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INSTRUMENTATION AND CONTROLS DIVISION

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ANNUAL REPORT • *Period Ending September 1, 1971*

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INSTRUMENTATION AND CONTROLS DIVISION

ANNUAL PROGRESS REPORT

For Period Ending September 1, 1971

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JULY 1972

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

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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.

The Division, which employed about 280 persons in fiscal year 1971, comprises two departments and a small group: the Instrument Department, the Reactor Controls Department, and the Basic Instrumentation Group. This document is a report of the accomplishments and activities of these three groups.

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.

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1. Pulse Counting and Analysis

1.1 POSITION-SENSITIVE PROPORTIONAL DETECTORS

C. J. Borkowski M. K. Kopp

The development of position-sensitive proportional detectors^{1,2} was continued. The main goal was to design two-dimensional position-sensitive detectors for application in the life sciences and for detection and localization of radioactive tracers in the human body and in chromatographic samples.

An experimental two-dimensional detector was designed, built, and tested. A planar array of 100 anode wires, separated 2 mm from one another, was centered between two 200-mm-long cathode planes. The detector was operated with a continuous gas flow of 90% Ar--10% CH₄. The spatial uncertainty along the wires was 0.7 mm (fwhm) for 6-keV x rays. Thus, the number of resolution elements (using only four preamplifiers) was 28,000 for 6-keV x rays. The spatial uncertainty for collimated ¹⁴C beta particles or ²¹⁰Po alpha particles was comparable to the spatial uncertainty for the 6-keV x rays.

A two-dimensional detector for the localization of x-ray and gamma emitters in the human body was designed, constructed, and is being evaluated. It has a sensitive area of 200 X 200 mm², is 75 mm deep, and operates with Xe to 4 atm. The spacing between the cathodes and anode wire plane is 3.25 mm. The rest of the 75-mm depth is an electron drift region in which the detection efficiency for x rays with energies up to 100 keV is increased.

New methods were developed to attach and connect the anode and cathode quartz wires to supporting springs in a way that permits baking at 200°C to avoid outgassing problems. A new technique was developed to construct nonfocusing collimators for two-dimensional detectors.

-
1. C. J. Borkowski and M. K. Kopp, *Rev. Sci. Instrum.* **39**(10), 1515 (1968).
 2. C. J. Borkowski and M. K. Kopp, *IEEE Trans. Nucl. Sci.* **NS-17**(3), 340 (1970).

1.2 ELECTRONIC CALIBRATION OF THE SENSITIVE VOLUME IN PROPORTIONAL DETECTORS

C. J. Borkowski W. A. Winchell M. K. Kopp

A new method for the reduction of radiation background in a proportional detector was developed and tested. In this system a position-sensitive detector (rise-time method) accepts events occurring only in a preselected volume of the detector, thus permitting elimination of detector end effects and calibration of the detector volume. With a 100-mm-long position-sensitive detector, collimated 22-keV x rays, and a strong uncollimated field of β particles, 98% of the background counts were rejected when the x rays were collimated in a 2-mm preselected detector length.

1.3 FLY'S EYE: A TWO-DIMENSIONAL COUNTING AND IMAGING SYSTEM FOR THERMAL NEUTRONS

J. B. Davidson A. L. Case C. C. Courtney

An improved detector was assembled using the following new components:

1. A single-stage image intensifier having a 150-mm-diam fiber-optic input screen, a 25-mm-diam output screen for coupling to the secondary electron conduction (SEC) camera tube, a P15 output phosphor, a flux gain of 40 at 450 nm, and a limiting optical resolution (referred to the input) of 4 to 5 line pairs/mm (1200 to 1500 TV lines).
2. An SEC vidicon camera tube with a fiber-optic input window.
3. A camera control for the SEC tube, designed around commercially available standard vidicon circuit boards and packaged in a six-unit wide NIM module.

The optically flat input faceplate and the design of the housing will permit easy changing of phosphor screens, thus enabling tradeoff between efficiency and spatial resolution and ready investigation of new phosphors. The camera is being tested at the Oak Ridge Research Reactor (ORR). Figure 1.3.1 shows a resolution test using a cadmium mask and collimated thermal neutrons.

Fig. 1.3.1 Analyzer readout of a preliminary test of the horizontal resolution of the detector. The target consisted of a Cd sheet placed over the detector with pairs of 0.125- and 0.25-mm holes having center-to-center spacing of 0.25 and 0.5 mm, respectively. A beam of thermal neutrons was directed onto the target.

For studies of liquid structures by neutron diffraction, the possibility of simultaneously obtaining many points on the scatter intensity vs angle curve was considered. In a preliminary study,¹ further experiments are planned with the new equipment.

Application of the counting system to neutron radiography using weak sources was tested. Some imaging tests were tried,² using a weak neutron beam from the ORR and from an 8- μ g ^{252}Cf source. With 150 to 200 neutrons $\text{cm}^{-2} \text{sec}^{-1}$ from the reactor, discernible images of simple objects were obtained in 3

to 5 min on the display screen of a two-parameter pulse-height analyzer used for data storage. The display was generated from the totaled counts in the memory of the analyzer. The ^{252}Cf source was too weak when collimated to produce an image above the reactor background within practical exposure times. Away from the reactor background, however, imaging should be possible with sources of this order of magnitude.

-
1. In cooperation with A. H. Narten, Chemistry Division.
 2. In cooperation with V. A. DeCarlo, Chemical Technology Division.

1.4 ENGINEERING SUPPORT FOR LRL¹ RADIATION COUNTING FACILITY²

R. E. Wintenberg R. T. Roseberry

Through periodic telephone conversations and trips to Houston, support was given to the Radiation Counting Facility to maintain the electronic system and to update the facility, which is now largely self-sufficient.

-
1. Lunar Receiving Laboratory, Manned Spacecraft Center, NASA, Houston.
 2. R. E. Wintenberg et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, p. 5.

1.5 NEUTRON MULTIPLICITY COUNTER BUFFER MEMORY AND PRINTER CONTROL LOGIC

R. T. Roseberry

J. Halperin¹ R. L. Macklin² R. W. Stoughton¹

An instrument was developed and constructed to print a record of the time occurrence and input channel number (from 1 to 10) of pulses initiated by neutrons detected by a ten-channel detector system. The instrument contains a 2-MHz crystal-controlled oscillator. Each detected input pulse strobes the status of a nine-decade scaler, the detector channel number, the status of both the coincidence and the anticoincidence windows, and fully opens the coincidence window.

A printer, capable of operating at 20 lines/sec, is driven by a 10-word stacking buffer with a 48-bit word length. The printout desired is selected by setting front-panel switches to print all input pulse information or only multiplicities of two or more, or three or more, pulses within a preset coincidence window. The coincidence window can be set in 1- μsec increments from 0 to 999 μsec by digital thumbwheel switches.

-
1. Chemistry Division.
 2. Physics Division.

1.6 INSTRUMENTATION FOR ^{252}Cf SOURCE ASSAY SYSTEM

J. T. De Lorenzo M. M. Chiles H. E. Cochran

Standard NIM modules were specified and purchased for a ^{252}Cf source assay system for the Transuranium Processing Plant (TRU) facility. The modules include a sum-invert amplifier, a pulse amplifier (with a selectable active filter), a single-channel analyzer, a linear count-rate meter, a scaler (10^{10} counts), an electronic timer, a dual high-voltage power supply, and a pulse generator. The signal for the system is obtained from two ^{238}U fission chambers connected to two charge-sensitive preamplifiers. The fission chambers, which have a fast-neutron sensitivity of $1 \times 10^{-3} \text{ count sec}^{-1} \text{ mv}^{-1}$, were covered with cadmium foil to reduce their sensitivity to thermal neutrons.

1.7 EXPERIMENTAL ELECTRONIC ACTIVITIES

R. W. Ingle J. H. Todd

Continuing assistance was given to the Neutron Physics Division cross-section measurements program. This program includes measurement of capture and fission cross sections as function of neutron energy for the fissile isotopes ^{233}U , ^{235}U , ^{239}Pu , ^{240}Pu , and ^{241}Pu ; measurement of capture cross section and neutron transmission of ^{238}U ; and measurement of neutron production per fission of ^{239}Pu .

Development, procurement, and testing of data handling and acquisition instrumentation, investigations of the most efficient techniques and materials for gamma-neutron discrimination, and investigations of the various neutron detectors were continued in this activity.

1.8 DUAL-SCALER - BRPE-11 PUNCH CONTROL, Q-5104

J. W. Woody, Jr.

A simple and inexpensive counts vs time analyzer was designed for application to diagnosis of reactor malfunctions.

The storage and readout device is a Teletype BRPE-11 paper-tape punch. The control logic was designed and constructed in a two-unit-wide NIM module. Since the time channels required were compatible with the punch speed, the magnetic pickup synchronizing pulse from the punch was used for the basic time base (54.6 msec). The analyzer system accumulates counts alternately in the two channels of a T.S.I. dual scaler. The control causes one channel to be punched out while the other is accumulating counts. Counting in each channel on alternate cycles results in a zero dead-time analyzer.

1.9 MODIFICATION OF THE K-25 MOBILE GAMMA SPECTROMETER

E. Madden

The K-25 mobile gamma spectrometer was equipped with additional automatic data accumulation units so that less intervention by the operator would be required. This unit was modified because errors made by operators resulted in paper-tape data errors, and these created problems for the computer data-reduction software routines. In this modified unit, test identification and computer action code information is entered automatically with thumbwheel switches.

2. Miscellaneous Electronics Development

2.1 FISSION CHAMBER CURRENT PREAMPLIFIER

J. K. Millard C. C. Courtney

To obtain high-resolution timing from fission chambers having terminal capacitance values as large as 100 pF, low-noise current preamplifiers with FET input stages were fabricated in accordance with a general current preamplifier design previously described.¹ The preamplifiers (Q-5097) consist of three gain stages selected to give a total current gain of about 5000. The 10-to-90% rise time is ~6 and ~20 nsec with 0 and 100 pF detector capacitance, respectively. The current output is linear to allow, after further signal processing, energy range determination. With a 100-pF fission chamber and an ORTEC 453 constant-fraction of pulse-height discriminator, the time resolution is about 1 nsec.

1. J. K. Millard, *An Investigation of Broadband Current Preamplification for Obtaining Simultaneous High-Resolution Energy and Time Information from Nuclear Radiation Detectors*, ORNL-TM-3252 (March 1971).

2.2 BORON-LINED IONIZATION CHAMBER CURRENT PREAMPLIFIER

J. K. Millard C. C. Courtney

A low-noise current preamplifier with FET input stages (Q-5091) was designed¹ to operate from the cathode of a Frisch-grid, boron-lined ionization chamber to improve the time resolution of detected neutrons. Because of the weak current signals resulting from the (n, α) reaction within the boron lining, the three-stage preamplifier was designed to yield a total current gain of 125,000. To achieve a reasonable signal-to-noise ratio for timing purposes, the bandwidth of the preamplifier was degraded to about 7 MHz by limiting the bandwidth of each of the three stages to 13 MHz. The preamplifier has two current outputs that can be used for time or energy analysis; it has a charge-proportional output for additional energy analysis. Performance tests were not completed.

1. J. K. Millard, *An Investigation of Broadband Current Preamplification for Obtaining Simultaneous High-Resolution Energy and Time Information from Nuclear Radiation Detectors*, ORNL-TM-3252 (March 1971).

2.3 CURRENT-PULSE PREAMPLIFIER WITH A DIFFERENTIAL INPUT FOR USE WITH FISSION COUNTERS

J. T. De Lorenzo C. C. Courtney

A preamplifier (Q-5095) with a differential input was designed and constructed for use in subcriticality measurements for the Liquid-Metal Fast Breeder Reactor (LMFBR) program. RDT Standard C 15-3T,

"Current-Pulse Preamplifiers for Use with Fission Counters" (Sect. 10.41), was followed as a guide during design and construction of the preamplifier. Except for minor, insignificant details, the preamplifier met the requirements of the Standard. Also, this experience revealed minor ways in which the Standard could be improved.

Initial problems with feedback that was sufficient to sustain oscillations were solved simply and inexpensively by shielding the individual stages from one another by constructing them in individual compartments, using cadmium-plated sheet steel. Procurement of electronic components conforming to MIL standards was delayed because it was difficult to find suppliers of such materials. In fact, four months passed until all components were received. Final assembly and checkout of the instrument required an additional month.

2.4 CURRENT-PULSE PREAMPLIFIER WITH BALANCED INPUT AND OUTPUT FOR THE ORR COUNT-RATE CHANNELS

J. T. De Lorenzo G. C. Guerrant

The vacuum-tube, charge-sensitive preamplifiers (Q-2617) on both count-rate channels at the Oak Ridge Research Reactor were replaced with a current-pulse, solid-state preamplifier (Q-2641). The new preamplifiers are identical to those installed at the High-Flux Isotope Reactor (HFIR). Standardization of circuits and reduced maintenance costs motivated the replacement.

A balanced signal to the new preamplifier is obtained from a pulse transformer located at a position formerly occupied by the vacuum-tube preamplifier in the "snake" assembly. A triple-shielded, two-conductor cable connects the transformer to a preamplifier located 150 ft away in the ORR control room.

At first there was considerably more background noise at the ORR from operation of control relays and motors than at the HFIR where the input cable, although 50 ft long, is contained in a separate steel conduit from the subpile room to the control room. Further work at the ORR to isolate the input cable from the control wiring of the reactor reduced this noise to a tolerable level. Better isolation will be devised to reduce the interference even more.

2.5 VOLTAGE-SENSITIVE PREAMPLIFIER WITH TEMPERATURE COMPENSATION

M. K. Kopp

A direct coupled, series feedback preamplifier for proportional counters¹ was developed, built, and tested. The typical equivalent noise voltage is $1.5 \text{ nV/Hz}^{1/2}$ at room temperature and frequencies of $\sim 100 \text{ kHz}$. The dc output voltage of the amplifier is compensated against ambient temperature changes by a temperature-dependent FET current source that provides the bias current for the input FET. This connection combines the advantages of the low-noise characteristics of a single-ended input with the temperature compensation of a differential input stage. The following typical characteristics were measured for the amplifier: the open-loop voltage gain was 10,000, the closed-loop voltage gain was 50, the gain-bandwidth product was adjusted to 350 MHz, and the dc output voltage drift was $2 \text{ mV/}^\circ\text{C}$ for temperatures from -75 to $+75^\circ\text{C}$.

1. M. K. Kopp, *RSJ* 42(5), 714-15 (May 1971).

2.6 DETECTOR BREAKDOWN PROTECTION CIRCUIT FOR PREAMPLIFIER

M. K. Kopp

A simple diode clipping circuit (Fig. 2.6.1) was developed and tested to protect the input transistor of a high-input-impedance amplifier against 2.5-kV breakdown surges from high-capacitance (>200 pF) proportional counters.

ORNL-BWG 72-4828

Fig. 2.6.1. Detector breakdown protection circuit.

2.7 120-MHz PRESCALER

J. H. Todd

A quad 120-MHz prescaler was designed and built to improve the capabilities of existing 10-MHz scalars and to extend the stored data capacity by one decade per unit used. Emitter-coupled, high-speed-logic integrated circuits (MECL III) were used in the design.

Input and output signals are standard NIM fast logic levels so that the units can be cascaded if desired. For simplicity of design, reset and readout were not included.

2.8 LINEAR COUNT-RATE METER WITH CONTROLLERS

J. H. Todd

A linear count-rate meter with a diode-transistor pump circuit, operational amplifiers, and voltage comparators was designed and built for use at the Oak Ridge Electron Linear Accelerator (ORELA). Because of its short dead-time characteristics even within low count-rate ranges, the instrument will accurately count pulsed random sources.

The rate meter consists of an input discriminator, an integrated circuit flip-flop and driver, a diode-transistor pump, a hybrid high-impedance operational amplifier, and an operational amplifier current output.

Noninterfering high and low adjustable controllers for use in the automated data systems at the ORELA were included in the design. These controllers consist of integrated circuit voltage comparators. The controllers produced both logic level voltage and relay contact outputs. Controller actuation is indicated by lamps on the front panel, immediately above the controller level set-point controls.

2.9 COINCIDENCE-ANTICOINCIDENCE UNIT

F. M. Glass

This instrument, a coincidence-anticoincidence unit (Q-3135), accepts pulses from ten separate neutron counters. (Each counter has two 20-in.-long ^3He detectors.) The unit determines whether the pulses are singles or coincidences of doublets, triplets, or quadruplets, and greater, and records them as such by incrementing a separate scaler for each type of event. When used with an appropriate anticoincidence mantle, it also determines whether the source of the neutrons being counted is from within the sample holder. This instrument is also useful in determining $\bar{\nu}$ (fission cross section) for unknown spontaneous fissioning nuclides because its coincidence gate can be opened by signals from a fragment detector placed within the sample volume. Such measurements require calibration of the counter with known emitters.¹

A built-in dead-time meter monitors the total time the anticoincidence gate is closed. By a selector switch this same circuit can be set to monitor the dead time of a buffer memory and fast printer that operates in parallel with the Q-3135 unit. A printer-inhibit circuit recognizes bursts of noise, and, if they persist, it generates an inhibit signal that shuts down the fast printer in the parallel system to avoid unnecessary wear of the printer.

1. R. L. Macklin et al., *Chemistry Div. Annu. Progr. Rep. May 20, 1971*, ORNL-4706, pp. 87-89.

2.10 ORIC AXIAL ION SOURCE MIRROR CONTROL SYSTEM

J. A. Russell, Jr.

A control system was developed for the newly installed Oak Ridge Isochronous Cyclotron axial ion source to automatically insert and withdraw the source mirror from the machine. Interlocks prevent insertion or withdrawal of the axial ion source, the radial ion source, or the rf Dee assembly whenever a potentially damaging interference condition exists between the elements. An automatic sequencing control permits withdrawal of the tip of the mirror into the vacuum lock or out of the machine without requiring that the vacuum tank be equalized to atmospheric pressure. The axial source electrodes are automatically withdrawn to a noninterfering position within the vacuum tank when the source mirror is withdrawn from the center of the machine. The position of the axial source mirror can be controlled from the control room when the cyclotron is in operation.

2.11 PULSE TRAIN GENERATOR

F. M. Glass

A pulse train generator was designed to provide positive 4.5-V square-wave pulses having 500-nsec widths and negative variable amplitude pulses with a rise time of 50 nsec and fall time of 280 μsec ($RC =$

127 μsec). These pulses are gated to form a pulse train having a selectable number from one to ten in each train. The gating frequency is also variable, providing pulse trains at rates of 1, 10, 100, or 1000 pulse trains/sec. The spacing between pulses within the pulse trains is set at 10 μsec by a 100-kHz crystal-controlled oscillator. The oscillator frequency is divided by five IC decade counters to select the desired gating frequencies. An IC monostable multivibrator gates another multistable vibrator that generates the 500-nsec pulses at the oscillator frequency.

This instrument was designed specifically to perform rapid checks on a neutron multiplicity counter. The positive output from this instrument is compatible with the TTL logic in the buffer memory and is used to test the complete logic circuit, including the fast printer. The negative output is shaped to serve as a test signal for ten preamplifiers and can be switched to any one of the ten output connectors on the pulse train generator. These ten negative outputs are permanently connected to the test signal inputs on the ten preamplifiers. This generator has made it possible to quickly detect and localize malfunctions in the neutron multiplicity counter system.

2.12 A KEYED HIGH-VOLTAGE SWEEP GENERATOR

F. M. Glass

A keyed sweep generator capable of generating 3.5-kV triangular waves with a linearity of 1% was designed for driving the deflection plates of an electrostatic energy analyzer, which is used in the ORMAK project with a gas conversion cell as a neutral atom spectrometer for measuring plasma ion temperatures in an energy region from 0.165 to 10 keV.

The generator is keyed by the logic level of the seventh scaler stage in the address of a 256-channel analyzer used in the multiscaler mode.

In the quiescent state the output of the generator is at ground potential because the reference voltage is clamped at ground potential. A signal from the 256-channel analyzer starts a positive ramp to 3.5 kV at the apex of a triangle that corresponds in time with channel 128. When the address closes the gate for channel 128, the shift in dc logic level starts a negative ramp which continues through channel 256. Since both the positive and negative ramps are started and terminated at fixed time intervals, rather than at fixed voltage levels, the reference voltage ramp is standardized by a clamp to ground potential for a few microseconds at the end of each negative ramp. This prevents cumulative errors that would have a magnitude equal to the product of the error of a single cycle and the number of cycles within a given operating time.

2.13 OPTICALLY COUPLED DETECTION SYSTEM FOR MEASUREMENT OF HIGH-CURRENT PULSES IN COAXIAL CABLES

J. K. Millard D. D. Bates

A pulse amplitude measurement technique was investigated for measuring, with no direct electrical connection, high-current pulses in coaxial cables. Of interest were current values ranging from 600 to 6000 A with durations of a few microseconds.

The procedure is to detect the voltage drop along a short section of the coaxial cable shield with a slightly forward biased light-emitting diode, transmit the light pulse through a light-pipe to a photodiode detector, and, after amplifications, correlate this pulse to the current pulse flowing in the coaxial cable.

To calibrate the output of the optically coupled detection system, high-current pulses for laboratory tests were generated by charging a 4- μF capacitor to several thousand volts and then discharging them through a short section of the test cable. The magnitude of these current pulses was measured by inserting a

$\frac{1}{4}$ -in.-long, 14.8-m Ω carbon resistor in series with the test cable and measuring the amplitude of the resulting voltage pulse.

2.14 ULTRASONIC TEMPERATURE TELEMETRY SYSTEM FOR TAGGING FISH

J. M. Rochelle

An ultrasonic telemetry system was developed for the Ecological Sciences Division for studying the behavior of various species of freshwater fish as a function of changes in the water temperature. The transmitter in this unit is small and has a long battery life, and the receiver is simple, inexpensive, and constructed from commercial components.

Because of its better circuit design, this unit has the following advantages over similar commercial units:

1. smaller size because its circuit requires fewer mercury cells and has a custom integrated circuit,
2. longer battery life due to operation at duty cycles down to 0.1%,
3. better calibration stability ($\pm 0.5^\circ\text{C}$) due to circuit compensation for battery voltage changes and temperature changes other than those sensed by the thermistor, and
4. simple and low-cost water-tight encapsulation which permits battery replacement and tag reuse.

In addition, the telemetry coding technique in this system is immune to errors caused by multipath propagation which prohibits the detection of conventional pulse-width-modulated signals.

2.15 IMPROVEMENTS ON KULICKE AND SOFFA THERMOCOMPRESSSION WIRE BONDER

J. T. De Lorenzo T. F. Sliki

Several improvements were made to the Kulicke and Soffa thermocompression wire bonder which considerably reduced the skill required to make reliable bonds. These improvements are (1) a vernier adjustment on the heat column assembly controls the chip position when the normal range of the micropositioner is exceeded, (2) a more sensitive rotameter on the hydrogen gas system reduces the hydrogen torch flame to a very small size and gives ball sizes smaller than previously attainable, and (3) a reversal of the movement of the hydrogen torch controls the motion of the torch during the first (and cutting) path across the gold wire.

The bonder was used successfully to interconnect a Silicon General SG3801 monolithic breadboard chip to produce a pulse amplifier and circuit for a fish tag temperature monitor.

2.16 POTENTIOSTAT

J. L. Lovorn

A potentiostat for corrosion studies (Q-3138) was designed in a single-width, 8 $\frac{3}{4}$ -in.-high NIM module. Readout is by a potentiostat metering module (Q-3139), a double-width NIM module. One metering module and ten potentiostats are used in each NIM bin.

The reference set voltage is supplied from the NIM power supply. The full-scale current ranges are from 0.1 to 200 mA in a 1, 2, 5 sequence at a maximum voltage of ± 9 V. A 30-hr. drift test of two units on dummy cells showed $< 0.02\%$ drift.

With monolithic integrated-circuit operational amplifiers and power booster, the unit can be fabricated at a very nominal cost.

2.17 HIGH-ENERGY MAGNET PULSER

D. D. Bates H. A. Mook¹

The high-energy magnet pulser for the autocorrelation, neutron time-of-flight spectrometer² (Sect. 7.1) was completed and placed in operation at the High-Flux Isotope Reactor (HFIR). Initial tests of the system were successful, and the system has continued to operate and collect data at a rate six to ten times faster than previously attainable. Not only is the system faster, but the energy resolution of the collected data is far superior to that of any neutron chopper system reported.

