.[1] This chamber has ten sections, with ten, complete, current-sensitive fast apmlifiers. Each of two sections in this chamber contains two plates coated with $^{235}$U, one section contains two plates coated with $^{239}$Pu and 95% $^{240}$Pu, and each of seven sections contains two plates coated with $^{240}$Pu.

Plates coated with $^{238}$U and $^{235}$U plates from fabricated chambers[2] were combined to study $^{238}$U fission in the subthreshold region, through the threshold region, and then to a few MeV. The chamber contained 4.7 g of $^{238}$U, which had a maximum impurity of 2 ppm of $^{234}$U, $^{235}$U, and $^{236}$U combined. In order to normalize to $^{235}$U data, another chamber was constructed, with some plates having 1 mg/cm$^2$ of $^{235}$U and other plates having 1 mg/cm$^2$ of a mixture of $^{235}$U and $^{238}$U evaporated on 0.5-mil-thick aluminum foils over a 4-in.-diam area (81 cm$^2$).

Experiments to determine the number of neutrons emitted per fission required placing $^{252}$Cf foils inside the fission chambers.

For future cross sections of the actinides (especially $^{241}Am$), different techniques will be needed. Gas scintillation is being studied to reduce alpha pileup.

1. By H. Adair, Solid State Division.
2. Designed by M. M. Chiles.

### 5.20 PHOTOMULTIPLIER TUBE GATING

J. H. Todd

Many pulsed neutron sources, including the ORELA, use the $(\gamma,n)$ reaction for neutron generation. Since this reaction produces an intense gamma flash with each burst of neutrons, every burst of neutrons is preceded by a gamma flash that generates a large overload signal in the detector. Such large overload signals cause a large gain shift in the photomultiplier-tube–scintillation assembly radiation detector. Since the recovery time following these large overload signals can be hundreds of microseconds long, measurements during the recovery period are made while the gain of the detector is changing.

In the past, we attempted to attenuate a timed arrival of a large signal by gating off the photomultiplier tube, that is, by operating on portions of the electron multiplier biasing network. However, this method does not eliminate gain shifts caused by changing conditions on the photocathode and other components in the electron multiplier preceding the sections that are operated on.

An improved method, similar to that reported by Lamaze,[1] has achieved a signal attenuation of greater than 1000, with a recovery time of approximately 400 μsec. The gating is done by injecting a pulse on a grid located externally on the face of the photomultiplier tube.

1. G. P. Lamaze et al., *After-Pulse Suppression for 8850 and 8854 Photomultipliers,* NBS Publ. 425 (October 1975), p. 106.

## VAN DE GRAAFF ACCELERATORS

### 5.21 VAN DE GRAAFF ACCELERATOR ENGINEERING ACTIVITIES

R. P. Cumby

A new ion-source test bench was constructed for development uses at the Tandem Van de Graaff Laboratory. Power supplies and other instrumentation were installed. Assistance in checking the ion source was provided.

Part of the terminal of the 5-MeV Van de Graaff was reworked to make room for an ion pumping system. Some of the vacuum-tube power supplies were changed to solid-state power supplies.

For the 3-MeV Van de Graaff, a trigger circuit was developed for firing a laser, using an optical coupling–lightpipe arrangement to prevent electromagnetic interference from escaping from the shielded room. A second trigger circuit with a variable digital delay was developed to coordinate the removal of the deflector plate voltage and the laser firing in studies of gas properties.

Engineering support was provided for making instrument setups for experiments on all the accelerators.

# 6. Automatic Control and Data Acquisition

## COMPUTER-BASED SYSTEMS

### 6.1 REAL-TIME, TV-BASED, POINT-IMAGE QUANTIZER AND SORTER[1]

A. L. Case J. B. Davidson

A device was provided for improving the vertical resolution in a television-based, two-dimensional readout for radiation detection, such as is used to determine the location of light or nuclear radiation impinging on a target area viewed by a television camera, where it is desired to store the data indicative of the centroid location of such images. In the example embodiment, impinging nuclear radiations detected in the form of scintillations occurring in a crystal are stored as charged images on a television camera tube target. The target is scanned in a raster, and the image position is stored according to a corresponding vertical scan number and horizontal position number along the scan. To determine the centroid location of an image that may overlap a number of horizontal scan lines along the vertical axis of the raster, digital logic circuits are provided with at least four series-connected shift registers, each having 512 bit positions according to a selected 512 horizontal increments of resolution along a scan line. The registers are shifted by clock pulses at a rate of 512 pulses per scan line. When an image, or a portion thereof, is detected along a scan, its horizontal center location is determined, and the present front bit is set in the first shift register and shifted through the registers one at a time for each horizontal scan. Each register is compared bit by bit with the preceding register to detect coincident set bit positions until the last scan line detecting a portion of the image is determined. Depending on the number of shift registers through which the first detection of the image is shifted, circuitry is provided to store the vertical center position of the event according to the number of shift registers through which the first detection of the event is shifted. Interpolation circuitry is provided to determine whether the event centroid is between adjacent scan lines and is stored in a vertical address accordingly. The horizontal location of the event is stored in a separate address memory.

1. Abstract of U.S. Patent No. 3,958,079 (May 18, 1976).

### 6.2 MICROCHANNEL-PLATE INTENSIFIER – SOLID-STATE IMAGER SPECTRUM-SCANNING SYSTEMS[1]

Yair Talmi[2] J. B. Davidson

Solid-state imaging devices (SSID) have such desirable features as geometric accuracy, compactness, simplified optical interfacing and cooling, and virtually zero image lag. In order to evaluate the performance of commercially available, state-of-the-art SSIDs, we purchased a 500-element, linear array, charge-coupled device (CCD), a 1024-element, silicon photodiode (SPD) linear array, and a 188 X 244 element-area array, charge-injection device (CID). The driver-amplifier circuit boards required for the operation of the SPD and the CCD and the complete CID camera were purchased from the manufacturers of the corresponding SSIDs. The CID camera was further modified (for one-dimensional applications) to allow an integration across an entire TV line (in addition to its normal raster-scan operation). The video outputs from these imagers were observed in real time on an oscilloscope screen and were simultaneously fed into a signal averager (used as a multichannel analyzer). The imagers were placed at the focal plane of a 0.5-m spectrometer. The spectrometer was used either as a monochromator photomultiplier tube (PMT) with a detector, or as a 35-mm focal-plane spectrograph with a Polaroid camera on an SSID detector. Thus, very useful comparisons between the performance of the various SSIDs, photographic emulsions, and PMTs, under identical spectrometric experimental conditions, were accomplished. As expected, signal-to-noise ratios (*S/N*) of all three SSIDs were substantially inferior compared with a 1-P28 PMT at the 200- to 550-nm spectral region. Above 550 nm, however, the *S/N* performance of all three imagers became much more compatible, even compared with PMTs with ERMA photocathodes.

Although the video output of the SPD array was substantially deteriorated by the characteristic switching noise component, the overall spectrometric performance of that device was better than that of the other two imagers. Its (linear) dynamic range was 200 (compared with less than 100 for the CID), it had a useful spectral response down to 200 nm, and its operation was much simpler and more flexible.

To enhance the sensitivity of the SSIDs, they were optically interfaced (with a relay lens) to a 25-mm, microchannel plate (MCP) image intensifier with an ERMA photocathode and a P1-P39 output phosphor. Because the photocathode has a poor quantum efficiency below 350 nm, it was coated with a thin (0 1 to 0.3 mg/cm$^2$) layer of sodium salicylate (a uv-to-visible converter). These intensified SSIDs (I-SSIDs) have shown an *S/N* gain of up to 1000 over the unintensified devices despite the very inefficient optical interfacing (relay lens). This sensitivity gain (multiplex advantage) varied with the wavelength because of corresponding variations in the quantum efficiency values of the photocathode and the silicon sensors.

A performance comparison between the SSIDs and the I-SSIDs was done by studying such parameters as lag, resolution, spectral response, blooming, dynamic range, noise, accuracy and precision, element-to-element response, and dark-current variations. At high light levels, blooming in the phosphor caused a definite deterioration of resolution, sensitivity, and accuracy. Within the scan rates used in this study (10 to 20 msec/scan), the I-SSIDs had virtually zero image lag.

We believe that, with redesign of the amplifiers and a more efficient optical coupling between the MCP intensifier and the imager (using a specially designed optical-fiber faceplate), the I-SSIDs should become photon-noise-limited multichannel detectors.

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1 Abstract of paper presented at the Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, March 1976

2 Current address Princeton Applied Research Corporation, Princeton, N J

## 6.3 EVALUATION OF ANOMALOUS DATA FROM THE NEUTRON MULTIPLICITY COUNTER

R. T. Roseberry J Halperin[1] B. H. Ketelle[1]

A study was started to determine the cause of anomalies (i e., preferential numbers) observed in recent experiments when data were stored in a PDP-9 computer. The neutron multiplicity counter was tested utilizing (1) fixed-rate data that had been output by the printer, removing the computer's interaction, (2) output as buffered raw data, isolating the data input section of the computer program, and (3) output as processed data on DECtape for evaluation on the PDP-10 From preliminary results, we believe that the structuring occurs in the least significant digit of the recording hardware

1 Chemistry Division.

## 6 4 TWO-DIMENSIONAL, POSITION-SENSITIVE DETECTION SYSTEM

E Madden E McDaniel S Spooner[1] R Childs[2]

A computer-based, automatic data collection and analysis system for neutron small-angle scattering studies, using refined "pin-hole" collimation, was designed and fabricated for the Solid State Division and placed on-line at the Oak Ridge Research Reactor (ORR) This system will be used to study nonspherical voids, superconducting fluxoids, and nonspherical critical scattering from ferromagnets and clustering alloys

The system has a Borkowski-Kopp, two-dimensional, position-sensitive, gas-filled proportional counter, which has a sensitive area of 200 X 200 mm. The counter is filled with 635 mm $^3$He, 867 mm Xe, and 58 mm $CO_2$, has a resolution of 5 mm for thermal neutrons, and was fabricated with low-noise, voltage-sensitive, Q-5100 preamplifiers

An HP 21MX computer is the base for the data acquisition system Its peripheral equipment includes a magnetic-tape transport, point plot display, punched-paper-tape reader, paper-tape punch, and controller to interface the computer to a pair of NS 621 analog-to-digital converters (ADCs), which couple to the front-end electronics The ADC-computer interface was designed to operate in the interrupt mode and the direct memory access mode A live-time clock mode is accommodated in the interface The present configuration of 16K of the computer memory restricts the accumulation region to one of 64 X 64 channels, but 128 X 128 is possible if memory capacity is added to the system.

The HP 5406B modular, computer-based, nuclear, multichannel analyzer system software was adapted to the 21MX computer for this application The software is modular, and the applications software package is configured from the system software prior to experiment run time The display software module was modified and rewritten to overcome hardware incompatiblities and to provide slice- and isometric-display capabilities

1 Chemistry Department, Georgia Institute of Technology, Atlanta
2 Solid State Division

## 6 5 POSITION-SENSITIVE DETECTOR SYSTEM

E. Madden E. McDaniel R E Zedler

A computer-based, automatic data collection system for thermal-neutron diffraction studies, using a Borkowski-Kopp position-sensitive gas-filled proportional detector, was designed and fabricated for the neutron and x-ray diffraction section of the Chemistry Division

The neutron detector is a 500-mm-long, 44.5-mm-diam, brass cylinder with a pyrolytic-carbon-coated quartz fiber. The counter is filled with 5% methane, 47.5% krypton, and 47.5% $^3He$ at 2 atm abs. Wide-band, low-noise, voltage-sensitive preamplifiers[1] with good temperature stability and high input impedance are installed with the proportional counter. The front-end electronics used to obtain spatial information from the crossover timing of the detector output pulses are commercial NIM modules such as amplifiers, crossover detectors, delays, and a time-to-amplitude converter.

A commercial nuclear analog-to-digital converter (ADC) converts the analog spatial information to digital data to be accepted by a PDP-8/E computer via an electronic digital interface.

The electronic interface was designed and fabricated to allow the PDP-8/E to acquire the data from an NS 621 ADC. ADC live-time information is generated and stored in channel zero. The interface includes a computer-controlled monitor counter for monitoring the primary neutron beam.

The automatic, repetitive data collection and spectra dump to punched-paper tape and teleprinter are programmed. Real-time, ADC live-time, and preset monitor count modes are accommodated. The operator may set the upper and lower bounds of the data region to be output.

1. M. K. Kopp, *Rev. Sci. Instrum.* 42(5), 714 (1971).

## 6.6 THREE-AXIS NEUTRON DIFFRACTOMETER EXPANSION

E. Madden

Drive and control electronics were designed, fabricated, and installed to add a sixth stepping motor to the three-axis neutron diffractometer at the High Flux Isotope Reactor beam hole 2 for the Solid State Division. The bifilar stepping motor ($2\theta_M$) drives the center portion of the monochromator shielding and arm 1 and the beam stop attached to the arm. The controller provides the motor coil drive currents and automatically switches the step-hold coil current between 4 and 1 A per winding, when the computer starts or stops stepping the motor.

A dual DECtape transport and controller, 12K words of core computer, memory, and an incremental digital plotter were added to the PDP-8/E three-axis diffractometer.

## 6.7 PUNCHED-PAPER-TAPE READER–PDP-8/E INTERFACE

E. Madden J. W. Woody

An Addmaster 601-1 punched-paper-tape reader was packaged in a three-unit-wide NIM module, and a reader–PDP-8/E interface was designed. Two reader units and two interface cards were fabricated for the Solid State Division. The interface, which was designed to operate with standard DEC, high-speed-reader, binary-loader software, will read paper tapes into the PDP-8/E at ~125 characters per second with the binary loader. The phototransistor bit amplifiers on the Addmaster driver card were modified to obtain more consistent switching levels and better dc noise margins from the bit amplifiers.

### 6.8 NS 621 ADC, PDP-8/E PROGRAMMED INPUT-OUTPUT INTERFACE

E. Madden W. Dress[1]

An interrupt-driven, programmed input-output module was designed, fabricated, and installed to interface an NS 621 ADC to a PDP-8/E computer. The interface includes a live-time clock channel. A Decus 8-620B, single-channel, double-precision, 1024-channel, PHA data acquisition and display program was modified and adapted for the applications software. A Fluke 330B programmable power supply is also interfaced to the system. The system runs under an OS-8 operating system with dual DECtape, disk, display, and LA36 printer.

1. Physics Division.

### 6.9 NS 621 ADC, PDP-8/E, DATA BREAK ACQUISITION INTERFACE

E. Madden

An NS 621 ADC, PDP-8/E, data accumulation interface was designed and fabricated to acquire pulse-height data via the NS 621 ADC and to store the data in a program-assigned buffer area of the PDP-8/E memory under the DEC data break mode of operation. Live-time clock operation is accommodated.

### 6.10 THERMONUCLEAR DIVISION COMPUTER SYSTEM SPECIFICATIONS

J. W. Reynolds J. K. Ballou[1] W. K. Dagenhart[1]
J. E. Francis[1] O. C. Yonts[1]

Computer specifications were prepared and ERDA Manual, Appendix 1801, requirements were completed for three computer systems and one extension. The computer specifications were TD-SP-156 for "An Interactive Data Acquisition System for the Superconducting Magnet Development Program" (SCMDP), and TD-SP-157 for "A Remote Job Entry Terminal for the SCMDP" to be located in Building 9204-1. The other items were as follows: (1) a PDP-11/40 system containing two disks, a CRT display, a line printer, and 32K words of memory with a CAMAC front end for acquiring data from the medium-energy test facility for neutral-beam development (NBD); and (2) a CAMAC extension from the NBD PDP-11/40-CAMAC system to a laboratory in Building 9201-2.

1. Thermonuclear Division.

### 6.11 RADIOISOTOPIC SAND TRACER STUDY

H. R. Brashear F. N. Case[1] K. W. Haff[1]

The joint program between the National Oceanic and Atmospheric Agency and the Energy Research and Development Administration to adapt the equipment and techniques of the radioisotopic sand tracer study was continued to include a field experiment in the New York Bight during November and December 1974 and January 1975, and a field test of a suspended sediment gage in Chesapeake Bay in December 1975.

The field experiment was designed to tag the sand with $^{103}Ru$ (40-day half-life) and to make periodic radiation surveys during winter storms. The experiment was successful, experiencing several wintry storms and one major storm. Sediment transport at a water depth of 20 m during normal winter weather was east-northeast, approximately parallel to the Long Island, N.Y., coast, which is the general direction of the water mass flow in that region of the bight The apparent average transport rate during these times was approximately $3 \times 10^{-3}$ g $cm^{-1}$ $sec^{-1}$. During the major storm, there was a dramatic reversal of the transport pattern, and the average rate during this time was approximately 0 15 g $cm^{-1}$ $sec^{-1}$, which indicates that most of the sediment transport in that region takes place during storms.

A gamma-ray transmission gage was designed and fabricated at ORNL. It was tested in the Chesapeake Bay to determine when sediment became suspended and to determine the density of the suspended sediment as a function of height above the bottom of the bay during various ocean conditions The gage consisted of a 1-Ci, $^{153}Gd$ source (100-keV gamma ray), a $1 \times 1$ in. NaI(Tl) crystal, a photodiode, and a Varactor bridge electrometer mounted on a sled. A cable between the gage and ship supplied power to the gage and carried the signal to the shipboard data collection system A density change of 3 parts per thousand, due to suspended sediment and salinity changes, was observed. A long-term drift of the detector was also observed, and an ionization chamber was designed to replace the crystal and photodiode

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1 Operations Division

## HARD-WIRED SYSTEMS

### 6.12 MAGNET POWER SUPPLY AND DATA ACQUISITION CONTROLLER

E. Madden

A four-unit-wide NIM module was designed, fabricated, and installed at the Oak Ridge Research Reactor for the Solid State Division in order to execute the following repetitive sequence of tasks reduce to zero current an Eastern Scientific Instruments Corp , model 7, 100-A magnet power supply, degauss the magnet, accumulate data in the lower half (256 channels) of an ND 1200, 512-channel, pulse-height analyzer until a preset monitor scaler overflows, ramp the magnet current up to a preset value, accumulate data in the upper half (256 channels) of the pulse-height analyzer until the previously mentioned preset monitor scaler overflows, ramp the magnet current down to zero, and repeat the operation This cycle is repeated a maximum of 999 times, accumulating data in the summing mode. The actual monitor count and actual full-cycle count are displayed on LED readouts on the front panel of the controller The magnet power supply was modified to accept this control system.

### 6.13 MAGNETIC-TAPE RECORDING SYSTEM FOR POSITION-SENSITIVE DETECTOR DATA

C. J. Borkowski R. T. Roseberry

A magnetic tape that records in industry-compatible format was used as memory to log data acquired from a Borkowski-Kopp position-sensitive proportional counter by a conventional pulse-height analyzer. An important application of the system is nuclear medicine image acquisition and storage.

Data processed by the analyzer are picked off the memory buffer by the magnetic-tape control as the data are being stored in the analyzer memory. Since the analyzer memory contains only 4096 words, image data is stored in a 64 X 64 matrix. However, the analyzer digitizes the data as a 256 X 256 matrix, which is stored in full resolution on magnetic tape. Data thus recorded can be processed by computer or converted back to analog form and fed to a scan converter for observation

## 6.14 DATA COLLECTION FROM A MULTIDETECTOR SYSTEM FOR AN AUTOMATICALLY SCANNING ELECTRON SPECTROMETER

R. T. Roseberry C. R. Mitchell M. O. Krause[1]

The conceptual design for data collection from a multidetector array placed in the focal plane of a scanning electron spectrometer[2] was formalized into a hardware design. Construction is nearing completion The instrument is packaged in a four-unit-wide NIM module.

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1 Chemistry Division

2 R T Roseberry and M O Krause, "Data Collection from a Multidetector System for an Automatically Scanning Electron Spectrometer, a Conceptual Design," *Instrumentation and Controls Div Annu Prog Rep Sept 1 1974,* ORNL-5032.

## 6.15 DATA ACQUISITION SYSTEM

D. W. McDonald

A microprocessor-based data acquisition system was developed for the Metrology Research and Development Laboratory. The system can handle 100 low-level channels. After a system operator specifies which channels are to be scanned and the time interval between scans, the microprocessor controls the multiplexing and timing. The data are transferred to a Teletype, where they are labeled, typed, and stored on paper tape.

## 6.16 AUTOMATED ELECTROCARDIOGRAM DATA ACQUISITION SYSTEM

R. L. Simpson

Continuing support was given to the automated electrocardiogram data acquisition system Approximately 700 ECGs were recorded and analyzed monthly for all four plants. A new program was developed to store all ECGs on magnetic tape for future comparison of an individual's current ECG with his previous ECGs.

## 6.17 COMPUTER-BASED DATA ACQUISITION AND CONTROL SYSTEM FOR HTGR-GRAPHITE CREEP IRRADIATION TESTS AT THE ORR

J. M. Jansen J. A. McEvers R. L. Simpson F. R. Gibson

A computer-based data acquisition and control system was developed, installed, and operated to control and acquire data from the OC-1 series creep experiment at the Oak Ridge Research Reactor. The system was developed with a capability to add five existing experiments which use a Beckman Dextir system for data acquisition. The control requirements for OC-1 and the requirements for phase-out and replacement of the 1960-designed Dextir system dictated a computer-based system.

The OC-1 experiment has ten zones containing independently controlled electrical heaters, which supply supplemental heating to four stacks of specimens in the experiment capsule. The computer performs a direct-digital, two-mode, control algorithm to maintain a uniform specimen temperature profile across the heated zones. Bellows pressures for two loaded specimen stacks, containment pressures, sweep-gas flows, and several auxiliary temperature inputs are also monitored and checked against prescribed operating limits. A backup analog control system takes control if the computer should malfunction during scheduled maintenance periods.

The system prints periodic hard-copy logs of scanned parameters in engineering units, a CRT display of temperature profiles and temperature control limits, and alarm annunciation and logging.

## 6.18 COMPUTER-CONTROLLED DATA ACQUISITION SYSTEM FOR THE THERMAL HYDRAULIC TEST FACILITY

A. F. Johnson J. L. Redford K. J. Cross

A 10,000-channel/sec, digital data acquisition system was operational at the Thermal Hydraulic Test Facility since the second quarter of 1975. The system was used for acquisition and limited analysis of data for simulated, pressurized-water-reactor loss-of-coolant accidents.

The data acquisition system was expanded to 512 analog input channels, primarily for monitoring thermocouples in the heated rod bundle. A 160-character/sec printer was installed to speed up data logging and program development functions.

System software is based on the FOCAL interpreter, with modifications and extensions for fast data acquisition. Significant recently implemented features include (1) periodic (0.25 sec) foreground limit check of all channels for either high or low alarms, (2) automatic start of fast scanning and recording if the system should scram, (3) ability to manipulate ASCII characters, (4) storage of programs on magnetic tape, (5) a vector function for CRT plotting, and (6) a command to renumber program lines

Application software, also coded in FOCAL, was written for checkout and operation of the facility An instrumentation data base, containing instrument application numbers, instrument type code, and calibration factors, was built and is maintained on the disk. A package of several codes was developed to assist in verification and calibration of the instrumentation during pretest preparation and during test startup. A general-purpose, CRT plotting code is available for on-site evaluation of test data. Codes were also prepared to provide the facility operators with pertinent information during loop steady-state operation.

A more sophisticated data acquisition system is being purchased to replace the present system. The primary requirements are (1) to increase the number of sensors monitored from 512 to 730, (2) to retain an acquisition rate of 20 samples/sec for all channels, (3) to permit simultaneous operation of multiple tasks (operations, instrumentation, and analysis), and (4) to increase the on-site, "quick-look" data analysis capability. Expansion of the present data acquisition system to satisfy these criteria is not feasible.

## 6.19 DATA ACQUISITION AND REDUCTION FOR THE THERMAL HYDRAULIC TEST FACILITY

N. E. Clapp, Jr.

As part of the blowdown heat transfer program, the Thermal Hydraulic Test Facility was constructed to investigate the performance of an electrically heated rod bundle (49 rods) during depressurization. Data are obtained from the facility using a computer-controlled data acquisition system (CCDAS). Computer codes were developed so that the data system would be capable of several modes of data acquisition and could supply the facility operator with performance information. Programs for the IBM-360 were developed to convert the CCDAS data tape to an engineering-units, IBM compatible tape. Other IBM-360 programs were developed to plot data and to perform statistical analysis.

## 6.20 INSTRUMENTATION UNCERTAINTY ANALYSIS FOR THE THERMAL HYDRAULIC TEST FACILITY

M. J. Roberts

The uncertainties in measurement of pressures, temperatures, coolant density, flow, and electric power were determined for the purpose of establishing confidence limits on data taken during blowdown tests and results calculated from those data. These limits will also determine the confidence one can place in evaluating the computer codes used to predict heat transfer coefficients, by comparing the predicted values with experimentally determined values.

## 6.21 DATA ACQUISITION AND REDUCTION FOR SINGLE-ROD BURST TESTS

K. J. Cross

Programming support was furnished to the single-rod burst-test loop for data acquisition from the test and for data reduction. This loop had been constructed to investigate the effects of test parameters and to resolve some of the temperature prediction errors for the multirod burst test facility. Data are obtained from the loop by a PDP-8/E computer-based acquisition system. Computer programs were written to acquire the data and to perform instrument verifications prior to a test. Programs were also developed to plot and tabulate the data on both the PDP-8/E and IBM-360 computers.

## 6.22 DATA ACQUISITION SYSTEM FOR THE ATDL

K. J. Cross

A data acquisition system was developed for the atmospheric turbulence and diffusion laboratory of the National Oceanic and Atmospheric Administration to acquire and record data from environmental monitoring instruments. The system consists of a 200-channel crossbar switch, which scans 25 channels per second; a 15-bit integrating analog-to-digital converter; a PDP-8/E computer with 4096 words of core memory; and an 800-bpi, seven-track magnetic-tape transport and controller. Up to six scan tasks can be run simultaneously with the operational software. Each task can periodically scan any number of channels (up to 200) at any time interval. The executive program also includes facilities to set up scan tasks or scan tables, print the scan tables and the status of the scan tasks, and record on and print records from magnetic tape for testing.