The computer-controlled pulser generates multiple-width current pulses <100 A at a duty rate $<50\%$. Various autocorrelation codes <11 ΔT widths can be used with this pulser.

By developing better crystals, the Solid State Division has further refined the total spectrometer system. A crystal that now operates successfully with 70-A current pulses would have required 200-A current pulses only three years ago.

1. Solid State Division.

2. D. D. Bates and E. E. Wagh, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 12-13.

2.18 TESTING AND EVALUATION OF EG&G T105/N DUAL FAST DISCRIMINATOR FOR PULSE-MODE-TYPE ANALYSIS IN LMFR SUBCRITICALITY STUDIES

J. T. De Lorenzo

An EG&G dual fast discriminator (T105/N) was tested and evaluated for use as a pulse discriminator in a pulse-mode neutron detection system for Liquid-Metal Fast Breeder Reactor subcriticality studies. Since this unit has a ten-turn potentiometer with a precision dial for threshold adjustment, it is preferred to discriminators of a similar type that are limited because of their fixed input threshold.

Other requirements for the discriminator in this application are that (1) there will be no dead time for pulse rates up to 100 MHz (i.e., the device will generate another output pulse immediately after termination of the preceding pulse for output pulse widths as narrow as 10 nsec); (2) there will be no multiple pulsing for any pulse exceeding the input threshold; (3) the output current pulse will be 14 mA minimum and stable both in width and amplitude and independent of the input pulse shape; (4) the output pulse width will be adjustable from 10 to 150 nsec (a timing cable is acceptable for width control although not preferred); (5) the input threshold will be adjustable from 50 to 500 mV with good linearity and temperature stability; and (6) the input impedance will be 50 Ω with dc coupling.

Tests and experience indicate that the EG&G discriminator will adequately meet these requirements. In addition, measurements with the unit as part of the neutron pulse-mode detection system show less counting loss than the units presently in use. This indicates that there is less hysteresis in the T105/N discriminator, which becomes evident when random pulses with exponential tails are counted — a typical signal for this application.

2.19 RC CURRENT PULSE INTEGRATOR FOR PULSE-MODE-TYPE ANALYSIS FOR LMFR SUBCRITICALITY STUDIES

J. T. De Lorenzo N. J. Ackermann, Jr. R. C. Kryter

A device (Q-3136) that integrates the current output pulse of the pulse-mode system discriminator (Sect. 2.18) was designed, built, and tested for use in noise analysis or inverse kinetic measurements to determine the subcriticality of Liquid-Metal Fast Breeder Reactors.

In the noise analysis mode, the device develops an ac output voltage representative of neutron density fluctuations in the reactor. Any of four ranges, 10^6 , 10^5 , 10^4 , or 10^3 counts/sec, can be selected, and the RC integration time constant can be selected to give upper cutoff frequencies for power spectral density measurements of ~110, 100, 55, and 20 kHz, respectively. The device also includes an RLC filter which gives an additional 12 dB/octave roll-off at 500 kHz. Each range is adjusted to give a 0.5-V rms full-scale output with a crest factor not exceeding 11.4.

In the inverse kinetic measurement mode, the device performs as a conventional count-rate meter and develops a dc output voltage that describes the transient state of the reactor immediately after a reactor perturbation, such as a rod drop. The transient response is used as the input to the point source reactor kinetics equations which are solved to determine the reactivity. Any of four ranges, 5×10^6 , 5×10^5 , 5×10^4 , and 5×10^3 counts/sec, can be selected for this mode; the full-scale output is ~1.4 V dc for each range. The integration time constant is a fixed value of ~1.5 msec for each range, which is long enough to give reasonable statistics but short enough to give a faithful reproduction of the reactor transient.

2.20 IMPROVED SUBAUDIO, LOW-NOISE AMPLIFIER

F. M. Glass R. C. Kryter

A low-noise, subaudio, differential-input amplifier¹ (Q-2968) designed for high-gain noise analysis of current signals from a neutron-sensitive ionization chamber was modified for voltage amplification of noise signals from thermocouples and similar sensors. The principal circuit changes were to substitute an Analog Device's model 118A operational amplifier in the first stage and to install a gain balance control. After these changes, the low-frequency flicker noise was 10 times less and common-mode rejection ratio increased from 40 to 100 dB at 60 Hz.

1. F. M. Glass, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1968*, ORNL-4335, p. 14.

3. Detectors of Ionizing Particles and Radiation

3.1 CHARGE CARRIER TRAPPING IN GERMANIUM DETECTORS

R. J. Fox

Lithium-drifted plane-parallel gamma-ray detectors fabricated from Ge crystals grown at ORNL¹ were tested with collimated ^{60}Co gamma rays. By this means charge loss in the detector due to either electron or hole trapping could be measured to a lower limit of 0.05%. Both the energy and time resolutions of the detectors were closely correlated with the fraction of the charge lost to traps as indicated by this test. Made from a crystal with no observable charge loss ($<0.03\%$), a 40-cm³ coaxial detector showed an energy resolution of 2.2 keV fwhm for ^{60}Co gamma rays and a time resolution of 4 nsec fwhm for annihilation radiation.

1. By R. D. Westbrook, Solid State Division.

3.2 NEUTRON FLUX MONITOR USING A ^6Li GLASS SCINTILLATOR

R. W. Ingle H. Weaver¹

A neutron flux monitor was developed for measurements of the fission and capture cross sections of fissile isotopes by a Neutron Physics Division group at the Oak Ridge Electron Linear Accelerator (ORELA). To accurately determine neutron cross-section values requires an accurate measurement of the neutron flux vs energy for the neutron beam used. The cross section of the neutron detector must be known accurately, and the signal-to-noise ratio, timing resolution, and overload recovery time of the detector all must be good. At ORELA, the gamma-flash recovery time limits the upper energy range over which measurements can be made.

Using the $^6\text{Li}(n,\alpha)\text{T}$ (triton) reactions, the detector (Fig. 3.2.1) is a thin (1 mm), 3-in.-diam ^6Li glass disk mounted so that its face intercepts the 3-in.-diam collimated neutron beam. The disk is suspended in a lighttight, 4-in.-diam cylindrical aluminum housing; the interior of the housing is painted white to reflect light. Two RCA, type 8575, 2-in.-diam photomultipliers -- one at each end of the housing -- are mounted ~1 in. from the edge of the disk to intercept photons emitted from the glass scintillator. There is no physical light-pipe; the coupling is through the air, and the ends of the cylinder are tapered to reflect light to the photomultipliers. The beam traverses thin Mylar windows in passing through the detector.

The gain of each tube is balanced by adjusting the high voltage applied to the resistor divider string. The fast output signals from the photomultipliers are summed together, amplified, and shaped through an ORTEC 454 timing filter amplifier and passed to an ORTEC 453 constant fraction discriminator which furnishes the timing pulse to the data acquisition instruments.

Fig. 3.2.1. ^6Li glass neutron detector.

The pulse-height resolution of the two-photomultiplier system is 26% fwhm, and the timing resolution is ~ 3 nsec. At maximum accelerator power, the overload recovery is ~ 2.5 μsec . The timing resolution of this detector is about 20 to 1 better than the presently used parallel-plate BF₃ chamber.

1. Neutron Physics Division.

3.3 NEUTRON SENSORS FOR EXTREME ENVIRONMENTS

D. P. Roux

W. T. Clay A. R. Buhl F. J. Davis¹ D. W. Gidley²

A program was started to develop optimized neutron sensors with unusually high gamma rejection capabilities for operation at extremely high temperature, with the ultimate goal of operating adequately in a 10^7 R/hr and 1200°F environment. At present, a fission counter is the only candidate sensor for such environment.

Experimental studies of gamma pileup in fission counters as a function of detector material, electrode configuration, and gas filling were performed to obtain basic information for optimizing the detector design. Detailed digital computations were started to verify the experimental results; the intent is to develop an analytical method for designing detectors that will have minimum gamma sensitivity and will operate at high temperature.

Pulse collection time data were obtained by measuring electron drift velocity of noble gas mixtures (Ar-He and Xe-He) for high-temperature application. A mixture of 96% Ar-4% He yielded the fastest drift

velocity W . For example, for $E/p = 2 \text{ V cm}^{-1} (\text{mm Hg})^{-1}$, W is $1.2 \times 10^6 \text{ cm/sec}$ compared with $0.5 \times 10^6 \text{ cm/sec}$ for pure Ar.

Mineral-insulated coaxial and triaxial cables were evaluated for use with fission counters at 1000°F . A French cable manufactured by SODERN seemed very promising. This coaxial cable comprises a copper center wire clad with stainless steel, an insulator of 99.5% pure magnesium oxide, and an outer sheath sandwich of stainless steel--copper--stainless steel. The copper in the outer sheath provided an adequate electrical shield. No noticeable temperature pulse breakdown was observed at 1100°F when 600 V was applied.

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1. Health Physics Division.
 2. Albion College, Albion, Michigan.

3.4 DOUBLE CONTAINMENT ^{252}Cf FISSION CHAMBER

M. M. Chiles

A fission chamber (Q-5106) was designed (Fig. 3.4.1) for double containment of a ^{252}Cf plated foil to be used as a source of randomly occurring neutron pulses.¹ The outer stainless steel container was HeliarC welded and equipped with an alumina--ceramic hermetically sealed connector. The inner stainless steel container was also welded and equipped with a ceramic insulator feed-through. Plastic components were avoided to reduce contamination of the filling gas.

The gap between the ^{252}Cf and the signal collection plate was set at 1 mm to achieve a fast rise time. The chambers were filled with CH_4 at 1 atm abs pressure.

1. J. T. Minahan, *Use of ^{252}Cf as a Randomly Pulsed Neutron Source for Prompt Neutron Decay Measurements*, Y-DR-41 (January 1971).

3.5 BETA-SENSITIVE 1-in.-diam IONIZATION CHAMBER

M. M. Chiles

Several ionization chambers (Q-2818A¹) were modified so that they could be used to locate beta contamination inside radioactive processing cells. Slots were machined in the outer shell and high-voltage electrode to allow beta particles to enter the chamber. The outer shell was covered with 0.002-in.-thick stainless steel foil; the high-voltage electrode was covered with 0.001-in.-thick aluminum foil. The original Q-2818A chambers are pressurized with Xe gas, but this modified model is limited to 1 atm abs of Xe because of the thin outer shell.

1. H. R. Brubaker, R. K. Abels, and W. T. Clay, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1967*, ORNL-4219, p. 34.

3.6 SUPPORT FOR EXOELECTRON RESEARCH

F. E. Gillespie

Support was given to the Health Physics Division in the development of several instruments for thermally stimulated exoelectron emission (TSEE) dosimeter research. A system consisting of a flat-plate ionization chamber and vibrating reed electrometer was developed to measure doses up to 10^6 R on BeO disks.¹ This application also required a special heater having good electrical shielding.

Fig. 3A.1. Pinen chamber, Q-5106.

Development of an electron multiplier detector was started. A filament was used to supply electrons to check the electron optics. The use of a proportional counter instead of a Geiger counter was investigated.

1. Klaus Recker et al., *Health Phys. Div. Annu. Progr. Rep. July 31, 1970*, ORNL-4584, pp. 165-79.

3.7 ASSISTANCE WITH RADIATION DETECTOR TECHNOLOGY IN MEXICO

R. L. Shipp, Jr.

Through the International Atomic Energy Agency, the author spent six months in Mexico City, assisting the Comision Nacional de Energia Nuclear (CNEN) of Mexico in lithium-drifted-germanium detector production and utilization technology.

3.8 DEVELOPMENT OF A GAMMA IONIZATION CHAMBER FOR THE OFFICE OF CIVIL DEFENSE¹

W. T. Clay

Two ionization chambers (Q-5043) were developed for the OCD to be used in their radiological environmental monitoring systems. The chambers have an effective volume (air equivalent) of 450 cc and 1000 cc to cover the dose rate range from 0.1 to 10^6 R/hr. Physically both chambers are identical; only the gas mixture (N_2 and Ar) and total pressure are varied for proper energy response and sensitivity. The energy response of both chambers is flat (5%) from 70 keV to 1.3 MeV. The response for the top and side of the chamber, over this energy range, was within 4%. An internal beta source was used for calibration.

1. Abstract of report ORNL-TM-3474 (July 30, 1971).

3.9 DEVELOPMENT OF SMALL PROPORTIONAL-COUNTER GAMMA SURVEY INSTRUMENTS

R. E. Zedler F. M. Glas

Several small proportional counters of different dose rate sensitivities were fabricated and tested to determine their feasibility as Office of Civil Defense (OCD)¹ gamma survey instruments.

Initial investigation indicates that small proportional counters can be fabricated reproducibly at nominal cost with the following approximate characteristics:

1. a dose rate sensitivity of $1 \text{ count sec}^{-1} \text{ mR}^{-1} \text{ hr}^{-1}$,
2. a plateau slope of 10% per 100 V from 1000 to 1100 V as measured with a system comprising a charge-sensitive preamplifier, a linear amplifier, and a scaler (2.5×10^{-15} coulomb input sensitivity and 0.25 μsec double-differentiating and integrating time constants), and
3. a useful life of more than 10^{10} total counts.

Since the project was discontinued for lack of funds, the detector energy dependence and operation in a flux greater than 20 R/hr were not determined.

1. Work performed on OCD contract DAHC-20-69-C-0132.

3.10 EXTERNALLY QUENCHED HALOGEN G-M TUBE CHARACTERISTICS AND CIRCUIT DESIGN CONSIDERATIONS

F. M. Glas H. N. Wilson

This investigation is a continuation of previously reported¹ research under OCD contracts DAHC-20-71-C-0038 and DAHC-20-69-C-0132. Additional information from this investigation is as follows:

1. Data on such characteristics as dead time, deionization time, and charge per pulse are meaningless unless the anode circuit in the test setup is described in detail down to the last fraction of a picofarad of stray capacitance.
2. Although the dead time of a counter tube is influenced by the external anode circuit and the anode voltage, minimum dead time is a basic property of the counter tube. How close the achieved dead time is to the inherent lower limit of the G-M counter depends on the trade off the designer makes on the plateau slope and plateau length.

3. The fast high-current spikes in the cathode circuit (rise times <15 nsec and current <90 mA) are much better signals than those from the anode circuit for achieving a system resolution that is closer to the inherent minimum counter dead time.
4. Most published plateau data give a better indication of the sensitivity, overload characteristics, and resolution of the amplifier-scaler combination used in making the plateau measurements than the true plateau characteristics of the G-M counter tube.
5. A system resolution of 7.5 μ sec was observed with the new Amperex 18509 halogen-filled G-M counter tubes by taking a highly differentiated signal from the cathode.
6. Much can be done to improve the resolution of systems employing the nominal 500-V halogen-filled G-M counter tubes, but no circuits have been designed that take full advantage of the information obtained in this investigation.

1. F. W. Manning et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 22-26.

3.11 RADIOLOGICAL INSTRUMENT DESIGN INVESTIGATION FOR OCD, JANUARY 1970 TO OCTOBER 1970, ANNUAL REPORT¹

J. T. De Lorenzo F. M. Glass E. J. Kennedy F. W. Manning
J. M. Rochelle H. N. Wilson R. E. Zedler

Circuit and electronic component designs for OCD radiological instrumentation were studied in accordance with Interagency Agreement 40-170-69 (as amended January 1970) between the Office of Civil Defense and the Atomic Energy Commission.

Miniature gas-discharge ionization chamber instruments were studied, and two experimental modules were constructed and tested. Additional observations and data were recorded to determine radiation effects on metal-oxide field-effect transistors. A low-power, solid-state electrometer circuit constructed in module form was investigated, and an experimental instrument was constructed by combining the meter, ionization chamber, and packaging of a model CD V-715 instrument with the electrometer circuit module. We estimate that this instrument, if engineered for production, could be produced for about \$75 each in quantities of 10,000. The production cost of the 1962 model was \$25 to 30.

A commercial operational amplifier was studied for application to electrometer-type radiological instruments.

A study of proportional counters for use in OCD gamma survey meters was started. Utilization of breadboard-type integrated circuits was investigated.

1. Abstract of published report ORNL-TM-3370 (March 31, 1971).

4. Radiation Monitoring

4.1 RUGGED LOW-COST, PORTABLE DIGITAL DOSIMETER

J. M. Rochelle C. C. Courtney

A portable digital dosimeter was developed to determine whether a gas discharge recycling ionization chamber of small size¹ could be utilized for dosimetry in fallout shelters and similar applications. In this instrument, an ionization chamber is recycled by a simple gas discharge device which eliminates the expensive and delicate mechanical discharge mechanisms normally required in personal ionization-type dosimeters.

The detector is an ionization chamber connected so that the parallel capacitance is alternately charged through a gas diode (such as a neon glow lamp) and discharged by ionizing radiation at a rate proportional to the incident gamma dose rate. The dose received per cycle (or per pulse) is, therefore, constant and independent of the dose rate. The size of detectors of this type has previously been limited to a minimum of about 100 cc (referred to STP air) owing to the nonideal behavior of the gas diode. Special circuit techniques were developed to overcome this basic limitation and allow much smaller chambers.

In this digital dosimeter the chamber volume is ~50 cc. Its dose sensitivity of 0.01 R/pulse allows the integrated dose to be read directly from a digital register that counts the detector pulses. The dose per pulse is constant within $\pm 10\%$ over a range from 40 mR/hr to 100 R/hr, determined with a ^{137}Cs source.

The dosimeter is operated from a single D cell, which lasts for at least two weeks in continuous operation when no counts are received or for at least 40,000 counts received at a maximum rate of 7 counts/sec. This maximum rate is due to an anti-jamming circuit that ensures against blockage at dose rates greater than 100 R/hr. Bias voltages of 16 V for the circuit and -190 V for the chamber are supplied by a feedback-controlled blocking oscillator converter.

A shirt-pocket size alarm dosimeter was also developed. Its 10-cc chamber has a sensitivity of 50 mR/pulse. The necessity for and significance of this development is explained in the preceding paragraph.

1. This detector is covered by U.S. Patent 3,177,363.

4.2 CRITICALITY MONITORING SYSTEM, BUILDING 4508

J. A. Russell, Jr.

The pilot installation of the Criticality Monitoring System in Building 4508 was monitored for performance over an extended period of time during the year. When the balance of the state of charge of each cell in the 24-V battery power supplies could not be maintained, the Ni-Cd electrolyte batteries originally installed were replaced with wet electrolyte batteries. Another experience was that the signal that actuated the audible evacuation alarms was marginal and some of the horns occasionally failed to operate. This system was modified to improve its reliability.

After testing was completed and sufficient operating experience had been gained, the system was declared operational in June 1971.

4.3 ION EXCHANGE COLUMN SCANNER

G. W. Allin R. L. Shipp R. E. Toucey

A remotely controlled motor-driven radiation scanning device was designed and fabricated for use in the ^{233}U processing plant which is part of the Light-Water Breeder Reactor (LWBR) support program. This device periodically scans the primary column to detect the location of the thorium band front so that by backwashing this column the operators can prevent breakthrough of thorium to the secondary column of the ion exchange system.

An ORNL gamma ionization chamber, enclosed in a lead-filled shield with a simple window collimator, is driven parallel to the vertical resin column over its effective length of 18 in. The drive assembly is a $\frac{1}{2}$ hp dc motor connected to parallel ball-bearing lead screws with a light-duty roller chain. A 15-turn potentiometer supplies a signal to the position indicator. A transistorized SCR motor control allows the operator to select a scan speed from $\frac{1}{2}$ to 15 in./min.

The radiation intensity proportional signal from the ionization chamber and the position indication signal are recorded simultaneously by a two-pen recorder.

4.4 REVIEW OF OPERATING AND SAFETY FEATURES OF THE UT-AEC VARIABLE DOSE RATE IRRADIATION FACILITY

J. L. Anderson B. G. Eads

At the request of the UT-AEC Agricultural Research Laboratory, the operating and safety features of the Variable Dose Rate Irradiation Facility were reviewed. The facility was inspected, and all pertinent engineering drawings, operating procedures, and safety procedures were examined. A detailed report was issued, with specific recommendations stated as to where improvements were judged necessary or desirable, including an order of priority based on the importance and urgency of the advised modifications.

4.5 DEVELOPMENT OF TWO SYSTEMS FOR MONITORING ALPHA-EMITTING PARTICULATES IN RADIOACTIVE GAS DISPOSAL STACKS¹

R. L. Shipp, Jr.

A modified alpha constant air monitor which is used for monitoring alpha-emitting particulates in the effluent of the 3039 stack at ORNL is not designed to ignore alpha activity due to a naturally occurring radon and thoron background and will actuate an unwanted alarm when the background count rate rises to a preset level. Two new monitoring systems were developed as possible replacements for this monitor. One of these systems, a radon rejecting air monitor, makes use of alpha energy spectral data to reject radon and thoron background. This monitor has been field tested for three years. An alpha energy spectrometer can be added to this system to enable identification of the alpha contaminants. The second system, a cyclic spectral air monitor, displays the alpha contamination as alpha energy spectra with good resolution. This display enables rapid identification of the contaminants, and operating personnel can determine whether the alpha activity is due to radon-thoron background or has been released from a nuclear or radiochemical processing facility discharging its off-gases to the stack.

In this report, results from laboratory mock-ups of the two new monitors are presented along with a discussion of problems experienced during a field test of the radon rejecting air monitor. Features of all three monitors are compared.

¹ Abstract of published report ORNL-TM-3165 (December 29, 1970).

5. Support for the Van de Graaff Accelerator Program

5.1 HELICALLY LOADED SUPERCONDUCTING CAVITY

J. P. Judith

C. M. Jones ¹	W. T. Milner ¹
R. F. King ²	P. Z. Peebles ³
J. A. Martin ¹	R. F. Reed ⁴
F. K. McGowan ¹	P. H. Stehon ¹

The investigation of the design, fabrication, and operation of a helically loaded superconducting cavity for accelerating heavy ions was begun. A magnetically shielded and vibration-isolated cryostat was set up to accept a cavity and two coaxial transmission lines whose coupling to the cavity can be adjusted. Various measurements were made as a function of temperature and coupling constants, with a lead-plated cavity to a temperature $<1.7^\circ\text{K}$. The resonant frequency of the cavity was ~ 136 MHz. Electrical decay time; incident, reflected, and transmitted rf powers; and vibration-induced resonant-frequency changes were observed.

Other measurements made at room temperature on a copper cavity of identical geometry permitted inference of the loaded Q, unloaded Q, axial electric-field distribution and intensity, and surface resistivity of the superconducting cavity. Unloaded Q's of $\sim 2 \times 10^8$ at 4.2°K and 5×10^8 at $<3^\circ\text{K}$ were measured. With the cavity filled with He gas to temporarily sidestep the multipactoring problem, an accelerating field of about 0.6 MV/m was achieved.

A superconducting, helically loaded cavity would offer the advantage of a comparatively inexpensive, low-power rf system and smaller size than other heavy-ion accelerators.

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1. Physics Division.
 2. Consultant to the Physics Division.
 3. University of Tennessee; also consultant to the Physics Division.
 4. Solid State Division.

5.2 PRECOUNTDOWN MODULE FOR THE ADJUSTABLE REPETITION RATE ION SOURCE PULSER

J. P. Judith

To study atomic excitation states of some noble gases, a pulsed proton beam from the 3-MV Van de Graaff accelerator strikes a target cell containing the gas and excites it to states which may decay by photon emission. The decay time, which is a function of the target gas pressure, sometimes must be observed for time intervals considerably longer than 32 μsec , the longest time interval previously available from the ion source pulser.¹

A precountdown module was constructed, incorporating a commercially available integrated circuit comprising four cascaded, binary-triggered flip-flops. With the precountdown module installed, the interval between pulses can be set by a switch at the control console at 8, 16, 32, 64, 128, or 256 μ sec. A timing signal is produced by the proton beam pulses when they pass through the beam-stripper-beam-pulse-pickoff assembly² mounted at the entrance to the analyzer magnet. This arrangement has the added merit of simultaneously displaying on a sampling oscilloscope the H^+ , H_2^+ , and H_3^+ beam currents whose relative intensities give a sensitive indication of proper ion source operating conditions.

During hundreds of hours of operation, the precountdown module has demonstrated satisfactory reliability in the presence of tank sparks, but on a few occasions such sparks have destroyed the integrated circuit element.