## 6.23 DEXTIR–PDP-8 SYSTEM SUPPORT

C. D. Martin, Jr.

The software system for the Dextir–PDP-8 data acquisition system in Building 9201-3 was modified for the Fuel Failure Mockup Facility to list data from 250 channels on two teleprinters. This increase of 100 channels over the previous system, and insufficient storage, required the packing of two, eight-bit ASCII characters per 12-bit computer word for temporary storage and subsequent unpacking for printing. The electronic interface between the Dextir and PDP-8 units was also modified to eliminate unwanted interrupts generated by spurious noise pickup.

## 6.24 DATA ACQUISITION SYSTEM FOR FUEL FAILURE MOCKUP FACILITY

J. L. Redford

The data acquisition system for the Fuel Failure Mockup Facility was modified to accommodate an increase in the size of the test loop. The hardware was expanded by adding 24K words of core memory, 1.6M words of disk memory, and 128 channels to the analog signal multiplexer. The FOCAL software was improved to visually display selected data during high-speed scan (10,000 samples/sec) and high- or low-limit checking of all signals, both during high-speed scan and ¼-sec periodic scan. Limit checking allows the computer to shut down the experiment when a selected number of signals are out of limits.

## 6.25 HIGH-LEVEL LANGUAGE TRANSLATOR FOR MICROPROCESSORS

K. J. Cross

A compiler for PL/M, a high-level language for programming the INTEL 8080 microprocessor, was made available to all users of the PDP-10 time-sharing system. There has been significant interest in PL/M outside the Instrumentation and Controls Division, because its use considerably reduces program development time for INTEL 8080 systems.

## 6.26 DIVISION SUPPORT PROGRAMMING

F. R. Gibson

An administrative program was developed to assist in the management of work orders written to Section B of the Instrument Department of this division. The data base includes work-order numbers, account numbers, dates, project names, job names, estimated costs, divisions responsible, project engineers, and funding account numbers. The input format of the program, written in TECO for use with a DEC OS/8 operating system, is a question-answer style that leads an inexperienced operator through the sorting and listing options.

## 6.27 MAINTENANCE INFORMATION SYSTEM

R. L. Simpson

Continuing support was given to the Maintenance Information System of this division. New forms were designed for entering estimates for fabrication jobs, miscellaneous work, and nonprogrammed maintenance.

Estimates were stored on disk for all instruments on programmed maintenance. New programs were developed to calculate and report (weekly) the backlog for each maintenance file point, supervisor, group, section, and division.

## 6.28 INTERFACE FOR VISHAY SCANNER AND SILENT 700 TERMINAL

J. A. McEvers

An interface was developed to allow strain data obtained by a Vishay strain gage scanning system to be recorded by a Texas Instruments, Silent 700 terminal. The data are formatted during transmission and printed seven channels per line, while simultaneously being recorded on a magnetic-tape cassette. The data can be edited and/or transmitted to a computer for further processing.

## 6.29 MATERIALS TESTING AXIAL-DIAMETRAL STRAIN CALCULATOR-CONTROLLER

J. T. Hutton

An instrument was developed to provide control signals for special cyclic fatigue and short-term tensile testing of hourglass-shaped metal specimens by the Metals and Ceramics Division. Inputs to the instrument are the load on a specimen (measured by a strain-gage load cell) and the change in specimen diameter (measured by an LVDT diametral extensometer). The calculator section of the instrument manipulates these variables, the initial diameter of the specimen, and the elastic Poisson ratio for the material under test in order to derive stress, total diametral strain, total axial strain, elastic diametral strain, and plastic diametral strain signals. These signals can be used as feedback to a control servo and as data outputs. Two strain ranges are available: 0 to 4% (axial) for fatigue testing, and 2 to 90% (axial) for short-term tensile testing. Operational amplifier circuitry plus multiplier-divider and logarithmic modules implement the calculator section.

When used with a commercially available digital function generator, the controller section of the instrument can provide control signals for special cyclic fatigue testing. Switch-settable stress and axial-strain trip points and CMOS integrated-circuit logic are used to program specimen test cycles. For example, the controller section can be programmed to strain the specimen at a constant rate in tension until a preset strain is reached, strain the specimen at the same rate into compression until a preset stress is reached, switch from strain control to stress control and hold until a preset compressive strain is reached, and then switch back into strain control and repeat the cycle. The changes in control mode, from strain control to stress control and back, are executed with negligible specimen upset using ORNL-designed, mode-transfer tracking amplifiers.

## 6.30 DATA ACQUISITION FOR THE MINI-ZWOK EXPERIMENT

J. M. Jansen F. R. Gibson

Remote dial-up capability for a single experiment was implemented on the CODAS III computer system operated by the Metals and Ceramics Division to permit sharing their data acquisition and computation system with the mini-ZWOK experiment.

A telephone-switched network and local teleprinter at the mini-ZWOK site that are acoustically coupled to the CODAS computer enable data acquisition and processed data output. Multiple thermocouple signals are switched and manually selected for readout by the computer, using two dedicated signal lines and a thermocouple switching device.

### 6.31 PROGRAMMABLE LOGIC CONTROLLER DISASSEMBLER

J. M. Jansen F. R. Gibson

A disassembler program was developed for use with a DEC industrial 14/series programmable logic controller. The program, written for use with the OS/8 software system, will accept as input the binary output tape produced by the VT14 display and will output a listing or a paper tape (or both) of the assembly language code. The output paper tape can be input to the DEC CREF program to produce a cross-reference listing of all input, output, and internal function references and allocations.

### 6.32 MODIFICATIONS FOR THE AQUATIC LABORATORY

J. A. McEvers R. C. Muller R. E. Toucey T. F. Sliski

The computer-based control system in the aquatic laboratory began routine operation in February 1975. A library of temperature-vs-time profiles that simulate daily and seasonal temperature variations was assembled and is used to control the water temperature in eighteen 200-gal tanks.

A semiportable control panel was designed and built for use with small aquarium tanks to supply water at a desired temperature to a maximum of ten tanks. Water temperatures to individual tanks can be controlled by a manual adjustment on the control panel, or they can be automatically controlled by the computer system. The mixing valves that control water temperatures are nonclogging and self-cleaning. They were designed and built at ORNL.

A linearization circuit was developed to enable an independent temperature readout on multipoint strip-chart recorders from the thermistor temperature sensors used for temperature control.

# 7. Reactor Instrumentation and Controls

## 7.1 NUCLEAR DETECTION INSTRUMENTATION FOR REACTIVITY MEASUREMENTS WITH THE FAST-FLUX TEST FACILITY ENGINEERING MOCKUP CORE[1]

M. V. Mathis J. T. De Lorenzo M. M. Chiles J. T. Mihalczo

Four multichannel detection systems, two operating in an integrated current mode and two in a pulse mode within the engineering mockup core for the Fast-Flux Test Facility reactor, successfully furnished signals during a five-month reactivity surveillance procedures experiment for evaluation of reactivity measurement methods and associated instrumentation for liquid-metal fast breeder reactor applications. In addition, the adequacy of the low-level flux monitor design for the Fast-Flux Test Facility was verified.

1. Summary of paper presented at the Nuclear Power Systems Symposium, Washington, D.C., Dec. 11–13, 1974, and published in *IEEE Trans. Nucl. Sci.* **22**(1), 691–93 (February 1975).

## 7.2 REGULATORY GUIDES FOR NUCLEAR REACTOR SURVEILLANCE AND DIAGNOSTICS

R. C. Kryter D. N. Fry J. C. Robinson[1] J. E. Mott[1]

Specialized services (analysis and computation, consultation, technical input, and technical review) were provided to the Nuclear Regulatory Commission to aid its staff in preparing regulatory guides for reactor system surveillance and diagnostics. In particular, we helped to formulate two new guides ("Inservice Monitoring of Gross Lateral Motion of the Core Support Barrel in PWRs" and "Loose Parts Detection Program for the Primary System of Light-Water-Cooled Reactors"), to defend them technically before review committees, and to answer technical questions raised by the nuclear industry and the general public.

We also served on a newly formed ASME Subcommittee on Vibration Monitoring, which has been assigned the task of writing standards for preoperational testing and in-service surveillance in this area for nuclear power plants.

1. Adjunct research participant, Nuclear Engineering Dept., University of Tennessee, Knoxville.

## 7.3 DETECTION OF SODIUM BOILING IN THE FUEL FAILURE MOCKUP FACILITY[1]

W. H. Sides, Jr. W. H. Leavell R. F. Saxe[2]

Tests were performed in the Fuel Failure Mockup (FFM) Facility at ORNL in order to determine (1) whether sodium boiling in the FFM could be detected acoustically, (2) whether the boiling site could be located, and (3) whether noncondensable gas entrained in the sodium coolant would affect the sensitivity of the detection system.

The results indicate that sodium boiling can be detected acoustically. The site of boiling could not be located by measurement of the acoustic pulse arrival time at the sensors. Entrained noncondensable gas in the sodium coolant at void fractions greater than 0.4% attenuated the acoustic signals sufficiently that boiling was not detected. At a void fraction of 0.1%, indications of boiling were seen on the two acoustic detectors closest to the boiling site.

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1. To be published as ORNL/TM-5355. This work is also reported by W. H. Leavell and W. H. Sides, Jr., "Effects of Entrained Gas on the Acoustic Detection of Sodium Boiling in a Simulated LMFBR Fuel Bundle," *Trans. Am. Nucl. Soc.* **22**, 399 (1975)
2. Consultant, Nuclear Engineering Dept., North Carolina State University, Raleigh.

## 7.4 CORE COMPONENT VIBRATION MONITORING IN BOILING-WATER REACTORS USING NEUTRON NOISE[1]

D. N. Fry   J. C. Robinson[2]   R. C. Kryter   O. C. Cole

Neutron noise from in-core fission detectors in a boiling-water reactor (BWR) was investigated to determine its effectiveness as a monitor of mechanical vibrations of core components. In this study, the general properties of BWR neutron noise were characterized, and a signal-enhancement method was implemented to improve the measurement sensitivity.

Neutron noise is being used to monitor the movement of core barrels in pressurized-water reactors (PWRs). However, neutron noise has not been used for this purpose in BWRs, because some noise analysts have predicted that the neutron noise caused by boiling voids would likely mask reactivity noise in BWRs, which is introduced by mechanical vibration, and thereby limit the usefulness of neutron noise for monitoring such vibrations.

We postulated that the masking effect of local boiling noise might be reduced by cross-correlating the signals from two in-core detectors at different radial core positions.

To test this postulate, neutron noise signals from 43 radially spaced in-core fission ionization chambers in the Browns Ferry Unit 2 BWR were analyzed at power. The results show that the cross-power spectral density analysis eliminates the uncorrelated local boiling noise at frequencies greater than ∿1 to 2 Hz.

We therefore conclude that, in the future, neutron noise will prove to be as useful in BWRs as it has been in PWRs for monitoring vibration of in-core components. However, because of the global noise, it will probably prove useful only at vibration frequencies >1 to 2 Hz.

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1. Abstract of published paper: *Trans Am. Nucl Soc.* **22**(1), 623 (November 1975)
2. Consultant, Nuclear Engineering Dept., University of Tennessee, Knoxville.

## 7.5 DIAGNOSIS OF IN-CORE INSTRUMENT TUBE VIBRATIONS IN BWR-4s[1]

N. J. Ackermann, Jr.   D. N. Fry   R. C. Kryter   W. H. Sides, Jr.
J. C. Robinson[2]   J. E. Mott[2]   M. A. Atta[3]

In-core instrument tube vibrations have been diagnosed in BWR-4s through the use of neutron noise analysis. While neutron noise analysis has been employed previously for monitoring in-core component vibrations in PWRs, to our knowledge this is the first successful application in BWRs. Noise analysis of signals from fission chambers located in these instrument tubes has confirmed that some of the tubes are vibrating excessively, and visual inspection of fuel assemblies from two BWR-4s has revealed excessive wear on some of the fuel channel boxes.

The following conclusions have been drawn.

1. In-core instrument tube vibrations can be observed by neutron noise analysis, using either the percent peak-to-peak noise in traversing in-core probe traverses or the more detailed power spectral densities (PSDs) of in-core, fission-chamber signals.
2. Noise analysis signatures are translatable from one reactor to another of similar design.
3. The instrument tube vibration is highly dependent on flow.
4. The observed noise in the detector signals is neutronic in origin, not microphonic, as determined through PSD measurements for the same fission chamber with different applied detector voltages.
5. Power spectral densities must be normalized in absolute units to afford quantitative and unambiguous translation of results from one reactor condition to another condition and from one reactor to another reactor.

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1. Abstract of published paper: *Trans. Am. Nucl. Soc.* 22(1), 624 (November 1975).
2. Consultant, Nuclear Engineering Dept., University of Tennessee, Knoxville.
3. IAEA Fellow.

## 7.6 NEUTRON NOISE MEASUREMENTS TO EVALUATE BWR-4 CORE MODIFICATIONS TO PREVENT INSTRUMENT TUBE VIBRATION[1]

M. V. Mathis D. N. Fry J. C. Robinson[2] J. E. Jones[3]

Neutron noise analysis was successfully applied to determine the degree to which the impacting of in-core instrument tubes in a BWR-4 plant was reduced after holes in the core support plate were plugged to reduce the upward flow of coolant water around the tubes. Fuel channel boxes in BWR-4s have been damaged by impacting from in-core instrument tubes located in the bypass flow region between the boxes. The tube vibrations are caused by excessive coolant flow around the tubes. Previous neutron measurements have shown that tube vibrations could be reduced by decreasing the flow, and in several plants the coolant bypass holes in the core support plate are being plugged to reduce the bypass flow.[4]

Neutron noise measurements were made at a BWR-4 plant before and after the coolant holes were plugged. Signals were obtained from installed fission chambers (local power range monitors) at 31 radial core locations. Four detectors (labelled *A*, *B*, *C*, and *D*, and referred to as a string) were equally spaced in each instrument tube from the bottom to the top of the core. Normalized power spectral density of the *C* and *D* detectors and the normalized cross-power spectral density between these detectors in each string were computed utilizing an on-line minicomputer-based noise analysis system.

Based on these measurements, the noise analysts concluded that 26 instrument tubes were impacting against the surrounding fuel boxes before plugging and that there is no evidence that any of the 31 instrument tubes were impacting after plugging. Furthermore, they believe that periodic neutron noise monitoring could provide a means to monitor other in-core component vibrations similar to the type described here.

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1 Abstract of published paper *Trans Am Nucl Soc* 23, 466 (June 1976)
2 Consultant, Nuclear Engineering Dept , University of Tennessee, Knoxville
3 Research Assistant, Nuclear Engineering Dept , University of Tennessee, Knoxville
4 See "GE Believes It Has Solved the In-Core Instrument Vibration Problem," *Nucleonics Week* 17(3), 10 (Jan 15, 1976)

## 7.7 DETECTION OF IMPACTS OF INSTRUMENT TUBES AGAINST CHANNEL BOXES IN BWR-4s, USING NEUTRON NOISE ANALYSIS[1]

J. E. Mott[2] J. C. Robinson[2] D. N. Fry M. P. Brackin[3]

By applying neutron noise analysis, the authors have devised a method for detecting the onset of impacting of in-core instrument tubes in a BWR, using available in-core detectors. Such information is especially significant, since flow-induced vibrations of in-core instrument tubes have occurred in BWR-4s, and when the amplitude of these vibrations becomes large enough, the tubes impact the fuel channel box and cause wear and eventual perforation of the box wall.

Neutron noise spectra were compared with signals from accelerometers mounted on the instrument tube flange immediately below the pressure vessel.

The magnitude of the normalized cross-power spectral density (NCPSD) of the upper two detectors in the instrument tube, at a frequency between 3.5 and 6 Hz (the exact frequency is indicated by a peak in the coherence), was determined to be an indicator of impacting.

We conclude that when the magnitude of the NCPSD between the upper two detectors exceeds $2 \times 10^{-6}\ Hz^{-1}$ in the 4-Hz region, impacting is probably occurring.

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1 Summary of published paper *Trans Am Nucl Soc* 28, 465 (June 1976)
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## 7.8 DETERMINATION OF VOID-FRACTION IN BWRs, USING NEUTRON NOISE ANALYSIS[1]

M Ashraf Atta[2] J E. Mott[3] D. N Fry

A technique was developed to determine the local void fraction in the four fuel bundles surrounding an in-core detector string in a boiling-water reactor (BWR). The void fraction is a principal parameter in the operation of BWRs, since the void distribution in a particular channel influences the neutron flux shape and reactivity balance. The heat flux in a BWR channel is generally nonuniform, and very few measurements of void fraction under these conditions have been reported. Even so, none of these (as far as we know) was in a reactor. The complexity of two-phase flow has prevented an adequate theoretical treatment, and thus this parameter has been inferred through empirical or semiempirical correlations.

In our measurement technique, we detect the perturbation in the neutron flux caused by a steam bubble passing near a neutron detector. The steam velocity is determined from the travel time between two detectors located a known axial distance apart. From this steam velocity, the channel power distribution, and the mass flow rate, the local void fraction is determined Measurements were made at an operating BWR and are compared with a recent semiempirical correlation.

We conclude that the determination of the void fraction profile in BWR channels, using neutron noise, appears promising, but additional measurements should be made under various operating conditions to fully establish the accuracy of this method. Moreover, since the presently installed in-core detectors in BWRs are at the center of four fuel bundles, such a measurement provides only the average void fraction of all four channels.

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1 Summary of published paper *Trans Am Nucl Soc* **28**, 466 (June, 1976)
2 IAEA Fellow on leave from Pakistan, Institute of Nuclear Science and Technology, Nilore, Rawalpindi
3 Consultant, Nuclear Engineering Dept , University of Tennessee, Knoxville

## 7.9 ANALYSIS OF NEUTRON-DENSITY OSCILLATIONS RESULTING FROM CORE BARREL MOTION IN A PWR NUCLEAR POWER PLANT[1]

D. N. Fry R. C. Kryter J. C. Robinson[2]

Neutron noise signatures were obtained on August 3, 1973, that were due to abnormal movement of the core barrel at the Palisades Nuclear Plant. Frequency spectra, rms noise, and amplitude probability density were recorded as sensed by ex-core and in-core neutron detectors. These signatures will serve as reference data for future studies of core-barrel motion at the Palisades plant. Also, the results are presented in units that should make them useful for noise diagnosis in other pressurized-water reactors.

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1 Abstract of paper presented at the Specialists Meeting on Reactor Noise from Critical Assemblies to Power Reactors, Rome, Italy, Oct 21–25, 1974, and published in *Ann Nucl Energy* **2**, 341–51, (1975) Also published in *Trans Am. Nucl Soc* **19**, 383 (October 1974)
2 Consultant, Nuclear Engineering Dept , University of Tennessee, Knoxville

## 7.10 DETERMINATION OF CORE BARREL MOTION FROM NEUTRON NOISE SPECTRAL DENSITY DATA-SCALE FACTOR[1]

J. C. Robinson[2] Farshid Shahrokhi[3]

An analytical technique was devised for obtaining the scale factor ($F$) to be used to infer core barrel motion from spectral density data obtained from ex-core ionization chambers in PWRs. The spectral density used is assumed to be the normalized power spectral density (NPSD) from a single ex-core ionization chamber or the normalized cross-power spectral density (NCPSD) obtained from two ex-core ionization chambers 180° apart. The units of the normalized spectral density are fractional reaction rate squared per hertz, that is, $(\Delta R/R)^2$ Hz$^{-1}$, where $R$ is the observed output (proportional to reaction rate) of the chamber.

Both direct and variational calculational techniques were explored in both one- and two-dimensional geometries. The result from the one-dimensional analysis was $F = 0.038\%\ \Delta R/R$ per mil.

For a detector located in line with the assumed direction of motion for the two-dimensional model, $F = 0.019\%\ \Delta R/R$ per mil. A value of $F = 0.008\%\ \Delta R/R$ per mil was obtained for a detector located at an angle of 60° relative to the assumed line of motion.

From the analysis of this study, we conclude as follows

1 It is necessary to make a two-dimensional analysis to obtain the actual $F$ factor for a given generic type of PWR

2 The $F$ factor used to infer core barrel motion from neutron noise measurements can be computed using a fixed source, nonmultiplying, medium-type calculational model

3 An $S_4$ quadrature $P_1$ cross-section set is sufficient to calculate $F$

4 A readily available cross-section set used in shielding calculations is sufficient to calculate the $F$ factor

5 The contribution of the gamma groups to the $F$ factor can be ignored

6 The $F$ factor can be obtained from direct calculations, adjoint calculations, or variational techniques

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1 Abstract of published paper *Trans Am Nucl Soc* **23**, 458 (June 1976)
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## 7.11 CORE BARREL MOTION CALIBRATION FACTOR CALCULATION

F Shahrokhi[1] J. C Robinson[2]

Calculations were carried out to establish the calibration factor for inferring core barrel motion (in mils) from spectral density measurements, using ex-core ionization chambers The calculations were for one dimensional (ANISN code) and two-dimensional $R$-$\theta$ (DOT code) geometries The calibration factor was obtained in units of "percent fractional change in detector reaction rate per mil of core barrel motion " The two-dimensional results are reported per mil of maximum core barrel displacement

The calculations were made by using forward flux formulation, difference flux formulation, direct adjoint formulation, and adjoint difference approximation formulation in both one- and two-dimensional geometries The results from all methods are in agreement (less than 4% discrepancy), assuring adequate convergence and establishing the applicability of perturbation techniques

The result for the one-dimensional model was 0 04% $\Delta R/R$ per mil, where $R$ represents the reaction rate in the detector

The two-dimensional model was first applied to the same problem (model) used for the one-dimensional model The results from the two-dimensional techniques were identical to those obtained from the one-dimensional techniques, thereby establishing the proper use of the tools as well as adequate convergence criteria The physical problem is that the core barrel moves inside the reactor vessel Therefore, there is a change in the thickness of the water gap between the core barrel and the ex-core ionization chambers

We find the scale factor for a detector located at 60° relative to the direction of motion is $\sim$0 007% per mil A detector located along the direction of motion has a scale factor of $\sim$0 015% per mil The actual case would probably be somewhere in between, since the actual motion would most probably not always be in the assumed direction Therefore, a value for the scale factor of 0 01% per mil is recommended for the problem being analyzed

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## 7.12 DIGITAL COMPUTER APPLICATIONS IN PROTECTION SYSTEMS

J. B. Bullock J. L. Anderson
S. J. Ditto T. Tang
A. Iqbal

Technical assistance was provided to the Nuclear Regulatory Commission (NRC) in evaluating computerized protection systems using low departure-from-nucleate-boiling-ratio and high local-power-density trip actuation. In these systems, data supplied by both directly and indirectly measured salient plant parameters are evaluated by digital computers, and protective action is initiated when the computed functions depart from acceptable values.

Assistance was provided as follows: (1) review and recommendation of techniques for evaluating software programs, considering program analysis, reliability estimation, and tests of input data state; (2) review and evaluation of software design, fault detection techniques, and overall test plans; (3) review and evaluation of criteria for hardware used in the computer systems; (4) review and evaluation of test results in response to the test plan; and (5) consultation with NRC staff and vendor representatives to obtain information and facilitate the exchange of technical information as required.

The results of this review are being used to assist in the preparation of a safety evaluation report on the system submitted for licensing by a vendor. The work is being continued in order to resolve potential problems discovered as a result of this review and to provide a basis for establishing regulatory guides for subsequent applications of digital computers in protection systems.

## 7.13 POWER GRID STABILITY STUDIES

R. E. Battle F. H. Clark

A computer code developed by the Philadelphia Electric Company to study power flow and stability in electric power grids was obtained and adapted to the IBM 360 computer system at ORNL. The code is to be used for the Nuclear Regulatory Commission in the licensing process for nuclear reactors. After a model of a particular power system is obtained, a dynamic analysis of the grid can be performed to determine the effects of off-site power system transients on operating nuclear power reactors serving the grid.

## 7.14 CALCULATION METHODS FOR INVESTIGATING BOILING-WATER REACTOR STABILITY

F. H. Clark P. J. Otaduy[1]

The need for a method to calculate the stability of a boiling-water reactor (BWR) led to a search of existing computer programs. The program FABLE was obtained, which we may use under certain restrictions. The capabilities of this program appear to be comparable with those of the most widely used frequency domain code for BWR stability calculations.

In a parallel effort, development of a frequency domain BWR stability calculation with explicit three-dimensional capabilities was begun. We believe that this work will permit more faithful representation of large reactors, that higher frequencies will be more faithfully calculated, and that data from spatially separated detectors will be more meaningfully analyzed than in a point reactor model (as used in previous calculations).

1. Student from the University of Florida.

## 7.15 CORE FLOW TEST LOOP DYNAMICS SIMULATIONS

S. J. Ball

Simulations were used to predict the dynamic behavior of several proposed design concepts for the helium circulation system in the gas-cooled fast reactor, core flow test loop to assist in the selection of an adequate loop configuration and control system. The primary design objective was to provide the capability of inflicting rather severe but carefully controlled flow, temperature, power, and pressure transients on the test section, while minimizing the deleterious effects of these transients on system pressure boundaries. The simulations indicated that satisfactory loop performance could be achieved by using a two-heat-exchanger and three-control-valve configuration.

## 7.16 STUDY OF THE PROBABILITY AND CONSEQUENCES OF THE LOSS OF ELECTRIC POWER AT NUCLEAR GENERATING STATIONS

F. H. Clark

Loss of all ac electric power at a nuclear generating plant represents a diminution of function that must be evaluated for its potential effects on the plant protection systems. A total of 20 applicable cases of loss of normal off-site ac power supply have been identified

The most serious consequence of power loss would be a loss-of-coolant accident, followed at critical time intervals by simultaneous random failure of the off-site power and the emergency backup power. Our estimated probability that this combination of events could occur agrees with that of WASH-1400 (which is based on fewer cases of off-site power loss).