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1. R. F. King, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1964*, ORNL-3782, p. 147.
 2. J. P. Judish, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, p. 33.

5.3 POLARIZED ION SOURCE FOR THE TANDEM VAN DE GRAAFF ACCELERATOR

J. W. Johnson C. D. Moak¹ G. F. Wells

Installation of a polarized negative ion source² on the ORNL EN Tandem Van de Graaff accelerator is about 75% complete. Major components of the source were mounted on separate carriages which can be moved on and held in alignment by a track. All services are being connected through flexible lines. This mounting arrangement has greatly facilitated the initial installation and will reduce the time required for maintenance.

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1. Physics Division.
 2. J. W. Johnson et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 31.

5.4 100-kV POWER SUPPLY FOR THE NEW 6-MV VAN DE GRAAFF TERMINAL

W. T. Newton R. F. King¹

A 100-kV, 1-mA power supply for the new high-current terminal of the 6-MV accelerator was completed (Fig. 5.4.1). The supply will furnish accelerator voltage for the beam within the terminal before the beam is injected into the accelerator tube. Since, for testing purposes, the terminal must be operated with the Van de Graaff tank removed, the supply must operate in air. Therefore, for insulation between components, the circuit is mounted in a pressure tank containing a 75-psi mixture of CO_2 and SF_6 .

Two 50-kV einzel lens supplies of similar design were also constructed for the terminal.

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1. Consultant; formerly a member of the Instrumentation and Controls Division.

5.5 NEW COLUMN RESISTORS FOR THE 6-MV VAN DE GRAAFF ACCELERATOR

W. T. Newton

All column resistors in the 6-MV accelerator were replaced because they failed frequently and the carbon-composition S. S. White resistors were not available for making repairs. A complete new set of column resistors of a different design could have been purchased from a commercial vendor for about \$11,000. However, the S. S. White resistors were replaced with standard Allen-Bradley 2-W carbon resistors. The results of the change are as follows: (1) the voltage-resistance linearity was improved, (2) the change of resistance with age has been slight, (3) after 2500 hr of use there were no resistor failures, and (4) the total cost of the operation was only \$300.

PHOTO 1474-71

Fig. 5.4.1. 100-kV power supply and pressurizing housing for ORNL 6-MV Van de Graaff terminal.

6. Support for the Oak Ridge Electron Linear Accelerator Development

6.1 IMPROVEMENT PROGRAMS

T. A. Lewis

The program to improve the Oak Ridge Electron Linear Accelerator (ORELA) was continued. Results from several activities contributed significantly to the performance and reliability of the accelerator.

The beam peak-current monitor system¹ proved valuable in the optimization of accelerator parameters. About 90% of the redesign and fabrication of an improved injection system (Sect. 6.2) was completed.

Work to improve the electron gun performance was continued, and several design modifications are being evaluated.

Studies of techniques of improving the peak current accelerated in a 3-nsec burst were initiated and will be continued for at least another year (Sect. 6.3). Subharmonic prebunching schemes appear to be the most promising.

1. J. K. Millard, T. A. Lewis, and G. W. Allin, *IEEE Trans. Nucl. Sci.* NS-18(3), 929-31 (June 1971).

6.2 ELECTRON INJECTION SYSTEM IMPROVEMENTS

J. H. Holladay	G. W. Allin
C. C. Courtney	W. E. Lingar
J. K. Millard	E. E. Waugh

An improved electron injection system for the ORELA was designed and fabrication was 90% completed. With this new system, the accelerator should be more reliable, and it should be easier to make adjustments with its improved circuits. To reduce accelerator downtime, all electronic circuits were fabricated in interchangeable, modified NIM modules to allow maintenance by substitution of a defective module with a spare module. The defective unit can be repaired on a test bench without affecting accelerator operation.

Since the thyatron has the shortest life expectancy of any component in the electron injection tank, a spare thyatron was installed on the thyatron modulator chassis to allow remote changeover to the spare unit without depressurizing and opening the tank. This can extend the intervals considerably between shutdowns for routine maintenance.

The size of the pressure vessel was increased to make it easier to maintain, modify, or expand the circuits inside the tank. Several changes were made to improve the safety of the pressure vessel, including a double fastener for securing the quick-opening clamp ring. Design of the injection system was reviewed by appropriate committees and the quality assurance coordinator of each division concerned with this program and equipment.

6.3 PREBUNCHING OF ELECTRONS

F. H. Clark T. A. Lewis R. S. Boeth

Preliminary studies were made of analytical methods to assist in design of a prebunching scheme for electrons injected into the ORELA accelerator. The internal energy of the span charge was evaluated, with the conclusion that it is within the voltage capacities of the system.

Development of a hybrid program to simulate the system and make interactive design possible was started.

6.4 INSTRUMENTATION FOR THE NEW GUN TANK

E. E. Waugh C. C. Courtney G. A. Holt

Improved instrumentation for the new ORELA gun tank was designed, consisting of interchangeable, modified NIM modules and bins.

The system consists of nine modules and numerous other special assemblies. The mechanical strength of the modules and bins required special consideration, since some of the units weigh up to 25 lb mainly because special chokes and transformers were installed in the power supplies. A complete spare set of instruments and a test stand were constructed for standby maintenance to decrease the downtime of the gun tank.

The quality of the system was improved throughout by simplifying its design, installing more reliable components, and using better fabrication techniques. Banana jacks and plugs were replaced with standard HN connectors. Modified General Radio to HN adapter connectors were replaced with standard HN connectors, because the modified connectors had arced between the center contact and the outer shell. Since soldering can cause damage to the dielectric, crimped ferrules were used to attach low-inductance gold-plated strips to the coaxial cable braids in the construction of the special inverter assembly. Interconnected wiring assemblies, which can be replaced as a unit, were fabricated to facilitate maintenance.

6.5 ADJUSTABLE CURRENT SOURCE FOR BIASING APPLICATIONS

W. E. Lingar

A current source was designed to bias the ferrite lines to provide pulse width control in the ORELA gun tank.

A current output of either polarity from this source is proportional to the rotational position of a ten-turn potentiometer. The midpoint of the potentiometer corresponds to zero output current. One end of the potentiometer corresponds to maximum negative current and the other to maximum positive current. The maximum current output is 5 A into a load having a maximum resistance of 1 Ω .

The output stage is composed of complementary Darlington transistors. Series-series feedback results in linear and stable performance.

6.6 REPETITION RATE PROGRAMMER

J. H. Todd

A unit was developed and built to program the repetition rate of either the gun or modulators (or both) of the ORELA. The time base of the unit is derived from the basic clock of the ORELA and permits

operation in the following modes:

1. operating the gun at $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, and $\frac{1}{64}$ of the basic machine repetition rate,
2. operating the modulators at $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, and $\frac{1}{64}$ of the basic machine repetition rate,
3. operating both the gun and the modulators as above, and
4. operating in any of the above modes on a selectable cyclic basis when there is a period of normal operation and then a period of lower repetition rate.

Signals are generated to indicate the mode of operation and the cycle being entered.

6.7 BURST TIMING PULSE DISTRIBUTION SYSTEM

J. H. Todd

A timing pulse is initiated by the gamma flash produced when a burst of electrons from the accelerator hits the neutron-producing target.

The detector, a 2-in.-diam photomultiplier (56AVP) in the target room wall, has a direct view of the target (through $\frac{1}{8}$ -in. aluminum). Since there is no scintillator, the signal is derived from the direct interaction of gamma rays from the target with the photocathode of the photomultiplier. Contributions to the signal from dynode-gamma interactions are negligible. The signal from the photomultiplier is transmitted to the control console where a monitor output and a fast discriminator are located.

The large pulse power range of the accelerator requires adjustment of the signal amplitude. This is done by adjusting the high voltage whenever operating conditions of the accelerator are changed.

The timing pulse generated by the fast discriminator goes through a fan-out system and then through a balanced and isolated distribution system to all laboratories and some flight stations at the ORELA. Jitter of the timing pulse is 0.7 nsec and is due to the nonphased microstructure of the electron burst.

6.8 BALANCED ISOLATION UNITS

J. H. Todd

Units having balanced and isolated outputs were designed and fabricated for the ORELA for distribution of common pulses such as timing pulses and those from neutron monitors.

These balanced isolation units consist of input buffering, fast current switching transistors, and balanced ferrite-core-wound transformers for signal enhancement and common-mode noise rejection.

The inputs are single-ended and accept standard-NIM fast logic levels. The signal amplitudes are twice those of standard-NIM fast logic levels. The outputs can be used either as an isolated, single-ended output or as a balanced pair. The output rise time is ~ 1.5 nsec. The 50% droop time is 2.5 μ sec. These characteristics can be varied by the choice of type of ferrite core used.

6.9 DEVICE CONTROLLER¹

R. E. Wintenberg J. W. Reynolds

A device controller (Q-5098) was designed and built for connection to the scaler interface (Q-5036) of DAC-1 or DAC-2 (SEL-810B computers). Its purpose is to control and accept data from equipment used by an experimenter. The unit was designed for general use, but it can also be used for special purposes.

The device controller can control and accept data from up to 8 devices and 8 scalars, with 96 control pulses available. The pulses can be used to set or reset flip-flops for dc control levels.

The unit was constructed using DEC logic cards so that only the circuits needed by a particular experimenter need be plugged into the wired panel and power supply.

1. J. W. Reynolds et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 58-59.

6.10 GROUND ISOLATION¹

J. W. Reynolds R. P. Rosenbaum

An isolation system to eliminate ground loops among experiments connected to the SEL 810B data acquisition computers at the ORELA was designed, constructed, and installed in three parts on the two SEL 810B data acquisition computers.

Part one of the isolation system was for the SEL 810B/PDP-4/PDP-9 link, using four-unit-wide NIM modules at the SEL 810B and at the PDP-4. The ground isolation was installed as part of the PDP-9 interface. Installation was completed in May 1971.

The second part was for isolating the multiplexer inputs from each experiment. Two types of four-unit-wide NIM were used with two methods of power and ground supply in one of the types. Installation was completed in August 1971.

The third part was for isolation between the scaler interface and the experimental device controllers in a four-unit-wide NIM. Installation was completed in August 1971.

1. J. W. Reynolds et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 58-59.

6.11 SHADOW BAR POSITIONER

J. W. Johnson R. L. Macklin¹

The gamma-ray flash suppression system² for the neutron time-of-flight experiments at the ORELA incorporates a shadow bar in the first collimator to block gamma rays produced at the center of the electron target. Alignment of the shadow bar is important because a moderate misplacement has resulted in an increase of the flash pulse by three orders of magnitude.³ To determine if more careful alignment will further reduce the gamma flash, a motor-driven remotely operated positioner (Fig. 6.11.1) was designed and built.

The shadow bar positioner provides for low-speed movement in any of five degrees of freedom that can be controlled from the remote target location in the 40-m station.

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- 1. Physics Division.
 - 2. R. L. Macklin, *Nucl. Instrum. Methods* 91(1), 79-84 (1971).
 - 3. Private communication from G. De Souza.

6.12 ADDITIONS TO THE LINEAR FILTER SYSTEM

R. W. Ingle

The linear neutron filter system on flight paths 5 and 6, which is used by the Neutron Physics Division cross-section group, was modified to include automatic control by a sequence timer. This timer permits automatic insertion and withdrawal of the beam filters from the neutron beam tube at preset times, adjustable to a 6-hr minimum. Signals are presented to the external data handling instrumentation by the

Fig. 6.11.1. Shadow bar positioner.

timer chassis to allow separation of data into filter "in" and filter "out" categories. This unit has been successful for self-indication experiments of ^{238}U , using ^{238}U filters at liquid N_2 temperatures.

Similar linear filter control systems are presently being fabricated for flight paths 4 and 8. The path 8 system is nearly complete and is being tested. The path 4 system is in the preliminary stages of fabrication. Both manual and computer control of these systems are being fabricated.

6.13 ENGINEERING DEVELOPMENT SUPPORT

J. H. Todd

Engineering support was given to eliminate areas of difficulty in the accelerator and to extend the useful life of the machine.

The trigger generator, which performs the logic of preventing unacceptable machine operating conditions and initiates all timing in the accelerator, was redesigned.

A system for processing and testing the accelerator gun was developed, and construction of some parts of the system was started.

6.14 ANALYSIS OF ORELA DATA WITH A HYBRID COMPUTER

R. S. Booth

Work begun last year on interactive curve fitting using the hybrid computer operated by the Reactor Controls Department was continued so that three special-purpose programs can now be used for ORELA data analyses. The first program, BIOFIT, fits a special set of functions to the measured neutron energy spectrum incident upon the foil. The second program, BGFIT, allows the operator to systematically identify and remove backgrounds from the data. The third program, RESFIT, fits Breit-Wigner formulas with Doppler and self-shielding corrections to the measured cross section vs energy. In each program, the data and current fit are displayed on the oscilloscope screen, and the fit is accomplished by a trial-and-error method, with a fraction of a second turnaround time. Changes in the fitting function are made by the user by changing the positions of hand-set pots on the AD-4 analog computer. Continued progress was made in the human engineering aspects of these programs.

6.15 TRAINING COURSE FOR ORELA ACCELERATOR OPERATORS

R. E. Wintenberg T. A. Lewis H. A. Todd

To improve technical communication between the ORELA operators and experimenters, an intensive course in electronics was given to the accelerator operators while the gas tank was out of operation. The operators studied 4 hr/day for 4 weeks on the job.

7. Automatic Control and Data Acquisition

7.1 COMPUTER CONTROL SYSTEM FOR AN AUTOCORRELATION NEUTRON TIME-OF-FLIGHT SPECTROMETER¹

F. W. Snodgrass¹ H. A. Mook²

A computer-based system (Fig. 7.1.1) for the control and acquisition of data from a neutron time-of-flight (TOF) spectrometer was built, installed, and tested. The system is now operating at beam hole 4 at the High-Flux Isotope Reactor (HFIR). The spectrometer³ utilizes a magnetically pulsed neutron beam for inelastic neutron-scattering investigations of liquids and solids. The beam is pulsed by changing the direction of the atomic magnetic moments in a ferrite crystal with an applied magnetic field. A sequence of pseudorandom pulses is generated, with duty cycles up to 50%.

The interface electronic units contain over 400 small- and medium-scale TTL integrated circuits. Tests to date indicate extremely reliable operation. With the exception of a timing delay problem, which has since been corrected, no malfunctions were observed. Exceptionally good data were acquired on the first experimental test. A recent phonon experiment conducted with copper produced approximately six times the counting rate (with only a single detector) that has been observed using the triple-axis neutron spectrometer at the HFIR.

Fig. 7.1.1. Diagram of control electronics for autocorrelation neutron time-of-flight spectrometer.

The electronic unit consists mainly of plug-in modules with integrated circuits mounted on wire-wrap socket boards. These modules are contained in a CAMAC⁴ crate with a common dataway. Communication by the various functional modules with the computer (a PDP-15/30) is through the controller module. The programmed pulse generator module continuously and repetitively generates the pseudorandom code that drives the magnetic pulser. Synchronized to the pseudorandom code, the time-of-flight scaler accepts pulses from up to 16 detectors and sends the time information with detector identification to the computer. Autocorrelation methods are used to extract the desired information. Other modules include a 16-stage interrupt register, a motor clock generator which serves as a time base when running the motors, and a monitor prescaler to provide information on the intensity of the incident neutron beam. Five stepping motors (with capability of eight) set the physical parameters of the experiments.

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1. F. W. Snodgrass and H. A. Mook, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 38.
 2. Solid State Division.
 3. H. A. Mook and M. K. Wilkinson, "A Magnetically-Pulsed Time-of-Flight Spectrometer for Inelastic Neutron Scattering," pp. 173-80 in *Instrumentation for Neutron Inelastic Scattering Research*, IAEA, Vienna, 1970.
 4. CAMAC, *A Modular Instrumentation System for Data Handling, Description and Specification*, ESONE Committee Report EUR 4100e (March 1969).

7.2 HB-3 DIFFRACTOMETER CONTROL SYSTEM

E. Madden W. C. Koehler¹

A proposal and an estimate for a new data collection and control electronics system for a long-wavelength diffractometer, located at beam hole HB-3 at the Oak Ridge Research Reactor (ORR), were completed, funds were approved, and design of the system was started.

In this new system a PDP-8/e computer will drive five shafts. The computer-diffractometer interface will be built on quad printed circuit boards which will be mounted on the computer. The software for the diffractometer control system will be compatible with the High-Flux Isotope Reactor (HFIR) beam hole 1 diffractometer system. Reduced data will be recorded on a Houston DP-1 incremental plotter. Operator control will be through an ASR-33 Teleprinter.

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1. Solid State Division.

7.3 HB-4 TRIPLE-AXIS NEUTRON SPECTROMETER CONTROL SYSTEM

E. Madden H. G. Smith¹

A proposal and an estimate for a new data collection and control electronics system for a triple-axis neutron spectrometer were completed, funds were approved, and design of the system was started. The spectrometer, which has been operated at beam hole HN4 of the Oak Ridge Research Reactor (ORR) since 1964, was moved to the HB-4 beam hole at the High-Flux Isotope Reactor (HFIR), where the new electronic control system utilizing a PDP-8/e computer will be installed.

The computer-spectrometer interface will be built on quad printed circuit boards which will be mounted on the computer. The system will drive five shafts. Software for the spectrometer will be compatible with the spectrometer located at HFIR beam hole 3. Operator control will be through an ASR-33 Teleprinter.

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1. Solid State Division.

7.4 DOUBLE-ARM SWEEP-GAGE INSPECTION MACHINE

E. Madden R. E. Wintenberg R. Marcum¹

An SEL 810B computer-controlled parts inspection machine² was completed for the Fabrication Systems Development Department of Y-12. The system was checked out and delivered, and is now being used to inspect scheduled production parts. The ORNL system control interface has experienced no recorded failures since installation was completed in September 1970.

A manual control panel was designed and built for use with the inspection machine. This manual control panel overrides the digital system and allows the various modes of servo operation to be controlled with switches and multiturn potentiometers.

1. Fabrication System Development Department, Y-12.

2. E. Madden and R. E. Wintenberg, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 39.

7.5 ORELA DATA HANDLING SYSTEM¹

J. W. Reynolds

N. A. Betz ²	J. A. Harvey ³	G. G. Slaughter ³
J. G. Craven ²	F. C. Maierachin ⁴	C. L. Thompson ²
C. E. Hammons ²	R. W. Peck ⁴	D. R. Winkler ²

The ORELA data handling system (Fig. 7.5.1) consists of a series of computers for realtime data acquisition and on-line analysis of the acquired data.

In phase 1, two data acquisition computers were installed for the Oak Ridge Electron Linear Accelerator in December 1968 and accepted in April 1969. The first experimental interface was connected in June, and data collection was started in August 1969. The software for multiple use of each data acquisition computer was operational in August 1970. Simultaneous data acquisition from six experiments is now a normal operating mode. A maximum of four experiments, with a data base of 30 bits each, can be stored at a combined update rate of 4900 events/sec on the fixed head disk on each computer. A typical disk allocation (750K disk on DAC1) is 350K, 200K, 100K, and 100K channels. DAC2 has 350K channels. A moving window display of each experimenter's data is available upon command through a Teletype and a light pen.

The immediate analysis and coordinating computer (IACC) was installed in April 1971. Testing of the phase 2 system hardware was completed in May 1971. The special software tests, including the BSCI¹ hardware on the SEL 810B, will be completed in November 1971. The extended acceptance tests will be completed by January 1972. Phase 2 is a display-oriented time-sharing computer system⁵ having a response time of less than 1 sec to user requests through the display console. The final data analysis will be accomplished by the IBM 360/75 when the IACC computing time is greater than several minutes.

Besides being a display operation for ORELA, the IACC will serve as a coordinating computer for communication of "dedicated" computers (a computer whose function is to perform one specific task, such as control or data acquisition, and not general-purpose computing) with the IBM 360/75. The display applications software will be written by Mathematics Division personnel.

1. J. W. Reynolds et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620. pp. 58-59.
2. Mathematics Division.
3. Physics Division.
4. Neutron Physics Division.
5. J. W. Reynolds, *Application Notes on the Immediate Analysis Display System for ORELA Data Acquisition and Handling*, ORNL-TM-2116 (January 1968).

J. W. Reynolds J. H. Holladay R. P. Rosenbaum

Installation of the PDP-9 connection to the SEL 810B/PDP-4 link required some modifications to the PDP-4 interface control. A ground isolation chassis (Q-2956-38) was also built and installed for the PDP-4. The maximum transfer rate is 14,700 sixteen-bit words/sec.

An alternative path was provided for both the PDP-4 and PDP-9 to input experimental data into the SEL 810B multiplexer interface by changing cables at the PDP-9. The maximum data rates are 38,450 and 12,980 eighteen-bit words/sec on the PDP-9 and PDP-4, respectively.

7.7 BINARY SYNCHRONOUS COMMUNICATIONS INTERFACE FOR THE SEL 810B

J. W. Reynolds

N. A. Betz¹ C. E. Hammons¹ R. W. Peele²

A binary synchronous communications interface³ was supplied by SEL in March 1971 and installed in late April 1971. The functional check of the hardware, using test routines written by SEL and ORNL, was completed in May 1971. Integration into the IACC was completed in June 1971.

1. Mathematics Division.

2. Neutron Physics Division.

3. J. W. Reynolds et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 59.

7.8 EIGHT-STAGE STACKING BUFFER MEMORY

R. E. Wintenberg J. W. Reynolds A. R. Smith¹

A prototype, 8-word, 30-bit stacking buffer memory² was debugged, modified, and placed in operation at the Oak Ridge Electron Linear Accelerator (ORELA).³ Mainly the input/output circuits of the original design were modified to synchronize the flow of data with the internal clock rate.

This unit, placed in service in May, accepts data in bursts from an EG&G model TDC-100 time digitizer. The data are stored in the memory until they can be accepted by a data acquisition computer at a much lower instantaneous rate.

1. ORAU Trainee from Houghton College, Houghton, New York.

2. Designed by A. R. Smith.

3. J. W. Reynolds et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 58-59.

7.9 INTERFACE FOR CDC PERIPHERALS TO A PDP-10 COMPUTER

R. E. Wintenberg J. W. Reynolds C. E. Murphy

An interface was designed, built, and installed for the hybrid computer facility operated by the Reactor Controls Department.¹ The hardware system, which was essentially completed in March, extends the system's capability to include a CDC, model 1612 line printer, a model 1615 magnetic tape controller, and two model 606 magnetic tape drives.

The interface was constructed of DEC logic modules, with type B681 power inverters modified to drive the CDC equipment.

1. R. S. Stone, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 92.

7.10 NEUTRON INELASTIC SCATTERING PROGRAM

J. W. McConnell J. A. Biggerstaff¹

Most of the software for the PDP-7 computer used by the Neutron Physics Division at the Van de Graaff accelerator laboratory was modified to make use of the disk storage system,² because the manufacturer was unable to supply a replacement core memory from stock. As a result, the computer could not be used efficiently for about four months. Due to the excessive time and difficulty in obtaining a replacement memory, a new 8K core memory system was purchased. Design and construction of the interface and control logic were completed, and this equipment will be installed after it is moved to the Oak Ridge Electron Linear Accelerator (ORELA) in 1971.

Design of a disk controller for the computer is nearly complete, and construction of an interface for a digital clock and modifications to the existing ADC interface were started.

1. Physics Division. On leave of absence to the Australian Atomic Energy Commission (AAEC).

2. J. W. McConnell and J. A. Biggerstaff, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 33.

7.11 HESS, HYBRID INTERFACE SUBSTITUTE SUBROUTINES FOR USE IN DEBUGGING HYBRID PROGRAMS¹

H. Patterson² O. W. Burke R. S. Booth

A set of FORTRAN IV subroutines identified as HESS (Hybrid Interface Substitute Subroutines) was prepared so that by using the extensive printout and monitor system of the IBM-360 computer one can debug a hybrid computer program or test its output against a sample calculation. HESS extensively tests the CALL statements unique to a hybrid program; the resulting error messages, warnings and facts, and statements for future reference help the programmer to convert his initial hybrid program to a production code. HESS also is a file of the hardware and software available on the hybrid computer and of experience and insights in the use of the hybrid.

1. Abstract of published report ORNL-TM-3287 (Feb. 5, 1971).

2. Summer participant (1970) from Huntingdon College, Montgomery, Alabama.

7.12 MULTISCALER INTERFACE

F. W. Snodgrass

The NHO6L-LRS Scaler Interface unit (Q-5090) is a three-unit-wide NIM module that was built to place a LeCroy Research Systems Corporation (LRS) 8-channel multiscaler, model 150A, and associated readout control unit, model 152C, under computer control. Binary 24-bit data are transferred into the PDP-9 computer through the NHO6L 7-ADC¹ control unit built by DEC. Basically, the module converts the multiscaler to an analog-to-digital converter unit, with the appropriate signals patched through the NHO6L patch panel. Scaler information is displayed on the LRS, model 156 digital display unit during automatic and manual read operations. During each readout cycle, data are transferred as sixteen 12-bit bytes.

1. F. W. Snodgrass, Jr., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4499, p. 47.

7.13 HIGH-SPEED, STRAIN-GAGE-ORIENTED, COMPUTER-BASED DATA ACQUISITION SYSTEM

R. L. Moore T. M. Cate C. D. Martin, Jr.

Preliminary acceptance tests of this system¹ were performed at the vendor's plant in December 1970. The system passed the acceptance tests, and in many cases its performance greatly exceeded specification requirements. After shipment to Oak Ridge and reassembly and checkout of the system by the vendor's personnel, the final acceptance tests were performed by ORNL personnel in January 1971. The performance of the system was well within specifications, and the accuracies of the system were consistently better than specified by factors of 5 to 10. The system was accepted on January 19, 1971.

The system has been operated continuously without failure or serious problems. The software was modified to increase its capability or to accommodate changing requirements. During the period of January 19 to July 15, 1971, three experiments used the system on a continuous basis.

Ease of expansion, one of the prime specified requirements for this system, will enable the addition of 192 strain-gage channels and a magnetic-tape recorder which are being purchased.

¹ R. L. Moore, T. M. Cate, and C. D. Martin, Jr., *Instrumentation and Controls Div. Annual Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 57.

7.14 HIGH-SPEED ANALOG DATA ACQUISITION

C. B. Williams B. C. Duggins

In continuation of a program previously described,¹ engineering assistance and equipment were made available to research personnel for gathering transient data on oscillograph recorders. A description of some significant instances of assistance follows.

At the Gaseous Diffusion Plant at Paducah, 30 channels of thermocouple information from compressor tests were recorded simultaneously on ORNL equipment with a frequency response of 100 Hz. The operational amplifiers in three Electronic Associates TR-10 analog computers amplified the thermocouple

ORNL-DWG 72-4851

Fig. 7.14.1. Typical circuit for one data channel of compressor test.

signals, utilizing the circuit shown in Fig. 7.14.1. These chopper-stabilized amplifiers performed well, and their frequency response and stability far exceeded the requirements. The versatility and compactness of the TR-10 make it a useful tool in signal manipulation for recording.

Following the tests at Idaho, assistance was given in other compressor tests at the Oak Ridge Gaseous Diffusion Plant. In these tests, signals were conditioned and recorded from 30 strain gages and 4 resistance temperature detectors.

Temperature and pressure data were gathered for the Reactor Chemistry Division and the Metals and Ceramics Division in different experiments relating to high-temperature failure of Liquid-Metal Fast Breeder Reactor (LMFBR) fuel rods.

The Isotopes Division was assisted in studies of high-temperature and high-pressure waste oxidation.

1. C. B. Williams and B. C. Duggins, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 64.

7.15 DIRECT DIGITAL COMPUTER CONTROL OF THE HFIR

J. B. Bullock W. H. Sides, Jr.

A primary objective of the computer control program was the establishment of a reactivity balance algorithm that would protect against a reactivity anomaly for both manual and automatic reactivity increases.¹ This objective was realized with the successful demonstration of direct computer shimming of the High-Flux Isotope Reactor throughout fuel cycles 53 and 54. During the 23-day fuel cycles, all shim rod motions for increasing or decreasing the reactivity or for maintaining the rods in a symmetrical array were carried out by the control computer, using reactivity balance as a control parameter. The control limits were adjusted to inhibit rod movement if the reactivity anomaly exceeded 50 cents.

The proper operation of the shim inhibit due to reactivity anomaly was observed at the beginning of cycle 53. During the shimming operations following a rod drop test, the computer would not concur with the rod withdrawal requests because of an apparent reactivity anomaly. Subsequent analysis revealed that the inner control cylinder had been replaced with one of less reactivity worth without a corresponding adjustment to the reactivity balance program. As a consequence, the computer correctly treated this as a reactivity anomaly and would not participate in rod withdrawal.

1. B. R. Lawrence, J. B. Bullock, and H. P. Danforth, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1966*, ORNL-4091, pp. 157-58.

7.16 DATA ACQUISITION SYSTEMS AT THE HFIR AND ORR

R. F. Hyland

J. W. Cunningham R. L. Durall O. W. Russ¹

The system at the High-Flux Isotope Reactor² has completed another year of continuous, trouble-free operation, collecting data from experiment HRB-2. Computer processing of the data produced a series of plots for each reactor cycle which correlated reactor power, experiment position, and experiment temperatures and pressures.

Experiment HRB-3 is being designed for connection to the system.

The system at the Oak Ridge Research Reactor³ has also been operated continuously the past year and has performed extremely well. Data were collected from three uranium nitride capsule experiments (UN 5,

6, and 7), and the computer output was modified to calculate the mean and standard deviation for each thermocouple value and the linear heating rate for each fuel-pin calorimeter. The cladding temperature was calculated using the calculated linear heating rate. The plotting routines were altered to accommodate the newly calculated variables.

Extension of the system party-line cable to experiment ORTC-4 was completed, and the apparatus was operated during ORR cycle 99. A unique feature of the DEXTIR system was used to measure the loop resistance of the center line W3Re/W23Re thermocouple at a maximum temperature of 4028°F. The data system, while scanning, automatically switched in a stable, constant-current power supply for a period of 100 msec. This was of sufficient duration to make a reliable loop resistance measurement without causing Peltier heating of the thermocouple junction. A similar scheme was used to measure the loop resistance of the ultrasonic thermometer coil circuit.

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1. ORNL Mathematics Division.
 2. R. F. Hyland et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 56.
 3. Ibid.

7.17 COMPUTER SYSTEM FOR DESALTING EVAPORATOR STUDIES

J. L. Redford C. D. Martin, Jr. R. K. Adams

Specifications were reviewed for a small computer-based data acquisition system for the Office of Saline Water (OSW). The Instrumentation and Controls Division is assisting with the installation of the computer system at the OSW three-stage flash evaporator facility, Wrightsville Beach, N.C.

The system utilizes a PDP-8/E computer with 8192 words of core memory to control a 200-channel scanner for collection and analysis of data from the evaporator.

In addition to the bid evaluation and vendor liaison, some of the vendor-supplied software is being modified to facilitate analysis of the data. Sample programs were prepared for the acquisition of data, conversion to engineering units, and some of the performance calculations for printing on the teletypewriter and for paper-tape output.

7.18 COMPUTER-BASED DATA ACQUISITION SYSTEM FOR REACTOR DIVISION EXPERIMENTS

R. F. Hyland

R. M. Burnett C. D. Martin, Jr., A. H. Voelker

An extension of the DEXTIR/PDP-8 data acquisition system¹ for processing data on-line was completed and has operated since April 1971.

A major new programming system was developed, using the disk version of the real-time executive program (Sect. 7.25) to process data from any 24 data-gathering boxes connected to the DEXTIR system. Hardware interfaces added to two additional teletypewriters enable an output of data simultaneously on three machines. The existing Teletype switching system was modified so that more teletypewriters can be added as satellites to one of the three machines.

Modifications were also made to the DEXTIR/PDP-8 interface to eliminate spurious interrupts which have been a problem in the past.

Since the DEXTIR system can accommodate up to 100 data-gathering boxes, the 24 boxes to be monitored by the computer must be specified in the programming system along with the type of conversion and the engineering units identifier for each of the 24 channels of each box. After these parameters are specified by the system engineer, the individual experimenters using the system may request data from any

of the 24 computer-monitored boxes to be printed on any of the three system teletypewriters each time the boxes are scanned. The use of disk storage for buffering all teletypewriter output allows the data from 18 boxes to be queued for listing by one teletypewriter when the standard data output format is used. Disk storage of programs allows special processing of data from designated data boxes employing programs coded in assembly language. This feature enables use of a special format for listing data from the Failed Fuel Mock-Up Test Facility.

Hardware requirements for future expansion are an additional 4K of core memory (making 8K total) and 32K of disk memory (making 64K total). This will enable use of FOCAL by experimenters to program calculations with real-time data.

1. R. F. Hyland et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 55-56.

7.19 CODAS COMPUTER SYSTEM¹

J. M. Jansen, Jr. C. D. Martin, Jr.

The computer-operated data acquisition system (CODAS) in the Physical Properties Laboratory of the Metals and Ceramics Division was expanded by adding hardware and software. The system now contains the following hardware: A DEC PDP-8, an 8K-word core memory (12-bits/word), a 96K-word disk memory (13-bits/word), an ASR-33 Teletype, a Kennedy model 1500R magnetic tape transport, a 100-Hz crystal-controlled clock, 12 DPDT program-controlled relay outputs, 12 contact input sensing circuits, 6 channels of analog input with individual channel suppression, a successive approximation analog-to-digital converter and buffer amplifier (12 bits), a digital-to-analog converter (10 bit, unipolar), a Carson-Dice Electronic Micrometer 5-BCD digit interface, a Digitronic photoelectric paper-tape reader and controller, and a 15-bit programmable, binary-weighted, Kelvin-Varley voltage divider for providing suppression voltages in increments of $1 \mu V$.

The FOCAL interpreter was extensively modified with the addition of several commands and functions for operation of the digital input-output hardware, the analog input-output equipment, and the real-time clock. Commands were also implemented for performing program storage on and retrieval from the magnetic disk memory and data storage on and retrieval of data from both the magnetic disk memory and the magnetic tape storage device.

1. J. T. Hutton et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, pp. 48-49.

7.20 COMPUTER SYSTEMS SUPPORT FOR THE FFTF TEMPERATURE TEST FACILITY

J. L. Redford C. D. Martin, Jr.

About 0.5 man-year was spent to improve the reliability of the data acquisition and control system¹ for the FFTF temperature test facility:

1. The "watchdog timer" was changed from a mechanical clock that was reset by a computer-actuated contact closure to an all-solid-state device reset by a pulse from the computer.
2. The software system was rearranged to provide more memory for data storage and to automatically restart the system without losing time information stored in memory.

3. Automatic turn on and off circuits were added to the system Teletype to minimize running time on the unit. Previously, the Teletype motor had operated continuously 24 hr/day while data were being printed only about 5 min/day.
4. Direct digital control of the test facility furnaces was improved by incorporation of a software data filter in the control algorithm to reject random noise and by replacement of relays for furnace power control by zero-fired, solid-state switches.

During the past year the system operated 24 hr/day, 7 days/week, with an availability of 97.2%. Teletype problems accounting for 1% of the system downtime were improved by the automatic turn on and off feature.

1. R. F. Hyland and B. G. Eads, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 41.

7.21 A DIGITAL COMPUTER CODE FOR SIMULATING LARGE MULTISTAGE FLASH EVAPORATOR DESALTING PLANT DYNAMICS¹

J. G. Delene² S. J. Ball

A digital simulator was developed for large multistage flash (MSF) evaporator plants. This simulator can calculate the time response to various perturbations of the evaporator system, predicting liquid levels and temperatures, etc., in each stage. The evaporator system, the equations used to describe the plant dynamics, and the method of solving these equations are discussed. The results of a sample problem and other calculations are also presented. The simulator can calculate a 1-hr transient in a 50-stage MSF plant in a running time of 4.5 min on the IBM 360/91 at Oak Ridge National Laboratory.

1. Abstract of published report ORNL-TM-2933 (September 1971).
2. Reactor Division.

7.22 HYBRID COMPUTER PROGRAM FOR PARAMETER OPTIMIZATION OF MODELS DESCRIBING DYNAMIC BEHAVIOR OF FLASH EVAPORATORS

N. E. Clapp, Jr.

A hybrid computer program was developed for determining the optimum values of several coefficients in a mathematical model of the dynamic behavior of an evaporator stage, using data obtained from a flash evaporator. A model, a set of nonlinear differential equations, was studied on the analog portion of the hybrid computer. The digital portion transferred measured data to the analog as input forcing functions, measured the response of the analog model, calculated the difference between the measured and computed responses, and, using a gradient search routine, optimized parameters of the model.

7.23 PROGRAM AND FUNCTION OPTIMIZER

F. H. Clark

A rather general program was developed which can drive almost any other program (or function) to a maximum or minimum solution. The only apparent restrictions on such programs are that (1) they can be converted to subroutines, and (2) their data entry procedures can be abstracted and placed in a separate

initializing subroutine. At present, the domain of search may be restricted, with respect to each of the independent variables, to regions with boundaries that are constant.

The program is written for the PDP-10 computer in the hybrid system. It will optimize hybrid or digital programs. With very little effort the program can be adapted to the 360, and the nature of the domain restriction boundaries can be made arbitrary.

If a function, rather than an operating program, is presented for optimization, constraints represented by arbitrary equalities as well as the inequality specified domain constraints can be imposed.

Since data fitting, to least squares or other criteria, is itself an exercise in minimizing an error function, this program system has obvious application to data and model fitting.

7.24 COMPUTER SOFTWARE DEVELOPMENTS, STUDIES, AND EVALUATIONS

J. M. Jansen, Jr. R. L. Simpson D. L. Wilson¹

In a continuing effort^{2,3} to furnish system software which is both easy to use and sufficiently flexible to perform the varied tasks associated with research, development, and control, a number of functions and commands were implemented and changed in the FOCAL language. The modifications include extended software for an integrating digital voltmeter, revisions for accumulation of real time-of-day using a 100-KHz crystal-controlled clock, and additions to existing functions for operation of contact input seasing and contact output control to operate the DEC universal digital controller (UDC8).

Significant improvements were made in the disk data storage function (FSTR) for increasing the data throughput rate to and from the disk. The LIBRARY command was extended to permit both normal (3-word) floating point and extended (4-word) floating-point calculation programs to be written and simultaneously stored on a disk. In addition, several new functions and commands were implemented to permit read-write operation of a Kennedy model 1500R magnetic tape unit interfaced to a PDP-8 computer⁴ and a Peripheral Equipment Corporation (PEC) DEC model TRO2NA magnetic tape unit. Both magnetic tape units are incremental write and continuous read.

Investigations were started to determine the feasibility of using cartridge or cassette tape units for on-line storage of programs and data rather than disk storage in FOCAL. Criteria for determining suitability are cost, access time, capacity, reliability, and long-term data storage.

Modifications were made to the FOCAL software system for the Process Control and Instrumentation Section PDP-8/I computer for use with the PS/8 monitor system.

The PS/8 programming system provided by DEC for the PDP-8 family of computers provides the user with a keyboard-oriented program development library system that includes such features as (1) two loaders, (2) an editor for program creation and modification, (3) an assembler, (4) a FORTRAN compiler and operating system, and (5) a device independent I/O structure. This new system was used as the basis of the library system for the Process Control and Instrumentation Section PDP-8/I. Additional device handlers for the Sykes COMPU/CORDER 100 cassette tape unit, the Tektronix 611 storage oscilloscope, and three PTO8 Teletype interfaces were acquired, written, or modified for use with the PS/8 system. The PS/8 system provides the possibilities of FORTRAN or FOCAL control of experiments while retaining the ability to use the system disk and support software for machine language assembly, editing, and debugging which was impossible under the DF32 Disk Monitor System supplied by DEC.

Several new I/C subroutines for operation of the system hardware were written for use in FORTRAN.

A FORTRAN program, PALFTN, was written to assemble programs written in the PAL and PAL-D languages for the PDP-8 computers. The new assembler, based on earlier versions by W. R. Busing⁵ and S. P. King,¹ will accept input statements on 80-column punched cards and produce a binary tape, assembly

listing, several programmer aid tables, and error indications. A detailed description of the new features and procedures for using the assembler on the IBM 360 computers at ORNL is being prepared.

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1. Mathematics Division.
 2. R. K. Adams et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 50-51.
 3. J. M. Jansen, Jr., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, pp. 54-55.
 4. Ibid, pp. 48-49.
 5. Chemistry Division.

7.25 SMALL-COMPUTER REAL-TIME EXECUTIVE PROGRAM FOR PROCESS CONTROL AND DATA ACQUISITION

C. D. Martin, Jr.

A real-time executive program for data acquisition and process control was developed for a PDP-8/I computer with 4096 words of core memory, 32,768 words of disk memory, one Teletype, and a programmable real-time clock. The program functions are to: (1) schedule the various operations to be performed by a system, (2) maintain priority among system operations, (3) handle all computer interrupts, and (4) coordinate all input-output operations to and from the computer.

Real-time executive programs are generally available from manufacturers of medium- to large-scale digital computers used for process control and data acquisition. The inexpensive, small (or mini) computers available today are also applicable in process control and data acquisition systems. However, real-time executive programs for the small computers are not always available from the computer manufacturer.

The program was designed to accommodate, without modification, up to 32,768 words of core memory, 131,072 words of disk memory, multiple Teletypes, extended arithmetic hardware, a high-speed paper-tape reader and punch, and power failure detection circuitry. A console utility program was included to facilitate program development with the system on-line.

7.26 TRANSMISSION OF PAPER-TAPE DATA TO THE ORNL COMPUTING CENTER

J. L. Redford C. D. Martin, Jr. J. M. Jansen, Jr.

There are numerous electronic data acquisition systems at Oak Ridge National Laboratory that record data on punched paper tape for analysis by one of the large computers at the ORNL Computing Center. Unfortunately, paper-tape data must be transcribed on punched cards or magnetic tape for entry into the large computers, thus adding an extra step in the data processing procedure and increasing the turnaround time on the job.

An investigation was made to determine the costs and feasibility of transmitting paper-tape data over existing telephone circuits and data sets to the Computing Center. Although many experimenters could use a Teletype machine for reading ASCII coded paper tape on ASP-33 Teletype machines at 10 characters/sec and transmitting the data as input information to the Conversational Remote Batch Entry (CRBE) system on the IBM 360/75, this method is extremely slow and, consequently, offers little advantage. To transmit at a higher speed, additional hardware would be required at both ends of the transmission line, and special programming would be required to accommodate the data on the IBM 360/75. Since the cost of these additions appears to be excessive for the benefits gained, this approach was not implemented.

Installation of a PDP-10 computer at the ORNL Computing Center might make possible high-speed transmission of data not previously available. Personnel of the Mathematics Division and the Instrumentation and Controls Division are studying a relatively inexpensive solution to the problem that would utilize a PDP-10 computer.

7.27 APPLICABILITY OF THE D-17 DIGITAL COMPUTER TO ORNL USES

C. D. Martin, Jr.

By the end of 1974 many model D-17 digital computers will have become surplus property. In response to inquiries from several ORNL scientists regarding the usefulness of these computers, two were acquired: one for test, evaluation, and development; and one for spare parts.

It is not readily apparent that the use of these machines will be economically advantageous to ORNL. Each machine will require a large power supply, forced air circulation for cooling the computer logic electronics, circulating water for cooling the computer power module, and a man-machine interface. All programming must be done in machine language, not assembly language. There are no assemblers, compilers, loaders, etc., available for the computer. Since the computer has only disk memory (no core memory), the programming techniques required differ from those routinely used in programming machines with core memory. Although a few spare parts exist, they are not readily available, and spare memories are nonexistent except in other such computers.

The potential usefulness of the computer in its present form appears to be in its capability to sense 48 discrete digital input lines and several incremental (square-wave pulse) inputs, and to set 32 discrete digital output lines and three 8-bit digital-to-analog converters. This is the type of capability that is missing in the low-cost minicomputers available today. The application of the computer appears to be most promising in the sense of an input-output device (a data acquisition or process control interface) for a minicomputer.

A group consisting mostly of colleges and universities was formed to exchange information pertinent to the use of the computer. The Union Carbide Corp., Nuclear Division, is a member. Among the various projects known to be in progress by members of this group are Teletype input-output interfaces and a "cross-assembler" to run on an IBM 360 computer. It is not anticipated that time and manpower will be available for investigation of potential uses of the D-17 computer at ORNL until the interfaces and assembler are available.

7.28 RADIOISOTOPIC SAND TRACER STUDY

H. R. Brashear	J. M. Rochelle
E. H. Acree	P. L. Simpson
F. N. Case ¹	F. W. Snodgrass
J. M. Jansen	R. E. Wintenberg

The Radioisotopic Sand Tracer Study (RIST)²⁻⁶ is a continuing cooperative program of the AEC Division of Isotopes Development and the U.S. Army Corps of Engineers. Its purpose is to develop methods and equipment for the study of the movement of littoral sediment along the coastlines of the United States. Two additional field studies were conducted this year: at Point Mugu, California, in November 1970; and at Masonboro Inlet, North Carolina, in March 1971.

At Point Mugu, testing of the core insertion device⁷ was continued, and an initial test of a bottom elevation monitor was conducted. The bottom elevation monitor consisted of a ¹⁹⁸⁻¹⁹⁹Au source buried ~10 in. in the sand at 15 ft of water depth with a 2 X 2 in. CsI(Na) scintillation detector positioned ~8 in. above the sand surface directly over the source. The detector was operated in a current mode into a differential operational amplifier on shore. The amplifier output was recorded on a strip-chart recorder. Changes of ±1/4 in. in the sand surface elevation were indicated by a deflection of ±5% of full scale on the recorder. Since the rapid source decay (~3 day half-life) required frequent standardization of the monitor, a license amendment to allow use of a ¹³⁷Cs source has been submitted.

A small general-purpose computer, a DEC PDP-8/I with an 8K core, a high-speed paper-tape reader, a storage oscilloscope display unit, and an incremental magnetic-tape transport, was added to the onboard RIST data collection system. During the Masonboro field study, the computer system processed the data in real time, stored it, and developed it. Data from the data collection system (punched-paper tape) were read into the computer by the high-speed reader in this initial field test of the computer system. Work was started to design and build an interface between the data collection system and the computer system to achieve real-time data processing and display.

In addition to on-line data processing, the computer was operated each night to plot "count-rate surfaces" over the area surveyed that day. From this information, a radiation material balance was computed and zonal sand-transport vectors were plotted to aid in planning the next day's activities. All operational programs were written in a modified version of FOCAL.

Design and construction of a portable, rugged, and battery-operated radiation detection and data collection system for RIST were started. The scheduled completion date is October 1971. Data will be stored on magnetic tape in a cassette tape transport, either directly from the data collection system or after the data have been processed by a small general-purpose computer. This unit will be used by the U.S. Army Corps of Engineers for making routine sand transport studies in existing problem areas along the United States coastlines. The present system will continue to be utilized in studies of the fundamental mechanisms of sand transport.

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1. Isotopes Division.
 2. H. R. Brashear, E. H. Acree, and F. N. Case, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1967*, ORNL-4219, p. 35.
 3. H. R. Brashear et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1968*, ORNL-4335, p. 42.
 4. H. R. Brashear et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, p. 43.
 5. H. R. Brashear, E. H. Acree, and F. N. Case, *Ibid.*
 6. H. R. Brashear et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 63.
 7. F. N. Case, E. H. Acree, and H. R. Brashear, "Nuclear Techniques in Environmental Pollution," IAEA, Vienna, Austria, 1971.

7.29 RADIOISOTOPIC SAND TRACER (RIST) STUDIES COMPUTER SYSTEM

R. L. Simpson J. M. Jansen, Jr.

To enhance the rate at which data reduction is carried out during experiments, an on-line computer system was developed for the Radioisotopic Sand Tracer (RIST) program (Sect. 7.28). The computer system is used on board a radiation detector tow vessel for data acquisition of tow vessel position, time, and radiation level. The computer calculates range coordinates and displays on a storage oscilloscope the towed detector position along with an indication of the detected radiation. The data are stored on IBM-compatible magnetic tape for further processing.

The computer system includes a DEC PDP-8/I computer with 8192 words of 12-bit core memory. It is further equipped with a Digitronics photoelectric high-speed paper-tape reader, an ASR-33 Teletype, a Tektronix-type 611 storage display oscilloscope, and a PEC incremental write-continuous read magnetic-tape transport.