In determining the effects of power failure upon reactor cooling requirements, we learned that it is important to study the probability of the simultaneous loss of off-site and on-site power for a duration of several hours. (Such an extended and simultaneous loss has never occurred.) In making such a probabilistic estimate, one must determine whether the losses of on-site and off-site power can be considered independently. In regard to this last point, the record shows that some kind of difficulty is frequently encountered in bringing backup diesel power on-line after normal off-site power has been lost. These malfunctions appear to be short term and are possibly related to imperfect load sequencing.

## 7.17 TWO-PHASE FLOW SENSORS

M. J. Roberts

Two important parameters in the calculation of heat transfer coefficients in reactor core simulation experiments are the flow regime and the quality of the steam-water coolant mixture during a simulated loss-of-coolant accident. Two-phase flow sensors were investigated for use in the core and in the coolant inlet and outlet piping. We are not sure whether a commercial sensor will meet the environmental requirements unique to these experiments, and if they do not, a more rugged sensor will be developed. By correlating two or more sensors, we expect to determine steam and water velocities as well as quality and flow regime.

## 7.18 NUCLEAR DESALINATION PLANT CONTROL STUDIES

S J Ball  N E. Clapp, Jr.

Studies of the dynamics and control characteristics of advanced evaporators that utilize combined vertical-tube evaporator (VTE) and multistage flash (MSF) processes were completed. A report was written which describes a digital simulator for the Fountain Valley, California, VTE-MSF evaporator [1] Dynamics tests were performed on the plant in March 1976, and preliminary analyses of the data indicate good agreement with the predictions.

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1 N E Clapp, Jr , and S J Ball, *A Digital Simulator for the Fountain Valley VTE MSF Evaporator,* ORNL/TM-4857 (May 1975)

## 7.19 A DIGITAL SIMULATOR FOR THE FOUNTAIN VALLEY VTE-MSF EVAPORATOR

N. E. Clapp, Jr.  S. J Ball

A digital simulator was developed for predicting the dynamic behavior of the vertical-tube evaporator, multistage flash evaporator at Fountain Valley, California (Water Factory 21). Model equations were developed, and sample simulator results were calculated.

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1 Abstract of ORNL/TM-4857 (May 1975)

## 7.20 RELIABILITY AND SAFETY ANALYSES OF HIGH-TEMPERATURE GAS-COOLED REACTOR SYSTEMS

Paul Rubel

Participation in the HTGR Safety Program at ORNL was continued in the areas of system reliability and accident risk analysis. A program report[1] was issued that describes general logical structuring of accident events and presents information pertinent to two major classes of HTGR accidents Additional work was devoted to the identification of unusual stresses that could be encountered by vital components under accident conditions, and of consequent failure modes.

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1 Paul Rubel, *Organization of Selected Event Sequences in HTGR Postulated Accidents,* GCR-S 75-14 (July 1975)

## 7.21 HTGR SAFETY STUDIES: ANALYTICAL METHODS

S. J. Ball

N. E. Clapp, Jr  R. A Hedrick[1]
J. C. Cleveland[1]  L. G. Johnson[2]
J. G. Delene[1]  T. W. Kerlin[3]

Studies of HTGR safety characteristics were continued in order to develop and evaluate analytical methods used to simulate accident sequences. These studies include model verification tests that make use of data from the Fort St. Vrain reactor.

The dynamic analysis work is divided into two categories (1) overall nuclear safety system evaluation by the ORTAP code and (2) emergency core-cooling analyses by the ORECA code. Both codes are operational.

The ORTAP core simulation utilizes a coupled heat transfer–neutron kinetics model for an "average" fuel stick and the surrounding graphite moderator and coolant channels. The once-through steam generator module is represented by a multinode, fixed-boundary, homogeneous flow model, which includes equations for conservation of energy, mass, and momentum for both helium and water, and energy equations for the tube metal. Detailed models are also included for the turbine-generator plant, the feedwater supply system, and the turbine-driven circulators for the primary system coolant.

The ORECA code solves the three-dimensional, thermal-hydraulic equations for HTGR cores for emergency cooling and shutdown-mode operation. Simulations were also developed for the auxiliary cooling heat exchangers.

Studies done under a University of Tennessee subcontract have concentrated on evaluation of alternative steam generator modeling methods and on derivation of model verification methods for dynamics tests planned for the Fort St. Vrain reactor.

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## 7.22 HTGR SAFETY STUDIES. TEMPERATURES

O. W. Burke

HTGR safety studies consisted of two major tasks (1) calculation of temperature gradients in the core support structure and (2) calculation of the temperatures in a control rod with the guide-tube, inlet coolant holes blocked.

The core support structure of this reactor will be stressed because of temperature changes during some transients, that is, temperature gradients will be generated in the core support members by changes in the temperature of the helium coolant gas surrounding them. Examination of the results of transient calculations furnished by General Atomic (GA) indicates that the most severe helium temperature excursions will occur during a reactor trip with retention of full helium coolant flow. Accordingly, results from GA for the core exit helium temperature as a function of time, following a reactor trip, were used as input to an analog computer model to calculate the temperature gradients in the core support members. Our conclusion is that the calculated temperature gradients were not high enough to be of concern.

For the second task, the following plant conditions were postulated

1. The plant would be operating at full power with seven control rods half inserted and with the remainder of the control rods fully withdrawn.
2. The coolant inlet holes in the guide tube of one of the half-inserted control rods would be suddenly plugged, with subsequent loss of helium coolant flow in this control rod channel.
3. The plant would continue to operate at full power.

The problem was to calculate the resulting temperatures in the affected control rod.

Our conclusion is that the calculated temperatures resulting from conservative input values were high enough to warrant a more detailed calculation using a more sophisticated approach.

## 7.23 HTGR SAFETY STUDIES: INSTRUMENTATION

J. L. Anderson R. E. Battle M. J. Roberts

The adequacy of safety instrumentation, primarily sensors and sensing systems in the reactor shutdown system, proposed for large HTGRs by the Gulf Atomic Corporation (GAC) was assessed. The study included moisture monitoring, nuclear instrumentation, thermometry, and helium flow measurement. In addition, the logic and equipment requirements for engineered safeguards and other safety related systems were studied, including the steam generator isolation and dump system, the core auxiliary cooling system, the core auxiliary heat-exchanger isolation system, and the orifice control system. A few selected design criteria developed by GAC were reviewed. Some of the information reviewed is proprietary to GAC, and access to the reviews is controlled. A report, *Preliminary Assessment of Safety Instrumentation for Large HTGRs,* will be issued covering the nonproprietary review. The overall assessment is incomplete, and this study has been terminated because of a realignment of the U.S. gas-cooled-reactor development program.

## 7.24 DYNAMIC TESTING AND ANALYSIS OF HTGR FUEL CAPSULES IN THE HFIR[1]

W. H. Sides, Jr. J. G. Thakkar[2] J. E. Swander[3] T. W. Kerlin[2]

Dynamic testing and analysis techniques were used to investigate the heat transfer characteristics of a high-temperature gas-cooled reactor fuel test capsule irradiated in the High Flux Isotope Reactor. The dynamic tests yielded the frequency responses of temperatures to internal heat generation rates, including the asymptotic, steady-state response (the response at zero Hz).

A mathematical model was used to predict the temperature responses at the two model nodes that best approximated the locations of thermocouples in the capsule: the temperature of the inner surface of the fuel region and the temperature in the graphite region near its inner surface.

Comparison of the responses calculated from the model with those measured experimentally showed that the measured responses at each location were substantially slower than predicted, indicating a lower heat transfer rate into (and out of) the region where the thermocouples were located than was predicted by the model. This behavior is attributed to the insulating effect of the near-stagnant helium gas gaps surrounding the thermocouples. The comparison also indicated the presence of a faster responding process, which may be direct gamma heating of the thermocouple junction. The determination of the effect of these processes may aid the design of future fuel capsules and the interpretation of data obtained from the thermocouple readings.

1. Abstract of published paper: *Trans. Am. Nucl. Soc.* **21**, 373–74 (June 1975).
2. Consultant, Nuclear Engineering Dept., University of Tennessee, Knoxville.
3. Deceased.

## 7.25 ORNL SAFETY REVIEW OF THE PLANT PROTECTION SYSTEM FOR THE ADVANCED TEST REACTOR

O. W. Burke S. J. Ditto L. C. Oakes

The plant protection system of the Advanced Test Reactor, which is operated by the Aerojet Nuclear Company at the Idaho National Engineering Laboratory, is to be upgraded; that is, most of its hardware will be replaced with state-of-the-art equipment. ERDA has given the task of reviewing this upgrading operation to ORNL. The scope of the task now in progress is as follows:

1. Review the original safety analysis report and system design description for the proposed upgrade program, both preliminary and final.
2. Compare the plant protection system design bases described in the original safety analysis report with those of the proposed system as described in the documents cited above, specifically regarding accidents covered, performance requirements of subsystems, and relative reliability requirements.
3. Report the results of the work to ERDA, including an assessment of significant differences between the old system and the proposed upgraded system.

## 7.26 POWER BURST FACILITY CONTROL AND SAFETY INSTRUMENTATION

J. L. Anderson R. E. Battle S. J. Ditto

Engineering assistance and consultation for the Power Burst Facility at the Idaho National Engineering Laboratory were continued. Activities included review of design changes made by the facility operator, the Aerojet Nuclear Company, and review of the engineering design of control and protection system changes to permit the use of a different type of fuel. The new fuel loading will require additional safety and control rods and the associated circuitry and instrumentation. The instruments are being fabricated at ORNL.

## 7.27 BULK SHIELDING REACTOR ROD POSITION INDICATORS

R. E. Battle J. B. Ruble

A new Bulk Shielding Reactor rod position indicator that uses digital readout was designed to replace the direct selsyn-driven analog readout. The digital readout gives a much clearer display on the closed-circuit television monitor in the remote control room and eliminates some of the readout errors attributable to the gearing of the synchro receivers. One rod position indicator system was converted to the new display in order to allow engineering and operations evaluation.

## 7.28 TIGER IN THE FAULT TREE JUNGLE[1]

Paul Rubel

There is yet little evidence of serious efforts to apply formal reliability analysis methods to evaluate, or even to identify, potential common-mode failures (CMFs) of reactor safeguard systems The prospects for event logic modeling in this regard are examined by the primitive device of reviewing actual CMF experience in terms of what the analyst might have perceived a priori Further insights of the probability and risk aspects of CMFs are sought through consideration of three key likelihood factors (1) prior probability of cause ever existing, (2) opportunities for removing cause, and (3) probability that a CMF cause will be activated by conditions associated with a real system challenge. It was concluded that the principal needs for formal logical discipline in the endeavor to decrease CMF-related risks are to discover and to account for strong "energetic" dependency couplings that could arise in the major accidents usually classed as hypothetical. This application would help focus research, design, and quality-assurance efforts to cope with major CMF causes. However, unless extraordinary challenges to the reactor safeguard systems are experienced, there must continue to be virtually no statistical evidence pertinent to that class of failure dependencies.

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1 Abstract of paper presented at the Seventh Annual Pittsburgh Conference on Modeling and Simulation, Pittsburgh, Pa , Apr 26 27, 1976, and published in the conference proceedings

### 7.29 BONSAI: CULTIVATING THE LOGIC TREE FOR REACTOR SAFETY[1]

Paul Rubel

Much of the difficulty in understanding reactor safety stems from a lack of information coherence between fundamental accident descriptions and the in-depth analyses that investigate related effects Efforts to unify safety information and analyses with the aid of accident diagrams are described in this paper Proposed is a strategy to represent accidents initially in broad, conceptual terms by decision trees or equivalent matrices, which can then be expanded into engineering and system detail via subsidiary fault trees. While the methods are specifically intended to focus safety dialogue and define interim analysis objectives, the resulting sets of logic models should also ultimately provide a basis for comprehensive risk analysis.

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1 Abstract of paper presented at the 1975 Reliability and Maintainability Symposium, Washington, D C , Jan 28 30, 1975, and published in the symposium proceedings (IEEE Cat No 75 CHO 918–3 RQC)

### 7.30 NATIONAL ADVANCED REACTOR RELIABILITY DATA SYSTEM

Paul Rubel G. F. Flanagan[1]

The Energy Research and Development Administration is studying the need for a unified reliability data system, devoted to components of advanced reactor systems such as the HTGR and the LMFBR. We assisted this study through participation with a committee of ERDA, NRL, and contractor reliability specialists who provided recommendations regarding program scope and organization, data validation methods, and appropriate statistical techniques.

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1 Neutron Physics Division

### 7.31 HUMAN RELIABILITY ANALYSIS

E. W. Hagen

This edited version of *Human Reliability Analysis* was taken from the risk-assessment analysis as originally presented in report WASH-1400, *The Reactor Safety Study* The analysis involves a significant effort in estimating the reliability of human responses under normal and emergency conditions and the influence of routine, stress, and other factors on error rates for the performance of various tasks. The humans referred to are those of an operating staff for a nuclear power plant. Interactive effects of human participation on the design, control, and operation of an industrial process or plant are discussed with respect to observed human behavior in an editor's short, concluding philosophical postscript. The references given in the draft report are supplemented by those in the postscript, and a short bibliography is appended.

1 Abstract of published article *Nucl Saf* **17**(3), (May–June 1976)

## 7.32 QUANTIFICATION OF MAN-MACHINE SYSTEM RELIABILITY IN PROCESS CONTROL[1]

E. W. Hagen

Authoritative discourses on the subject of human reliability in control systems are available in journals devoted to ergonomics, cybernetics, and human factors. However, the subject is also of prime interest to operations in the nuclear industry. Therefore an overview of the subject of operator reliability is presented by both a digest of a previously published paper and an added short bibliography

1 Abstract of published article *Nucl Saf* **16**(3), 316–17 (May–June 1975)

## 7.33 IEEE NUCLEAR POWER SYSTEMS SYMPOSIUM[1]

E. W. Hagen

This article reviews the nuclear-safety-related portions of the 6th IEEE Nuclear Power Systems Symposium held in Washington, D.C., Dec. 11–13, 1974. The meeting, held concurrently with the 21st Nuclear Science Symposium and the 14th Scintillation and Semiconductor Counter Symposium, was sponsored by the Institute of Electrical and Electronics Engineers and the U.S. Atomic Energy Commission. It was the latest in a series of meetings designed specifically for electrical engineers who are involved with nuclear power generation. Several sessions were devoted to updating information on standards, startup and operating experiences, and instrumentation development.

1 Abstract of published article *Nucl Saf* **16**(5), 557–63 (September–October 1975)

## 7.34 ANTICIPATED TRANSIENTS WITHOUT SCRAM. STATUS QUO[1]

E. W. Hagen

The purpose of report WASH-1270 is to ensure a high degree of reliability for the plant safety systems of water-cooled nuclear power plants to protect the health and safety of the public. Implementation of the requirements set forth in the cover letter sent with that report to the power utilities has been proposed by the utilities, and reviews of these responses and analyses are under consideration by the Nuclear Regulatory Commission. Acceptance of the utilities' positions has not been granted, nor has further guidance or direction been proposed for power plants now operating or under construction. Future plants apparently will have to incorporate some as yet undefined design for a dual-acting plant safety system.

The automatic reaction of the protection system is to cause the control rods to move rapidly into the reactor core to shut down the nuclear reaction. This most drastic form of automatic response of the protection system, which results in a very rapid shutting down of the reactor, is called the "scram." . . If such a transient should occur and if, in spite of all the care built into the reactor shutdown system, a scram should not result, then an ATWS event would have occurred.

1 Abstract of published article *Nucl Saf* **17**(1), 43–54 (January–February 1976)

## 7.35 STANDBY EMERGENCY POWER SYSTEMS, PART 2 – THE LATER PLANTS

E. W. Hagen

This is the second part of a two-part article that reviews the standby emergency electric power systems for commercial nuclear power plants. Part 1 appeared in the **14**(3) issue of *Nuclear Safety* and discussed these systems as they applied to the early plants; Part 2 updates the design criteria and considerations set forth in Part 1 and offers some suggestions for improving reliability and availability for these systems. Today, even within the confines of a single large utility, the system designs vary because of the different architect-engineers involved with the various plants, plant characteristics vary from site to site, and even concepts change with time within a given design group. Some of the design problems and operating experiences for the follow-on plants are exemplified, quality-assurance procedures are mentioned, and some considerations concerning reliability, which has not changed significantly for the later plants, are discussed. Since high availability of the standby emergency electric power systems appears to be the more attainable characteristic to strive for, some methods for achieving this are proffered.

1. Abstract of published article: *Nucl. Saf.* **16**(2), 162–79 (March–April 1975).

## 7.36 NUCLEAR SAFETY INFORMATION CENTER

E. W. Hagen

The responsibility for collecting, evaluating, indexing, and disseminating information pertaining to nuclear control, instrumentation, and power plant electrical systems was continued for the Nuclear Safety Information Center. This center is in its thirteenth year as a national center for collecting, storing, evaluating, and disseminating nuclear-safety information generated throughout the world.

The documents handled related to all phases of design, application, installation, and operations for reactor instrumentation (component, modular, and system) and for the plant electrical system (supply, generation, and distribution). Approximately 3100 of these documents were reviewed, as were another 6200 pertaining to the licensing process, and were abstracted for the computerized information retrieval system. A total of 80 direct requests for specific information were received from the national and international nuclear communities.

## 7.37 NUCLEAR SAFETY JOURNAL

E. W. Hagen

Publication of *Nuclear Safety* under the auspices of the Nuclear Safety Information Center was continued. This journal is in its seventeenth year of publishing topical reviews and new information that have a particular significance for safety to members of the technical nuclear community. Its primary emphasis is safety in reactor design, construction, and operation; however, safety considerations in reactor fuel fabrication, spent-fuel processing, nuclear waste disposal, handling radioisotopes, and environmental effects of these operations are also treated. Responsibility was continued for the acquisition, preparation, and editing of material related to reactor controls and instrumentation. Five of the sixteen articles published in the Control and Instrumentation Section of *Nuclear Safety* during this period were authored by personnel of this division.

## 7.38 PWR SIMULATOR FOR AMERICAN MUSEUM OF ATOMIC ENERGY

R. S. Stone

One of the exhibits at the museum is a dynamic model of a pressurized-water reactor, nuclear power plant. Control rods of the physical model are tied to simulated reactivity in the computer model. The outputs from the computer model drive "technimated" indications of power level and show coolant flow rates in various portions of the plant.

Our part of this exhibit included analog simulator programming (previously reported), writing technical specifications for the simulator, assisting with bid evaluations, helping to oversee construction and checkout of the system, and writing a manual for its operation. This exhibit is complete and operational as a demonstration model.

## 7.39 HFIR SAFETY SIMULATION OF LOW-POWER MODE

R. S. Stone

There is interest in operating the High Flux Isotope Reactor in the low-power mode 3 for safety studies of shutdown margin. Operational problems have been experienced because the safety system was designed for the fast-response requirements of high-power operation. The requirements for low-power operation are different: the speed of response can be far slower, but the sensitivity to noise must be greatly reduced. It was proposed that mode 3 operation be made more reliable and orderly by removing the rate trip (which was never intended for this mode) and by adding a smoothing capacitor across the ionization chamber amplifier.

Such proposals require reactor dynamics studies to assure that the safety of the reactor would not be lessened by adoption of a proposal. In the low-power, no-flow mode 3, the startup accident (uncontrolled withdrawal of all control rods) is the design basis accident. To test the effects of slower safety action, the HFIR system was simulated on an analog computer. A conservative startup accident was tested: the control plates came out at a constant rate of 0.44%/sec until a scram occurred. (In actuality, this high rate is obtainable for only 1 in., the stroke of the regulating rod mechanism.) The present system (10 msec unlatching time and no capacitive smoothing) tripped via the rate circuit and reached a peak power of 8 kW and a temperature rise of 0.02°F. With level scram only, these values changed to 125 kW and 0.18°F. With a smoothing time constant of 40 msec and a lengthened (for conservatism) release time of 15 msec, a level scram only (no rate trip) led to a peak power of 820 kW and a 1°F temperature rise. The effects of the proposed change are a one-hundred-fold increase in peak power but a completely negligible energy release.

Low-power operation is vulnerable to spurious, noise-induced scrams, but the enormous amount of "head room" available in mode 3 permits the use of slower, noise-insensitive circuits. Such circuits would not be permissible in mode 1, where by compensation they are not needed.

# 8. Fuel Reprocessing and Shipping

## 8.1 HTGR FUEL RECYCLE DEVELOPMENT: PROGRAM OVERVIEW

W. R. Hamel

Support for development of the fuel cycle for the high-temperature gas-cooled reactor (HTGR) included fuel reprocessing and refabrication. The manpower support increased from $\sim$3.5 man-years in FY 1975 to $\sim$8 man-years in FY 1976. The current level is expected to continue through FY 1978.

Activities for fuel reprocessing were primarily related to program planning, including definition of the project scope, estimation of the fiscal budget, and statements of preliminary design criteria for different program options.

For fuel refabrication, plans for experimental work leading to development of refabrication procedures were prepared with the Metals and Ceramics Division. Some project funds were allocated for the development of instrumentation and data management methods needed for demonstration of remote refabrication of HTGR ($^{233}$U fissile) fuels. Other engineering activities included the design and development of many nonradioactive, fuel refabrication process equipment demonstrations on an engineering scale.

## 8.2 FUEL REFABRICATION PILOT PLANT

W. R. Hamel B. J. Bolfing J. M. Jansen
A. F. Johnson H. E. Cochran B. C. Duggins

A conceptual design[1] was prepared for an interim fuel refabrication facility. The instrumentation design engineering was provided by this division.

The basic structure planned for the facility is a network of control subsystems, one for each process unit operation, and an overall supervisory plant data management system. The instruments and control subsystem planned for each unit operation is an integrated system that comprises process minicomputers, programmable logic controllers, and other instrumentation and control hardware. Plant supervisory and data management functions will be provided by a large-scale minicomputer system, which will be connected to each unit control subsystem to perform process data acquisition and storage, product quality assurance documentation, plant fissile inventory maintenance, and plant operational support functions.

1. *Conceptual Design Report for HTGR Fuel Refabrication Pilot Plant, Project No. 75-5-f,* GCR: 74–30.

## 8.3 HOT ENGINEERING TEST FACILITY

W. R. Hamel

A remotely operated, hot engineering test facility is being designed in order to evaluate the effects of radioactive recycled HTGR fuels that contain the $^{232}U$ daughter product chain on the performance of fuel reprocessing and refabrication operations. This division has supported the UCC-ND Engineering Division in the early stages of this project by preparing cost estimates and preliminary design criteria to be used by all contractors for reprocessing and refabrication equipment design and for facility modifications.

## 8.4 RESIN LOADING DEVELOPMENT

H. E. Cochran

The reference fuel kernel for recycle of $^{233}U$ to an HTGR is prepared by loading carboxylic acid cation exchange resins with uranium and by carbonizing at controlled conditions. An engineering-scale, resin loading system was fabricated and operated to develop and demonstrate all the process operations on a nonradioactive pilot plant scale. The process is controlled by in-line pH instrumentation. Instruments were provided to evaluate the maintainability and reliability of the system.

## 8.5 RESIN CARBONIZATION DEVELOPMENT

B. J. Bolfing W. R. Hamel D. R. Miller

HTGR fuel-resin particles are carbonized in a fluidized bed furnace. A gas-flow control system was developed for the 4-in.-diam furnace to maintain a desired fluidized bed turbulence during furnace temperature-time programs. Because the furnace temperature flow characteristic was nonlinear, the final control system developed for routine operation has a PROM-based, digital function generator.

A 9-in.-diam resin carbonization furnace was built and installed. The control system for the furnace consists of (1) independent feedback temperature control loops with SCR heater power amplifiers for each furnace zone; (2) time function set-point programming for each zone temperature control loop; and (3) argon fluidized gas flow control, including flow-temperature characterization. This system also has a PROM-based, digital function generator for flow-temperature characterization.

A pneumatic (argon) particle transfer system that has many prototypic features was installed as part of the 9-in. furnace system. A development programmable logic controller system was programmed to operate the resin particle handling loop, responding to operator input from a local process control panel and continuously maintaining safety interlocks by monitoring all process sensors and actuators.

## 8.6 MICROSPHERE COATING DEVELOPMENT

B. J. Bolfing
W. R. Hamel M. E. Galyon
R. E. Toucey G. W. Allin

Instrumentation support to operate the 5-in., microsphere coating furnace involved a number of activities. The coating gas supply system and flow controls were modified to provide additional coating gas ratio and diluent gas combinations. Flow control rangeability was increased to 10:1 through use of laminar flow sensing elements. An automatic optical pyrometer was installed for evaluation as a possible remote, high-temperature (1800°C), feedback control sensor.

A system was built to automatically unload particles from the 5-in. furnace. Precision weighing systems with a specified accuracy of 0.01% were purchased and are being evaluated for this process.

A sensor was developed for the microsphere coating loop to measure the level of high-temperature fuel particles in the furnace discharge hopper. The sensor has a self-compensating level probe that is insensitive to particle size and temperature. A mockup unit has demonstrated ±5% accuracy.

## 8.7 FUEL ROD FABRICATION DEVELOPMENT

S. P. Baker
B. J. Bolfing M. M. Chiles
M. E. Galyon J. W. Woody

A magazine loader-unloader was designed and fabricated for the purpose of assessing one means of intermediate storage of refabricated fuel rods. A minicomputer-based control system remotely loads or unloads fuel rods from a fuel rod storage magazine. The minicomputer supervises an open-loop position control system consisting of three axes of preset, indexer-stepping motor drives: two axes for magazine vertical and horizontal translation motion and one axis for magazine unloading actuator position. Absolute digital encoders verify positions on all three axes and restart the mechanism after a power failure. This minicomputer is interfaced to a development programmable logic controller that controls the discrete (on-off) operation of the fuel rod loader. This control system loads or unloads a magazine in either a manual mode or an automatic mode.