The software (programming repertoire) was developed to use FOCAL, which was modified to contain additional commands and functions for use with the magnetic tape and for plotting on the storage oscilloscope.

Whereas the initial and primary function of the computer system was to perform real-time data processing, display, and storage, actual use during experiments revealed additional benefits. These accrue

from the ability of the system to produce a count-rate surface, radiation material balance, linear transport vectors, and an estimate of the volume rate of sand transport while the field experiment is in progress. This allows improved direction of the course of the experimental procedure, because a long wait for data processing at ORNL is circumvented.

8. Process Instrumentation and Control

8.1 TRANSURANIUM PROCESSING PLANT

H. E. Cochran	B. Lieberman
M. M. Chiles	W. R. Miller
J. T. DeLorenzo	B. C. Thompson
C. C. Hall	R. E. Zedler

Following a shutdown of the Transuranium Processing Plant (TRU) for modifications, repairs, and additions, a year-long program of operations was started in November 1970 to recover 230 mg of ^{252}Cf .

After a test model of a Hopcalite-bed-charcoal-bed radioiodine removal system¹ had been operated successfully, a larger system of equipment and instrumentation was fabricated and installed to remove radioiodine from the off-gases from all vessels and cubicles in the entire plant. Remote readout instruments and controllers were installed on the main panelboard for temperatures, flow, bypass valves, and CO_2 analysis. Solid-state amplifiers were designed and installed to give correct signal information received over some signal lines ~250 ft long. An additional power panel and switch gear were installed in the emergency generator building to obtain 30 kW required for the heater in the iodine removal systems. This new installation and temporary connections and instruments used for calibration had to be installed and operated in a radioactive area. A 10-in. venturi with a straight 18-ft length of 10-in. steel pipe was temporarily installed to calibrate the flow instrumentation.

A portable decontamination facility was installed so that various containers and capsules of transuranium materials could be decontaminated prior to shipment. The facility has a cubicle approximately 3 X 4 X 4 ft which is completely shielded by 3 ft of water and weighs 30 tons. It is equipped with two manipulators and a small electrically operated hoist. Instruments were installed to remotely control an ultrasonic cleaner inside the cubicle.

The decontamination facility is also used as a sending-receiving station at one end of a pneumatic tube that connects the TRU Building with cell G in the Thorium-Uranium Recycle Facility (TURF). When required, transuranium material is sent to cell G for processing and encapsulation, after which it is returned by the pneumatic transfer tube and prepared for shipment. The pneumatic tube with controls, alarms, and communication instrumentation was designed, fabricated, and installed. An ORNL-designed neutron monitor was installed in the vicinity of the decontamination facility to warn personnel of the presence of radioactive material and to indicate the passage of a loaded capsule through the pneumatic tube.

A typical shipment of the refined product was made in seven platinum shipping packages containing about 50 mg of ^{252}Cf . The packages were placed in stainless steel containers welded closed, transferred by pneumatic tube to TRU for decontamination, and shipped to the Savannah River Laboratory. Instruments and control devices were designed and installed for handling these packages and containers and for storing an inventory of product material. A solid-state interface between the welding machine and a fast trace

recorder provides a noise-free signal. Controllers were included to adjust the recorded curve to fit the chart, regardless of the welding parameters. A usable record of the welding "signatures" is now available for each container welded.

To measure the neutron source strength from fabricated ^{252}Cf sources, a fast-neutron detection system was designed and installed.

Other peripheral installations were modified as follows:

1. The building air supply was connected to air compressors at the High-Flux Isotope Reactor building where a surplus of air was available (Sect. 9.6). This permits the two TRU air compressors to be shut down for maintenance and then held in standby if the building air supply pressure drops below 70 psig.
2. To check on the vessel off-gas system, an alpha monitor with ORNL standard radiation instruments for remote recording and alarming at the main panelboard was designed and installed.
3. Solid-state, silicon-diode detectors of neutron and alpha particles were incorporated into a special design (ORNL) in a cubicle test setup for radiochemical analysis purposes.

¹. H. E. Cochran et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 65.

8.2 INSTRUMENTATION FOR THE LWBR SUPPORT PROGRAM

R. E. Toucey

The design of instrument systems for the Light-Water Breeder Reactor Program at ORNL was almost completed. In this program several hundred kilograms of ^{233}U will be stored, purified, and converted to oxide. Installation of the storage and processing equipment was begun in the Radiochemical Processing Pilot Plant, Building 3019. Instrumentation for the purification process was installed and tested. Instrumentation for the storage system was completed and in use as previously reported.¹

Equipment for conversion of uranyl nitrate to oxide is being installed and is scheduled for completion by January 1972. Instruments for the oxide conversion line will require a panelboard ~16 ft long and 10 small subpanels mounted locally at the glove box enclosures. The small subpanels will contain controls for 90 remotely operated on-off valves mounted inside the alpha enclosures. The large panelboard will have alarms and instruments for indicating, recording, and controlling the following measured variables: temperature, pH, liquid level, gas flow, the proportion of hydrogen in air and in argon, and the proportion of oxygen in air.

An in-cell scanning device was designed, fabricated, and installed (Sect. 4.3) to monitor the radiation level in the ion exchange column. The scanner will show the height of gamma-emitting contaminants in the column and indicate when elution is required. A device purchased for weighing the UO_2 powder prior to scanning is accurate to 1 part in 15,000 over a range from 100 to 1000 g. Each weight will be automatically corrected for the tare weight and printed on gummed labels as well as paper tape in ASCII code.

¹. R. E. Toucey, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 66.

8.3 THORIUM-URANIUM RECYCLE PROGRAM

H. E. Cochran C. D. Martin, Jr.

About midyear an engineer was assigned half-time to the Thorium-Uranium Recycle Program to become familiar with the program in its earlier stages and, later, to coordinate the Instrumentation and Controls

Division effort on all instrument requirements for the program. Fuel inventory control and material balance, data acquisition, process control, and quality control of the end product will require much instrumentation assistance and equipment.

To date, direct assistance has been given to design a particle size analyzer (Sect. 8.23). Also, the gas flow requirements have changed since the original coating furnace control panel and valves were designed, purchased, and installed.¹ New control settings, scales, and ranges for operating the originally installed valves and panel instruments were determined and are being used.

A requirement to automatically acquire and perform calculations on microsphere cross-section data from a split-image microscope was studied to determine the best type of equipment for this purpose. A small, general-purpose digital computer system was proposed, and a like system was demonstrated, using the Instrumentation and Controls Division PDP-8/I computer² programmed in FOCAL. An ADP Committee proposal was prepared, and a PDP-8/E computer including interfaces was ordered. An existing Teletype and cabinet will be used. This small system is expandable and capable of servicing other engineering experiments in the Thorium-Uranium Recycle Program in the future.

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1. C. S. Lisser et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1967*, ORNL-4219, p. 68.
 2. R. K. Adams et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 51.

8.4 IMPROVEMENTS TO ORNL SANITARY SEWAGE TREATMENT PLANT

B. C. Duggins

At the request of the Operations Division, the ORNL sanitary sewage treatment plant was evaluated, instruments and controls were added to improve its efficiency, and an automatic sampling system was designed and installed to monitor the plant operation.

The plant, constructed in 1949, was of traditional design in that the influent flowed by gravity into a wet well and was pumped periodically into a settling basin (Fig. 8.4.1) controlled by level switches. The solids settled in this basin, and the liquid overflowed into a channel leading to a natural stream.

To minimize environmental pollution, the plant efficiency was studied and found to vary significantly. This variation was attributed to the pattern of flow into the settling basin, in that, when the wet well became full, the lift pump started and pumped into the settling basin at several times plant capacity. As a result, residence time of the sewage in the basin was inadequate to allow efficient separation of solids from liquid. The system was improved by adding new valves and a proportioning recirculation control system. The lift pump is operated continuously, and the flow to the settling basin is "averaged" to allow a maximum residence time in the basin consistent with the quantity of plant influent.

Equipment was also added to automatically collect samples from the influent and effluent streams for analysis at a selectable interval of accumulated flow. The sample valves open wide for a selectable period, typically 10 sec. at a selectable accumulated flow, typically 10,000 gal (Fig. 8.4.2). Sampling this way enables a good evaluation of the average plant efficiency because some samples are collected at high-flow conditions and some at low-flow conditions. In a sampler, an input stream from the sample point flows tangentially into an annular space between two concentric vertical pipes and overflows down into the inner pipe. This accomplishes two purposes: (1) it keeps the solids and liquid mixed, and (2) it maintains a small but constant head on the sampling valve. Each valve is relatively large to prevent clogging and is located close to the sampling chamber to avoid a stagnation space. Since both the head across the valve and the time that the valve is open are controlled, the same sample volume is delivered each time the sample sequence is actuated.

Fig. 8.4.1. Recirculation control for continuous sewage flow to settling basin.

Fig. 8.4.2. Sewage sampling method.

8.5 ORNL LIQUID WASTE EFFLUENTS

A. H. Malone

Radiation monitoring of liquid waste effluents from buildings and other outlets at ORNL has been a standard procedure to prevent the escape of radioactive materials into the nearby waters. After review and curtailment of water and steam usage, the volume of liquid waste effluents was reduced to one-fourth. Because of this drastic reduction and a need for more accurate accounting of the volume of water and concentration of radioactivity in the water, the measuring and sampling equipment was resized and upgraded.

In the ORNL system about 14 flow-measuring, radiation-monitoring, and waste-sampling systems are installed in manholes that collect waste flow from the various buildings and areas in Bethel Valley. After the waste from these areas is sampled, it is either discharged to White Oak Creek or held in the waste ponds for treatment before being discharged to the creek. Final monitoring and analysis takes place at the outlet of the settling basin and at station 3 in White Oak Creek.

All of these measuring stations were reviewed by the Instrumentation and Controls Division. The ranges were changed so that records are produced at approximately midscale instead of <10% of full scale. Tree roots, sediment, and other types of accumulated debris were removed from the upstream ponds of weir plate dams. All recorders and telemetry transmitters were thoroughly overhauled in the Instrument Shop after >10 years of continuous service, using revised procedures to give accuracies within 0.5% of full scale from 0 to 100%. Routine check and maintenance procedures were started. Better sampling devices that will deliver a more representative sample are being studied since future requirements indicate that even greater accuracies will be needed in the measurement and sampling of these liquid wastes.

8.6 ENGINEERING SUPPORT FOR THE METALS AND CERAMICS DIVISION

B. G. Eads

Beginning in February 1971, instrument engineering support was scheduled half-time to the Metals and Ceramics Division.

A hydrogen leak detection system in Building 4508 was examined to determine the advisability of purchasing a new system. The system was tested to determine its ability to perform its specified functions, and maintenance problems and costs for the system were checked closely for a six-month period. Because there were many maintenance problems and a high cost of repair and many operational difficulties, a new detection system was recommended.

A system for acquisition of data for the Creep Rupture Facility was installed. The system consists of linear, variable differential transformers (LVDT's), demodulators, and a digital voltmeter with 20 switch-selectable input channels.

Additional channels of LVDT instrumentation, with on-site calibration of each LVDT with its demodulator, were installed for in-cell creep test machines in Building 3025.^{1,2}

Assistance was given in tuning and improving the performance of existing temperature control systems.

1. L. H. Thacker and J. W. Starken, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1967*, ORNL-4219, pp. 71-72.

2. R. E. Toucey, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 129.

8.7 EXPLODING-WIRE AEROSOL GENERATOR¹

H. E. Cochran B. Lieberman H. N. Wilson

An exploding-wire aerosol generator (Fig. 8.7.1) for the production of metallic oxide smoke was fabricated for the National Air Pollution Agency of HEW.

The major components were obtained commercially. The unit operates from a 120-V power source. It is a self-contained, 3000-J pulse energy system with voltages ranging from 10 to 25 kV. It has a peak current

PHOTO 0365-71

Fig. 8.7.1. Exploding wire aerosol generator.

capability greater than 0.5 MA. The portable unit comprises control and power modules, an ultralow inductance capacitor (15 μ F/20 kV), a high-voltage switch and generator, an explosion chamber, and a remote firing switch. Interlocks prevent exposure of operating personnel to high voltage when they dismantle the chamber to insert a new wire across the capacitor electrodes.

A 7.5-kV pulse from the high-voltage generator actuates the high-voltage switch to discharge the capacitor through a wire of known mass. The aerosol produced in the chamber can be sampled for particle size analysis, collected for yield and reproducibility studies, or used for animal inhalation studies and other research.

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1. F. G. Kazioris and B. R. Fish, *J. Colloid Sci.* 17, 155-61 (1962).

8.8 SUPPORT FOR THE FISSION PRODUCTS DEVELOPMENT LABORATORY

B. Lieberman

To assist the Isotopes Division in continuing operation of the Fission Products Development Laboratory, Building 3517, ~75 man-days of technician and 20 man-days of engineering assistance were expended to modify and maintain the instruments in this facility. Two of the more significant instances of engineering assistance were (1) low-coolant-flow, orifice-type, interlock and alarm switches were replaced with rotameter-type (constant-head loss) flow switches so that the availability of cooling water would not be reduced at the normal flow condition; and (2) a system was installed to dissolve and flush plugs from instrument dip pipes, remotely, so that technicians would not have to enter radioactive zones to do this.

8.9 SHORT-DURATION TEMPERATURE PROGRAM GENERATOR

B. C. Duggins J. M. Googe¹

A temperature program generator was developed, using inexpensive operational amplifiers, in which the set point generated for a temperature controller can be made to vary either linearly or exponentially with time. The programmer is simple and inexpensive to build and fills a need for a short-duration (1 hr) unit, which is not available in standard process programmers. In the programmer circuit (Fig. 8.9.1), positive feedback around an operational amplifier connected as an integrator directly yields an exponential response.

The exponential response represents a compromise with that actually desired, as indicated in the equation for $T_2(t)$ in Fig. 8.9.1. However, it could be realized only by using amplifiers, and parameters were chosen by least-squares curve fitting to make the exponential equation adequately fit the desired equation.

The generated set-point signal can be used directly with commercial temperature control systems of modular design in which the set point is compared with a thermocouple signal value by a deviation amplifier.

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1. Consultant from the Department of Electrical Engineering, the University of Tennessee, Knoxville.

8.10 THERMOCOUPLE ANOMALY DETECTOR

B. C. Duggins J. M. Googe¹

Development of methods was begun for in-place testing of thermocouples installed in reactors for actual or incipient failure. This work is part of the Liquid-Metal Fast Breeder Reactor (LMFBR) program. Of

Fig. 8.9.1. Function generator for T_1 and T_2 .

particular interest are failure modes other than burnout, such as formation of multiple junctions (wires shorting together), grounding (a short to the sheath), or detachment of the thermocouple from the point of attachment where a temperature measurement is desired. Previously used methods of testing thermocouples are inadequate, because either they do not reveal failure modes as described or they are too cumbersome and expensive. In the work done to date thermocouple "signatures" were recorded, with the expectation that certain characteristics of the signatures (or changes in the characteristics with time) would indicate the failure modes described. Two distinct types of signatures were investigated: (1) signatures produced by time domain reflectometry (TDR), and (2) the transfer function of the thermal system as measured at the thermocouple terminals.

Time domain reflectometry refers to the technique of observing traveling electromagnetic waves that move along a distributed circuit, usually called a transmission line, in response to an excitation at one point on the line. Equipment, such as the Tektronix 1S2 TDR Unit,² is commercially available for both generating an appropriate excitation and for observing the resulting waveforms. There also exists a well-defined body of transmission line theory that is useful for understanding the characteristics of the TDR signature.³

Conclusions from preliminary testing are that a sheathed thermocouple does behave to some extent like a lossless transmission line. However, since line resistance tends to obscure important characteristics of the waveform, an improved analysis method over the lossless line theory will have to be developed if one wishes to detect more than gross discontinuities in the thermocouple. The TDR signatures for sheathed $\frac{1}{8}$ -in. thermocouples are compared in Fig. 8.10.1.

To detect that a thermocouple has become detached from the point of attachment where a temperature measurement is desired has always been a perplexing problem. A promising way to detect such detachments (made feasible by digital data reduction methods now available) is to determine changes in the transfer function of the thermal system through measurements made at the thermocouple terminals. Methods for

Fig. 8.10.1. Comparison of time domain reflectometry (TDR) transients in 64-cm-long, $\frac{1}{8}$ -in-OD sheathed Chromel-Alumel thermocouples. (a) Closed-circuit thermocouple. (b) Open-circuit thermocouple.

determining these transfer functions from data obtained from systems operating under steady-state conditions are well-known.⁴ These methods are based on obtaining the response of the system to random inputs and recovering the system transfer function by correlation and Fourier-transform operations. The utility of the methods depends on the statistics of the random input which, in the practical situation of a thermocouple in a reactor, depends on the turbulent flow conditions.

To develop this method of testing, it will be necessary to establish these statistics and to develop correlation and Fourier algorithms suitable for the physical situations in the LMFBR program. To date, a flow test facility consisting of a simple water loop and an associated PDP-8/I computer has been established. The computer was programmed to collect step response data and to obtain the transfer function of the tested assembly using Samulon's method.⁵ The transfer functions are plotted in the traditional gain-phase manner on the computer system storage scope and are thus available for immediate interpretation. A sample transfer function plot as photographed on the storage scope is shown in Fig. 8.10.2.

1. Consultant from the Department of Electrical Engineering, the University of Tennessee, Knoxville.
2. *Time Domain Reflectometry, Programmed Instruction*, 1 and 2, Tektronix Publications 062-0703-00 and 062-0704-00, Beaverton, Oregon, 1966.
3. W. C. Johnson, *Transmission Lines and Networks*, McGraw-Hill, New York, 1950.
4. V. V. Solodovnikov, *Statistical Dynamics of Linear Automatic Control Systems*, Van Nostrand, Princeton, N.J., 1965.
5. H. A. Samulon, "Spectrum Analysis of Transient Response Curves," *Proc. IRE* 39(2), 175-86 (1951).

FREQUENCY RESPONSE DIAGRAM

FREQUENCY-- 0.10000E-01 TO 0.10000E+03
RADIANS/sec

MAGNITUDE RATIO-- 0.01 TO 10.0

PHASE-- -360 TO 0 DEGREES

Fig. 8.10.2. Transfer function plot of a typical thermocouple test assembly.

8.11 PRECISION TEMPERATURE CONTROL SYSTEM FOR OXIDATION STUDIES

B. G. Eads

Instrumentation was furnished for an oxidation analysis facility for evaluation of the corrosion protection provided by ion-plated and sputtered metallic coatings. This facility is operated by the Development Division at Y-12.

To achieve stable control of furnace temperature to within $\pm 0.1^\circ\text{C}$, the most important system specification, the thermocouple signal is suppressed and then amplified to produce a narrow span about the set point, and then the amplified output signal is fed back to a controller. Vacuum pumps and instrumentation were also furnished.

8.12 RDT STANDARDS FOR PROCESS INSTRUMENTATION

C. S. Lissner J. A. Russell

Work for the USAEC Division of Reactor Development and Technology (RDT) Standards Program¹ was continued to the extent of about $1\frac{1}{4}$ man-years. Consultation services were made available to RDT and

its contractors. New standards for process instrumentation were prepared, others were revised to accommodate review comments, and standards prepared by others were reviewed.

Eight process instrumentation standards were approved for issue as "Tentative Standards," with three others awaiting approval. The work done on specific standards this year is shown in Table 8.12.1.

Table 8.12.1 Status of RDT standards for process instrumentation

Number	Title	Work done	Status Sept. 1 ^a	
			1970 ^b	1971
C 2-1	Determination of Insulation Compaction in Ceramic Insulated Conductors	Approved as "Tentative Standard"	4	1
C 2-3	Thermocouple Time Response Test	Draft issued for internal review	1	1
C 4-1	Orifice Plate for Orifice Flange Union	Approved as "Tentative Standard"	4	5
C 6-1	NaK Transmission High-Temperature Pressure Transmitter for Liquid Metal Service	Issued for review; turned over to LMEC	2	3
C 6-3	Liquid Metal Pressure Measurement System, Flush-Mounted, Eddy-Current Type, Inductive, Absolute or Gage	Reviewed for LMEC		
C 6-5	NaK Transmission High-Temperature Pressure Transmitter for Molten Salt Service	Draft issued for internal review		1
C 7-5	Thermocouple Material, Chromel-P vs Alumel, Magnesium-Oxide Insulated, Stainless Steel Sheathed	Issued for review		3
C 7-7	Thermocouple Materials, Platinum and 90% Platinum-10% Rhodium Wires, Noninsulated Reference and Standard Grades	Draft issued for internal review		2
C 7-15	Thermocouple Connectors and Thermocouple Connector Panels	Submitted for approval as "Tentative Standard"	1	4
C 7-16	Thermocouple Assemblies, Magnesium-Oxide Insulated, Stainless Steel Sheathed	Submitted for approval as "Tentative Standard"	1	4
C 8-2	Liquid Sodium Bearing Film Thickness, Variable Reluctance Sensor Proximity Measure System	Reviewed for LMEC		
C 9-1	Single-Point, Strip-Chart Recording Potentiometer	Approved as "Tentative Standard"	4	5
C 9-2	Multipoint Strip-Chart Recording Potentiometer	Approved as "Tentative Standard"	4	5
C 11-2	Pyrometer, High Sensitivity, Indicating and Controlling	Submitted for approval as "Tentative Standard"	3	4
C 13-1	General Purpose Stored Program, Digital Computer	Evaluated for combination with PNL BWNL-1378	1	Hold
C 19-1	Cardiac Pacemaker Electronic Circuits, for use with Radioisotope Power Supply	Reviewed for NUMEC		
F 3-11	Mass Spectrometer Helium Leak Detection for Instruments and Small Components	Rewritten from version numbered C 2-2		2
F 4-1	Maintenance Program Requirements	Reviewed		
F 4-20	Operation and Maintenance Manuals	Reviewed		
M 3-20	Polyethylene Instrument Tubing	Issued for review		3

^aNormal progression is (1) draft, (2) internal review, (3) issued for review, (4) submitted for approval, and (5) approved.

^bC. S. Lissner et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 74-75.

A detailed proposal was submitted to RDT covering the preparation of process instrumentation system standards, that is, those concerned with guiding RDT contractors in the design, installation, and operation of process instrument systems. When funded, these standards will become part of a new series of standards, the Engineering Technology References.

Active participation in the work of the Instrument Society of America SP 60.00 (Control Centers) Committee was started.

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1. C. S. Lissner et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 74-75.

8.13 DESIGN AND APPLICATION OF A TIME-OPTIMUM CONTROLLER FOR A CLASS OF NONLINEAR PROCESSES¹

B. G. Eads

A procedure is presented for extension of time-optimum control for linear processes to a class of nonlinear processes. The nonlinear processes considered are those having nonlinear gain, that is, steady-state gain which varies with operating point. Bang-bang control is combined with the conventional three-term (proportional-integral-derivative, referred to as PID) controller to provide time-optimum control for set-point changes and good regulator operation. The dual-mode controller is implemented in a small digital computer.

An overdamped second-order transfer function with dead time is assumed to describe the process dynamics. The nonlinear gain is determined either empirically or theoretically from process considerations. The optimum control function is determined using phase plane analysis.

Comparison of settling time for step set-point changes with dual-mode control is made to PID control alone. The improvement that time-optimum control provides over conventional control is further demonstrated. Dual-mode control was successfully applied to hybrid simulations of a linear process and a process having nonlinear gain. Successful application was also made to an actual process having nonlinear gain.

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1. Abstract of M.S. thesis (University of Virginia) and published report ORNL-TM-3178 (September 1971).

8.14 STANDARDS LABORATORY SERVICES

M. H. Cooper W. W. Johnston, Jr.

The Standards Laboratory of the Instrumentation and Controls Division continued to provide temperature, pressure, and electrical measurement standards for ORNL research programs, such as new instruments and techniques for high-temperature measurements for the Liquid-Metal Fast Breeder Reactor (LMFBR) and test and evaluation of thermocouples and platinum resistance thermometers for the Fast Flux Test Facility (FFTF). The laboratory also continued development studies to maintain a capability to accurately measure the volts and temperatures in the optical pyrometer range and to ensure traceability of its pressure standards.

The major part of the routine work load was to calibrate 300 temperature sensors, obtaining a computer print-out of the emf vs temperature characteristic for most units.

Special projects involved development of techniques for determining the melting points of small samples of silver-copper alloys, calibration of niobium-zirconium sheathed thermocouples, preparation of inspection procedures, and supervision for specification compliance testing of thermocouples for the Zircaloy-clad LMFBR Fuel-Failure Mock-Up (FFM) experiment.

A system was set up to ensure that correct records would be filed for all thermocouple materials and fabricated thermocouples with regard to the ORNL Quality Assurance Program for RDT sensors. Work was started to organize a file system for traceability of quality assurance documentation and standards.

The Standards Laboratory continued to cooperate with the National Bureau of Standards in the development of thermocouple tables for the International Practical Temperature Scale of 1968.

8.15 SELF-ADAPTIVE CONTROLS FOR AUTOMATIC WELDING INSTRUMENTATION

W. R. Miller

A series of self-adaptive controls are being developed at ORNL to permit application of an automatic pipe-welding system¹ to remote welding for nuclear reactor fabrication and maintenance.

Digital and analog techniques sense the voltage drop across the arc, develop corrective signals, and readjust the torch to work spacing (Fig. 8.15.1). The corrective action is applied to vertical, horizontal, and oscillatory drive motors located in the orbiting weld head. Thus, corrections are made automatically for perturbations and misalignments normally encountered in remote welding operations.

Fig. 8.15.1. Self-adaptive controls for automatic welding instrumentation.

The overall system consists of three interrelated control functions: (1) automatic vertical control (AVC), (2) automatic horizontal control (AHC), and (3) automatic oscillator control (AOC).

1. Developed for the U.S. Air Force by North American Rockwell.

8.16 AUTOMATIC REMOTE WELDING SYSTEM

R. L. Moore

W. A. Bird	G. A. Holt	W. R. Miller
C. C. Courtney	E. C. Keith	C. A. Mossman

Assistance was continued^{1,2} toward an immediate objective of developing equipment, welding procedures, and programmed controls so that welds with quality suitable for nuclear reactor systems can be produced without manual adjustment. A more distant objective is the development of automated welding systems for use in remote maintenance of molten-salt reactor systems.

During the past year Division personnel completed several tasks, as follows:

1. Completed preparation of construction drawings for fabrication of additional programmers.
2. Developed an arc-length control circuit and incorporated this circuit in the prototype programmer (Sect. 8.15).
3. Developed interlock circuits that protect equipment and minimize damage to the weld and to the welded component if the welding system malfunctions or operates improperly. These circuits also prevent startup of the welder or shut it down if the flow of gas or water to the torch becomes too low and initiate a programmed shutdown if the torch "stubs" (touches down).
4. Modified an optically coupled isolation amplifier circuit to replace an optical coupler which was no longer available and for which no exact replacement could be found.
5. Fabricated and checked out three additional programmers in-house.
6. Specified, purchased, and modified two multichannel recorders that will be used for diagnosis and obtaining permanent welding records.
7. Initiated and monitored a contract for commercial fabrication of two additional programmers.
8. Developed check-out and calibration procedures for the programmer and assisted with preparation of an operations manual in which these procedures will be included.
9. Provided engineering assistance to diagnose and correct programmer malfunctions.
10. Assisted with the development of weld setup and operational procedures.
11. Participated in an industrial cooperation conference (welding symposium) held at ORNL, February 25, 1971, and sponsored jointly with the Air Force Rocket Propulsion Laboratory.

The programmers fabricated this year will be delivered to TVA and RDT for use in the construction of the Brown's Ferry Reactor, the Fast Flux Test Facility, and in other AEC projects such as the Sodium Pump Test Facility (SPTF) and the Liquid Metals Engineering Center (LMEC).

1. R. L. Moore, W. A. Bird, and C. C. Courtney, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, p. 71.

2. R. L. Moore, W. A. Bird, and E. C. Keith, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 72.

8.17 40-kV PLANE DATA TRANSMISSION SYSTEM

W. R. Miller

A system (Fig. 8.17.1) for transmitting a single channel of precision analog data from equipment operating at 40 kV aboveground to equipment operating at ground potential was designed and built.

Fig. 8.17.1. 40-kV plane data transmission system.

Digital and analog techniques are used to produce an overall system precision of 0.1% of full scale. Data are transmitted across the 40-kV gap by pulsing a light-emitting diode through a single Lucite rod that is coated to exclude ambient light. The pulsed light signal is received by a silicon photovoltaic cell.

On the 40-kV side, a 100-kHz crystal oscillator pulses a binary counter whose output feeds a digital-to-analog converter (DAC). The stair-step output of the DAC is referenced to the analog data signal at the input of a high-speed comparator. The comparator output produces pulses that reset the binary counter and feed the light-emitting driver.

On the ground side of the system, an identical 100-kHz crystal oscillator pulses a binary counter and a DAC through a set of strobed latches. This side of the system has some digital logic to route the oscillator pulses and to produce strobe and reset pulses.

By this method, the output signal from the DAC does not stairstep to the analog value each cycle, but is simply updated and can be used without being smoothed or filtered.

One obvious advantage of this system vs typical ADC, DAC conversion is that only one light pipe is required across the isolating gap.

8.18 CURRENT PROFILE PROGRAMMER

J. L. Redford

An in-pile device was proposed for accurate measurement of dimensional changes of a graphite specimen while it is being irradiated. The device will have a linear, variable differential transformer (LVDT); to calibrate the LVDT, its core will be moved periodically by a solenoid to fix its calibration positions.

Fig. 8.18.1. Computer plot of current output.

To prevent damage to the specimen or the calibration limit stops, the current to the solenoid must be carefully controlled to raise and release the core. To do this, a solid-state current profile programmer was designed, making use of a commercial diode function generator. When the solenoid is not being used, the power supply output is shorted (to discharge the filter condensers), and the circuit to the solenoid is opened. The current programmer controls the output of a power supply with 30-A, 60-V output capability.

The profile programmer was tested by a PDP-8/I computer with an oscilloscope display.¹ The computer listed and plotted (Fig. 8.18.1) the input and output signals to the profile programmer, allowing changes to be tried and evaluated rapidly.

1. R. K. Adams et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 51-52.

8.19 FLOW FLUORIMETER-PHOTOMETER

L. H. Thacker

A new instrument, combining a fluorimeter and a photometer in a single miniaturized detector head (Fig. 8.19.1), developed for use in the body fluids analyses program, is being used in a study aimed at developing a new and unique method of carbohydrate detection for liquid chromatography.

Both the fluorescence and the transmittance measurements are made at an excitation wavelength of 254 nm; effective use of the instrument as a fluorimeter is limited to the detection of materials that are significantly excited at this wavelength and emit fluorescent light at wavelengths >300 nm.

The excitation radiation from a miniature low-pressure mercury lamp passes through a 254-nm interference filter. Sample and reference streams flow through cells embedded in a small cylinder of solid acrylic plastic; the cells have quartz windows at each end and are painted with white reflective paint except

Fig. 8.19.1. Flow fluorimeter-photometer.

over the windows and over the surface coupled to the photomultiplier tube. The acrylic plastic functions as a selective filter, providing very effective blocking of the 254-nm exiting radiation from the photomultiplier. The transmittances of the sample and reference streams are measured by a pair of photoconductors, and the fluorescent emission is detected by a miniature photomultiplier.

8.20 OPTICAL LEVEL SENSOR

L. H. Thacker

An optical level sensor was developed to replace an electrical conduction type previously used on a system for desalting protein solutions. The substitution was made to reduce the possibility of damage to the protein molecules by the electrical current that the earlier detector passed through the solution. Three new sensors are in service; two provide low-level signals on each of two acrylic columns, and the third controls addition of liquid to the system.

The sensor (Fig. 8.20.1), attached outside the acrylic columns, consists of an aluminum body, an incandescent lamp, and a photocell. Acrylic plugs inserted in the body and cut to the contour of the column provide optical coupling to the column without deflection of the light beam. When the liquid level is below the sensor, the light strikes an acrylic-air interface and is reflected to the photoconductor, lowering its resistance. A sensitive relay is actuated when the lighted state of the photocell is changed, and appropriate control actions are initiated.

The sensor performs satisfactorily even when there is a layer of foam on the liquid, and the electronic circuit wire shuts down the system if any of the lamps burn out.

ORNL-DWG 70-8918K

Fig. 8.20.1. Optical liquid-level sensor.

8.21 DENSITY GRADIENT TUBE SCANNER

L. H. Thacker

An instrument was designed and built for scanning density gradient centrifuge tubes to determine the location of both light-scattering and fluorescent bands. The tubes are filled with a solution that varies

Fig. 8.21.1. Density gradient tube scanner.

linearly in specific gravity from top to bottom; a sample placed on top of the liquid in the tube and spun in the centrifuge will form a band in the tube at a level corresponding to its own specific gravity. The instrument is used in the Molecular Anatomy (MAN) Program to implement a newly developed technique that shows when an antibody-antigen reaction has taken place, and, in addition, allows the researcher to quantitatively measure extremely small amounts of antigen. An advanced version of the scanner is being designed.

The tube scanner (Fig. 8.21.1) consists of an axial light source, a mechanical drive for passing the sample tube along the axis of a circular slit, a light collection system, and a photomultiplier for detecting scattered or fluorescent light. For operation in the scattering mode, the light source is a 150-W quartz-iodine lamp connected to the instrument with a fiber optic light pipe. Fluorescent response is obtained by substituting a low-pressure mercury lamp with appropriate filters directly in the instrument housing. The light to be recorded is defined by a pair of angular slits, each $\frac{1}{32}$ in. wide, separated 1 in. Light scattered or emitted in a full 360° circle is collected by a Lucite ring surrounding the slit system. The ring, in turn, is coupled to the photomultiplier tube through appropriate filters. For detection of fluorescent light, the collector ring itself is a major part of the filter system, passing the fluorescent emission with high efficiency while blocking the 254-nm excitation radiation almost completely. The output is recorded as response vs position on an x-y recorder.

8.22 BACK-MIXING DETECTOR

L. H. Thacker

An instrument system was designed and assembled for making back-mixing measurements to determine the feasibility of using a spiral ultrafiltration membrane cell to concentrate peaks eluted from a liquid chromatograph column. These measurements by the Chemical Technology Division show this peak concentration technique to be promising.

The system has two identical channels separated by various cells and lengths of plastic tubing through which experimental liquids are forced by compressed air. A clearly defined segment of liquid containing a dye can be inserted into the flowing stream. The dye-laden liquid passes sequentially through one of two detector cells, a length of tubing containing an ultrafiltration cell, and the second detector cell. In each detector cell the optical transmittance of the liquid is measured continuously, at 570-nm wavelength, and recorded on an oscillograph.

In a test run, the shape and amplitude of the two transmittance curves were analyzed to obtain back-mixing measurements, and the velocity of the liquid was obtained precisely from the separation of the two peaks.

8.23 PARTICLE ANALYZER

L. H. Thacker W. R. Miller T. F. Sliski

A particle analyzer for counting and measuring the cross-sectional area of nuclear fuel microspheres was designed and built to replace a commercial analyzer which never had worked satisfactorily. Only the ten-decade registers of the original system were used to build the new analyzer.

The new system has a silicon photovoltaic cell and transistor integrated circuits. Its detector head contains, in addition to the photovoltaic cell, an intensity controlled incandescent lamp and a vibrating photochopper (an advanced type manufactured by the Bulova Watch Co., utilizing a tuning fork) with micrometer positioning to aid in system alignment and calibration.

The instrument is being tested and calibrated prior to routine use.

8.24 MINIATURE PHOTOMETERS FOR LIQUID CHROMATOGRAPHY¹

L. H. Thacker

S. Katz² W. Wilson Pitt² C. D. Scott²

A series of miniature photometers has been developed for use as on-stream detectors in systems for liquid chromatography. All of the detectors feature dual-beam, dual-wavelength operation without mechanical or electrical switching of either wavelength or signal. The two types of detectors originally developed – ultraviolet (254 and 280 nm) and colorimetric (any two choices of visible wavelengths) – have been integrated into a single modular instrument that can be converted from ultraviolet to use with visible wavelengths by substituting source and filter modules. Both straight-through vertical quartz tube flow cells of 3-mm ID and Z-cell modules with 10-mm light pathlengths are available. A single-unit power-source and range-switching box is used with any configuration of the detector.

1. Abstract of journal article: *Chn. Chem.* 16, 626 (1970).

2. Chemical Technology Division.

8.25 A MINIATURIZED ULTRAVIOLET FLOW PHOTOMETER FOR USE IN LIQUID CHROMATOGRAPHIC SYSTEMS¹

L. H. Thacker C. D. Scott² W. W. Pitt, Jr.²

A miniaturized ultraviolet photometer for continuously monitoring chromatographic column effluents at 254 and 280 nm has been built and tested at the Oak Ridge National Laboratory. The instrument is of double-beam design and employs dual solid-state electronic circuits for operation without wavelength switching and multipoint recorder synchronization. Performance tests have shown that the ultraviolet

photometer can provide greater sensitivity and less band spreading of chromatographic peaks than the modified spectrophotometer that was used previously.

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1. Abstract of journal article: *J. Chromatogr.* 51(2), 175-81 (1970).
 2. Chemical Technology Division.

8.26 IRRADIATION OF FUEL CENTER-LINE THERMOMETRY CARTRIDGE ORTC-4

R. L. Shepard H. E. Robertson¹ R. F. Hyland A. H. Malone

An irradiation cartridge, based on a mixed-oxide Liquid-Metal Fast Breeder Reactor (LMFBR) fuel pin with a W26Re center-line well, was built and irradiated in the B-2 core position of the Oak Ridge Research Reactor (ORR) for 338 hr to study the behavior of two center-line temperature sensors: a hafnia-insulated W3Re/W23Re thermocouple and a rhenium ultrasonic thermometer. The W-Re thermocouple operated properly for most of the irradiation period, accumulating a thermal neutron fluence of about 10^{20} neutrons $\text{cm}^{-2} \text{sec}^{-1}$ in two periods of 140 and 198 hr at temperatures between 2000 and 2200°C. The electrical connections to the ultrasonic thermometer opened on first warm-up of the experiment, and no useful information was obtained from it. Precise measurements were made continuously of the thermocouple loop resistance, and the data are being correlated with thermocouple emf and examined to identify causes for some periods of erratic thermocouple behavior. Time domain reflectometry and noise analysis techniques were used for thermocouple analysis.

Modifications of the previous ORTC-3 design² successfully eliminated sodium temperature fluctuations and maintained the integrity of the thermocouple penetration seal. The behavior of the experimental loop and operation of the positioner were improved to a satisfactory status. The W26Re fuel-pin center-line well contained the fuel until the end of the test when it apparently ruptured during withdrawal and cooling of the cartridge.

The apparatus was operated to maintain the fuel-clad temperature at 1100 to 1175°F (595 to 635°C) by adjusting the insertion depth of the cartridge into the core, varying from 8 to 9 in. above the core center line. A four-wire connection to the W-Re thermocouple, that is, two compensating leads and two coaxial leads, enabled precise measurement of the thermocouple loop resistance, excluding extension wire resistance, and use of a time domain reflectometer to observe the behavior of the thermocouple loop.

During the 332-hr period at 30-MW reactor power, the indicated temperature of the W3Re/W23Re thermocouple decreased ~340°C from an initial maximum of 2240°C. Some portion of the decrease was due to fuel densification and some to thermocouple drift. The thermocouple loop resistance increased 10% during this time at operating temperature. Both the center-line thermocouple emf and loop resistance measurements were sufficiently sensitive to show reactor power changes of 1% or position changes of $\frac{1}{8}$ in. During two periods of several hours, the thermocouple emf jumped several millivolts, but there was no corresponding increase in other temperature indications or power production and no change in loop resistance. During one period of erratic thermocouple output, an increase in loop resistance was observed.

Analysis of the thermometer and cartridge behavior is continuing, with dissection of the cartridge. An experiment is planned for study of the ultrasonic thermometer.

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1. Reactor Chemistry Division.
 2. R. L. Shepard, J. G. Morgan, and H. E. Robertson, *Instrumentation and Controls Div. Annu. Prog. Rep. Sept. 1, 1970*, ORNL-4620, p. 76.

8.27 ULTRASONIC THERMOMETER SENSOR DEVELOPMENT

R. L. Shepard H. E. Robertson¹ A. J. Moorhead²

An optimized ultrasonic thermometer sensor line was developed for use in the ORTC-4 fuel-pin center-line temperature irradiation experiment. The requirements were that the line (1) measure temperature from ambient to 2300°C, (2) fit within an 0.012-in.-diam insulator hole, and (3) extend about 14 in. overall.

Several sensor line styles were fabricated by Panametrics, Inc., for test at ORNL. These included an all-Re, etched-shoulder, 0.010-in.-diam line; an all-W23Re, etched-shoulder, 0.009-in.-diam line; and several welded-shoulder lines that had either W3Re or W23Re 0.009-in.-diam lead lines to which were welded etched or drawn 0.006-in.-diam Re wires. Calibrations of these lines demonstrated that the preferred line was a W3Re lead line welded to a 2-in.-long Re sensor. An all-Re line suffered too much from ultrasonic attenuation at high temperatures in the lead line; an all-W-Re alloy line had low attenuation but too low a sensitivity (about one-fourth that of Re) at high temperatures.

Welding fabrication techniques were developed at ORNL for fabrication of additional lines, joining 0.010-in.-diam refractory wires end-to-end.

Calibrations of Re sensor ultrasonic lines to 2300°C produced, in best cases, agreement with calibrations done independently at Engelhard by Panametrics within 1%, or 20°C, the limit of resolution of the digital timing system used. There were some large discrepancies between some sensors, as much as 200°C above 1500°C, which may have been due to misalignment of the welded joint, roughness of etched wires, furnace contamination, or other causes under study.

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1. Reactor Chemistry Division.
 2. Metals and Ceramics Division.

8.28 DRIVER COIL CURRENT BIASING AND CONTROL CIRCUIT FOR AN ULTRASONIC THERMOMETER

R. L. Shepard A. H. Malone J. L. Horton

A dc bias current of about 50 mA was applied to the driver coil of an ultrasonic thermometer, replacing a permanent magnet biasing which had sometimes been used and increasing the magnitude of the ultrasonic echo signal by more than a factor of 2. Permanent magnet biasing is impracticable for in-pile use where the ultrasonic thermometer is used for fuel temperature measurements, such as the ORTC-4 experiment.

Use of dc bias current and a shunting capacitor for transmission line impedance matching permits the sensor echo signal to be increased without much increase in the background echoes, thus extending the useful range of a Re ultrasonic thermometer several hundred degrees above the normal ultrasonic attenuation threshold at about 2100°C. To optimize the performance of the model 5010 Panatherm control unit supplied by Panametrics, Inc., the dc bias current was controlled by an echo amplitude signal fed back from the Panatherm unit. In this way, a maximum receiver gain could be used at low sensor temperatures without exceeding front-end saturation limits; at higher sensor temperatures, dc coil current bias increased the received signal without changing the receiver gain. With a feedback circuit to modulate the dc coil current, connected with the Panatherm unit, stable performance of the Re sensor was achieved over a temperature range from ambient to 2400°C without manual changes in the control units.

8.29 NUCLEAR REACTOR APPLICATIONS OF NEW ULTRASONIC TRANSDUCERS¹

L. C. Lynnworth²

E. P. Papadakis² K. A. Fowler²
D. R. Patch² R. L. Shepard

New high-temperature and broadband magnetostrictive and piezoelectric ultrasonic transducers have been developed for testing, measurement, and control. Potential reactor applications include measuring fuel center-line temperature, sodium temperature profile (ten points with only one wire), occurrence and location of bubbles in liquid coolants, liquid level, flow, gas pressure, nondestructive testing, and acoustic emission surveillance.

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1. Abstract of published paper: *IEEE Trans. Nucl. Sci.* NS-18(1), 351-62 (1971).
 2. Panametrics, Inc.

8.30 METHODS TO CALCULATE TRUE TEMPERATURE PROFILE USING DATA FROM A THERMOCOUPLE WITH HIGH-TEMPERATURE SHUNTING ERRORS¹

J. R. McDearman² J. M. Googe³

This report describes an algorithm which can be used to calculate the true temperature profile from a series of temperature measurements made with a thermocouple having shunting errors due to insulator leakage. Inputs to the program are a series of voltages measured at the cold end of the thermocouple as it is inserted into the temperature gradient and the physical and material characteristics of the thermocouple.

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1. Abstract of published report TID-25632.
 2. Department of Electrical Engineering, the University of Tennessee, Knoxville.
 3. Consultant from the Department of Electrical Engineering, the University of Tennessee, Knoxville.

LMFBR TEMPERATURE SENSOR PROGRAM

8.31 LMFBR TEMPERATURE DEVELOPMENT

M. B. Herskovitz

K. R. Carr J. L. Horton C. S. Lissner
F. H. Clark W. W. Johnston, Jr. C. A. Mossman
K. V. Cook¹ W. P. Kinser J. L. Redford

C. B. Williams

Temperature development work for the Liquid-Metal Fast Breeder Reactor program was continued.² In addition to preparing standards and testing high-reliability Chromel-Alumel sheathed thermocouples for the Fast Flux Test Facility (FFTF), test apparatus and procedures and standards for platinum resistance thermometers are being developed. Consultation to AEC programs is provided. A new responsibility is the calibration and testing of stainless steel sheathed thermocouples that have been irradiated by fast neutrons to 2.4×10^{22} nvt at 1200°F. Analysis of this data should provide information on the effects to be expected in the Fast Test Reactor (FTR).

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1. Metals and Ceramics Division.
 2. M. B. Herskovitz et al., *Instrumentation and Controls Div. Annu. Prog. Rep. Sept. 1, 1970*, ORNL-4620, pp. 79-85.

8.32 THERMOELECTRIC INHOMOGENEITY

K. R. Carr C. A. Mossman

The previously reported work¹ was continued to provide additional analysis and test information on the fundamental problem of thermoelectric inhomogeneity in sheathed Chromel-Alumel thermocouples. The effect of thermoelectric inhomogeneity in thermocouple wire is that the output is a function of the shape of the thermal gradient along the thermocouple length, which may result in errors as large as 25 times the specification limit.

The thermoelectrically inhomogeneous system was analyzed to determine the conditions and possibilities for inhomogeneity compensation through use of more than the conventional two dissimilar thermoelectric wires in the circuit.² Such a compensation method would be valuable in applications where thermocouples cannot be recalibrated or replaced during long service. To apply the compensation method, a three-wire sensor (thermotriple) is the most advantageous of any sensor with more than two wires; it is better than a thermocouple because analysis of voltage readings made at the reference junction gives a strong indication of the condition of the sections of wire affecting the output. Complete compensation of inhomogeneity error is possible through analysis of voltage readings at the thermotriple reference junction if the aging characteristics of the wires meet defined conditions.

An experimental evaluation was made of a method to predict thermocouple error in specified thermal gradients when the inhomogeneity profile along the thermocouple is known. The error estimation method yielded reasonable estimates of the actual inhomogeneity error in several cases (Fig. 8.32.1). However, the data indicate that the inhomogeneity effect cannot always be assumed to be linear with temperature, as was done in the estimation method.

Fig. 8.32.1. Comparison of estimated and experimental errors of an inhomogeneous Chromel-Alumel thermocouple in a 530°F salt bath.

Data on the effects of inhomogeneity growth indicate that Chromel-Alumel thermocouples will generally perform within specification limits for more than 4500 hr at 1600°F when left in the same thermal gradient in which they are aged. However, if the thermal gradient is moved only 4 in. along the thermocouple, errors beyond specification limits may occur within 144 hr.

1. K. R. Carr and C. A. Mossman, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 83.

2. K. R. Carr, *Testing and Analysis of the Thermoelectrically Inhomogeneous Thermocouple Circuit*, ORNL-TM-3413 (August 1971).

8.33 THERMOCOUPLE INSULATION WATER ABSORPTION

J. L. Horton

Studies were continued to determine the effect of water absorption on the electrical leakage resistance of MgO in sheathed thermocouples. Tests were performed in addition to those previously reported¹ to gain a better understanding of the mechanisms involved and to specify proper thermocouple fabrication and handling procedures for both manufacturers and users.

The insulation resistance of sheathed MgO-insulated thermocouple material is rapidly reduced by the absorption of moisture when left unsealed in normal room air. A small amount of moisture on the MgO at the open end quickly reduces the insulation resistance several decades due to surface leakage. The material continues to absorb moisture throughout the length, with a continued decrease in insulation resistance until equilibrium is reached. If the material is heated and then cooled in moist air, both air and moisture are drawn in owing to thermal contraction, and the rate of decrease of the resistance is greater than if the material is precooled in very dry air.