A programmable logic controller was installed and programmed to operate an existing, laboratory-scale, fuel rod molding machine for the purpose of demonstrating that such a control system can reliably and remotely operate this complex machine.

An important specification of refabricated fuel is fuel rod surface and edge integrity. An integrity inspection system was designed and fabricated, using a multinozzle air ring gage coupled to solid-state pressure transducers and electronic signal processing. The system has detected surface flaws 0.008 in. deep at operating speeds of commercial rod molding machines. This resolution is an order of magnitude below anticipated fuel specification values.

Development of techniques was started in order to determine the distribution of constituents and to assay fabricated fuel rods. Experimental work was started on fuel rod homogeneity, delayed-neutron nondestructive assay, and neutron-activation nondestructive assay methods.

## 8.8 FUEL ELEMENT ASSEMBLY DEVELOPMENT

H. E. Cochran J. G. Grundmann
R. C. Muller M. J. Roberts

For fuel element assembly, instrumentation and control activities supported the design of a large fuel element carbonization and annealing furnace in two phases: (1) design and installation of a development furnace and (2) detailed design for the large furnace. For the first phase, we prepared instrumentation and controls flowsheets, descriptions of activities, and a cost estimate.

For the second phase, we prepared six flowsheets that show all the individual instrument components for the furnace temperature profile controls, the inert gas supplies and off-gas processing, the cooling-water controls, and the automatic sequential controller for element transport and handling.

We helped design the high-current electrical connections for the furnace. Critical contact voltages for the connector material were used to determine the contact resistance, and the apparent interfacial area and mechanical connection force were calculated and used in the design of the furnace electrical contacts. The electromagnetic forces on the furnace element and the natural resonance frequencies of a furnace element were calculated. One segment had an undesirable geometry that produced a 50- to 60-Hz resonance frequency, and changes in the element design were required.

A dynamic heat transfer model of the carbonization and annealing furnace was completed, using the IBM continuous-systems modeling program, to verify the design of all furnace temperature controls and to ensure that the desired time-temperature history can be maintained for all fuel elements passing through the furnace.

A closed-loop, velocity-time vs position profile control was designed for the furnace unloader mechanism, using a dc torque motor drive with tachometer feedback. The elevator system that will transport fuel elements through the vertical furnace will require a two-speed position controller with slightly different loading and position requirements. The same design with appropriate parameter adjustments will be used for both controllers. Both control system were simulated using continuous-systems modeling programs.

## 8.9 SAMPLE INSPECTION ANALYSIS

D. W. McDonald W. L. Bryan

An instrument for calibrating and troubleshooting the HTGR fuel-particle-size analyzer was developed. In the analyzer, a particle falls between a light source and a light sensor, and the reduced intensity in received light is correlated to the diameter of the particle. The calibrator has a separate light source whose intensity is electronically varied. When connected to the analyzer, the calibrator simulates the passage of the full range of anticipated particle sizes.

The calibrator can also be connected to bypass the analyzer light sensor. In this mode, voltage pulses simulating the passage of particles are injected directly into the electronic system of the analyzer. Since the calibrator simulates either the light source or the signals from the light sensor, it can be used for troubleshooting.

An opto-electric sensor and recording system was developed to determine rabbit (sample) transport line characteristics and to evaluate the rabbit transmitting and receiving station designs.

## 8.10 PLANT MANAGEMENT DEVELOPMENT

B. O. Barringer B. J. Bolfing W. R. Hamel

Instrumentation and control hardware for HTGR fuel refabrication processes will include complex, general-purpose devices such as minicomputer-based packages, microcomputers, and programmable logic controllers. Also, control systems for fuel recycle processers will comprise a network of these general-purpose devices and other types of hardware. We began a study of the effect of synchronization and interfacing requirements for refabrication equipment by creating a real-time environment, with the operation of various engineering-scale process developmental equipment analogous to that expected to exist in an actual recycle facility.

We began an evaluation of types of applicable general-purpose devices in a simulated process environment with engineering-scale refabrication machinery to quantitatively evaluate real-time interfacing techniques between refabrication machines, programmable logic controllers, and minicomputers. A process control minicomputer and programmable logic controller are being used to control the laboratory-scale, fuel-rod molding machine, the resin particle handling loop, and the fuel-rod storage magazine loader-unloader. The computer also provides computational support to remotely located radioassay development equipment.

A fuel refabrication development computer system being used for program development and for instrumentation and control of several activities includes a PDP-11/40 computer with core memory, memory management hardware, floating-point instruction set, two 1.2M disk drives, and paper-tape reader-punch. The RSX-11M real-time executive, which supports FORTRAN IV, is being used as the software system. This computer system is being used in the fuel-rod storage magazine loader-unloader control system and the fuel-rod nondestructive assay multichannel analyzer system. The system was interfaced to a development programmable logic controller (PLC) system through a 9600-baud serial link. This interface will provide maintenance and program development support to the PLC from the PDP-11/40.

A generalized binary coded decimal (BCD) instrument interface was designed, constructed, and installed for the fuel-rod storage magazine loader-unloader control system. This unit was designed to convert large amounts of parallel BCD to an asynchronous serial format for efficient remote transmission to a centrally located process computer. Control logic packaging of an Intel 8080 microprocessor was used, and programming was done in assembly language.

For the fuel-rod nondestructive assay development, a terminal dial-up capability (via acoustic coupler) was programmed into the RSX-11M software system, and a dedicated 1200-baud line was installed between the fuel refabrication computer system and the multichannel analyzer system. A 300-baud dial-up line is used to remotely communicate with the PDP-11/40 in initializing the needed data acquisition programs.

The refabrication process includes many discrete sequential operations ideally suited for PLCs. A PLC system was procured and is being used to control the laboratory fuel-rod fabrication machine, the resin carbonization furnace particle handling loop, and the fuel-rod magazine loader-unloader. The system includes an Industrial 14/35 controller, a VT/14 cathode-ray tube display programming terminal, and a standard Teletype. The experience to date has demonstrated the versatility and reliability of PLC controls for remote refabrication equipment. The real-time monitoring capability of the VT/14 programming terminal provides a powerful tool for machine maintenance and troubleshooting for remote applications. Failures of in-cell sensors and actuators can be isolated through an out-of-cell push-button procedure.

## 8.11 MATERIAL HANDLING DEVELOPMENT

J. G. Grundmann  R. C. Muller

A conceptual design of a material handling system with improved dexterity, speed, and operating safety for remote maintenance and production support of fuel recycle process systems was completed. This design comprises an overhead, bilateral master-slave electromechanical manipulator with remote TV viewing. A crane was included to move heavy equipment. Collision of process equipment is avoided by minicomputer control. Teach and playback robotic manipulator action increases the operating speed and reduces task completion times for routine and repetitive operations.

The existing programmed and remote systems electromechanical manipulators in the thorium-uranium recycle facility were examined to determine the changes necessary to provide a system with state-of-the-art dexterity and speed. Both the electrical and mechanical aspects of the manipulators were evaluated. The results indicate that the mechanical design of the system is adequate, but its functional control capability (no master-slave control) and level of automation (no minicomputer control) are insufficient.

As a first step toward master-slave manipulator control, we designed, fabricated, and installed position feedback servo loops on the bridge and carriage of a manipulator (cell E). Position control performance of the bridge and carriage was excellent. Stable operation with a 0.010-in. deadband was attained.

An interagency contract between ORNL and the Office of Automation and Control Technology Development of the National Bureau of Standards was executed for development of computer software for the robotic operation of electromechanical manipulators. FORTRAN programs for interface checkout, point-to-point control, and continuous-path control were received.

## 8.12 HIGH-INTENSITY FLUOROMETER

L. H. Thacker

An instrumentation system was developed for high-intensity excitation and fluorescence measurements in uranium processing systems. Light from a 200-W xenon-mercury lamp with a highly regulated power supply is received by a small grating monochromator which, in turn, furnishes the excitation illumination to a fiber-optic fluorometer designed for this application. The fluorescence emission returns through the alternate leg of the bifurcated quartz fiber optic to a second monochromator and thence to the measuring photomultiplier tube. Although the performance of the instrument is satisfactory, the parasitic fluorescence and absorption of other components in the solutions prevent measurements at the desired sensitivity level. New quartz fiber optics with an improved fiber distribution, which should alleviate some of these problems, were ordered and will be tested.

# 9. Process Systems and Instrumentation Development

## 9.1 INSTRUMENTATION FOR THE COAL TECHNOLOGY PROGRAM

W. F. Johnson R. L. Durall A. A. Shourbaji M. E. Galyon N. C. Bradley

The services of the coal technology group concerned three main projects: the coal block pyrolyzer, the atmospheric-pressure hydrocarbonization facility, and the bench-scale coal hydrocarbonization experiment.

The pyrolyzer was equipped with a furnace-temperature control system, which enables an operator to program the heating rate and the final controlled temperature of a coal specimen. The heating rate is variable from 0.1 to 10°C/min in a range from 0 to 900°C to an accuracy of 5%.

Coal was converted into liquid, gas, and solid fuels by hydrocarbonization in a fluidized bed, with hydrogen gas at nominally atmospheric pressure in one experiment and at pressures up to 300 psig and temperatures up to 649°C in the bench-scale unit. The explosive hydrogen feed gas required monitoring instrumentation that sounded an alarm if (1) any leaks were detected in the process piping, (2) an excessive amount of hydrogen flowed into the process, or (3) the operating area ventilation system failed. The atmospheric pressure system was equipped to manually shut down the hydrogen gas supply and introduce nitrogen purge gas if necessary; the bench-scale unit was equipped to perform this shutdown automatically. These systems were also equipped to admit a controlled flow of nitrogen purge gas to eliminate oxygen during the startup or to purge the hydrogren prior to the shutdown of an experiment.

## 9.2 HYDROGEN AND HYDROCARBON GAS ALARM SYSTEM

W. R. Miller

A multisensor hydrogen and hydrocarbon gas monitor and alarm system was designed and was installed in the coal hydrocarbonization project facility.

Fifteen individual sensor boxes with new sensors are installed at critical points in the process and connected to a central alarm unit in the control room by five wire cables. Each sensor box derives its power from redundant power supplies in the central unit, and each box develops its own "high concentration of gas" and "sensor failure" alarm signals. Through diode matrixing, these signals trigger constant or intermittent audible and visual signals at the central unit.

Individual light-emitter diode pilot lights indicate which sensor has failed or whether the five-wire cable has broken. A meter and selector switch allow readings of gas concentration to be taken from any of the sensors.

## 9 3 ADDITIONS AND MODIFICATIONS TO THE ORNL STEAM PLANT CONTROL SYSTEMS

W R Hamel

Changes of the control systems for the No 1, 2, 3, and 4 boilers of the ORNL Steam Plant were completed Boilers 3 and 4 were modified to meet National Fire Protection Association Codes 85B and 85D Changes of boilers 1 and 2 were delayed by uncertainties in fuel resource The Instrumentation and Controls Division supplied engineering manpower for preparing contract specifications, evaluating bids, and checking the control panel at the seller's installation A contract was awarded for a turnkey installation

The combustion control systems provide fully automatic oil and gas firing The burner management systems for safety control of oil and gas burners were designed using ladder-diagram-processor programmable logic controllers This division supplied engineering support during the installation and checkout of the combustion control and burner management systems, including development of maintenance documentation and diagnostic procedures for the burner management system A spare parts inventory, including a complete ladder-diagram processor, was procured These systems are completely operational and, because of their safety features, are being used as the first line of steam generation capacity at the Laboratory

## 9 4 STUDY OF AUTOMATED VAULT STORAGE

W R Hamel

A study was begun for the Office of Standards Development of the Nuclear Regulatory Commission to develop design criteria for automated storage of special nuclear materials in commercial fuel recycle facilities A multidisciplinary team was assembled, which included engineers from the Chemical Technology Division, the UCC-ND Engineering Division, and the Instrumentation and Controls Division The instrumentation and control aspects of automated vault storage include control of the material handling system, inventory control of stored material, and physical surveillance The team made a technology assessment survey, traveling to domestic and foreign installations, both government and commercial The final criteria document is to be issued late in FY 1977

## 9 5 ORNL PILOT PLANT FACILITY SAFEGUARDS SYSTEM

W R Hamel

Some preliminary work was started to design an integrated facility safeguards system for the Radiochemical Separations Pilot Plant (Building 3019) as a part of the Laboratory Security and Safeguards Upgrading Project

## 9 6 INSTRUMENTATION FOR BSR-HSST MATERIAL IRRADIATION FACILITY

G N Miller J M Googe[1]

The in-pile radiation test for the heavy-section-steel testing project was moved from the Battelle reactor to the Bulk Shielding Reactor at ORNL in 1975 In this project, up to 4 tons of thick steel test specimens will be irradiated at 550°F for up to one year The experimental design was loosely based on the previous experiment, but the instrumentation and control system was improved and automated

A system analysis of the temperature control resulted in an implementation of two temperature control loops one to control the nominal bulk temperature of the experiment and one to minimize the inherent temperature difference in the experiment caused by uneven distribution of the reactor flux The control systems are equipped with electric heaters and controlled conductivity gas gaps to control the bulk temperature and differential temperature

A 100 point data logger was purchased and installed for continuous, automatic digital data recording Other instrumentation was installed for control, alarm, and safety functions required for unattended and continued operation of the experiment

A shakedown was completed in May 1976, and testing was started in June 1976

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1 Consultant, Electrical Engineering Dept University of Tennessee, Knoxville

## 9 7 WASTE MANAGEMENT OBSOLETE CASK DROP PROGRAM

W L Bryan N C Bradley

In the waste management obsolete cask drop program, seven casks and sixteen specimens were dropped Instrumentation was provided and operated for measurement of acceleration, force, and strain at various locations on the cask specimen, impact pad, and drop tower High-speed oscillographic records and digital transient display of test results were provided to the experimenter Several instruments were developed to improve the reliability of impact data acquisition, including an active low-pass filter module with switch-selectable roll off frequency, a current-limited driver module for oscillographic galvanometers, a laser-plus-digital delay triggering system for starting recording devices, and an interlocked firing system for the frangible-nut cask safety release mechanism An analog FM magnetic-tape recording system was ordered for high-speed data storage

## 9 8 ELIMINATION OF NOISE IN THE MINI-ZWOK EXPERIMENT

J L Horton

The commercial, 8-kW radiant tungsten lamp furnace for the mini-ZWOK experiment created a noise problem with type-S thermocouple signals slight errors were induced in the local galvanometer system, and the remote data line amplifier was driven into saturation Changes in guarding, shielding, and grounding corrected the galvanometer errors, but the best common-mode rejection techniques on the amplifier did not adequately reject the noise A low-pass RC filter (50 $\Omega$ and 6 $\mu$F) was connected in each of the two input leads to the differential amplifier to eliminate the SCR-generated noise The computer for this experiment, with its fast sampling ability, was used as a digital transient recorder to show the feed-through magnitude and approximate waveform of the noise

## 9 9 PORTABLE SMOKE- AND GAS-MONITOR REDESIGN

W R Miller

Two new commercial components prompted redesign of smoke and gas monitors

1 A new dc-operated gas sensor (TGS-812) from Figaro Engineering Company, Inc , Japan, permits using three-terminal voltage regulators to achieve stability and repeatability on a 0- to 500-ppm scale

2 Days, rather than hours, of use between battery recharging is now possible with new sealed, lead-acid Gates energy cells.

## 9.10 ANALYSIS OF HFIR SAFETY INSTRUMENTATION UNCERTAINTY

M J Roberts

As a part of the background information for preparation of technical specifications for the High Flux Isotope Reactor, the uncertainties in measurements by the safety system of parameters, such as heat power and coolant temperature, were estimated by statistically combining the uncertainties in the individual components of each measurement system. These estimates will allow conservative settings of the safety system trip points for emergency shutdown so that the probability of an undetected unsafe condition is negligible

# 10. Thermometry

## 10.1 ULTRASONIC AND JOHNSON NOISE FUEL CENTERLINE THERMOMETRY[1]

R. L Shepard
C. J. Borkowski J. K. East
R J. Fox J. L. Horton

Rhenium ultrasonic and Johnson noise thermometers (UST and JNT) were used to measure fuel centerline temperatures of 900 to 1500°C in capsules irradiated in the High Flux Isotope Reactor for periods of 1000 to 3000 hr Transmutation of rhenium by thermal-neutron absorption caused large drifts in UST calibration but none in JNT calibration Whole-capsule, postirradiation calibration was used to measure drift of the UST and to provide a calibration correction Calculation of the temperature and the resistance of JNT rhenium sensor elements by noise power measurements have shown no temperature drift in over 1100 hr at 1250°C. Performances of tungsten-rhenium thermocouples, UST, and JNT in fuel irradiation centerline thermometry are compared.

1 Abstract of paper presented at the International Colloquium on High-Temperature In-Pile Thermometry, JRC Petten, Netherlands, December 12–13, 1974

## 10.2 TEMPERATURE MEASUREMENT ERRORS IN THERMOCOUPLE THERMOMETRY[1]

T. G. Kollie

Errors in thermocouple thermometry can be attributed to seven sources (1) thermal shunting, (2) electrical shunting, (3) calibration, (4) decalibration, (5) extension wire, (6) reference junction, and (7) data acquisition. Each source generally increases with increasing thermocouple hot-junction temperature, has a magnitude that depends on the techniques employed, and differs for each type of thermocouple. These seven sources are discussed and means of minimizing their effects are suggested. Engineering temperature measurements above room temperature are shown to have errors of ±2 to ±5% when care is exercised, and errors of ±10% are not uncommon. Temperature measurement errors less than ±1% are difficult to achieve.

1 Abstract of paper presented at a Metals and Ceramics Division seminar, October 21, 1975, to the Reactor Division, May 27, 1976, and August 8, 1976, at ERDA headquarters, May 9, 1976, at the Y-12 Development Division, December 15, 1975, and at the ASTM Workshop on Temperature Measurements in Creep Determinations, June 25, 1976

## 10.3 CORRECTION OF IRRADIATION-PRODUCED DRIFT IN TUNGSTEN-RHENIUM FUEL CENTERLINE THERMOCOUPLES[1]

R. L. Shepard T. G. Kollie

The calibration drift occurring in tungsten-rhenium fuel centerline thermocouples in an in-pile experiment can be determined quantitatively during irradiation, it can be corrected for by measuring both the thermocouple output and electrical resistance of the thermocouple loop and by applying Matthiesen's rule to interpret the results The temperature error in a particular experiment is strongly affected by the temperature gradient along the thermocouple Some generalizations can be made about the effects of irradiation temperature and neutron flux on the thermocouple drift rate, however, variations in the temperature gradient among experiments preclude direct comparisons and make postirradiation calibration difficult to interpret. These complications require development of an on-line method for drift correction, as is described in this paper.

1 Abstract of paper presented at the International Colloquium on High-Temperature In-Pile Thermometry, JRC Petten, Netherlands, December 12–13, 1974

## 10.4 TEMPERATURE MEASUREMENT ERRORS WITH TYPE K (CHROMEL VS ALUMEL) THERMOCOUPLES DUE TO SHORT-RANGED ORDERING IN CHROMEL[1]

T G. Kollie
J. L. Horton K. R. Carr
M. B. Herskovitz C. A. Mossman

After annealed, type K (Chromel vs Alumel) thermocouples were heated above 200°C, their temperature measurements were found to be in error up to 1.3%, as determined by comparison calibrations with working standard 90% Pt–10% Rh/Pt thermocouples or platinum resistance thermometers. Reannealing of the type K thermocouples removed the errors The errors were due to changes in the thermal emf vs temperature relationship, which from previous work of others can be attributed to short-ranged ordering of the Chromel thermoelements. Reannealing of the thermocouples removed the errors because the order-disorder transformation is reversible, that is, short-ranged ordering of the nickel and chromium atoms of the Chromel alloy occurs between 200 and 600°C, and disordering occurs above 600°C. The traveling gradient method was used to determine the effects of heat treatment on the thermal emf of type K thermocouples, to investigate the kinetics of ordering of Chromel, and to determine the amount of order produced by heat treatments

Though the order-disorder transformation could not be stopped, our results demonstrate that there exists an optimum amount of order in the Chromel thermoelement which will yield a repeatable thermal emf vs temperature relationship for a type K thermocouple in a specific application. When the experimental conditions of the application were controlled, the order-induced temperature measurement errors were essentially eliminated by isothermal heat treatment performed to produce the optimum order in the Chromel thermoelements and by calibration of the type K thermocouples prior to use. The optimum amount of order depended on the application and was determined experimentally. Variations from the optimized heating or cooling cycles, changes in the depth of thermocouple immersion during use, or modification of the temperature gradient on the thermocouple caused temperature measurement errors of up to 1% with ordered and calibrated type K thermocouples.

1 Abstract of published paper *Rev Sci Instrum* **46**(11), 1447 (1975)

## 10 5 PROBLEMS IN HIGH-TEMPERATURE THERMOMETRY[1]

R L Anderson T G Kollie

The error sources or problems in temperature measurements are reviewed for the temperature interval 500 to 3000°C Emphasis is given to the problems due to metallurgical and chemical changes that occur above 500°C and affect the property used to measure temperature, e g , resistance, thermal emf, emittance, etc Problems covered have to do with resistance and thermocouple thermometry and optical pyrometry, as well as several newer techniques A review of temperature scales and sensor calibration tactics precedes the discussion of the problems

1 Abstract of published paper *Critical Review Series in Analytical Chemistry* ed B H Campbell, CRC Press Cleveland, Ohio, 1976

## 10 6 FUEL IRRADIATION CAPSULE THERMOMETRY

R L Shepard W P Eatherly[1]
J K East J L Horton
B H Montgomery[2] K R Thomas[2]
M J Kania[1] K H Valentine

Fuel centerline temperature sensors and measurement techniques were developed for gas cooled reactor irradiation capsules and were tested in the Oak Ridge Research Reactor (ORR) and the High Flux Isotope Reactor (HFIR) Platinum-molybdenum thermocouples and Johnson noise thermometers (JNTs) were used to measure temperatures in carbon-coated fuel and graphite creep tests during irradiations of 5000 to 10,000 hr Their indicated temperatures were compared with centerline temperatures calculated from dimensions and thermal properties of capsule materials and from temperatures indicated by peripheral Chromel-Alumel thermocouples

Pt–5% Mo/Pt–0 1% Mo thermocouples with platinum sheaths and alumina insulation were used to measure (1) graphite temperatures of 900 to 1100°C in the OF-2 capsule irradiated in the ORR for 8000 hr and (2) coated-fuel temperatures of 1100 to 1300°C in the HRB-11 capsule irradiated in the HFIR for 5000 hr The OF-2 thermocouples showed no radiation-induced decalibration The HRB-11 thermocouples shifted calibration, apparently due to a short from loop to sheath at the hot junction The HRB-11 platinum-molybdenum thermocouple loop resistance was monitored, and the thermocouple wires showed significant changes in resistance during irradiation A whole-capsule-gradient furnace calibration of this thermocouple after 2200 hr of irradiation showed a slight effect, that is, an error of about 10 to 15°C at 1100°C. Out-of-pile furnace tests of platinum-sheathed platinum-molybdenum thermocouples showed chemical reactions between the sheath and the carbon environment A vapor-deposited Re-ZrC or W-ZrC sheath coating is being tested as a potential carbon barrier for the platinum-molybdenum thermocouple intended for irradiation in the HRB-13 capsule

The JNT was used to measure fuel centerline temperatures in three HFIR irradiation capsules HRB-9, -10, and -12 In HRB-9 the JNT operated at 1300 to 1500°C for 4500 hr without decalibration, even though 80% of the rhenium-sensing resistor had transmuted to osmium Some prompt irradiation-related noise was observed, apparently due to breakdown pulse noise in the cable insulators In HRB-10 the JNT operated satisfactorily for 1300 hr, and then an open circuit in the sensor connections caused failure Postirradiation examination of this sensor showed that a massive reaction had occurred between the molybdenum-rhenium sheath and the coated fuel particles during the 3800-hr exposure of the sensor to a

1500°C carbon environment. A ZrC-coated rhenium sheath was used in the fabrication of the JNT for the HRB-12 experiment. The HRB-12 capsule was operated at about 1300°C for 3000 hr. The dual-resistor JNT, showing microphonic characteristics, picked up nonthermal noise from vibrations of the water pump and control plate and has usually indicated temperatures several hundred degrees above those calculated for the fuel centerline.

Thermal analysis of the HRB-11 and -12 capsules shows that the temperatures indicated by the centerline thermometers are significantly greater than the fuel temperature. This disparity is due to the prompt effects of gamma and beta absorption by the sensor, an absorption of 15 to 45°C for the JNT in HRB-12, and 50 to 150°C for the platinum-molybdenum thermocouple in HRB-11. These calculations require an estimate of the heat transfer between the thermometer and the inside surface of the fuel. Methods being studied to measure the heat transfer coefficient $h$ in situ at operating temperatures include the use of the loop-current step response of the thermometers and the use of electrical loop heating to provide a measured equivalent of the radiation heating.

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1 Metals and Ceramics Division
2 Reactor Division

## 10.7 PLATINUM-MOLYBDENUM LOW-NEUTRON-CROSS-SECTION THERMOCOUPLES

R. L. Shepard W. W. Johnston, Jr.
G. W. Weber[1] R. K. Williams[1]

Platinum alloy thermocouples containing constituents with low thermal-neutron capture cross sections ($\sigma$) are being developed for in-pile irradiation capsule measurements of temperatures from 1000 to 1500°C They will replace platinum-rhodium ($\sigma$ = 150 b) and tungsten-rhenium ($\sigma$ = 86 b) thermocouples. The thermoelectric power and electrical resistivity of platinum thermocouple alloys containing molybdenum ($\sigma$ = 2.5 b), ruthenium ($\sigma$ = 2.5 b), niobium ($\sigma$ = 1 b), and chromium ($\sigma$ = 3.1 b) are being measured by the Metals and Ceramics Division. Commercially obtained platinum-sheathed, alumina-insulated, Pt–5% Mo/Pt–0.1% Mo thermocouples are being used in the irradiation experiments OF-2 at the Oak Ridge Research Reactor and HRB-11 at the High Flux Isotope Reactor to measure graphite or carbon-coated fuel temperatures of 1000 to 1300°C. Two 1500°C furnace tests lasting 500 hr were performed to determine the compatibility of these thermocouples with a carbon-containing, inert gas environment. Carbon solubility in platinum of about 0.1% by weight at 1100°C and excessive recrystallization of the platinum sheath caused several tests to fail A multilayer Re-ZrC or W-ZrC protective coating for the platinum sheaths is being tested to provide a carbon diffusion barrier.

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1 Metals and Ceramics Division

## 10.8 PARTICIPATION IN ASTM COMMITTEE E.20 ON THERMOMETRY

M. B. Herskovitz
W. W. Johnston, Jr. T. G. Kollie R. L. Shepard

The researchers in this group, in their capacity as members of the ASTM Committee on Thermometry, helped prepare and review standards, in particular those for subcommittees E.20.02, Optical Pyrometry (Johnston, member), E.20.03, Resistance Thermometers (Johnston, chairman, Herskovitz, member), E.20.04, Thermocouples (Herskovitz, subsection chairman, Johnston and Shepard, members), E.20.06, Acoustic Thermometers (Shepard, chairman); and E.20.08, Medical Thermometers (Johnston, member). Kollie presented a paper on "Temperature Measurements for Creep Testing" at a joint meeting of the ASTM and ASME, and Shepard presented "New Developments in Johnson Noise Thermometry" at a meeting sponsored by subcommittees E.20.04 and E.20.06.

The deliberations on the following specifications were authored or chaired by this group:

1. "A Standard Method of Test for Industrial Resistance Thermometers," for publication in 1977 by E.20.02 (Johnston).
2. "Specifications for Platinum Industrial Resistance Thermometers," under preliminary discussion by E.20.02 (Johnston).
3. "Specification for Metal-Sheathed Base-Metal Thermocouples," E-20-D-1, draft 5 (May 17, 1976), based on ASTM Specification E-235, ready for section ballot (Herskovitz).
4. "Specification for Sheathed Base-Metal Thermocouple Material," based on RDT Standard C 7-6T, ready for society ballot.
5. "Specification for Thermocouple Wire, 97% Tungsten–3% Rhenium and 75% Tungsten–25% Rhenium," E-20-D-4, draft 3, ready for section ballot (Shepard).
6. "Recommended Test Method for Homogeneity Testing for Thermoelements," in subcommittee discussion (Johnston and Shepard on task force for revision).

In addition to the above, the following test methods and specifications were reviewed, and comments by the authors were included in the revisions:

a. "Recommended Practice in Optical Pyrometery," in review.
b. "Standard Method of Calibration of Thermocouples by Comparison Techniques," E 220, issued.
c. "Standard Temperature Electromotive Force (EMF) Tables for Thermocouples," E 230, issued.
d. "Standard Specifications for Thermocouples, Sheathed, Type K, for Nuclear or for Other High-Reliability Applications," E 235, issued and now being reviewed.
e. "Liquid Baths for Thermocouple Temperature Measurements," issued as a tentative specification.
f. "Preparation of Thermocouple Measuring Junctions," issued as a tentative specification.
g. "Properties of Thermoelement Materials," issued as a tentative specification.
h. "Temperature–Electromotive Force (EMF) Tables for Tungsten-Rhenium Thermocouple Systems," issued as a tentative specification.
i. "Recommended Practice for Application of Thermocouples in Creep and Stress Rupture Testing to 1000°C in Air," in committee review.
j. "Standard Specification for Duplex, Base Metal Thermocouple Wire, Fiberglass or Silica Fiber Insulation," draft 6, in ballot.
k. "Methods of Test for Comparing EMF Stability of Single-Element Base Metal Thermocouple Alloys in Air," in ballot.
l. "New Recommended Practice for Preparation and Use of Freezing Point Reference Baths," in ballot.

Two members of the group (Johnston and Shepard) served on the E.20 Advisory Board; Johnston was assigned responsibility by ERDA for conversion of RDT standards to ANSI standards.

## 10.9 TEMPERATURE SCALES, CALIBRATIONS, AND RESISTANCE THERMOMETRY[1]

R. L. Anderson

Temperature scales form the basis for accurate temperature measurements. The Kelvin thermodynamic temperature scale (KTTS) is the fundamental scale. The international practical temperature scale of 1968 (IPTS-68), which has been constructed to agree closely with the KTTS, is a scale more easily realizable. The Metrology Research and Development Laboratory in the Instrumentation and Controls Division maintains standards to calibrate thermocouples, resistance thermometers, and optical pyrometers on the IPTS-68.

Temperature measurements of the highest accuracy in the range from 13 K to 1064°C employ platinum resistance thermometers To achieve precision of 1 mK or better requires care to avoid (1) errors due to lack of adequate immersion, (2) mishandling of the thermometer, (3) measurement errors due to thermal emf's in the system, and (4) changes in lead resistance. Germanium resistance thermometers are frequently used below 20 K for precise temperature measurements

1 Abstract of paper presented at a Metals and Ceramics Division seminar, Oct 21, 1975, and at a meeting of the Reactor Division, May 27, 1975

## 10.10 JOHNSON NOISE THERMOMETER ANALOG DATA PROCESSOR

D. W. McDonald

A thermometer based on measurement of the random thermal motion of electrons was developed The measurement of this electron movement, or noise, is independent of the composition of the material in which the measurement is being made. This makes the Johnson noise power thermometer ideal for use by industry in nuclear applications where transmutation of materials due to neutron flux often occurs. Because of the interest expressed in the thermometer by industry, we developed an analog data processor to replace a computer-based data analysis system. Though the analog data processor is less accurate and has a reduced dynamic range as compared with the computer (0 5% over the temperature range from 900 to 1300°C), it costs much less and offers an improvement over presently achievable long-term temperature accuracy in deleterious environments.

## 10.11 ZWOK CALIBRATION AND NICKEL FREEZING POINT

W. W. Johnston, Jr. R. L. Anderson

The accuracy requirements of the zirconium-water oxidation kinetics (ZWOK) program required a special calibration of the thermocouple material to 1500°C. Insulation leakage required special shielding arrangements above 1000°C to isolate the low-voltage thermocouple circuits Two thermocouple standards included in the calibration assembly agreed with each other within 1 $\mu$V over the entire range of calibration – an excellent agreement.

The freezing point of nickel was determined, to confirm the high temperature range of the ZWOK calibration. To do this, one of the ZWOK, type S thermocouples was used to measure the temperature of the freeze point cell, giving a nickel freezing point of 1455.4°C with a measurement uncertainty of ±0.4°C. The value on the IPTS-68 is 1455°C.

## 10.12 TIMING DEVICES FOR THERMOCOUPLE INVESTIGATION

W. R. Miller

Two timing devices were developed and built to eliminate the magnetic effects which occur in thermocouple wire during response time determinations. Both units pass an alternating current through a thermocouple to cause heating, but interrupt the heating when the magnetic flux is at zero so that accurate time-of-response measurements can be made.

The first unit was designed to pass a predetermined number of whole cycles and a predetermined fractional number of the last cycle of 1000-Hz power at a current level of 10 A.

The second unit was designed to pass 1000-Hz power at a level of 10 A for a predetermined time, and then to ramp the power to zero at a predetermined rate.

## 10.13 TEMPERATURE MEASUREMENT ERRORS DUE TO THE EFFECT OF ALTERNATING MAGNETIC FIELDS ON THERMOCOUPLES WITH FERROMAGNETIC THERMOELEMENTS

D. W. McDonald

The noise at the output of thermocouples in electrically noisy environments was investigated. Most thermocouples were found to be immune to noise pickup when properly grounded; however, this was not true for an important group of thermocouples, those with ferromagnetic thermoelements such as Alumel, Nisil, and iron. When thermocouples with ferromagnetic thermoelements were placed near large alternating currents, series-mode voltage spikes were generated within the thermocouples. The amplitude of these spikes, which corresponded to large temperature errors, was directly related to the amplitude and frequency of the current and inversely related to the distance between the current-carrying conductor and the thermoelement. The amplitude was also dependent on the geometry of the thermoelement in relation to the current flow and was inversely related to temperature, approaching zero as the thermoelement temperature approached the Curie temperature of the ferromagnetic thermoelement.

## 10.14 PLATINUM VS PLATINUM-MOLYBDENUM THERMOCOUPLE WITH CHROMEL-ALUMEL REFERENCE JUNCTION EXTENSION WIRES

R. J. Fox R. L. Shepard W. W. Johnston, Jr. R. L. Anderson

An unusual thermocouple was constructed using a platinum-alloy-sheathed Pt–0.1% Mo/Pt–5% Mo thermocouple, with a pair of Chromel-Alumel thermocouples used both as extension wires and as thermometers to measure the platinum-molybdenum reference junction temperatures. This configuration was required because the available platinum material was too short for the assembly and the temperatures to be measured were too high for other available materials. Special fabrication techniques were required to produce a dual-diameter ($\frac{1}{16}$–$\frac{1}{8}$ in.) sensor for use in the HRB-11 capsule irradiation experiment.

## 10.15 INHOMOGENEITY TEST FACILITY

R. L. Anderson T. G. Kollie J. D. Lyons

The inhomogeneity test facility was used extensively to study mechanisms of decalibration in thermocouples and to rapidly screen large batches of thermocouples. The basic apparatus in the facility was modified to improve repeatability and to quantify the results.

All thermocouples purchased for ORNL stores stock are acceptance-tested in the facility to evaluate the homogeneity of the entire length of each thermocouple in the as-received and after-calibration conditions. Calibration evaluates only the condition of the part of the thermocouple in the temperature gradient of the calibration furnace, which is seldom the same as the use gradient. For uses where defective thermocouples cannot be tolerated, such as in radioactive cells, 100% testing is performed. The test requires only about 10 min per thermocouple.

## 10.16 OIL BATH STIRRER

G. W. Allin R. L. Anderson

Inhomogeneity testing of thermocouples requires the use of an isothermal oil bath in which the temperature of the oil is closely controlled. The existing oil bath has a propeller stirrer on the centerline of the cylindrical vessel, this lessens the clear area available for testing thermocouples. In order to remedy this disadvantage, a new stirrer was designed and is being tested. In the proposed configuration, a centrifugal impeller at the bottom of the oil bath draws oil down the center of a smaller concentric inner tube and discharges the oil into the annulus for return to the top of the bath. This arrangement leaves a free clear area for insertion of the thermocouples to be tested. A small heater is mounted on the outside of the inner tube for adding small amounts of regulating heat to the oil bath. The rate of oil circulation can be adjusted by varying the motor speed.

## 10.17 THERMOCOUPLE THERMOMETRY FOR CORE-FLOW TEST FACILITY

T. G. Kollie R. L. Anderson J. D. Lyons

The core-flow test facility (CFTF) program of the Reactor Division for the study of postulated accidents in gas-cooled nuclear reactor simulators was assisted in evaluating its proposed thermocouple thermometry techniques. The error sources in the CFTF thermometry, 0.5-mm-diam sheathed thermocouples, were identified, means of minimizing three sources of error – thermocouple decalibration during use, electrical shunting of the thermal emf above 800°C, and noise pickup – are under study

Because of the small (~0.1 mm) diameter of the thermoelements, changes in their thermal emf can occur in a relatively short time at high temperatures (1000°C). Type K (Chromel P–Alumel) thermocouples in type 310 stainless steel sheaths and in Inconel-600 sheaths, and Nicrosil-Nisil thermocouples in type 310 stainless steel sheaths were tested. After 52 hr at 1000°C, the type K thermocouples in stainless steel had decalibrated so much that a change in position of the temperature gradient on a thermocouple caused a measurement error from +8 to –21°C. At 600°C all thermocouples behaved well, with no appreciable decalibration, although the type K thermocouples underwent an order-disorder transformation in the 200 to 500°C section of the thermocouple temperature gradient. The Nicrosil-Nisil thermocouples were the most stable at 600°C, although at 1000°C their behavior was less stable than that of the type K thermocouples by a factor of about 2.

Inhomogeneity tests performed after calibration to 1350°C showed that type B (Pt–30% Rh/Pt–6% Rh) thermocouples were more stable than type S (Pt–10% Rh/Pt) thermocouples for both Pt–10% Rh or tantalum-sheathed assemblies. Significant changes in the stability of both types of thermocouples can be attributed to differences in manufacturing procedure

Electrical shunting of the thermal emf of thermocouples above about 800°C is caused by a decrease in the electrical resistivity of the MgO or $Al_2O_3$ insulator at high temperature and the close proximity of the thermoelements and sheath. Two furnace tests indicated an error of only 0.3°C in working-standard thermocouples (0.25-mm-diam, type S thermoelements in high-density, high-purity, 1.7-mm-diam $Al_2O_3$ insulators) for a hot-zone furnace temperature of 1400°C and a thermocouple hot-junction furnace temperature of 25°C. From this small temperature error we conclude that calibrations and other tests performed on sheathed thermocouples are essentially unaffected by electrical shunting errors in the standards. Two-furnace tests of CFTF-type sheathed thermocouples were started.

## 10.18 INSULATION EFFECTS IN SMALL-DIAMETER THERMOCOUPLE MATERIALS

R. L. Anderson T. G. Kollie

Small-diameter (0.020 in.) sheathed thermocouple materials are used in simulation tests of reactor fuel rods. Stringent requirements on temperature measurements for these tests and the relatively recent availability of small-size thermocouple materials led to an experimental program to measure the insulation properties of these materials, particularly at higher temperatures.

On the first heating cycle, the insulation resistance decreased sharply at about 100°C because water absorbed by the MgO insulation was released. When one zone of thermocouple material was heated to high temperatures (up to 1000°C), the absorbed water in the heated zone was released and diffused to the cooler portions near the ends of the furnace. When the end seal of the thermocouple in the hot zone was cut off so that the water vapor could escape, the insulation resistance was much higher. As the temperature was decreased to below about 100°C, water was reabsorbed, which lowered the insulation resistance.

At higher temperatures and with larger-diameter materials, we observed serious errors (up to 400°C) due to insulator shunting and to the creation of "virtual junctions" when portions of the thermocouple assembly were at a higher temperature than that of the measuring junction. With 0.020-in.-diam thermocouples, errors up to 36°C were observed with a hot-zone temperature of 1000°C.

## 10.19 ANOMALOUS THERMOCOUPLE ERRORS

R. K. Adams R. L. Anderson J. L. Horton T. G. Kollie
M. J. Roberts B. G. Eads

Although the sources of most errors associated with thermocouple thermometry are understood, during the first powered calibration runs of the Thermal Hydraulic Test Facility (THTF) of the Blowdown Heat Transfer Program, there were large unexplained errors in the temperature readings of the Chromel-Alumel-sheathed thermocouples in the heater rods. The errors were characterized as follows:

1. very large magnitude (up to 300°F) at low temperatures (165°F), lesser magnitude as the temperature was increased, and very small magnitude above the Curie point for Alumel (about 330°F);
2. both positive and negative signs for thermocouples, with apparently similar characteristics in all other respects;
3. abrupt disappearance when the dc to the rod bundle was turned off.

After item 1 was separated out, the errors increased as heater-rod power was increased.

After isothermal, nonpowered calibration of the thermocouples and analysis of the data from several 16-hr THTF experimental runs, we ruled out all the common thermocouple and instrument errors as major contributors to these errors. Characteristic 1 and 3 indicated a thermomagnetic phenomenon in the ferromagnetic Alumel thermoelement, that is, a mechanism involving the vector cross product of a relatively large thermal gradient transversely across the thermoelement and a perpendicular magnetic field (caused by the dc heating along the rod). This is the Nernst effect. No one in thermocouple thermometry had ever indicated that the Nernst effect could produce such large errors, and there is no reliable literature data on the effect in Alumel.

We have duplicated the THTF errors under more controlled conditions, but additional work is needed to yield accurate values for:

1. the Nernst coefficient for several thermocouple materials, especially Alumel and Chromel;
2. the magnetic permeability of several thermocouple materials, especially Alumel, as a function of temperature and applied magnetic field;
3. transverse thermal gradients in sheathed thermocouple assemblies.

Although our understanding of the Nernst effect in the THTF is incomplete, we can prepare thermocouple application guidelines for interpreting the experimental data. Since most operating conditions of the THTF will be well above 350°F, the Nernst effect is not expected to severely affect the test data.

## 10.20 THERMOCOUPLE TIME RESPONSE IMPROVEMENT BY SIGNAL PROCESSING

M. J. Roberts

In many research and development programs, the requirements for temperature measurement are demanding ever faster time responses to temperature transients. One way to achieve a faster response is to make smaller thermocouples; but this would be at the expense of mechanical strength. A more desirable method is to process the signal with first- and second-derivative amplification to speed up the signal's approach to its final value. This was done with both digital and analog methods, and as a result, the rise time decreased by a factor of 10 or more. This work is being continued with emphasis on reducing the noise problems in the method.

## 10.21 ANALYTICAL METHODS FOR INTERPRETING IN SITU MEASUREMENTS OF RESPONSE TIMES IN THERMOCOUPLES AND RESISTANCE THERMOMETERS[1]

T. W. Kerlin[2]

The loop-current step response (LCSR) method is a means for in situ determination of the response time of thermocouples and resistance thermometers. Response time information is crucial for temperature sensors in safety systems where time-varying signals are used to indicate plant malfunctions. In an LCSR method test, the sensor's temperature is increased a few degrees above ambient temperature by resistance heating within the sensor. After steady state is reached, the resistance heating is stopped, and the sensor output is monitored as it cools. The output indicates the response of the sensor to changes in internal heating.

The actual information required, however, is the response of the sensor to changes in the temperature of the fluid outside the sensor assembly. In this report, an analytical method is developed for transforming LCSR method test results into the response that would be observed following such a change in fluid temperature. The procedure is to determine the system time constants by least-squares fitting of the LCSR test data. Then the time constants are used to construct the equation for predicting the response to fluid temperature changes. The transformation is limited to systems with predominantly one-dimensional heat transfer. Numerous applications using actual test data indicate that the analytical method and its underlying assumptions are adequate.

1. Abstract of ORNL/TM-4912 (March 1976).
2. Consultant, Nuclear Engineering Dept., University of Tennessee, Knoxville.

## 10.22 THERMOCOUPLE-EMF POLYNOMIALS FOR MINICOMPUTER DATA CONVERSIONS

J. L. Horton

Orthogonal curve fitting programs were written in FOCAL for use on PDP-8/E machines to generate polynomial expression coefficients from point-by-point data. These programs were for calibrating and preparing tables for platinum-molybdenum thermocouples used in the in-pile capsule experiments OF-2 (at the Oak Ridge Research Reactor) and HRB-11 (at the High Flux Isotope Reactor).

NBS Monograph 125, "Thermocouple Reference Tables Based on the IPTS-68," provides coefficients for polynomial expressions of $E = f(T)$. FOCAL programs were written to convert these coefficients for $E = f(T)$ to coefficients for $T = f(E)$, which are being used by several data acquisition systems.

When computation speed is not important, and when data conversion directly traceable to Monograph 125 is preferred, emf's can be converted to temperature, using the $E = f(T)$ expression from Monograph 125 in an iterative computational process. These iterative programs are being used for thermocouple calibration in this division.

## 10.23 AUTOMATIC PYROMETER CALIBRATOR

L. H. Thacker

To eliminate the tedious and subjective procedure of manually balancing the color temperature of an optical pyrometer filament against that of a calibration lamp, an instrument was designed and built to scan an image of the superposed filaments and to display a trace on an oscilloscope, showing match or mismatch of temperature. Tests with a crude prototype were sufficiently successful to lead to design and fabrication of the present instrument, which will be tested in the Metrology Research and Development Laboratory of this division.

## 10.24 THERMOCOUPLE THERMOMETRY FOR MULTIROD BURST TEST

T. G. Kollie J. D. Lyons

The Reactor Division multirod burst test (MRBT) program, which is studying postulated loss-of-coolant accidents in pressurized-water nuclear reactor simulators, was assisted in its thermocouple thermometry needs. Thermocouples were designed, specifications were written, procurement was accomplished, and acceptance tests and evaluation were performed.

Type K (Chromel P–Alumel) thermocouple assemblies with a diameter of 0.75 mm, sheathed in either type 310 stainless steel or in Inconel 600, were attached to the inside wall of the Zircaloy fuel-element simulator cladding. Because there is a eutectic reaction between Zircaloy and nickel or iron at about 1000°C, more expensive and less available tantalum-sheathed assemblies were used from 1000 to 1400°C.

Error sources in the thermometery for this program were identified, and an investigation of means of achieving the desired ±1% temperature measurement was undertaken. Tantalum-sheathed, type S (Pt–10% Rh/Pt) thermocouple assemblies drifted −160°C during calibration, while similar type K thermocouple assemblies were stable to ±1°C. In preliminary tests, type S 0.25-mm-diam bare-wire thermocouples will be attached with an intrinsic hot junction to the outside wall of the Zircaloy cladding in order to verify the temperatures measured by the sheathed thermocouples. Errors which occurred above 800°C due to electrical leakage between the thermoelements of the sheathed thermocouples are being investigated.

## 10.25 TEMPERATURE MEASUREMENT ERRORS IN MATERIAL CREEP MEASUREMENTS

T. G. Kollie

Sources of temperature measurement errors in material creep measurements were identified for the Metals and Ceramics Division. Minimization of these errors is important because a 10°C (2%) error at 500°C will cause a 60% error in the creep rate of steel. The two major sources of error were (1) thermal shunting (+2°C at 600°C) of heat to the hot junction of the thermocouple through the thermocouple wires, and (2) decalibration of the thermocouples (+2.5°C at 600°C after 1000 hr). Experiments in one creep apparatus at 400, 600, and 800°C showed probable errors of ±5.3, ±4.6, and ±5.3°C after 20 hr of operation. These temperature deviations would contribute errors of ±49, ±23, and ±17% to creep rate measurements respectively. Methods of reducing the errors were suggested to the Metals and Ceramics Division.

## 10.26 EFFECT OF COLD WORK ON THE EMF OF THERMOCOUPLES

T. G. Kollie J. D. Lyons

The effect of cold work on the emf of a 0.25-mm-diam, bare-wire, type S (Pt–10% Rh/Pt) thermocouple and a 0.75-mm-diam, type 310 stainless-steel-sheathed, type K (Chromel-Alumel) thermocouple was investigated using the inhomogeneity test facility. The cold work was typical of that done during thermocouple installation in a number of applications, and the emf changes caused by the cold work resulted in temperature measurement errors.

The error of type S thermocouples was essentially linear, as a function of the percentage elongation of the thermoelements (−0.7% error for 15% elongation). The error was twice as large in the Pt–10% Rh thermoelement; it was eliminated by heat treatment for 2 hr at 350°C, but was unaffected by treatment for 2 hr at 250°C. The maximum temperature measurement error due to a 15% elongation in a type S thermocouple was estimated as −1.4°C.

The errors of the sheathed type K thermocouples were linear, as a function of the tensile force applied to the sheath (−0.42% for a force of 133 N, with a threshold of 73.3 N). The thermocouple broke at a tensile force of 173 N. The effects of heat treatments on the error were distorted by the formation of short-ranged ordering above 300°C, which introduced positive errors in the thermocouple emf. The maximum temperature measurement error resulting from cold work in sheathed type K thermocouples was estimated at −1.7°C. These results may be extended to sheaths of other sizes by equating the tensile stress, rather than the tensile force, in the sheaths.

## 10.27 CAUSE OF TEMPERATURE MEASUREMENT ERRORS IN AN AGING FURNACE

T. G. Kollie J. D. Lyons R. L. Anderson

A 10% temperature measurement error, 35°C at 360°C, in an aging furnace caused an alloy of interest to the Y-12 Development Division to have a loss of mechanical strength (overaging). Their recalibration of the furnace control thermocouples, which were 1.7-mm-diam, bare-wire, type K (Chromel-Alumel), yielded conflicting results that were dependent on the depth of immersion of the thermocouple in the calibration furnace. Using the inhomogeneity test facility, we determined that the control thermocouple had seriously decalibrated (up to 27%) along the section between 10 and 25 cm from the hot junction, but that it had changed negligibly elsewhere along its length. These measurements explain the results of Y-12 recalibration and the cause of the temperature error in the aging furnace: the principal cause of the decalibration was preferential oxidation in the chromium of the positive thermoelement (Chromel) during a previous 0.5-hr exposure at 1100°C in an inert atmosphere having a low oxygen partial pressure. We screened several furnace control thermocouples for the Y-12 Development Division and suggested that they use sheathed thermocouples in certain applications to minimize temperature measurement errors due to decalibration.

# 11. Instrumentation for Reactor Division Experiments and Test Loops

## 11.1 HIGH-TEMPERATURE GAS-COOLED REACTOR GRAPHITE CREEP IRRADIATION TESTS

J. W. Cunningham    C. Brashear    P. G. Herndon

During this report period, instrumentation was designed, installed, and checked out, and operator assistance was secured during startup of the OC-1 capsule test. Engineering and drafting totaled 300 man-days.

Safety circuit tie-in to the reactor for over-temperature protection was made complicated by the existence of ten individually controlled zones of supplemental electrical heat, each one of which could overheat. Temperatures were controlled by a data acquisition and computer system which developed an output signal to a solid-state controller based on thermocouple signals from each heat zone. The solid-state controller was equipped with a memory which enabled it to continue controlling at the current temperature if the computer failed.

## 11.2 HIGH-TEMPERATURE GAS-COOLED REACTOR IRRADIATION EXPERIMENTS

J. W. Cunningham

Drawings were provided and instruments were obtained to modify existing facilities for the irradiation of two fuel capsules (P13T and OF-2) and one graphite capsule (OG-3) for the High-Temperature Gas-Cooled Reactor. The modifications consisted of (1) rearranging and adding thermocouple connections to recorders and to the Dextir data acquisition system; (2) making changes in the electrical wiring for alarms and switching to pure helium flow for emergency cooling; and (3) making alterations in the tubing and adding electrical flowmeters for measuring the helium, neon, and argon.