Fig. 8.33.1. MgO thermocouple insulation resistance of 6-in.-long samples in 75°F, 35% RH air, with no end seals.

Figure 8.33.1 illustrates the results of tests on 6-in.-long thermocouple samples with both ends unsealed. The wire-to-sheath insulation resistance was monitored as the samples cooled from 500°F in 75°F, 35% relative humidity (RH) air. The test was repeated, except that the samples were first precooled to room temperature in dry (4 ppm) air before exposure to 35% RH air. The initial increase of resistance of the 500°F samples shown in Fig. 8.33.1 is attributed to the inverse temperature-resistance relationship of MgO which controls before absorption of moisture becomes the dominant factor. The resistance decrease of the samples with time in the precooled test is believed to be due exclusively to moisture effects.

These results show the necessity of precautions to prevent moisture absorption in sheathed thermocouple material in fabrication and use.

1. J. L. Horton and C. A. Moskwa, *Instrumentation and Controls Div. Annu. Prog. Rep. Sept. 1, 1970, ORNL-4620*, p. 82.

8.34 THERMOCOUPLE END SEALS

J. L. Horton

Limited tests were conducted on the hermetic integrity of heat-shrinkable and epoxy end seals as may be routinely used on sheathed-type thermocouple material. The purpose of end seals is to prevent contamination of the MgO by foreign material such as moisture. Therefore, the insulation resistance (both wires to sheath) was used as an indication of seal moisture leakage into the MgO.

An assortment of 6-in.-long specimens of $\frac{1}{4}$ -, $\frac{1}{8}$ -, and $\frac{1}{16}$ -in.-OD sheathed material was first heated at 500°F for 24 hr, and then, while dry, the insulation resistance was measured on all and various types of seals applied to the specimens. Rayclad heat-shrinkable tubing, Armstrong epoxy, and Tra-Con epoxy were each used. All specimens were then exposed to 100% RH air for ≥ 48 hr, and resistance was remeasured.

After the 24-hr bakeout and before exposure to the humid air, the resistance of all specimens was $\geq 3 \times 10^{11} \Omega$. After exposure all specimens with properly applied seals (one seal was defective) the measured resistance was within a factor of 2 of the previous value, but the resistance of the unsealed reference specimens was 5×10^5 to $1 \times 10^6 \Omega$ less.

It was concluded that properly applied sealing to these materials does adequately hermetically seal, at least for limited periods of time. No long-term tests were conducted.

8.35 SURVEY AND EVALUATION OF THERMOCOUPLE MANUFACTURERS

M. B. Herskovitz

K. R. Carr W. W. Johnston, Jr. C. A. Mossman

An updated survey and evaluation was made as a supplement to earlier work¹ to provide current information on the interest and capabilities of manufacturers in the production of high-reliability thermocouples for reactor applications. The purpose was to acquire information on as many qualified sources of high-reliability thermocouples as possible. A questionnaire requesting both technical and business information was sent to about 125 thermocouple vendors. Only about 50 vendors responded, and more than 12 are now considered to be suitable sources for the high-quality thermocouples required.

1. M. B. Herskovitz et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1968*, ORNL-4335, p. 69.

8.36 FAILED FUEL MOCK-UP THERMOCOUPLES

M. B. Herskovitz J. L. Horton W. W. Johnston, Jr.

Special sheathed thermocouple assemblies were required for use in the Failed Fuel Mock-Up (FFM), which is a program for evaluating the consequences of blocked flow of sodium in the cooling system on the Fast Flux Test Facility (FFTF) core. In the FFM, the FFTF fuel pins and steel wrap wires are simulated with high-wattage electric heaters and the special thermocouple assemblies, respectively. The special assemblies were required to have 0.056-in.-OD sheaths and two grounded or ungrounded sensing junctions.

A fabrication technique was developed and tested, and grounded-junction, MgO-insulated, Chromel-Alumel assemblies were procured from two manufacturers. In the fabrication technique, the four 0.003-in.-diam thermoelectric wires were spot welded to the 0.036-in. ID of the sheath. A solid, 0.056-in.-OD wire was then welded as an extension of the sheath so that a steel wire wrap was simulated with thermocouple sensing junctions located along the wire wrap length rather than at the end.

The special assemblies were tested to verify that they met FFM requirements (calibration drift at 1200°F and thermal cycling between 500 and 1200°F). The results indicated that the special assemblies did adequately meet the requirements.

8.37 THERMAL CYCLING OF THERMOCOUPLES

M. B. Herskovitz K. R. Carr W. W. Johnston, Jr.

Thermal cycling tests of thermocouples were continued to determine their susceptibility to failure (wire breakage) caused by thermal stresses during temperature changes. The requirement for Fast Flux Test Facility (FFTF) thermocouples is that they survive 3000 thermal cycles between 1200 and 800°F with a maximum cooling rate of $-100^{\circ}\text{F}/\text{sec}$. The heating portion of the FFTF thermal cycle will require several minutes. Work previously reported¹ indicated that the proposed FFTF sensors ($\frac{1}{8}$ -in.-OD, Chromel-Alumel, MgO-insulated, stainless-steel-sheathed thermocouples) will have the necessary reliability in the specified thermal cycle conditions.

Because virtually no failures occurred in the simulated FFTF thermal cycle conditions, additional work was done at higher temperatures and transient rates. Thermocouples were cooled from 1840°F at $-250^{\circ}\text{F}/\text{sec}$ for 4 sec. The mean cycles to failure for insulated junction thermocouples were more than 19,000 and for grounded junction thermocouples were 6464. These results provide some guidelines for thermocouple specification, since grounded junction thermocouples are indicated to be less reliable than those with insulated junctions but are desirable in some cases because of their superior time response.

Most of the thermal cycle work has been done on short lengths (~ 1 ft or less) of thermocouples, and a test stand was constructed to verify that thermocouple failure is not a function of the length of thermocouple that is thermally cycled. Heating is done with direct current in the metallic sheath of the test thermocouple. The change in thermocouple length due to thermal expansion (~ 1 in./10-ft length) is accommodated with a spring-loaded holder assembly. A 10-ft-long, insulated junction thermocouple has survived 1300 thermal cycles (600 to 1570°F in 5 sec, cooling in ~ 1 min) without failure in this test.

1. M. B. Herskovitz et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 79.

8.38 CONSULTATION AND ASSISTANCE

M. B. Herskovitz W. W. Johnston, Jr.

Consultation and assistance in temperature measurement were provided in the following areas:

1. demonstration plant design (Westinghouse and General Electric),
2. thermocouple design for the FFM (Hanford Engineering Development Laboratory),
3. field-installed thermocouple end seals (ANL for EBR-II),
4. FFTF temperature measurement problems (AEC, LMEC, ANL, and Westinghouse).

8.39 ULTRASONIC TESTING OF THERMOCOUPLE SHEATH INTEGRITY

M. B. Herskovitz K. V. Cook¹

An investigation was made to determine if ultrasonic testing for thermocouple sheath integrity is an improvement over the costly helium leak² and fluorescent dye³ methods in common use. The object of testing sheath integrity is to determine both present and impending imperfections by the detection of holes, cracks, and scratches with dimensions of a few thousandths of an inch.

In the investigation, thermocouples were fabricated with sheath defects of known location and size. The ultrasonic method was then applied to determine the smallest sheath defect that could be detected reliably.

The sheath defects were electro-discharge machined notches ~ 0.003 in. wide, 0.0018 to 0.004 in. deep, and either 0.036 or 0.125 in. long. The notches were made in the 304 stainless steel sheath before fabrication of the $\frac{1}{8}$ -in.-OD Chromel-Alumel, MgO-insulated thermocouples.

All of the sheath defects were detected by the ultrasonic method, and indications of defects as large as the smaller notches were observed over much of the sample. The 0.125-in.-long, 0.004-in.-deep notches were easily detected, and there were no other indications comparable to these notches.

The results indicate that an automatic ultrasonic test may be superior to the sheath integrity tests commonly used at present. The detection of defects as small as 0.002 in. deep is a worthwhile goal since the corrosion of 304 stainless steel in the Fast Flux Test Facility (FFTF) environment (sodium at 1200°F) is estimated to be <0.001 in./year.

1. Metals and Ceramics Division.

2. "Standard Methods for Liquid Penetrant Inspection," ASTM Designation E 165-65, pp. 620-35 in *1968 Book of ASTM Standards, Part 31: Physical and Mechanical Testing of Metals-Metallography, Nondestructive Testing, Fatigue, Effects of Temperature*, American Society For Testing and Materials, Philadelphia, 1968.

3. "Standard Specification for Thermocouples, Sheathed, Type K, for Nuclear or for Other High Reliability Application," ASTM Designation E 235-67, *Ibid.*, pp. 833-44.

8.40 STATISTICAL ANALYSIS OF THERMOCOUPLE ACCEPTANCE TEST DATA

F. H. Clark M. B. Herskovitz W. W. Johnston, Jr.

Statistical analysis is being applied to acceptance test data taken on 124 thermocouples produced by three manufacturers and two fabrication methods. The goal is to determine the fabrication methods and design parameters that result in optimum thermocouple performance.

The data were from ten types of acceptance tests, which included insulation resistance, insulation compaction, calibration, and thermoelectric inhomogeneity measurements. The large amount of accumulated data is being statistically analyzed to determine correlation of the various test results. The data were transferred to punched cards in preparation for computer-aided statistical analysis.

8.41 LMEC STEAM GENERATOR

M. B. Herskovitz J. H. Day G. M. Slaughter¹

In a cooperative effort, the Metals and Ceramics and the Instrumentation and Controls Divisions are analyzing failures of the Liquid Metals Engineering Center sodium-to-water steam generator. Examination of failed $\frac{1}{8}$ -in.-OD, stainless-steel-sheathed, type K thermocouples revealed that massive corrosion had destroyed the sheath in the gas space above the sodium, the thermocouples had not been mechanically secured on the original installation, and no cold-end seals were provided. On the water side of the upper tube sheath, the $\frac{1}{8}$ -in.-OD, Inconel-sheathed, type K thermocouple had been installed improperly, causing loss of the sheath prior to operation. A conclusion from this study is that thermocouples installed in heat exchangers of this type should be $\frac{1}{4}$ in. OD or larger.

1. Metals and Ceramics Division.

8.42 THERMOCOUPLE WIRE BREAKAGE STUDIES

J. L. Horton

To understand how wire breakage occurs in sheathed thermocouple assemblies and to justify extrapolation of the results from tests on short assemblies to behavior of long lengths, tests were conducted

on a small number of stainless-steel-sheathed, MgO-insulated, Chromel-Alumel thermocouple assemblies of the type proposed for the Fast Flux Test Facility (FFTF) coolant system. Two problems were studied: (1) with MgO insulation compaction densities of 70 to 90% of maximum theoretical density (MTD), do the wires elongate equally with the sheath even though the thermal expansion coefficient of the sheath is greater; and (2) does repeated fast heating-slow cooling of the assemblies cause early wire breakage by stretching the wires by the greater thermal elongation of the sheath.

All tested assemblies were grounded-junction, 0.125 in. OD and 20 in. long. The sheaths were resistance-heated from 75 to 1800°F and cooled in static air. The temperature was monitored by a 0.005-in.-OD thermocouple welded to the sheath. With the junction end clamped rigid and the assembly heated, elongations of each wire and sheath were measured with dial gages.

Test specimens included one with a type 310 stainless steel sheath and 71.9% MTD MgO insulation, one with a type 304 stainless steel sheath and 89.8% MTD MgO, and one with a type 304 stainless steel sheath and 72.0% MTD MgO. All tests showed equal wire and sheath elongations in all cases, even after 20 or more cycles of fast (125°F/sec) heating followed by slow cooling. Measured elongations always closely approximated values given in the literature for the sheath material.

Repeated cycles of fast heating (110 to 125°F/sec) and slow cooling (10 to 12°F/sec) between 400 and 1400°F were applied to the type 310 stainless-steel-sheathed, 71.9% MTD MgO-insulated specimen. Its junction end was clamped in a rigid support and was therefore cooler than the remaining sheath. Temperature cycles from 400 to 1800°F were applied to a similar specimen which had an extension welded to the grounded junction end to allow the junction end to be fully heated with the sheath. Over 3000 thermal cycles were applied to each assembly; no wire failures were observed.

It was concluded that, in assemblies with MgO insulation compaction densities greater than 71.9% MTD, the wires are mechanically locked to the sheath and are strained uniformly along their length by the greater thermal expansion of the sheath. Therefore, failure rate data acquired on short assemblies should apply equally well to long assemblies. Also, 3000 heating cycles of 110 to 125°F/sec do not cause wire breakage in short assemblies, and should not cause long assemblies to fail.

FIFTH SYMPOSIUM ON TEMPERATURE

The progress in thermometry during the past decade was reported in 262 papers to an international audience of 503 people attending the 5th Temperature Symposium in Washington, D.C., June 21-24, 1971. At these symposia, held at ten-year intervals, the foremost thermometry experts disseminate important results in temperature measurement and instrument research. The proceedings will be published in the 4th volume of *TEMPERATURE, Its Measurement and Control in Science and Industry*, early in 1972.

ORNL contributed 11 papers, 10 of which were authored or cos authored by people of the Instrumentation and Controls Division. These papers report thermometry and temperature control studies that have been supported at ORNL by the Fast Breeder Reactor (FBR) and Liquid-Metal Fast Breeder Reactor (LMFBR) Thermometry Programs, the Molten-Salt Reactor (MSR) Program, and by other general studies.

R. L. Shepard of the Instrumentation and Controls Division served on the Program Committee with ten others to organize the Symposium and to solicit papers. He was responsible for the Omnibus Thermometry sessions in which 24 papers were presented covering newer methods in thermometry. Shepard and W. W. Johnston, Jr., also of the Instrumentation and Controls Division, and D. L. McElroy of the Metals and Ceramics Division served on the Thermocouple Thermometry Committee under the chairmanship of D. I. Finch. Johnston and Shepard served as chairmen of Symposium sessions.

Two sessions of ten papers on Thermocouples in Nuclear Environments, organized by Shepard and R. S. Flannors of GE-Canada, included five papers from foreign sources – France, Germany, Canada, Norway, and Japan – and five from AEC- or NASA-supported work in this country.

The ten papers authored or coauthored by Instrumentation and Controls Division personnel are summarized in the following ten abstracts.

8.43 TRACEABILITY, WHAT AND HOW, RELATING TEMPERATURE MEASUREMENT AT ORNL

W. W. Johnston, Jr. M. H. Cooper

The term "traceability" entered the language of the scientist and the engineer over a decade ago. Since then, concepts of the meaning, achievement, and applicability of this traceability have multiplied almost in direct ratio to its users. In essence, traceability relates any measurement to accepted fundamental quantities agreed upon by the International Conference of Weights and Measures, with appropriate documentation for its support. This paper deals with one approach as employed at Oak Ridge National Laboratory in the field of temperature measurement. Our definition, interpretation, and implementation are discussed. While this paper is limited to temperature measurements, other measurement quantities are interrelated and must be considered. The directly related subjects, for the realization of the International Practical Temperature Scale, through the use of fixed points, resistance thermometers, thermocouples, and optical pyrometers are considered.

8.44 REVIEW OF TECHNIQUES FOR DETERMINING THERMOCOUPLE EMF-TEMPERATURE CHARACTERISTICS

R. K. Adams R. L. Simpson

Techniques which include the use of computer-drawn plots were developed to assess the adequacy with which published thermocouple emf-temperature characteristics represent the actual thermocouple characteristics. The techniques enable comparison of data from several manufacturers and the assessment of "smoothness" of first- and second-difference curves. Although intended primarily for the validation of characteristics of new materials, the techniques are also useful for evaluating the adequacy of data smoothing and mathematical curve fitting applied to data from established thermocouple materials. By means of these techniques, it is possible to develop improved thermocouple characteristics to better meet some of the needs of temperature-related research. Information on the improved formulation of several thermocouple characteristics is discussed.

8.45 EQUIVALENT CIRCUIT MODELING OF INSULATOR SHUNTING ERRORS IN HIGH-TEMPERATURE SHEATHED THERMOCOUPLES

R. L. Shepard

R. F. Hyland J. M. Googe^{1,2} J. R. McDearman¹

Temperature indication errors up to 10% at 2700°K can be caused by a decrease of the resistance of the insulator materials that separate the wires in a typical high-temperature sheathed thermocouple. Various two-wire equivalent circuit models have been proposed whose solutions approximately correct shunting errors in cases where material properties and temperature gradient shapes are known. A three-wire model of a sheathed thermocouple was devised that includes the contribution of the sheath. This model was used to

correct such shunting errors to less than 1% for various materials, configurations, and known temperature gradient shapes. In using this model, supplemental cold-end measurements were made on a shunting thermocouple, such as loop resistance and loop-to-sheath resistance, which helped to reduce the indeterminacy in the error correction. A method was devised for providing true temperature measurements from a shunting thermocouple in an unknown temperature gradient by profiling, that is, inserting the thermocouple into the gradient incrementally.

1. Department of Electrical Engineering, the University of Tennessee, Knoxville.
2. Consultant to the Instrumentation and Controls Division.

8.46 THERMAL CYCLING LIFE TESTS OF METAL-SHEATHED THERMOCOUPLE ASSEMBLIES

M. B. Herskovitz

Test experience in thermal cycling $\frac{1}{8}$ -in.-OD stainless-steel-clad, MgO-insulated thermocouple assemblies for liquid-metal-cooled, fast reactor application is described. The number of cycles to failure as a function of rapid heat-up and faster cool-down is analyzed for both the grounded and insulated measuring junction case. Thermocouple assemblies were heated to 1840°F and cooled for 4 sec at a cooling rate of 250°F/sec, and the process was repeated automatically until the thermoelectric conductors failed. By testing thermocouples at temperatures much higher than will be experienced in operation, and by thermally cycling at rates faster than a reactor physical system can produce, statistical prediction of performance is possible. Actual testing of fast-neutron-irradiated thermocouples is planned as a basis of estimating life history in actual reactor use.

8.47 TESTING OF CERAMIC INSULATOR COMPACTION AND THERMOELECTRIC INHOMOGENEITY IN SHEATHED THERMOCOUPLES

K. R. Carr

Test methods were developed and applied to determine the ceramic insulator compaction and thermoelectric inhomogeneity in sheathed thermocouples. Two new reliable compaction test methods were shown to have an accuracy of $\pm 2\%$ of the maximum theoretical density (MTD) of MgO. The methods were applied to 0.16- and 0.32-cm-OD, MgO-insulated thermocouples obtained from 15 manufacturers. The compaction values ranged from 70 to 92% MTD, and all material having a compaction of 78% MTD was obtained from manufacturers who normally reduce the sheath diameter by swaging. In the thermoelectric inhomogeneity test method, the inhomogeneity of a test thermocouple was determined by comparison with a standard thermocouple as both were immersed through a short thermal gradient, and the differential output was recorded. The repeatability of the inhomogeneity test is generally within $\pm 20 \mu\text{V}$. The method was applied to measure inhomogeneity in type K thermocouples caused by cold work and by service at 870°C. Some sections of aged thermocouples had inhomogeneity errors as large as 35% when measuring a true temperature of 150°C.

8.48 EXPERIENCE WITH TYPE K THERMOCOUPLES IN AN EXPERIMENTAL NUCLEAR REACTOR

C. D. Martin C. H. Gabbard¹

More than 1100 type K thermocouples were operated for five years in an experimental nuclear reactor with only 15 failures. The thermocouple junctions were fabricated at Oak Ridge National Laboratory from

commercial, sheathed thermocouple material purchased to stringent specifications. The thermocouples were calibrated before being installed in the reactor where they were constantly monitored during the five years of operation. Many of the thermocouples accumulated more than 30,000 hr of operation above 900°F, with numerous heating-cooling cycles which are well documented. Additionally, 186 of these thermocouples were monitored continuously by a digital computer-based data acquisition system. A technique was developed for using the computer to minimize scatter among the thermocouples. Reliability, scatter, and long-term drift are discussed.

1. Reactor Division.

8.49 AN EVALUATION OF INDUSTRIAL PLATINUM RESISTANCE THERMOMETERS

K. R. Carr

Industrial platinum resistance thermometers were tested between 0 and 650°C to determine their performance and problem areas and to establish specification requirements for high-reliability service. The test units had ceramic insulation, a four-wire lead configuration, an Inconel or 300-series stainless steel sheath, and an ice-point (0°C) resistance of 100 Ω . The thermometers were tested to determine their calibration drift in service, performance when thermally cycled, and time response characteristics. Self-heating error, thermal emf's, and insulation resistance also were measured. After about 6000 hr at 650°C the maximum calibration drift in the products of two manufacturers was about 1°C. After 1000 thermal cycles between 650 and 260°C at a rate of 8°C/sec max, the typical calibration changes were about 0.1 to 0.4%, caused mainly by changes in α , the fundamental temperature coefficient of resistance. Several thermometers survived 2×10^3 cycles without complete failure, but other thermometers had lead or lead connection breakage when first subjected to a 650°C environment. The time response in water flowing at 3 ft/sec ranged from 2.2 sec for $\frac{3}{16}$ -in.-OD thermometers to 7.7 sec for $\frac{1}{4}$ -in.-OD thermometers.

8.50 APPLICATION OF SMALL COMPUTERS AS THERMOMETRY RESEARCH TOOLS¹

R. K. Adams et al.

The application philosophy, advantages, limitations, and significant details associated with using small computers to control and take data from thermometry research experiments are presented. Three applications are discussed in detail: (1) a materials research application involving pulse calorimetry methods for specific heat and electrical resistivity; (2) a thermocouple and resistance thermometer life-test, drift-test application in which data are taken at both low and high rates; and (3) a general-purpose laboratory application used for dynamic control of and data acquisition from a variety of short-term thermometry projects. Each of these applications has been in use since 1969 so that the reliability and adequacy of the approaches taken are based on two years of operating experience.

Interface equipment and techniques are discussed in terms of hardware-software trade-offs. The role played by the computer programming language in fostering or inhibiting computer-aided thermometry research is assessed.

1. This is a report of work done by several individuals at Oak Ridge National Laboratory, namely, B. C. Duggins, B. G. Eads, J. T. Hutton, R. F. Hyland, J. M. Jansen, Jr., T. G. Kelle, C. D. Martin, Jr., C. A. Moorman, J. L. Redford, R. L. Simpson, and A. H. Voelker.

8.51 MEASUREMENT ACCURACY OF A COMPUTER-OPERATED DATA ACQUISITION SYSTEM

T. G. Kollie¹ D. L. McElroy¹ R. K. Adams J. M. Jansen

An ORNL-designed, computer-operated data acquisition system (CODAS) has been employed to measure accurately the specific heat ($\pm 1\%$) and electrical resistivity ($\pm 0.5\%$) of a solid as a function of temperature. CODAS consists of a small digital computer interfaced with a 12-bit analog-to-digital converter (ADC) and is essentially an automated potentiometer. Signals to be measured are partially suppressed, and the resulting differential voltage is amplified and fed into the ADC via a six-channel multiplexer at rates up to 60 readings/sec. The digitized output of the ADC is stored in core or on a magnetic disk or both. The data acquisition sequence is programmable and is executed on a real-time base, and data output is to a teletypewriter or magnetic tape or both. Normal computer computational capabilities are available, and computer-activated relays and contact sensors allow experiment control and synchronization.

The accuracy of absolute and differential voltage measurements for the system were established by a determinate error analysis and by comparison with a potentiometer. For absolute measurement, the system has an accuracy of ($\pm 0.013\%$, $\pm 0.4 \mu\text{V}$) for an amplification gain of 10^4 and ($\pm 0.011\%$, $\pm 0.06 \mu\text{V}$) for a gain of 10^5 . Differential measurements are accurate to ($\pm 0.06\%$, $\pm 0.13 \mu\text{V}$) and ($\pm 0.21\%$, $\pm 0.013 \mu\text{V}$) over the 1000- and 100- μV ranges, respectively. Effects of temperature drifts of the instrumentation are evaluated, and suggestions are made for their minimization.