Tungsten-rhenium thermocouples are used to measure temperatures in the hotter regions; Chromel-Alumel thermocouples are used for all other temperatures. Approximately 30 thermocouples are used in each experiment.

Instrumentation was completed by monitoring two thermocouples and by double-tracking the experiment containment pressure with a connection to the reactor circuits for safety.

## 11.3 INTERMEDIATE VESSEL TEST V-7A FOR THE HEAVY SECTION STEEL TECHNOLOGY PROGRAM

T. M. Cate    J. L. Redford

Support for the series of intermediate vessel tests under the Heavy Section Steel Technology Program was continued. The latest test in this series, although instrumented at about the same level as its predecessors in the series, presented many unique problems. This test was designed to subject the vessel to pneumatic loading under conditions otherwise similar to the hydraulic test V-7 previously completed. The potential hazards involved in this test had a significant influence on the design and implementation of the instrumentation system used: (1) the test had to be performed at a site remote from the Oak Ridge area under conditions less than ideal for the type of equipment required, and (2) all sensors and their associated interconnection to the instrument system had to be weatherproof, and all interconnections between the specimen and the instrument system had to be at least 300 ft long. A system was designed, assembled, and successfully tested on schedule.

## 11.4 DATA INTERFACE FOR VESSEL-FRACTURE TEST

W. R. Miller

A two-channel data interface was designed and built for vessel-fracture testing. Each channel has components for signal amplification and low-pass filtering and a circuit to identify which channel receives the signal first. Signals from an additional circuit start up measuring instruments and actuate event pens on recording equipment.

## 11.5 THERMAL SHOCK TEST FACILITY

J. W. Krewson T. M. Cate

Design and construction of the Thermal Shock Test Facility was terminated late in 1974 in favor of a smaller system. Design, fabrication, installation, and checkout of instrumentation and controls for the smaller system were completed, and the originally planned thermal shock tests were performed. In this facility, an alcohol-water mixture, precooled to $-10^{\circ}$F, is suddenly injected into a preheated test vessel to produce a thermal shock.

The instrumentation and controls for this facility include:

1. process instrumentation for measurement and control of the alcohol-water process fluid flows, pressures, and temperatures and for pretransient (steady-state) control of test piece temperatures;
2. data acquisition instrumentation for controlling and recording steady-state and transient test data from approximately 40 thermocouples and 10 strain gages located on the test vessel, and from various pressure, flow, and level sensors located on the test vessel and associated facility piping and vessels;
3. instrumentation and controls associated with the foam system that provides automatic protection against the possibility of release and subsequent ignition of the alcohol-water process fluid.

Facility instrumentation was centralized on three standard ORNL panels. All data signals are input to a small, 120-point, computer-controlled data acquisition system. Several of these signals are also recorded on high-speed analog recorders to facilitate quick viewing and, in some cases, higher frequency response.

Design, installation, and checkout of this facility required approximately 1.5 man-years of engineering support from this division.

## 11.6 TRANSIENT TWO-PHASE FLOW INSTRUMENTATION

J. W. Krewson

Approximately 0.5 man-year of engineering support was furnished to the Blowdown Heat Transfer Program to study the thermal hydraulic characteristics of aqueous two-phase flow and the instrumentation problems associated with its measurement.

Tests and calibration were initiated to evaluate instrumentation used in the Thermal Hydraulic Test Facility (THTF), this instrumentation consists of turbine flowmeters, drag disks, and gamma densitometers for the measurement of velocity, momentum flux, and density respectively. The work is being conducted in a room-temperature, air-water facility in which various two-phase flow conditions are simulated by varying the air and water flow rates. The facility is being upgraded to a high-temperature, pressurized-water (blowdown) arrangement which will produce steam-water, two-phase flow conditions simulating those which occur in the THTF.

Information obtained from these tests is the basis for evaluation of the accuracy and performance of this instrumentation and for analysis of data obtained from the facility.

## 11.7 OCEAN THERMAL ENERGY CONVERSION HEAT EXCHANGER PROJECT

J. W. Krewson

Design of instrumentation and controls was started for a small facility for studying the heat transfer characteristics of a medium-temperature heat exchanger which will be used in a larger ocean thermal energy conversion facility. Instrumentation criteria for this facility, in which ammonia is the process fluid, include precise control and measurement of temperatures and protection against escape of ammonia into work areas.

## 11.8 FORCED-CONVECTION TEST FACILITY

J W. Krewson

Engineering support of the Blowdown Heat Transfer Program's Forced-Convection Test Facility[1] was continued intermittently during facility operations Numerous changes, ranging from minor revisions of instruments and control circuits to a major redesigning of the rod power supply system, were made to improve performance or adapt to changing programmatic requirements.

1 R L Moore and J W Krewson, *Instrumentation and Controls Div Annu Prog Rep Sept 1, 1972,* ORNL-4822, p 100

## 11.9 MOLTEN-SALT BREEDER REACTOR GAS SYSTEM TECHNOLOGY FACILITY

P. G. Herndon

Approximately six man-months of engineering effort were expended to complete the instrumentation and control systems for the molten-salt breeder reactor and to start water test operations after the molten-salt program was reactivated in March 1974, preparation of instruments for molten-salt operation was nearing completion when this facility was shut down. During the water test operations, a gamma-ray densitometer for measuring the gas bubble, or void, fraction in both water and molten salts was developed and installed. An instrument system was also designed and installed for measuring the dynamic displacement of the 100-hp pump shaft to aid in sizing the pump impeller and to analyze a hydraulic noise and vibration problem.

## 11.10 MOLTEN-SALT BREEDER REACTOR COOLANT SALT TECHNOLOGY FACILITY

P. G. Herndon

The instruments and control systems for the molten-salt breeder reactor were reactivated early in 1975 when this facility was placed in operation again after being shut down for about one year. It has been operated continuously since that time. In addition to routine engineering assistance, instrumentation for a tritium injection device was designed and installed. Equipment for heater control, temperature measurements, differential pressure measurement, and pressure regulation was installed in a single modular instrument cabinet.

## 11.11 THERMAL HYDRAULIC TEST FACILITY

B. G. Eads

| | | | |
|---|---|---|---|
| A. H. Anderson | C. Brashear | K. R. Carr | J. W. Cunningham |
| D. G. Davis | D. E. Gray[1] | A. F. Johnson | W. W. Johnston, Jr. |
| E. C. Keith | C. S. Meadors[1] | R. L. Moore | W. Ragan |
| J. L. Redford | E. R. Rohrer | M. J. Roberts | R. L. Shipp |

The Thermal Hydraulic Test Facility (THTF)[2] is part of the overall light-water reactor safety research program of the Nuclear Regulatory Commission set up to study the principal variables that are important to analysis of a loss-of-coolant accident in a pressurized-water reactor. The instrumentation system is designed to assure the reliable and safe operation of the experimental facility. Instrument channels monitoring critical test parameters provide data needed for the determination of system behavior under steady-state and transient conditions. Additional instruments are installed in the test loop and associated secondary systems to provide the operators with confirmation that the facility is operating normally. The instrumentation system includes means for detecting out-of-limit and unsafe conditions, alerting the operators that such conditions exist, and initiating appropriate protective actions on detection of such conditions.

Conceptual design of the instrumentation for this facility was first begun in FY 1972. Instrumentation and Controls Division support was increased from 1.3 man-years in FY 1972 to approximately 9 man-years in FY 1976. Design, installation, and checkout of the instrumentation for phase I of the THTF, which made isothermal blowdown tests possible, was completed in April 1975. The final phase, phase II, which allowed powered blowdown tests at a variety of conditions, was completed in May 1976.

In addition to the design work and the assistance given during installation and checkout, other engineering assistance was given as follows:

1. coordination of and assistance in maintenance, calibration, and pretest setup as a part of the facility operations; this required one to two engineers on a full-time basis;
2. preparation of calibration and operating procedures for instrumentation and data acquisition systems;
3. specification of and assistance in procurement and quality-assurance inspection of approximately 2000 small-diameter thermocouples for future test bundles;

4. error analysis to calculate theoretical error bands on the test data obtained in the THTF,
5. testing and analysis to determine the cause and magnitude of large errors in the rod sheath thermocouple readings in the THTF test bundle.

1 General Engineering Division
2 *Project Description of ORNL PWR Blowdown Heat Transfer Separate-Effects Program – Thermal Hydraulic Test Facility (THTF)*, ORNL/NUREG/TM-2 (February 1976)

## 11.12 CAPACITANCE DENSITOMETER

G. W. Allin R. L. Shipp

A capacitance densitometer was designed for the Thermal Hydraulic Test Facility for measuring the density of two-phase (steam-water) mixtures as they flow through a 4-in.-IPS pipe. A prototype was fabricated for testing at room temperature and low pressure. Testing has not yet been conducted. If the testing of the prototype is successful, an operating model will be built for use at 340°C and 1000 psi. The two designs will be similar, but some materials will be changed in the second model.

## 11.13 MOLTEN-SALT CORROSION LOOPS

G. W. Greene

Instrumentation of a molten-salt corrosion loop[1] (MSR-FCL-2) was expanded and modified to permit the operating temperature to be increased from 1150 to 1450°F in order to accommodate the higher melting point of a fuel salt proposed for the molten-salt breeder reactor.

Instrumentation systems were also designed for two similar molten-salt corrosion loops (MSR-FCL-3 and MSR-FCL-4). These two instrumentation systems were, respectively, about 90 and 65% complete when construction was terminated due to withdrawal of funding.

An obsolete molten-salt loop (MSR-FCL-1) was dismantled, and many instruments and components were salvaged for future use.

1 G. W Greene, *Instrumentation and Controls Div Annu Prog Rep Sept 1, 1972* ORNL-4822, p 103

## 11.14 THERMOCOUPLES FOR THERMAL SHOCK TESTS

K. R. Carr J. H. Butler[1] M. A. Perkins[2]

Specially processed and installed thermocouples were provided to the Reactor Division to measure thermal gradients under transient conditions in test specimens subjected to thermal shocks simulating pressurized-water reactor emergency core cooling conditions. Two special techniques were utilized to improve the accuracy of temperature measurement with these $\frac{1}{16}$-in.-OD, stainless-steel-sheathed, Chromel-Alumel thermocouples

1. A stabilizing heat treatment was defined and applied to avoid calibration changes due to short-ranged ordering.[3]

2. A method of spring-loaded installation was designed and utilized to ensure that the thermocouple tips at the sensing junctions remained firmly in contact with the material to be measured throughout the test. In this installation, drilled holes in the test material itself formed the thermocouple thermowells, and roll pins were used to hold the thermocouples in place to avoid the necessity of any additional welding or drilling of the test material.

A special thermocouple fabrication technique was also developed, although it was not utilized in the project. Two prototypes were constructed and tested. The time constants to 63% response were 20 to 25 msec. (The time constants of $^1\!/_{16}$- and 0.040-in.-OD thermocouples of this type are usually no better than ~90 and 30 msec respectively.) Each prototype was thermally shocked from ~550 to 70°F, and no lead or other apparent damage occurred. The laser welds of the 0.003-in.-thick disks successfully passed subsequent helium leak tests made in accordance with RDT Standard C7-6.

1. Reactor Division.
2. Y-12 Welding Development.
3. T. G. Kollie et al., *Temperature Measurement Errors with Type K (Chromel vs Alumel) Thermocouples Due to Short-Ranged Ordering in Chromel,* ORNL/TM-4862 (March 1975).

## 11.15 MULTIROD BURST TESTS

K. R. Carr  C. Brashear  K. J. Cross
T. G. Kollie  C. S. Meadors

The instrumentation design for the Multirod Burst Test Facility (MBTF), an installation for testing the pressure and temperature rupture characteristics of arrays of as many as 64 Zircaloy rods (one pressure measurement per rod and as many as four temperature measurements per rod), was completed. The MBTF will be located adjacent to the Thermal Hydraulic Test Facility and will share the data acquisition system and rod heater power generators used by that project. A small facility was also designed and constructed to test single rods, and operational support was provided for more than 30 tests with this facility. The information from these single-rod tests will provide guidelines for planning the later tests and a basis for verification of the MBTF instrument design.

The temperature and pressure measurements required for the rod burst project each have particular constraints and associated problem areas. The temperature sensors must be small so as to avoid appreciable measurement errors when they are attached to the thin-wall (0.43-in.-OD × 0.025-in.-thick) Zircaloy tubes. Materials compatability must also be considered, since eutectics between Zircaloy and some temperature-sensor materials may form at temperatures in the range of interest. Both type K and type S sheathed thermocouples and type S bare-wire thermocouples are being used. The pressure measurement transducers must be located at a point sufficiently remote from the heated rods so that the transducers will not be subjected to high temperature; an appreciable increase in the system internal volume must be avoided, however, for proper simulation of reactor fuel rod conditions. Also, mechanical constraints require that some portions of the connecting tubes between the transducers and the process have an inside diameter of 0.015 in. Preliminary experiments were run to show that these conditions could be met without significant degradation of the pressure data. The time delay in the pressure measurement data caused by the 0.015-in.-ID restriction in the line was no greater than 1 sec.

The total instrumentation effort in the rod burst program has amounted to approximately three man-years to date.

## 11.16 POTASSIUM-STEAM BINARY VAPOR CYCLE TEST FACILITY

P. G. Herndon

Design, construction, and startup of the instrumentation and control systems for operation of the potassium boiler module during the water testing phase were completed. This module has a design capacity of 20,000 Btu/hr. Five modular instrument panels for the combustion, feed-water, and cover-gas control instrument systems were also fabricated. These systems include remote-manual flow control valves, 10:1 range fuel- and air-flow measuring and recording equipment, an exhaust-gas oxygen analyzer, boiler feed-water level and flow controls, and 75 high-quality thermocouple assemblies. Cooling water flow-$\Delta T$ measuring equipment was also installed on a special, remotely positioned calorimeter device used to determine the output of individual boiler tubes.

Design of instruments and controls for the potassium vapor system was started. Primary elements for measuring potassium temperatures, pressures, flows, and levels at high temperatures (1540°F) are required. Proved devices such as electromagnetic flowmeters, resistance-type liquid level probes, and high-quality thermocouple assemblies, previously developed for use on other Reactor Division boiling-potassium and liquid-metals facilities, will be used for these applications.

This facility, halted during 1974 for lack of funding, was reactivated in 1975. Approximately one man-year of engineering effort has been expended since the program was reactivated.

## 11.17 IRRADIATION EXPERIMENTS IN THE HIGH FLUX ISOTOPE REACTOR

J. W. Cunningham    C. Brashear

Four capsules, HRB-9, -10, -11, and -12, were irradiated in the High Flux Isotope Reactor to test the effects of high-level nuclear radiation on the fuel materials proposed for use in high-temperature gas-cooled reactors. Instrumentation of these experiments was similar to that of previous HRB capsules, except that special temperature sensors being developed by this division were tested. A Johnson noise thermometer replaced the tungsten-rhenium thermocouple for measuring the fuel centerline temperature in most cases. In HRB-11, a platinum-molybdenum thermocouple with a Chromel-Alumel thermocouple on each leg to provide extension wires was used for the centerline temperature sensor.

The resistance of the center thermocouple was monitored at regular intervals to help analyze any suspected deviation in temperature reading. The resistance reading was obtained by using a current-regulated power supply and a relay system connected to certain of the Dextir data system channels, so that a data system scan first measured a voltage across the thermocouple in a forward direction and then, on a subsequent channel, a voltage with a reverse current.

## 11.18 TRITIUM MONITOR

J. W. Cunningham

An auxiliary loop to connect the equipment and instruments for measurement of tritium in the effluent gas was added to fuel irradiation test GB-10 for the gas-cooled fast-reactor. A moisture analyzer and hydrogen detector were included in both the inlet and outlet gases. Moisture was measured to 1 ppm.

The sweep-gas pressure control valve[1] for the GB-10 experiment failed to operate properly and continued to stick during early stages of operation: the trim in the valve must have very small clearances. Polishing the mating parts with rouge helped, but better results were obtained with a seat fabricated from graphite. The first graphite seat lasted nearly two years before being replaced.

1. J. W. Cunningham and R. L. Durall, *Instrumentation and Controls Div. Annu. Prog. Rep. Sept. 1, 1971*, ORNL-4734.

# 12. Environmental Science Studies

## 12.1 A COMPENDIUM OF RADIONUCLIDES FOUND IN LIQUID EFFLUENTS OF NUCLEAR POWER STATIONS[1]

R. S. Booth

A tabulation was made of radionuclides released in liquid effluents from power reactors in quantities high enough to suggest assessing their environmental impact; the expected annual releases of these substances were determined from published measurements and operating experience with 24 light-water reactors through 1972. This standard list of 63 radionuclides was used in the preparation of environmental impact statements for nuclear power stations. Use of this list helped ensure completeness in estimating the consequences of radionuclide releases from each reactor and yet precluded the necessity of considering repeatedly the several hundred radionuclides which could be released. The expected releases and their variations tabulated here were used to verify theoretical releases included in the impact statements for specific reactors.

Operating experience shows that the quantities of radionuclides released from similar reactors during any year and from the same reactor for subsequent years can differ by an order of magnitude. However, analysis of measured releases indicates that the probability of a given release decreases inversely with the magnitude of that release.

The average amount of $^{3}H$ released per year was ~900 Ci for pressurized-water reactors (PWRs) and ~25 Ci for boiling-water reactors (BWRs). The average release of gross beta and gamma radioactivities (in addition to $^{3}H$) was ~5 Ci/year for PWRs and ~10 Ci/year for BWRs. Average releases of individual radionuclides considered here varied from $\sim 10^{-4}$ to ~2 Ci/year.

1. Abstract of ORNL/TM-3801 (March 1975).

## 12.2 A SYSTEMS ANALYSIS MODEL FOR CALCULATING RADIONUCLIDE TRANSPORT BETWEEN RECEIVING WATERS AND BOTTOM SEDIMENTS[1]

R. S. Booth

Equilibrium radionuclide concentrations in waters receiving radioactive effluents and in bottom sediments associated with the receiving waters were calculated so that potential doses to man and biota and radionuclide buildup in the environment could be determined realistically. These calculations were performed to test the accuracy of simpler models in which receiving water concentrations were determined by neglecting the influence of bottom sediments. The simplified calculations were incorporated into environmental impact statements on nuclear power stations prepared by Oak Ridge National Laboratory for the U.S. Nuclear Regulatory Commission.

A four-compartment systems analysis model was developed to predict dynamic radionuclide transfer. The dependent variables of the model are the receiving water, interstitial water intermingled with the bottom sediments, bottom sediment particles that undergo sorption-desorption reactions with the interstitial water, and bottom sediment particles that undergo only sorption reactions with the interstitial water.

The model was used to generate two tables. The first table gives equilibrium radionuclide concentrations in the receiving water when radionuclide transfers to bottom sediments are possible, divided by the receiving water concentrations when transfers to bottom sediments are ignored. These factors are always less than unity, since radioactivity must be conserved, and adding sediments to the system adds another compartment where radionuclide concentrations will equilibrate. The other table lists ratios of equilibrium radionuclide concentrations in sediments, divided by their corresponding receiving water concentrations. These concentrations in the sediments can be used to calculate external doses to a person sunbathing or fishing.

Preliminary results indicate that the usual effect of a neglect of sediment interactions is an overestimate of the total potential dose to man from the radionuclides. The reason is that a neglect of sediment interactions overestimates receiving water concentrations which, in turn, overestimate potential doses from important pathways (drinking water or eating fish) directly related to the receiving water concentration. This would not be the case, however, for a situation where exposure to radionuclides in sediments is the critical pathway.

The results for $^{137}Cs$ are particularly interesting, since this radionuclide often causes a major fraction of the calculated dose for a typical release. For environmental parameters appropriate to freshwater lakes in the northeastern states, neglecting sediment interactions could result in potential doses $\sim$4 times too high from $^{137}Cs$ contained in potable water and edible fish. Further, increasing only the $K_d$ value of a sample of sediment from 27,000 to 270,000 (which reflects measured variations between various freshwater environments) increases this factor from $\sim$4 to $\sim$25.

1. Abstract of ORNL/TM-4751 (April 1975).

## 12.3 A RADIOLOGICAL ASSESSMENT OF RADIONUCLIDES IN LIQUID EFFLUENTS OF LIGHT-WATER NUCLEAR POWER STATIONS[1]

R. S. Booth S. V. Kaye[2] P. S. Rohwer[2]

This report summarizes information compiled and methodologies developed in the process of assessing the environmental impact of radionuclides released into aquatic ecosystems. The report allows one to convert a radionuclide concentration in the environment near nuclear facilities into potential doses to biota and man which take into account the more important ingestion pathways and external exposure pathways. As a guide to evaluating such calculations, the 65 most important radionuclides released in liquid effluents from power reactors were ranked according to their potential dose to man, and the critical (highest-dose-producing) radionuclides and critical pathways were identified. Sample calculations based on realistic environmental data were made to obtain indexes of radiological significance that are similar to but more general than maximum permissible concentrations, $(MPC)_w$.

The critical pathways identified were consumption of fish and ingestion of water for freshwater ecosystems and consumption of mollusks or crustaceans for saltwater ecosystems. The total potential dose to man from typical liquid releases of power reactors was <1 millirem/year of reactor operation, which is much less than the dose of about 100 millirems/year attributed to natural background radiation. Most of the dose was caused by a relatively few radionuclides $^{3}H$ (from pressurized-water reactors), $^{32}P$, $^{60}Co$, $^{95}Nb$, $^{131}I$, $^{134}Cs$, $^{137}Cs$, and $^{182}Ta$ for fresh water, $^{54}Mn$, $^{58}Co$, $^{60}Co$, $^{65}Zn$, $^{131}I$, and $^{137}Cs$ for salt water.

1 Abstract of ORNL/TM-4762 (June 1975).
2 Environmental Sciences Division

## 12.4 METHODOLOGY FOR ASSESSMENT OF DOSE TO MAN FROM ENVIRONMENTAL RELEASE OF RADIOACTIVITY[1]

R. S. Booth P. S. Rohwer[2]

The Cumulative Exposure Index (CUEX) was developed to assess environmental releases of radioactivity. CUEX makes possible the evaluation of potential dose contributions to man from all exposure pathways. It also allows for the summing up of the pathway contributions, the quantitative identification of critical radionuclides and exposure pathways, and the assessment of the estimated total doses to man in relation to the appropriate radiation safety standards.

Models were developed to predict radionuclide movement through the environment. These predictive models provide realistic estimates of man's total intake of, and/or external exposure to, radionuclides by numerous pathways. The design of the models is such that they can be applied to most radionuclides, even those for which few environmental data are available. Dose estimation models were coupled with the transport models to transform the exposure predictions into estimates of dose. The modeling strategy applied to this task emphasized several basic principles, which included (1) rigorous definition of the minimum modeling objectives and selection of the simplest model which achieves these objectives, (2) statement of model parameters in terms of measurable environmental parameters, since environmental parameters may be different at the various sites where the model is applied, (3) vigilance in performing validation tests of the models at every opportunity, (4) careful attention to the total uncertainty of our predictions and emphasis upon that link in the calculational chain which has the largest uncertainty.

An example of a model which incorporates these principles is presented and evaluated within the context of CUEX. Such a model, though conceptually simple, has been demonstrated to be adequate for realistic assessment of many radionuclide releases

1 Abstract of paper presented at the 4th National Symposium on Radioecology, Corvallis, Ore , May 12–14, 1975
2 Environmental Sciences Division

## 12.5 ENVIRONMENTAL FACTORS AFFECTING CALCULATIONS OF DOSE RESULTING FROM A TRITIUM RELEASE INTO THE ATMOSPHERE[1]

P. Otaduy[2] R. S. Booth C. E. Easterly[3] D. G. Jacobs[3]

An atmospheric transport code has been modified to include the conversion of tritium gas to tritiated water. Although neither the order nor the rate of the combined conversion reactions is known with any precision, a first-order rate of conversion is assumed This assumption will result in an overestimate of dose if the reaction is actually second-order with a rate greater than that of natural radioactive decay. Baseline calculations have been made to determine the effect of site-specific parameters on the estimation of individual and population dose resulting from the inhalation pathway, parameters studied included meteorological conditions, the initial HT/HTO mixture, the rate of conversion of HT to HTO, and the location of critical receptors.

Calculations have been made for tritium releases from a 100-m stack with a constant 1.7-m/sec wind under several atmospheric conditions. In calculating the dose resulting from a release of tritium under Pasquill type F stability conditions, the assumption that the entire release is in the form of HTO when it is actually HT can result, for a 3%-per-day conversion, in the overestimation of dose downwind from the source by factors of 400 at $10^3$ and 10 at $10^5$ m. The calculated dose as a function of distance is very much dependent on the rate of conversion from tritiated gas to tritiated water. The ratio of doses calculated for 0.1% conversion per day to those calculated for 10% per day vs distance is 2, 10, and 50 at $10^3$, $10^4$, and $10^5$ m respectively. If the conversion rate is known to within a factor of 5, for conversion rates of up to 10% per day, the dose to the critical receptor can be calculated to within a factor of 2. (The critical receptor for site assessment calculation is normally in the range of 1000 to 5000 m from the source )

Calculated doses are affected by plume depletion, current practice is to assume an effective deposition velocity based on yearly averaged data. The effect of this assumption on calculated doses varies with distance, initial HT/HTO mixture, and rate of conversion. The assumption of a 1-cm/sec deposition velocity (as compared with 0 cm/sec) for the HTO reduces the calculated inhalation dose at $10^5$ m by a factor of 3 for an oxidation rate of 10%.

Results of additional baseline calculations are presented, with summaries of the effects of uncertainties in site-specific variables on the resulting calculations of dose.

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1 Abstract of paper to be presented at the 2d American Nuclear Society Topical Meeting – The Technology of Controlled Nuclear Fusion, Richland, Wash , Sept 21–23, 1976

2 Graduate student, University of Florida, Gainesville

3 Health Physics Division

## 12.6 DECOMPOSITION OF ORGANIC MATTER IN SOIL

O. L. Smith

A mathematical model was developed to simulate the mineralization of organic materials deposited on and in the soil by dead plant and animal matter. Starting with a specified quantity of fresh organic material, the model simulates the many microbial processes which disaggregate the tissue and liberate carbohydrates, proteins, organic phosphates, and potassium. Some of these organic materials may be absorbed onto soil particle surfaces and made relatively resistant to further decomposition, others may be microbially reduced to inorganic nitrate, phosphate, and potassium. The mineralized nutrients combine with soil particle surfaces in exchangeable forms, or dissolve in the soil solution and become available for absorption by plants and microbes. The model remains to be tested and analyzed. When finished, it will be coupled to the nutrient utilization model previously developed

## 12.7 NITROGEN, PHOSPHORUS, AND POTASSIUM UTILIZATION IN THE PLANT-SOIL SYSTEM AN ANALYTICAL MODEL[1]

O. L. Smith

An intermediate-resolution analytical model of nitrogen, phosphorus, and potassium utilization in the plant-soil system was developed and tested. Starting from specified natural or artificial sources in the soil, element transport to root absorption surfaces was modeled in terms of diffusion, mass flow, and soil buffering mechanisms. Element uptake was described by carrier theory formalism, and assimilation was based on four premises about the roles of nitrogen, phosphorus, potassium, and photosynthate in cell chemistry.

There were three main objectives of the model. The first was to predict the first-order interactive growth response of particular plant species to any combination of these macronutrients supplied in the soil medium. Species parameters required by the model include root absorption rate and certain cell chemistry reaction rates. The second objective was to make the model sufficiently general to describe a broad range of species. It was built upon common-denominator principles of physiology condensed from available experimental data on corn, beans, pines, etc. In this generic sense it is a measure of what plants have in common. The third objective was to use the model to test several well-known theories of plant growth

The model was validated against reported experiments on ryegrass, oats, a legume (*Stylosanthes humilis*), and rutabaga, in which dry matter yield was measured as a function of factorial application of nitrogen, phosphorus, and potassium to the soil. The model shows that much of the deficient, optimal, toxic, and interactive response of plants to these nutrients can be explained in terms of strong linear response of cell chemistry to low nutrient concentrations and inhibition by nitrogen, phosphorus, and potassium at high nutrient concentrations. When the model is applied in a test of plant response to suboptimal nutrient concentrations, it strongly confirms the Liebig law of the minimum and refutes the opposing multi-limiting-element Baule product law. The model also shows that the Liebig theory of linear growth response to nutrient concentration and the opposing, nonlinear Mitscherlich law of diminishing return are not necessarily in disagreement, but rather may apply to different parts of the nutrient concentration range. The model confirms that the effects on growth of nitrogen, phosphorus, and potassium levels are more often additive on the reciprocal scale than on either the logarithmic or untransformed scales.

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1 Research supported by the Environmental Sciences Division

## 12.8 THE CONDOS II METHODOLOGY FOR ESTIMATING RADIATION DOSES FROM RADIONUCLIDE-CONTAINING CONSUMER PRODUCTS[1]

F R. O'Donnell[2] O. W. Burke F H. Clark

The computer code CONDOS II, a revision and extension of CONDOS,[3] was developed to estimate radiation doses to man from the distribution, use, and disposal of a variety of consumer products that contain radioactive materials. The advantages of CONDOS II over CONDOS are the following

1. It can calculate dose rates to internal organs as well as to the whole body.
2. It has a radionuclide library that contains data for all radionuclides commonly used in consumer products
3. It has a revised radionuclide library format that simplifies the addition of radionuclides to the data file.
4. The logic for accession to radionuclide data allows great flexibility in radionuclide selection. In CONDOS, only natural uranium or natural thorium can be selected, but any combination of radionuclide decay chains may be selected in CONDOS II.
5 The output format provides an easily readable listing of all input data.

The CONDOS II computer code is written in FORTRAN IV for use in the batch mode on an IBM 360 75/91 computer.

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1. Abstract of ORNL/TM-5190 (to be published).
2. Environmental Sciences Division.
3. F. R. O'Donnell, L. R. McKay, O. W. Burke, and F. H. Clark, *CONDOS – A Model and Computer Code to Estimate Population and Individual Radiation Doses to Man from the Distribution, Use, and Disposal of Consumer Products That Contain Radioactive Materials,* ORNL/TM-4663 (May 1975)

# 13. Miscellaneous Engineering Studies, Services, and Developments

## ENGINEERING STUDIES

### 13.1 DYNAMIC SIMULATIONS AND CONTROL SYSTEM DESIGN STUDIES FOR THE MODULAR INTEGRATED UTILITY SYSTEM COAL-FIRED GAS TURBINE EXPERIMENT

S. J. Ball

The fluidized-bed coal-fired gas turbine experiment is part of the Modular Integrated Utility System Program, which is jointly sponsored by the Department of Housing and Urban Development and the Energy Research and Development Administration. The dynamic characteristics of the experiment were investigated to determine specific control system designs required to satisfy varying electrical and waste heat demands and still keep plant component temperatures and stresses within acceptable limits. The simulations indicate that the present control system design will handle expected load transients satisfactorily.

### 13.2 COAL-FIRED GAS TURBINE POWER SYSTEM FOR MODULAR INTEGRATED UTILITY SYSTEMS

J. W Cunningham  R. L. Moore

A conceptual design of instrumentation and controls for the coal-fired gas turbine experiment was completed, and a preliminary design was started. Approximately 125 thermocouple measurements will be required in the fluidized-bed coal combustor, a like number will be required over the remainder of the system. Stack gas monitoring for $SO_2$, $O_2$, CO, $CO_2$, nitrogen oxides, and particulate matter is planned. Speed control of the turboalternator and the relation of the alternator to other parts of the system will be studied on a simulator.

### 13.3 ON-LINE ANALYSES FOR ENERGY CONSERVATION AND ANNUAL CYCLE ENERGY SYSTEM EXPERIMENTS

S. J. Ball

A digital-computer data acquisition system was connected to several experiments in the energy conservation laboratory for the Energy Division. Special FOCAL programs were written to analyze the data from these experiments, primarily from those associated with the annual cycle energy system (ACES) test.

Specifications were written for a data acquisition system to be used for the SOLAR and ACES houses being constructed at the University of Tennessee, Knoxville. Also, we helped develop on-line experiment analysis programs for the data acquisition system.

## 13.4 MOBILE HOME SPACE HEATING ENERGY USE EXPERIMENTS

S. J. Ball

Experiments were run on a 12-ft-wide, 50-ft-long mobile home located outdoors, to determine its energy use characteristics for both space heating and cooling. A main objective of the tests was to determine the energy savings that can be achieved by the addition of items such as storm windows, skirting, and extra insulation, and how these savings vary with weather conditions. Analysis of the space heating data shows that energy savings of up to 40% can be achieved. The results of the space cooling experiments were inconclusive.

## 13.5 PROGRAMMABLE LOGIC CONTROLLER TASK GROUP

G. N. Miller

Programmable logic controllers (PLCs) have several characteristics that make them very desirable for utilization at ORNL: ease of programming, reliability, ready reuse from task to task, and greater cost effectiveness than conventional relay panels.

A market survey was done to determine the best units for application to typical ORNL job sizes. The units were analytically and empirically analyzed to determine their relative advantages. The areas investigated included the output module, which determines switching time; the switching method; noise generated; output drive capability and failure modes; program memory types; and the logic type and design effectiveness. The input modules and programming requirements were also evaluated. The reliability of the selected PLCs is being studied on the basis of data from other PLC users and from the several PLCs at the Laboratory. This task is not complete.

Finally, the ORNL standardized annunciator panel system, which is no longer commercially available with the required features, is being studied to determine whether combining its functions within a PLC and a standardized logic panel is feasible.

## 13.6 MICROCOMPUTER DEVELOPMENT

M. J. Roberts

Since late 1973, this division has been using and learning about microprocessors and microcomputers. They have been applied in a water quality monitor, a portable analyzer, a rod positioner, and with a Johnson noise thermometer.

A committee was formed to keep up with all new developments in microprocessors, and it has met regularly since late 1974. An in-depth 12-week course was given to staff members of this division; a shorter course was offered to UCC-ND staff. Also, to widely disseminate the information obtained on microprocessors and microcomputers, we prepared an article for publication in the *ORNL Review* to inform the ORNL staff of the capabilities of these new devices.

## 13.7 MICROPROCESSOR TASK GROUP

C. D. Martin, Jr.

| | | |
|---|---|---|
| M. L. Bauer | K. J. Cross | M. J. Roberts |
| N. C. Bradley | J. T. De Lorenzo | J. H. Todd |
| J. B. Bullock | B. G. Eads | J. W. Woody |

A task group was formed to study the expanding field of microprocessors and to determine a reasonable course to take in the selection of these devices for ORNL applications. With more than 25 different microprocessors available, some degree of standardization is necessary to optimize applications at the Laboratory. The group initially recommended the INTEL 8080 microprocessor because a high-level programming language is available. Instrument engineers were taught how to apply and program this microprocessor. A talk covering an overview of the microprocessor field, with emphasis on the INTEL 8080, was presented to the UCC-ND general staff. The task group began an evaluation of new developments in microprocessors that appear promising for ORNL applications.

## 13.8 DESIGN ASSISTANCE TO REACTOR MAINTENANCE GROUP

J. L. Anderson R. E. Battle S. J. Ditto

The reactor projects group has a responsibility for significant design changes to the control and safety systems of operating reactors at ORNL. These changes are usually made to correct system deficiencies or to meet changing operational requirements; occasionally they are done to keep the system up to date with respect to state-of-the-art developments in the control and safety field. In areas where the changes do not involve basic control or safety questions, the group serves in an advisory and review capacity, with the reactor maintenance group providing detailed design changes.

During this report period a number of design changes were made in the six operating reactors. Most of these changes were minor. Participation by the reactor projects group served to give continuity to the individual reactor system designs and, equally as important, provided feedback to designers of future systems.

## 13.9 SUPPORT FOR THE COMPARATIVE ANIMAL RESEARCH LABORATORY

J. L. Anderson S. J. Ditto B. G. Eads

Assistance was provided to the University of Tennessee–ERDA Comparative Animal Research Laboratory in the review and upgrading of the protective features for personnel in the variable-dose-rate irradiation facility. Reviews were made at various times, and recommendations were made for improvements in the safety and operability of the facility. Some technical assistance was provided for the design of the modifications and improvements, and the completed facility was again reviewed for adequacy.

## 13.10 SAFEGUARDS PORTAL MONITORING

R. L. Shipp, Jr.

Problems associated with the monitoring of personnel to safeguard special nuclear materials were studied for the ORNL Office of Laboratory and Personnel Protection. Developers of portal monitors at

Y-12, Los Alamos, and Rocky Flats were consulted. Specifications of commercially available monitors and ERDA-NRC requirements were also reviewed. A preliminary draft of a performance specification for procurement of portal monitors was prepared.

## 13.11 STUDY OF THERMOPLASTIC FILM HEAT SEALING OPERATIONS AT ORNL

T. F. Sliski

Heat sealing of thermoplastic materials was studied for the ORNL Office of Laboratory and Personnel Protection to improve the integrity and reliability of the bagging of radioactive material at ORNL. All heat sealing machines were identified as being made by the same manufacturer, who verified the capability of these machines to properly seal the materials being used for bagging. From consultation with the manufacturer and investigation of bag sealing procedures and materials in use at the various locations at ORNL, we concluded that the materials and procedures recommended by the manufacturer should be made standard in all locations.

## 13.12 RADIO COMMUNICATIONS SYSTEMS

J. A. Russell

New radio transmitter-receivers were procured and incorporated into four of the major radio networks operated at ORNL. The new equipment consisted of 21 portable units, 7 mobile units, and 1 base station, for a total of 29 additional units installed during this report period. The Laboratory operates 169 units on five major radio networks.

Authorization to operate a mobile radio unit in conjunction with the state-wide ambulance-to-hospital emergency network was coordinated with state and local hospital authorities and approved by federal authorities. A special mobile radio unit for the Laboratory's new ambulance was installed.

A request was submitted for a new uhf frequency assignment for a selective call-tone-encoded and voice-paging system to replace the present Pagemaster unit. This equipment was built in 1961, and its performance has significantly degraded since then. Maintenance costs due to age have now increased to the point where replacement is warranted.

Revised federal performance standards for radio equipment will become effective in 1979. The Laboratory radio system was evaluated, and units in service that will not meet the new requirements were identified. An estimate of the cost of replacing this equipment was prepared, and it was submitted for inclusion in the FY 1977 budget.

## 13.13 RF CABLE SYSTEM

J. A. Russell A. L. Case J. L. Lovvorn

Conceptual planning was begun for the design and installation of a broad-band rf cable system for multichannel two-way video band-width communications within the Laboratory and between the Laboratory and outlying research facilities. The system will accommodate up to thirty-five 6-MHz channels on each cable. One cable will carry one-way communication from several Laboratory locations to a central monitoring location. A second cable will carry two-way communications by frequency separation techniques. This cable will carry the horizontal and vertical sync signals supplied by the monitoring equipment, which are required to maintain timing relationships between closed-circuit TV cameras supplying pictures to the system.

Commercial cable TV components were evaluated to determine their applicability to project needs. A survey and discussion with design engineers of several leading manufacturers confirmed that the concept was feasible. An architect-engineer design criteria report was prepared and submitted to ERDA for approval and implementation.

### 13.14 LABORATORY AUDIO-VISUAL NEEDS

J L Lovvorn  A C Morris, Jr

Recommendations and proposals were made to upgrade the four major conference rooms (Rooms 142, 246, K246, and 284) in Building 4500 North. Part of the recommendations have been implemented, but other parts must await the availability of funds. Recommendations were also made for upgrading the audio-visual facilities in the Central and East Auditoriums. A new xenon lamp, 2 X 2 projectors, and slide sync audio adapters were obtained to allow pre-taped audio slide presentations High-resolution projector lenses and miniature electret microphones were purchased. Old vacuum-tube audio amplifiers were replaced with new solid-state models. Changes in patching capabilities and the addition of mixer preamplifiers and a new glass window in the Central Auditorium will improve both operation and operator communication with the meeting in progress.

## ENGINEERING SERVICES

### 13.15 ENGINEERING SERVICES FOR ANALYTICAL CHEMISTRY

T. M. Gayle

Engineering and general consulting services for the Analytical Chemistry Division included specialized detector design, general instrument development, testing and evaluation of new instrument techniques, redesign and modification of existing instruments, and improvement of maintenance procedures.

Major assistance was given to the Bio-Organic Analysis Section in physically and chemically characterizing cigarette smoke and in evaluating and monitoring animal exposure (smoking) machines Although existing chromatographic techniques and filter pad analysis were employed for static or batch measurements, entirely new sensing devices, such as the optical concentration sensor, were developed for continuous in-line analysis Commercially available infrared and thermal conductivity instruments were modified for continuous gas-phase measurements of carbon monoxide and hydrogen levels

In other sections of the Analytical Chemistry Division, new detectors were developed for trace element analysis, and classical analytical detector systems were upgraded and refined.

## 13.16 ELECTRONICS ENGINEERING SERVICES

J A Russell

Over-temperature limit switches were installed on several ovens operated by the Environmental Sciences Division, to protect against the accidental destruction of organic environmental samples being prepared for analysis The samples are placed in paper bags, put in the ovens, and dried at moderate temperatures for an extended period of time to remove moisture without causing damage to their organic structure Thermal fuses were installed to prevent the temperature of the air in these ovens from exceeding 100°C.

Installation of a Teletype receiver was started in the ORNL Emergency Control Center. The receiver will be used to obtain emergency weather bulletins, so that if a severe storm warning is received, certain Laboratory operations can be shut down Parts are on order to modify the teletypewriter "stunt box" so that the teletypewriter can be remotely and automatically started and stopped

Drawings and documentation were completed for the axial source and probe control system of the Oak Ridge Isochronous Cyclotron The equipment documented included the automatic insertion-withdrawal system, the positioning controls, and the position indicators A preliminary design was begun for the addition of remote annunciator panels in the cyclotron vault and the utility equipment area

A test stand for the development of Van de Graaff sources was constructed Controls and isolation transformers were designed and installed to adjust and operate several high-voltage power supplies in the system Alternating-current supply transformers allow operation of the power supplies at reference levels of 30 and 60 kV as required by the source under test Automatic interlocks were installed in the controls to prevent access to the high-voltage part of the system when the power is turned on.

Engineering services were provided to support activities of the Laboratory Protection Division A design was started for the rearrangement of the Emergency Control Center, to improve the effectiveness of operations and to accommodate additional equipment to be installed there.

Assistance was given to develop criteria for the ORNL safeguards program and to prepare the architect-engineer design criteria report and the Title I design criteria. Work was begun on the Title I design for the project

## 13.17 CALIBRATIONS IN THE METROLOGY RESEARCH AND DEVELOPMENT LABORATORY

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

In 1974, calibrations were performed on 188 different items in the Metrology Research and Development Laboratory (MRDL). In 1975 the number of calibrations was 369. During this latter period, several pieces of equipment were acquired which can be integrated into a computer-controlled measurement system At present they can be used in a semiautomatic mode and have facilitated the taking of calibration data. The types of devices and instruments which have been calibrated include (1) electrical meters, (2) frequency counters, (3) bridges, (4) potentiometer standard cells, (5) rms transducers and meters, (6) thermocouples which can be used from −30 to 1500°C, (7) resistance thermometers which can be used from −30 to 1084°C, (8) gas bulb thermometers, (9) liquid-in-glass thermometers, (10) optical pyrometers, (11) pressure and vacuum gages, (12) differential pressure transducers, (13) load cells, and (14) testing machines.

The capabilities and ranges of MRDL calibrations routinely available are as follows

| | |
|---|---|
| volts | $10^{-9}$ to $10^3$ |
| amperes | $10^{-12}$ to $10^3$ |
| resistance | $10^{-6}$ to $10^{12}$ $\Omega$ |
| capacitance | $10^{-18}$ to $10^{-3}$ F |
| frequency | 1 to $10^7$ Hz |
| thermocouples | −183 to 1500°C |
| PRTs | −183 to 1084°C |
| pyrometers | 800 to 2200°C |
| pressure | $2 \times 10^{-8}$ to $10^4$ psi ($\approx 10^{-4}$ to $10^8$ Pa) |
| force | 0 to $10^5$ lb (0 to $4.5 \times 10^5$ N) |

## 13.18 METROLOGY RESEARCH AND DEVELOPMENT LABORATORY MOVE

R. L. Anderson

In June 1975 the Standards Laboratory was moved into renovated quarters, with about 25% additional floor space. The name of the laboratory was changed to the Metrology Research and Development Laboratory (MRDL) to more accurately reflect the type of work done Because of the nature of research work at ORNL, the services required of the MRDL are rarely routine Many special measurement problems require unique setups employing the precision apparatus available in the MRDL Part of the additional space in the MRDL is devoted to thermometry research, which regularly requires the highly accurate measuring equipment available there.

## 13.19 RDT STANDARDS PROGRAM

J A Russell

Amendments to three RDT standards were prepared and submitted to ERDA for approval The standards were C7-7T, "Thermocouple Materials, Platinum and Platinum−10% Rhodium Wires, Non-Insulated, Standard Grade", C6-2T, "Differential Pressure Transmitter, Pneumatic or Electric Output Signal", and C15-3T, "Current Pulse Preamplifier for Use with Fission Counters "

A major revision was prepared of C7-6T, "Thermocouple Material and Thermocouple Assembly, Chromel-P vs Alumel, Stainless Steel Sheathed, Magnesium Oxide Insulated "

Several ISA and IEEE standards were reviewed Comments were submitted to the issuing groups of these societies

## 13.20 REPAIR OF THE LOW-LEVEL GAMMA-RAY SPECTROMETER SHIELD AT THE LUNAR RECEIVING LABORATORY

T F. Sliski V A McKay

In January 1972, repairs[1] were made to the low-level gamma-ray spectrometer shield to remedy damages resulting from weakness in the foundation supporting the shield. Further repairs were made necessary by the growth or expansion of the fill material of the shield (Chemtree cement and lead shot), this material expanded with such force that it ruptured welds and deformed structural members. These repairs were made in October 1974. The structure was pulled together, and clamps, retaining plates, and tension members were applied at critical points.

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1 V A McKay et al, *Instrumentation and Controls Div Annu Prog Rep Sept 1, 1972* ORNL-4822, pp 22–23

# ENGINEERING DEVELOPMENTS

## 13.21 TORNADO WARNING SYSTEM

L. H. Thacker

Because of the threat of tornadic weather to Laboratory safety and security, a tornado warning system was designed and built. The system is based on reported rapid fluctuations of barometric pressure in a wide area around a tornado. Three major parts of the system are a *dP/dt* transducer and recorder in the Laboratory Shift Supervisor's office, six battery-powered *dP/dt* alarm units at supervisory locations in the Oak Ridge area, and light-passive (switch closure) *dP/dt* sensors in health physics instrument locations around the periphery of the Oak Ridge area, with phone line telemetry to an alarm unit in the Shift Supervisor's office.

The *dP/dt* recorder (the only segment of the system in operation at the time) recorded a unique signature when a tornado struck Newport, Tennessee, on February 18, 1976. No other tornados were reported in the area during the period of instrument testing.

## 13.22 TIME AND FREQUENCY STANDARD UPDATE

W. R Miller

The time and frequency standard was updated to allow extraction of the time-of-day code from the level shifts on the 60-kHz carrier This information is conditioned and used to drive a digital time display that is an integral part of the instrument.

## 13.23 LEAK DETECTOR PUMP DRIVES

G. W Allin

Premature failure of the V-belt drive on leak detector vacuum pumps exposes the entire leak detector to vacuum pump oil. Before the detector can be put back into service, the entire system must be disassembled and cleaned. Four years ago a V-belt manufacturer recommended a stronger belt having more cords, however, use of this belt has not resulted in any significant improvement.

A study indicates that the problem is primarily one of belt flexibility. The diameter of the small sheave is less than is generally recommended by belt manufacturers. Therefore, for an immediate solution, installation of a notched, considerably more flexible belt is indicated. Several notched belts were purchased and will be installed on selected units now in service.

For a long-range solution, we will increase the diameter of the small sheave. The motor will be replaced with one of lower speed to compensate for the larger diameter. One new motor and sheave were purchased and will be installed on this division's leak detector for testing.

## 13 24 HFIR LETDOWN VALVE STEM AND BELLOWS SUBASSEMBLY

T F Sliski H J Stripling E F Roy[1] J R McGuffey[2]

Frequent failure of the bellows in the stem assembly of the primary letdown flow control valve at the High Flux Isotope Reactor was a maintenance problem encountered during the report period Misalignment caused by multiple section stem construction and bellows squirm resulted in failure of the bellows because of rubbing on the stem

A one-piece stem was designed, and the single long bellows was replaced with a subassembly made up of four short bellows The stem was designed at ORNL and was fabricated at ORNL and the Y-12 Plant The bellows subassembly was designed and fabricated by a vendor whose welding procedures were examined and approved by the Inspection Engineering Department at ORNL Ten assemblies were fabricated

1 Plant and Equipment Division
2 Inspection Engineering Department

## 13.25 TIME-MARK GENERATOR FOR STRIP-CHART RECORDERS

G K Schulze

A clock counter circuit, which accurately marks the time on the event-marker channel of a Brown recorder, was designed and put into service in an experiment for the Environmental Sciences Division This device allows an experimenter to change chart speeds and still maintain an accurate time mark without the need for special chart paper The device was installed in an experiment at the Walker Branch Watershed site, where a number of wet- and dry-bulb thermocouples and several types of solarimeters have been set up to record the tree canopy environment of a white-oak forest

The counter derives the time from the 60-Hz line frequency and has a built-in battery holdup system to guard against lost time caused by momentary power outages The time is recorded on the chart as a series of marks from 1 to 12, corresponding to the hours

## 13.26 TEMPERATURE REGULATOR AND AIR-FLOW MONITOR FOR IN SITU ENVIRONMENTAL CHAMBERS

G K Schulze

An instrument for measuring low-velocity air flow and for maintaining the air temperature inside an environmental chamber at a level equal to the ambient temperature was developed for the Environmental Sciences Division After tests in a greenhouse experiment are completed, this equipment will be a part of the system used in the Walker Branch Watershed area to monitor the rate at which carbon dioxide is used by the white-oak tree

The instrument has circuits that will monitor up to six chambers Each chamber is monitored by semiconductor sensors for inside and outside temperatures, and a cooling system is controlled by a differential comparator to maintain the differential at less than 1 0°C Air is circulated through the chamber by 7 75-cm ducts at a flow rate of 100 liters/min The flow is sensed by cup-type anemometers and is converted to a dc signal by a tachometer circuit The accuracy of measurement at this low flow rate is 3%

This instrument is useful for field service where a rugged, lower-precision unit is desired instead of expensive laboratory-grade instrumentation.

## 13.27 CONTROLS FOR ENVIRONMENTAL SAMPLING OF $CO_2$ AND $O_2$

A. C. Morris, Jr.

A control and stepping-relay circuit to make $CO_2$ and $O_2$ measurements was designed and fabricated for the Environmental Sciences Division. This instrument will take readings continuously from 12 $CO_2$ probes and 10 $O_2$ probes, convert the readings from analog to digital units, and print (and paper-tape punch) these values such that each probe and its associated data can be separately and positively identified.

The instrumentation consists of a gas-valving and flowmeter chassis, an electronic timer and decoder board made from semiconductors and integrated circuits, and a stepping-relay control chassis for indexing the correct $CO_2$ and $O_2$ gas probes. The system will be tested using probes in the aquariums and microcosms under study in the Environmental Sciences Division laboratories.

# 14. Maintenance

## 14.1 MAINTENANCE ACTIVITIES FOR THE ENVIRONMENTAL SCIENCES, PHYSICS, AND SOLID STATE DIVISIONS AND THE INSPECTION ENGINEERING DEPARTMENT

J. D Blanton J L. Lovvorn

Instrument services were furnished to the Environmental Sciences, Physics, and Solid State Divisions and the Inspection Engineering Department by a supervisor and three technicians The services included routine maintenance, fabrication, modification, troubleshooting, and repair of electronic instruments and systems. Liaison was established between the experimenters and the engineering groups of this division to solve special design problems

The Instrument Inventory and Maintenance Information System was continued. Records of approximately 570 instruments have been put in the system to date.

## 14.2 ELECTRONIC SERVICES FOR THE ORELA

H A. Todd

The Oak Ridge Electron Linear Accelerator (ORELA) was operated for experimenters for more than 5000 beam hours during the past year The operation schedule during this time consisted of continual operation for ten days followed by a four-day shutdown in each two-week period. Preventive maintenance was carried out on equipment such as water pumps, gas blowers, and air filters in the modulators, and this maintenance decreased the amount of operating time lost as a result of mechanical failure

The specification for the ORELA was a maximum energy of 50 J per pulse, but after the rf power in the klystrons was increased, the accelerator successfully operated for extended periods with 65 to 70 J per pulse

## 14.3 LABORATORY ACCELERATOR MAINTENANCE GROUP

J. L Lovvorn E. W Sparks

The laboratory accelerator maintenance group consists of one supervisor and eight technicians Shops are located at the Oak Ridge Isochronous Cyclotron (ORIC) (Building 6000), the Oak Ridge Electron Linear Accelerator (ORELA) (Building 6010), and the Van de Graaff Accelerator Laboratory (Building 5500) At the ORIC, maintenance coverage was ten shifts per week, regular day-shift maintenance was provided at the ORELA and the Van de Graaff Laboratory. Emergency maintenance for the ORELA and the Van de Graaff Laboratory was provided from the ORIC shop for the evening shift.

Machine maintenance was provided at all facilities as the first priority. Items on the machines needing most attention were gun tanks, high-current regulated power supplies, and rf systems Maintenance services were also provided for experimental equipment, including NIM systems, Camac systems, vacuum measuring equipment, and power supplies. Field fabrication was provided to engineers and experimenters at all three facilities.

Maintenance was provided at the ORIC on a Hughes controlled machine for magnetic field measurements; and new instrumentation was fabricated for ORIC field measurements. Maintenance was also provided on the heavy-ion test bench and the University Isotopes Separator Oak Ridge.

Approximately 775 instruments are now in the Instrument Inventory and Maintenance Information System.

## 14.4 SPECIAL ELECTRONIC SERVICES SHOPS

J. L. Lovvorn R. L. McKinney G. G. Underwood

The maintenance section of the special electronic services group consists of one foreman and seven technicians, in three shops.

The shop in the Instrument Laboratory (Building 3500) maintained all oscilloscopes in the laboratory, as well as electronic instrumentation for this division, for that part of the Solid State Division located in the former Isotopes Division area, and for the section of the Analytical Chemistry Division located in the west end of the Laboratory. This shop also repaired amplifiers, digital multimeters, nuclear scalers, electrometers, power supplies, and similar equipment for all divisions in the Laboratory.

The shop located in Room E-1 of Building 4500N maintained all types of electronic instrumentation for the Chemistry, Analytical Chemistry, Chemical Technology, Metals and Ceramics, and Physics Divisions located in Buildings 4500N, 4500S, 5505, 5507, and 4501.

Two shops in Building 4500S were concerned with maintenance for the research group of the Health Physics Division and for the Nondestructive Testing Group of the Metals and Ceramics Division. Half of the work in these two shops consisted of construction and user's assistance.

Work control for all shops was accomplished by the Instrument Inventory and Maintenance Information System.

## 14.5 RADIATION MONITORING SYSTEMS

J. D. Blanton J. L. Lovvorn

The maintenance organization of the monitoring systems section consists of nine instrument technicians and one supervisor. Four technicians performed ~3734 services on ~1150 stationary health physics instrument systems installed throughout the Laboratory. These technicians performed bimonthly performance checks of fixed instruments installed in 13 facility radiation and contamination alarm systems, 3 facility alarm and containment systems, and 5 remote radiation alarm systems. These systems are in 21 buildings and consist of 295 radiation monitoring stations. Twenty-two local air monitor and fallout monitor stations were checked semimonthly, and seven perimeter air monitors were checked monthly for proper operation, and the conditions were logged and corrected as required.

Three technicians maintained and calibrated ~1278 portable health physics instruments at the health physics calibration laboratory. About 7890 service orders were completed by this group.

Two technicians assigned to the Operations Division serviced and maintained approximately 30 gas- and 31 liquid-waste-effluent monitors that relay alarms and other information by telemetry to the Waste

Disposal Control Center (Building 3105). The conditions were logged, and any malfunctions were corrected. Servicing and maintenance were also provided for three water-quality monitoring stations at three sites along the stream into which plant waste water flows and for the instrumentation located in the control center Performance checks were made on these systems on a biweekly basis.

## 14.6 TELECOMMUNICATIONS AND PERSONAL RADIATION MONITOR MAINTENANCE GROUP

J L. Lovvorn J Miniard

A total of 1595 service orders were completed during the report period on some of the 348 pieces of two-way radio equipment in service at the Laboratory. All radio equipment is on a six-month schedule for performance checks. The Instrument Inventory and Maintenance Information System was implemented and is up to date. This system was modified to include job estimation, thus allowing a computer readout of backlog. There are 274 personal radiation monitors in the Maintenance Information System, and 264 service orders were completed for these monitors. Service was also provided on public address, intercom, and closed-circuit television systems, radio paging receivers, and a microwave television system. A modern communications monitor was obtained to upgrade our capability and efficiency in maintaining equipment performance to ERDA requirements.

## 14.7 AUDIO-VISUAL SERVICES GROUP

C. C. Hall J. L. Lovvorn J Miniard A. C Morris, Jr

Public address systems and equipment for visual-aid projection and audio- and video-tape recording were furnished and operated for 1064 meetings at the Laboratory and for 45 off-site meetings (32 in Oak Ridge, 10 in Gatlinburg, and 3 in Knoxville). Our own audio-visual equipment, as well as similar equipment for other groups, was maintained Audio and video tapes were duplicated for several customers. Four technicians were employed full time for this work, with a shared-time supervisor In addition, an engineer planned and supervised off-site meetings where required. Technicians from other groups assisted during periods of peak loads to equalize overtime.

The Instrument Inventory and Maintenance System was implemented and modified to include job estimating, with attendant backlog information There are now 396 items for the Laboratory in the audio-visual equipment inventory

## 14.8 OPERATING REACTORS GROUP MAINTENANCE ACTIVITIES

K. W. West

Field maintenance activities for the six operating reactors and associated experiments were performed by six instrument technicians reporting to one foreman. The overall budgeted amount for engineering and maintenance was $700,000, not including the maintenance of experimental instrumentation. The maintenance group was assigned responsibility for the High Flux Isotope Reactor fuel element test instrumentation at the Critical Facility

All primary control and safety instruments were placed on the semiautomatic computer-controlled maintenance program for all of the facilities A total of 3253 maintenance calls were reported during this period, requiring 2085 man-hours.

The maintenance personnel training and qualification program was continued, with video tapes of FET circuit trouble-shooting, digital devices, and general solid-state circuitry fault analysis. Specific on-the-job training programs were held at all reactor sites, consuming ~424 man-hours.

Eighteen reactor controls design change requests were processed for the group. About 0.5 man-year was expended on preparation and updating of reactor controls maintenance procedures.

## 14.9 MAINTENANCE OF THE HIGH FLUX ISOTOPE REACTOR

D. S. Asquith J. M. Farmer K. W. West

In addition to routine maintenance activities, procedures for maintenance and checkout were prepared and updated, and the Maintenance Information System was adapted for the High Flux Isotope Reactor (HFIR).

Procedures for testing 160 annunciator points were prepared and approved. More than 300 separate tests will be performed to confirm the ability of the annunciators to respond to alarm conditions. Procedures for determining the overall accuracy of the process-safety heat-power systems were approved and are available for use. System checkout procedures for the nuclear safety, servo, and counting channels are being reviewed.

All instruments associated with the HFIR are included in the Maintenance Information System. Approximately 1000 instruments were assigned inventory numbers and cataloged. From this list, selected vital instruments were placed on the recall program for routine maintenance and calibration.

The majority of the programmed maintenance activities were performed on-line with the reactor operating. Less than 10% of the programmed work required that the reactor be shut down, and this generally involved single-channel instrument systems essential for reactor operation or instruments in areas of high radiation levels.

The susceptibility of the safety flux signal conditioners to electrical noise continued to be an operational problem, particularly during routine testing of the safety systems. Recent investigations have suggested that a minor modification of the signal conditioner module may be necessary; however, additional studies are required to confirm that this proposed modification will not degrade the overall response of the safety system.

## 14.10 MAINTENANCE OF THE OAK RIDGE RESEARCH REACTOR

J. M. Farmer J. B. Ruble K. W. West

Only one unscheduled shutdown of the Oak Ridge Research Reactor during the last 24 months was due to problems with instrumentation. A vacuum tube in a recorder associated with the GB-10 experiment failed and initiated a reactor setback.

Reactor control circuit changes included the following: (1) replacement of the servo rod drive mechanical relays with solid-state relays; (2) installation of equipment to simultaneously test all annunciators; and (3) modification of the connecting system for the OC-1 experiment to provide a channel of setback limited to 60% power level, in addition to the normal setback to $N_L$ for experiment protection. One dual PCP-111-106 ionization chamber was replaced due to failure. New checkout procedures for the reactor are approximately 80% complete.

Maintenance, technical, and engineering support was provided for the installation and maintenance of nine new in-core experiments for the Reactor Division and eight new in-core and nine new pool-side experiments for the Metals and Ceramics Division. In addition, all experiments in operation were checked out in accordance with procedures at eight-week intervals and approved for operation

## 14.11 MAINTENANCE OF THE BULK SHIELDING REACTOR AND THE POOL CRITICAL ASSEMBLY

J. M. Farmer    J. B. Ruble    K. W. West

Four unscheduled shutdowns of the Bulk Shielding Reactor during the last 24 months were caused by overheating of the etched wiring board in the magnet switch module. Modification of the output stage allowed a change of resistor values, thus reducing heat dissipation and eliminating further trouble.

One magnet coil failed because of shorted turns, it was replaced with a new coil. One dual PCP-111-106 ionization chamber was replaced because of a noisy output signal.

Reactor control circuit changes included (1) installation of a remote annunciator testing apparatus at the Oak Ridge Research Reactor, (2) modification of the flux trip latch lamp circuit in the dual-voltage comparator so that heating of the lamp filament would not affect the latching time, and (3) modification of the magnet switch module in the output stage so that resistor values could be changed to reduce heat dissipation.

The Pool Critical Assembly (PCA) was continued as an experimental facility for intermittent use in student training by the University of Tennessee, the University of Kentucky, the University of Oklahoma, Memphis State University, and Mississippi State University and in operator training by the Tennessee Valley Authority. At the PCA one control change was made two guide brackets for the ionization chambers were mechanically lowered so that the chambers could be inserted as far as the core centerline This change improved the time response of the fast scram system and provided a wider range of coverage by the log N channel.

## 14.12 MAINTENANCE OF THE TSR-II

J. M. Farmer    D. D. Walker    K. W. West

Performance of the control system of the Tower Shielding Reactor II was satisfactory One shutdown of the reactor occurred due to problems with instrumentation

The computer card system for programmed maintenance was put in service. Annunciator check sheets were originated and used to check out the annunciator system.

Instrumentation and controls changes included (1) relocation of the picoammeter and log N chambers to improve response at low power, (2) installation of an inverter to supply power to portions of reactor controls instruments during loss of ac power, and (3) relocation of a water activity monitor to prevent primary coolant water from penetrating the control room. Item (1) was made possible by the introduction of a new shield for the reactor. This shield consists of a stationary concrete unit with fixed cooling lines and a 26-ton movable lead shield that covers the beam aperture A movable concrete shield with an opening in the center replaces the lead shield during operation of the reactor.

The operation of the TSR-II at the Tower Shielding Facility was assumed by the Operations Division in August 1975. We continued to maintain the instrumentation for the experimental apparatus

## 14.13 MAINTENANCE OF THE HEALTH PHYSICS RESEARCH REACTOR

J. M. Farmer D. D. Walker K. W. West

The instrumentation and controls system for the Health Physics Research Reactor performed satisfactorily. There were four reactor shutdowns caused by erratic action of the log N channel. The causes of this intermittent trouble were difficult to determine, but they were ultimately found to be a noisy ionization chamber and poor power-supply ground connections. Corrections eliminated further trouble of this nature in the channel.

Annunciator test sheets were originated and used to check out the annunciator system. The use of a computer service card system for auditing instrument maintenance was initiated. No major change was made to the instrumentation and controls system.

The Operations Division assumed responsibility for operating this reactor in August 1975.

# Division Educational Program

R. K. Adams     R. A. Crowell

An educational program for the staff of the Instrumentation and Controls Division was conducted to upgrade experienced staff members and to introduce new members to the technology and practice of the Division. The professional staff pursued three types of educational activities: seminars, Division courses, and graduate school. The program and activities are summarized as follows:

| | |
|---|---|
| Number of seminars given | 22 |
| Average seminar attendance | 30 |
| Staff members taking graduate courses | 25 |
| Average number of course hours | 14 |
| Advanced degrees granted | 3 |

**Division Courses**

| Course title | Course hours | Attendance |
|---|---|---|
| Industrial Process Instrumentation and Control System | 18 | 10 |
| Fundamentals of Operation and Implementation of Microprocessor Systems | 20 | 40 |
| Secretarial and QA Procedures | 1.5 | 15 |
| Technical Publication Process | 1.5 | 15 |
| Remote Terminal BASIC Programming Course | 30 | 13 |
| Time Series Analysis: Digital Filtering | 24 | 28 |
| FOCAL Course | 1.5 | 12 |
| Calculus Review | 20 | 40 |
| HP-25 Programming Course | 1.5 | 10 |

| | | |
|---|---|---|
| Short Course on HP-7900 Disk-Driven Operation System | 3 | 15 |
| Statistics of Measurement Science | 6 | 15 |
| Differential Equations, Linear Algebra, and Transform Calculus | 30 | 23 |

For the remainder of the staff, through night school and university courses, two received bachelor degrees and two received associate degrees. A total of 883 person–quarter hours of course work was completed by 30 persons.

# Professional Awards, Achievements, Offices, and Memberships in Professional Groups Held by Instrumentation and Controls Division Personnel

## AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

H. J. Metz: Member

## AMERICAN INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE)

R. S. Burns: Member, IEEE-ISA Industrial Control Committee and Subcommittee

R. S. Burns: Control Systems Subcommittee

H. J. Metz: Liaison Member, IEEE Industry Applications Society, Industrial Control Systems Subcommittee

G. N. Miller: Member of Biomedical and Computer Groups

L. C. Oakes: Member of Advisory Committee of the Nuclear and Plasma Science Society

Paul Rubel: Member of Subcommittee SC-5.2 (Risk Assessment and Public Acceptance) of the Nuclear Power Engineering Committee

## AMERICAN NATIONAL STANDARDS INSTITUTES (ANSI)

W. W. Johnston, Jr.: Member of Committee C-96, Thermocouples

D. J. Knowles: Alternate Member with F. W. Manning of Committee N-42, Nuclear Instrumentation

J. W. Krewson: Member of Subcommittee, Liquid Level, under Committee B-88, Calibration of Instrumentation

C. S. Lisser: Member of U.S. Technical Advisory Group for International Electrotechnical Commission, Technical Committee 65

F. W. Manning: Member of Committee N-42, Nuclear Instrumentation

## AMERICAN NUCLEAR SOCIETY (ANS)

N. J. Ackermann, Jr.: Chairman of Public Information and Education Committee and member of Executive Board, Oak Ridge Section

J. L. Anderson: Member of Subcommittee ANS-4, Reactor Dynamics and Control, Standards Committee

R. S. Booth: Member of the National Technical Program Committee and member of Program Committee, Reactor Physics Division

C. J. Borkowski: Fellow

J. B. Bullock: Member of Computer Standards Working Committee 4.3-2

E. P. Epler: Fellow

F. W. Manning: Member of Subcommittee ANS-16, Nuclear Instruments Standards Committee

## AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

M. B. Herskovitz: Member of Committee E-40, Technical Aspects of Products Liability Litigation; member of Committee E-20, Temperature Measurement

W. W. Johnston, Jr.: Member of Committee E-20, Temperature Measurement; Chairman of Subcommittee (E20.03), Resistance Thermometers; member of subcommittees and sections under Committee E20.04, Thermocouples

R. L. Shepard: Chairman of Subcommittee (E20.06), Acoustical Thermometry, under Committee E-20, Temperature Measurement; member of subcommittees and sections under Committee E20.04, Thermocouples

## BURST REACTOR EXPERIMENT REVIEW

J. T. Mihalczo: Chairman

## ERDA NIM-CAMAC COMMITTEE

N. W. Hill: Member, Subcommittee on Analog Signals

G. A. Holt: Member, Executive Committee

J. W. Woody: Member, NIM Committee

## INSTRUMENTATION AND CONTROLS COMMITTEES

H. E. Cochran: Interplant UCC-ND Instrument Engineering Standards Committee; Design and Drafting Standards Committee

J. W. Cunningham: Design and Drafting Standards Committee

C. C. Hall: Vacuum Tubes, ORNL Stores Stock Advisory Committee

P. G. Herndon: Division Design and Drafting Standards Committee

P. W. Hill: Maintenance Information System Committee

R. W. Ingle: Chairman, Capacitors, ORNL Stores Stock Advisory Committee

W. E. Lingar: Semiconductors, ORNL Stores Stock Advisory Committee

J. A. Keathley: Maintenance Information System Committee

D. J. Knowles: Maintenance Information System Committee

J. L. Lovvorn: Maintenance Information System Committee; Operational Amplifiers, ORNL Stores Stock Advisory Committee; Semiconductors, ORNL Stores Stock Advisory Committee

F. W. Manning: Division Design and Drafting Standards Committee

J. A. Russell: Batteries, ORNL Stores Stock Advisory Committee; Division Design and Drafting Standards Committee

R. L. Simpson: Maintenance Information System Committee

H. J. Stripling. Division Design and Drafting Standards Committee

J. H. Todd Resistive Components, ORNL Stores Stock Advisory Committee

R. E. Toucey Maintenance Information System Committee

K. W. West Chairman, Maintenance Information System Committee, Chairman, Division Design and Drafting Standards Committee

J. W. Woody Semiconductors, ORNL Stores Stock Advisory Committee, Microprocessor Task Group

## INSTRUMENT SOCIETY OF AMERICA

R. K. Adams Fellow

C. S. Lisser Chairman, Control Centers Committee SP-60

E. W. Hagen Managing Editor, Oak Ridge Recorder, ISA, Oak Ridge Section

## INTERNATIONAL SOLAR ENERGY SOCIETY

H. J. Metz Member, U.S. Section

## NATIONAL CONFERENCE OF STANDARDS LABORATORIES

R. L. Anderson ORNL Delegate

## NATIONAL COUNCIL ON RADIATION PROTECTION AND UNITS

F. H. Clark Consultant

## NUCLEAR DIVISION REVIEW COMMITTEE

J. W. Woody Computer Maintenance

## NUCLEAR SAFETY

(A Bimonthly Technical Progress Review, Published by the United States Nuclear Regulatory Commission)

E. W. Hagen Section Editor Control and Instrumentation

## NUCLEAR SCIENCE SYMPOSIUM COMMITTEE

M. K. Kopp Program Committee

## ORNL REVIEW COMMITTEES

J. L. Anderson Neutron Physics Division Safety Review

J. B. Bullock. Reactor Operations

B. G. Eads Accelerator and Source Safety

L. C. Oakes· ORNL Reactor Experiment Review Committee

Paul Rubel Reactor Operations

J. A. Russell: Chairman, Accelerator and Source Safety

W. H. Sides: Reactor Operations

H. A. Todd: Neutron Physics Division Safety Review

H. N. Wilson: Electrical Safety

## ORNL AUDIO-VISUAL COMMITTEE

J. L. Lovvorn: Member

## SOCIETY OF NUCLEAR MEDICINE

F. H. Clark: Member, Computer Standards Committee

A. C. Morris: Member

J. W. Woody: Member, Computer Standards Committee

## SOCIETY OF PROFESSIONAL ENGINEERS

H. E. Cochran: PE, Tennessee

Tom Gayle: PE, Tennessee

E. W. Hagen: PE, Tennessee

H. J. Metz: PE, Tennessee

G. N. Miller: PE, Alabama; N.S.P.E.

R. S. Stone: PE, Tennessee

R. E. Toucey: PE, Tennessee

H. A. Todd: PE, Oklahoma

## REGISTERED AS ENGINEERS BY THE TENNESSEE STATE BOARD OF ARCHITECTURE AND ENGINEERING EXAMINERS, NASHVILLE, TENNESSEE (1976)

R. L. Anderson

S. J. Ditto

L. C. Oakes

## U.S. NUCLEAR REGULATORY COMMISSION

S. J. Ditto: Consultant, Advisory Committee on Reactor Safeguards

## WATTec

N. J. Ackermann, Jr.: Technical Program Chairman

## THE AMERICAN NUCLEAR SOCIETY MERITORIOUS SERVICE AWARD

G. DeSaussure, E. G. Silver, R. B. Perez, R. W. Ingle, and H. Weaver, "Measurement of the Uranium-238 Capture Cross Section for Incident Neutron Energies up to 100 keV," *For the Reactor Physics Division Best Publication* (1973–1974). (Note: only R. W. Ingle is a member of the Instrumentation and Controls Division.)

# Publications

**Some of the publications listed below were prepared jointly with members of other divisions and with consultants and other nonemployees. Their affiliations are footnoted.**


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3. Reactor Division.
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## Papers Presented at Professional Meetings

Some of the papers listed below were prepared jointly with members of other divisions and with consultants and other nonemployees. Their affiliations are footnoted.

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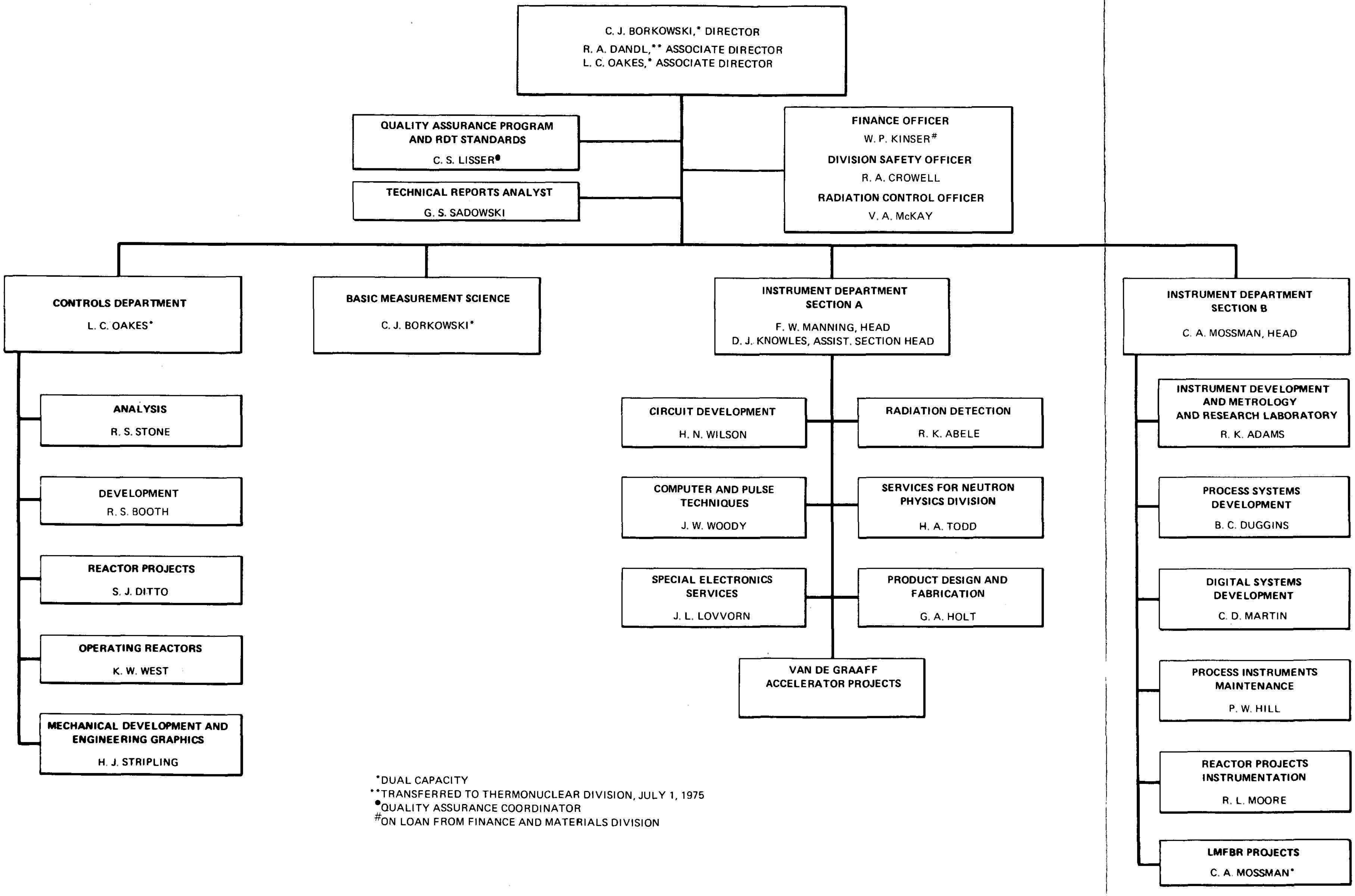
# INSTRUMENTATION AND CONTROLS

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