1. Metals and Ceramics Division.

8.52 EXPERIENCE WITH DIRECT DIGITAL CONTROL OF SEVERAL TEMPERATURE PROCESSES

B. G. Eads B. C. Duggins

Minicomputers were applied to the direct digital control (DDC) of several temperature processes as follows: a large-scale thermocouple evaluation program in which the computer capability for data management is a most important parameter, control of 120 water baths for research purposes in which the baths are temperature programmed, and control of calibration baths. The versatility of such computers for implementation of conventional and nonconventional control modes was determined for a proportional-integral-derivative response algorithm, cascade control, and time-optimum (bang-bang) control for best response to frequent set-point changes. The interrelationship between hardware and programming structure was studied. DDC utilizing minicomputers was demonstrated as feasible and dependable, and it can be implemented with reasonable effort.

9. Maintenance and Service

9.1 ENGINEERING ACTIVITIES OF THE MONITORING SYSTEMS DEVELOPMENT GROUP

Facility Radiation and Contamination (FRC) Alarm Systems

A. L. Case C. C. Hall D. J. Knowles J. A. Russell, Jr.

The FRC Alarm Systems at the Laboratory are changed on a continuing basis by this group. The changes accomplished in this report period were as follows:

(1) The original FRC system and the containment system in the Isotope Technology Building 3047 were updated by replacing the indicator and control panel with a solid-state Q-2563 modular system.¹ The older system, with diodes and relays, could no longer be expanded to accept additional channels required by several changes in building operations. Three constant alpha air monitors were added to the building system, as were remote alarms from temperature sensors in glove boxes. Besides accepting these and future additions, the more modern panel will also allow manual operation of containment from the panel.

(2) The FRC System in the High-Radiation-Level Examination Laboratory (Building 3525) was updated to the Q-2563 system. Since its installation in 1961, the cost of maintaining this system, with its meter movement relays, has steadily increased. Also, its automatic reset system required extra labor for routine checking as compared with the newer system.

(3) To accommodate changing operations in the Transuranium (TRU) Processing Plant (Building 7920), a monitron and a neutron monitor were relocated and a neutron monitor was added.

Effluent Waste Monitoring

Several changes and alterations in the Gaseous Effluent Monitoring System were made to improve the efficiency of both monitoring and maintenance. The redesign of the inert gas monitors (Q-2325-31) to an independent channel, ground level version (Q-2396)² was completed and one of the new monitors was installed at the High-Flux Isotope Reactor (HFIR) stack. The new monitor is easier to maintain, and recalibration is now possible routinely.

The monitoring operations at the three main operating stacks at ORNL were reviewed, and their cabinet placement and design were improved to make the systems safer and easier to maintain.

The Q-2363 alpha and beta-gamma system was redesigned to incorporate NIM module electronics and control modules, and one system was installed on the TRU vessel off-gas duct from Building 7920 to expand the effluent monitoring coverage of that facility.

In addition, an alpha and a beta-gamma version of the revised monitor (Q-2362) were assembled and shipped for use at the AEC facility at New Brunswick, New Jersey.

Engineering Assistance to Other Groups

Cost estimates were made and supplied to the General Engineering Division for radiation monitoring and intrusion alarm systems to be used in the conceptual design of the Source and Special Material Vaults (Buildings 3027 and 3100).

A cost estimate was made and supplied to the General Engineering Division for a facility radiation and contamination alarm system, gaseous effluent monitoring systems, and water monitoring systems to be used at the Radioactive Waste Repository in Salt at Lyons, Kansas.

Process Radiation Monitoring Systems

The obsolete "Quintector" monitoring systems in the Fission Product Development Laboratory (Building 3517) service tunnel and in the High Radiation Level Chemical Development Laboratory (Building 4507) operating area were replaced with NIM versions (Q-3006).³

1. J. H. Todd, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1963*, ORNL-3578, pp. 31-35.

2. C. C. Hall and J. H. Holladay, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, pp. 25-26.

3. The Q-3006 is the NIM version of the Q-2814 Wide-Range Gamma Process Monitoring System which replaced the "Quintector" system. The Q-2814 unit was described by F. M. Glass, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1965*, ORNL-3875, pp. 67-68.

9.2 TANDEM VAN DE GRAAFF MAINTENANCE AND DEVELOPMENT

G. F. Wells J. W. Johnson

Because the failure rate of the terminal charging system components (drive motor, terminal generator, and belt) had increased, the history of such incidents was reviewed. A relationship between failure rate and insulating gas was noted.

SF₆ is added to the insulating gas to increase the insulating strength of the gas and decrease the volume of gas to be handled and stored. From 1963 to 1968, the total gas pressure was decreased gradually from 200 to 100 psig, and the SF₆ content was correspondingly increased to 20%. In this same period, 22,000 operating hr were logged. Belts were replaced at 10,000-hr intervals. Drive motors averaged 3200 hr and terminal generators averaged 5500 hr in service before failure.

During 1969-1970, the total gas pressure was reduced to 50 psig, the SF₆ content was increased to 40%, and the 6.5-MV terminal voltage was maintained. However, the failure rate of the charging system components increased. The drive motors operated an average of 270 hr and the generators 1080 hr before failure.

In May 1971, the tank pressure was increased to 100 psig with 15% SF₆.

There was insufficient evidence to conclude that the change in insulating gas pressure and composition was the primary cause of failure. Each case of failure could be attributed to other causes as well. Nevertheless, the insulating gas pressure and mixture appears to be a contributing factor.

Bearing failures were the most frequent type of failure, and the bearings and their lubrication are being studied. At present, a single-row ball bearing with a steel ball-cage and grease retaining seals is being used. The lubricant is a fluorosilicone grease rated for a maximum of 400°F operation with a 0.5 to 1% MoS₂ additive. Electrical failure, although less frequent, is also a concern. Some electrical failures were attributed to improper motor winding. From studies of these failures, it was observed that even a well-wound motor can fail if it is not properly shielded from the electrostatic discharge of the accelerator. Early in the history

of the accelerator, the lead wire shielding had been improved, and in April 1971 a full electrostatic shield was installed at the drive-motor end of the accelerator.

In other support for the Tandem Van de Graaff accelerator, development of ion sources for pulsed O^- beams and dc U^- beams was begun. Efforts to produce such beams indicated problems to be solved.

The offset-arc duoplasmatron method of producing H^- beams can produce a 10- to 15- μA O^- beam. The maximum dc O^{+8} beam observed from the accelerator was a 4- μA O^{+8} beam at 20 MeV. If this beam were properly pulsed and bunched, it should produce a beam with a 150- μA pulse height and 1-nsec pulse width, which would be detectable with present fast Faraday-cup techniques. Other O^{+8} beams produce dc beams of various intensities down to 1 nA O^{+7} at 52 MeV (the maximum energy beam attainable). To continue this work, a different pulse detection system is required, and a secondary-electron emission and multiplier detector system is being studied.

The O^- buncher tube was moved from the H^- position, that is, 3 m from the entrance to the accelerator, to 1 m from the entrance, since the 100-kV O^- beam travels at one-fourth the velocity of a 100-kV H^- beam. As a result, the low-energy flight time of the O^- beam was reduced and higher bunching voltages can be used.

U^{+8} ions were produced, utilizing a source of UF^- ions or UCI^- ions. The UCI^- ions produced a strong background of Cl^{+8} ions, which interfered with the detection of U^{+8} ions. The F^{+8} ion background is much less. An axial sputter ion source that bombarded uranium metal with Kr^+ ions was tried, but the yield was very low (10 nA of U^- ions compared with 2 to 3 μA of UF^- ions). A better U^- sputter ion source is being developed.

9.3 PROCESS CONTROL FABRICATION AND MAINTENANCE GROUP

P. W. Hill J. H. Day J. B. Frisbie H. G. Linginfelter B. C. Thompson R. W. Tucker

The process control fabrication and maintenance group consisted of 1 supervisor, 5 foremen, and 28 technicians whose main function was to routinely maintain process, analytical, and vacuum instruments according to accepted practices of the trade. Recently, however, the group started quality assurance maintenance practices in which all test instruments used by the group and all portable potentiometers and pressure standards used by the Instrumentation and Controls Division are repaired and calibrated in accordance with Division quality assurance program standards. These instruments are recalled for recalibration by a computerized schedule at the Computing Technology Center.

The new quality assurance practices were also extended as a service to other ORNL divisions. A total of 174 portable potentiometers was maintained for them.

Computing Center scheduled services were applied to maintenance of 191 continuously operating temperature recorder-controllers, 17 temperature controllers, and 25 precision power supplies for the Metals and Ceramics Division and 16 recorders for the Isotopes Division.

The analytical instrumentation shop in the Central Research and Administration Building (4500S) had 1 foreman and 7 technicians who maintained chemical analysis instruments and categorized and documented records of maintenance of 485 analyzers and 54 high-frequency heaters. The group also maintained and modified special instruments for the Body Fluids Analysis Program for the NASA Skylab, the Smoking and Health Program (cigarette smoking machine) for the National Cancer Institute, the Exercise Physiology Program (treadmill for cardiac load studies and other information) for the Health Division, the Walker Branch Watershed Study Program, and cancer research for MAN. This shop completed 1325 requests for service.

The electronic recorder shop renovated 38 surplus recorders at a savings of about \$750 each, overhauled or modified 72 recorders, and answered 143 service calls for minor repair and calibration of instruments in service in the field.

The pneumatic shop repaired, modified, or calibrated 62 pneumatic transmitters or pneumatic-to-emf converters and 42 pneumatic recorders.

9.4 DESIGN ASSISTANCE TO THE REACTOR MAINTENANCE GROUP

J. L. Anderson C. F. Holloway S. J. Ditto

The Reactor Projects Group has a responsibility for significant design changes to the control and safety systems of ORNL operating reactors. These changes are usually made to correct system deficiencies or to meet changing operational requirements and, occasionally, 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 the current year 28 design changes were made in 6 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 valuable feedback to designers of future systems. This work will be continued at about the same level for some time.

9.5 BSR AND PCA MAINTENANCE

M. R. Belew

J. M. Farmer J. B. Ruble K. W. West

The Bulk Shielding Reactor experienced one shutdown as a result of a relay failure in the safety trouble monitor and eight shutdowns as a result of single-rod drops during the past 12 months. The replacement of high-voltage magnets and vacuum tube amplifiers with low-voltage magnets and solid-state electronics was completed in February 1971 (Sect. 10.29). There were no rod drops after this installation. Since there was no longer any use for the magnet amplifier section of the composite safety amplifiers, the latter were replaced with less-complex safety signal amplifiers.

The BSR instrumentation checkout procedures were revised to conform to a new reactor controls policy and to incorporate the new magnet control system. All pertinent instrumentation and control drawings were reviewed and updated.

A program to reduce and filter the ionization chamber polarizing voltage, similar to the Oak Ridge Research Reactor (ORR),¹ was started. A second channel of solid-state radiation monitoring of the primary exit water was installed to provide redundancy in operation.

The Pool Critical Assembly magnet thermistors were replaced by zener diodes to reduce their discharge voltage from 700 to 150 V.² The PCA facility was used intermittently by the Universities of Tennessee and Kentucky and by Mississippi State University for student training.

1. M. R. Belew et al., *Instrumentation and Controls Div. Annu. Prog. Rep. Sept. 1, 1970*, ORNL-4620, p. 124.

2. M. R. Belew et al., *Ibid.*, p. 125.

9.6 MAINTENANCE OF THE HFIR

D. S. Asquith C. T. Carney K. W. West

Experience continues essentially as that of the previous year. The scheduled maintenance programs were extensively reviewed and updated. Because of demonstrated reliability, the frequency of routine calibrations performed on the process heat power systems was reduced from twice to once each year.

Shortly after the High-Flux Isotope Reactor instrument air supply was increased to 100 psig to provide instrument air to the Transuranium Processing Plant (TRU) facility, the accuracy of the HFIR pneumatic instruments could be maintained only with considerable effort, because the change in operating pressures of the air dryers caused aluminum oxide dust to be injected into the air system and deposited in critical components of the pneumatic instruments. Branch filters were installed throughout the air supply system, and these proved to be effective.

The plate spacing combs were eliminated in the assembly of the HFIR fuel elements, yielding higher primary flow rates. The main safety and servo flow transmitters were recalibrated from 17,000 to 20,000 gpm full scale, and the heat power networks were adjusted to accommodate this new flow range.

The prototype electronic flux reset module¹ was susceptible to electronic noise when placed in service at the HFIR. Minor modifications were made to the module, and it is currently being evaluated in service.

The three second-generation counting channels presented only minor maintenance problems. The only failure was in a fission chamber.

One unscheduled reactor shutdown attributable to instruments occurred. The reactor was scrammed from two coincidental signals from the faulty-fuel-element detection system. The cause of the trips was not determined, but it was suspected to be radioactive debris.

1. D. S. Asquith, C. T. Carney, and K. W. West, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 123-24.

9.7 ORR MAINTENANCE

M. R. Belew

J. M. Farmer J. B. Ruble K. W. West

During the last 12 months, the Oak Ridge Research Reactor had only one unscheduled shutdown caused by instrument failure (an upscale spike) in one of the ¹⁶N channels. The cause is not known.

One PCP-III-106 chamber failed after 1 year of in-service life, and both PCP-II gamma chambers failed, with an average life of 6.5 years. The three remaining ionization chambers have an average in-service life of 6.5 years. The maintenance of these chambers was transferred from the Development Group of the Reactor Controls Department to the Radiation Detection Group of the Instrument Department. The latter group is also fabricating three PCP-III chambers as spare units.

The two counting-channel submerged preamplifiers were replaced. The new preamplifier could be installed in the control room because the detector-cable-preamplifier assemblies were equipped with pulse transformers and balanced lines that enable remote operation. This new installation is expected to reduce the number of in-pile instrument failures experienced during the past few years.

Monitoring of the dc "pony" motor and battery systems in the primary coolant system was expanded to cover additional possible failures, and the voltage and current monitors were replaced with solid-state units for greater reliability. Recently installed filters for the "normal" (mostly building air) off-gas system were equipped with temperature and radiation monitors.

9.8 MAINTENANCE OF THE HPRR

D. D. Walker K. W. West

With the exception of one relay malfunction, the instrumentation and control system of the Health Physics Research Reactor performed satisfactorily. When deenergized, the relay failed to drop out because of binding between the armature and its guide. Such malfunctions are rare: this was the first failure of the many relays that have been in service since installation in the control system approximately ten years ago. This failure rate, $\sim 10^{-7}$ /hr, is typical of relay performance at other ORNL reactors.

A planned inspection of the main control panel equipment, wiring, and accessories was completed. Another program was started, that is, preparation of formal maintenance procedures tailored to the instrumentation and control of this reactor. General procedures have been used at many of the ORNL reactors because of the similarity of the installed equipment. However, as the systems evolve, they become less and less alike, and individually tailored procedures are justified.

9.9 MAINTENANCE OF REACTORS OPERATED BY THE NEUTRON PHYSICS DIVISION

D. D. Walker K. W. West

The reactor control and instrumentation systems continued to perform satisfactorily.

One ionization chamber can at the Tower Shielding Reactor (TSR II) intended for dry-well service was replaced with another designed to operate under full reactor-coolant pressures. The bottom of the dry well, which is part of the coolant containment, had developed a small leak at a weld; because repair not only would be expensive but also would require an extended shutdown of the reactor, it was decided to redesign the chamber can and its mounting to become part of the containment. All points at which leaks might develop in this area are now either directly observable or easily accessible. Because of its containment function, the can was designed and fabricated to Laboratory quality level II requirements.

Two of the drum position detecting and indicating channels of the SNAP-10 reactor control and instrumentation systems gave trouble. In one case, a coil of the position sensor, designed for high temperature and high nuclear radiation environments, opened. The sealed enclosure of the sensor was opened, and several individual turns of the oxide-insulated, nickel-wire coil were corroded in spots; at one point the chemical action had parted the conductor. A replacement was obtained from the reactor fabricator and installed. Under present program conditions there is no incentive to investigate the failure further. Although the difficulty with the other channel has not been resolved, the sensor proved to be functioning properly.

9.10 CHANGES AND IMPROVEMENTS TO ORNL RADIO SYSTEMS

J. A. Russell, Jr.

During the first half of 1970, ORNL was informed that its radio network KIN295 was interfering with another government agency. Investigation showed that both agencies had been assigned the same frequency for operation. Since the other agency was the prime assignee, ORNL was assigned a new frequency. The frequency change was completed early in 1971.

Simultaneously with the frequency change, occasional interference was noted on the new frequency. This interference resulted from intermodulation due to transmissions at two other assigned frequencies in the vicinity: the interference occurred only when both transmitters were on at the same time. A resonant cavity filter installed in the KIN295 receiver eliminated the interference.

Usage of radio transmissions at frequencies assigned to the Laboratory continually increased owing to a need for communications that is not met by wire services, especially for point-to-point radio communications between field forces and between supervisors and personnel working in the field. Such communications systems have significantly improved the operational efficiency of these field groups. During the past year, 12 radio units were added to the three major radio networks.

9.11 MAINTENANCE ACTIVITIES OF THE MONITORING SYSTEMS DEVELOPMENT GROUP

J. D. Blanton

A. L. Case D. J. Knowles J. E. Inman P. P. Williams

The maintenance organization of the monitoring systems development group consists of 17 technicians and two foremen. The activities of this group remained approximately as previously reported.

A total of 1172 fixed health physics instrument systems are installed throughout the Laboratory. Four technicians performed 1435 services on these instruments this year. These technicians performed routine 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. Also, the local air monitor and fallout monitor systems were routinely checked semimonthly.

Three technicians calibrated and maintained portable health physics instruments at the health physics calibration laboratory. Approximately 4220 portable instruments were serviced by this group. Two technicians assigned to the Operations Division serviced and maintained approximately 33 gas and 34 liquid-waste effluent monitors with telemeter alarms and information to the Waste Disposal Control Center (Building 3105). These two technicians also serviced and maintained instruments located in the Control Center. Routine performance checks were made on these systems on a biweekly basis. Two technicians assigned to the Metals and Ceramics Division maintained instruments for nondestructive testing.

There were 285 pieces of radio equipment in service at the Laboratory. One instrument technician was assigned full time to service and maintain this equipment.

One technician serviced and maintained closed-circuit television and paging and intercom systems installed at the Laboratory.

A total of 288 radio paging receivers and 797 personal radiation monitors were in service. Approximately 123 receivers and 137 monitors were serviced by one technician during 1970.

Accounting of man-hours spent on various audio-visual activities has been altered since the beginning of the year. Since January, approximately 1191 man-hours of technician time has been devoted to assistance at 286 separate meetings. This does not include the audio-visual supervisor's time, which is essentially full time. The new accounting system also records time spent on other major activities, such as maintenance of audio-visual equipment for the Instrumentation and Controls Division and other divisions, radio and video taping, tape duplicating, etc.

Approximately 350 individual pieces of equipment were inventoried, and the inventory records were updated. As much as possible, the number of stored items is reduced by sending excess equipment to salvage or surplus as each section is inventoried.

Cooperation with the ORNL motion picture group was continued in making sound tracks.

The organization of the Electronics Section for maintenance and engineering activities was altered to increase its flexibility and to meet the conditions imposed by a reduction in the number of employees assigned to these activities. Essentially, the maintenance and engineering forces in the Monitoring Systems Development Group were merged with the forces of the Special Electronics Services Group under one supervisor, and subsequent reports will be on that basis.

9.12 SPECIAL ELECTRONIC SERVICES GROUP

J. L. Lowvorn R. L. McKinney W. Ragan E. W. Sparks

The Special Electronic Services Group supplies engineering and maintenance services with some technical consultation as requested by Laboratory research personnel.

Repair calibration, fabrication, and modification services were provided for the Inspection Engineering and Ecology Divisions (Building 2000), Solid State Division (Building 3001), and Electronuclear Division (Building 6000).

General maintenance service and other specialized service for oscilloscopes, recording spectrophotometers, discriminator, scalars, linear pulse amplifiers, counters, and digital voltmeters were provided from shops in Buildings 3500 and 4500.

Because of budget limitations, the number of technicians assigned to the group was reduced, and this required training the remaining technicians to handle the specialized services.

Toward the end of the year, the Special Electronic Services Group and the Monitoring Systems Development Group were merged.

9.13 DIGITAL SYSTEMS FUNDAMENTALS COURSE

J. W. Woody, Jr. R. K. Adams

To upgrade their skills, selected salaried personnel of the Instrumentation and Controls Division attended a course in modern digital electronics taught by engineers of the Division (J. M. Jansen, E. Madden, J. L. Redford, and R. E. Wintenberg). From October 1970 to March 1971, the course covered number systems, binary and decimal codes, Boolean operations, symbolic logic, digital integrated circuits, and memory devices. A similar course is being taught to selected instrument technicians. It will be completed in the fall of 1971.

9.14 ACQUISITION OF COMMERCIAL EQUIPMENT

J. W. Woody, Jr.

The Computer Engineering Group of the Electronics Section continued to provide other Laboratory divisions with expertise and experience in specifying, purchasing, and verifying the performance of pulse-height analyzers, small digital computers, and related digital systems. During FY 1971, twelve specifications were prepared (not including units for the Oak Ridge Electron Linear Accelerator (ORELA) complex) for purchase of equipment from commercial vendors costing about \$220,000. The Computer and Analyzer Maintenance Group tested the new equipment to determine whether it was acceptable, delivered and made the final installation, and maintained the systems after installation.

9.15 ACTIVITIES OF THE COMPUTER AND ANALYZER GROUP

E. McDaniel J. A. Keathley

This group of 15 persons maintained 38 small computers and 120 multichannel analyzers and associated input-output equipment.

Equipment at the ORNL Computer Center maintained by the group includes three C2-Comp plotting systems, a computer video display terminal, a CRT display terminal, and an ITEK printing system.

Two additional technicians assigned to computer sites assist the experimenters, and one other technician services the hybrid computer.

A spiral reader,¹ a high-speed measuring projector designed to measure bubble chamber film, was designed and built by the Lawrence Radiation Laboratory for the University of Tennessee and installed at ORNL for research in physics. Some units in the system were modified to increase the system reliability and performance.

The standard I/O connector² (Q-5063) for the ASR-33 Teleprinter was installed on 20 units at ORNL. Program plug drawings were prepared for the PDP-8 computers, Hewlett-Packard computers and model 2570A data coupler, Nuclear Data computer and multichannel analyzers, Geon/Camberra model 7000 multichannel analyzer, Western Electric model WD6-168 data set, General Electric model TDM-114 acoustic coupler, ORTEC model 432 TTY drive, and Tenclec TTY drive unit. As needed, new program drawings will be prepared.

A Hewlett-Packard microcircuit interface card was modified to enable the HP-2115A computer to acquire and display data directly from analog-to-digital converters.

Programs for acquisition and processing of data were changed so that the interrupt system could control the acquisition and display of the data.

Nuclear Data, Inc., made an NDP-812 computer available for test and evaluation. This computer was designed primarily to be an integral part of their nuclear spectroscopy systems. Since two of these systems have been purchased and installed at ORNL and possibly several more will be purchased, the computer was operated to gain knowledge of hardware organization and operation of the computer and expertise in programming.

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1. E. McDaniel and A. J. Millet, *Instrumentation and Controls Div. Annu. Prog. Rep. Sept. 1, 1970*, ORNL-4630, p. 41.
 2. *Ibid.*, p. 88.

9.16 INSTRUMENT FABRICATION

C. C. Courtney C. H. Tacker C. E. Ryan

The fabrication shop of the Instrumentation and Controls Division constructs electronic components and instruments when such devices are newly developed prototypes, require skilled and rigidly controlled fabrication techniques, or the quantity to be constructed to conform to rigid specifications is too small to be of commercial interest. The following examples were selected to illustrate the output of this shop.

After the TVA had successfully operated ORNL-supplied radiological air monitoring units at the Brown's Ferry nuclear station, additional units were constructed and placed in operation at the TVA Sequoyah nuclear plant. Commercial manufacturers had been given an opportunity to supply these instruments, but they were unable to meet the fabrication standards.

Electronic calibrator instruments (Q-5042)¹ designed by ORNL were fabricated for the Office of Civil Defense for calibration of CD-V-781 aerial survey meters.

A coulometric titrator (Q-4010)² and a potentiometric titrator (Q-1728B) were constructed for the ORNL Analytical Chemistry Division.

A differential current-pulse, field-mounted preamplifier (Q-5095) was fabricated that required special shielding and grounding techniques (Sect. 2.3). A fission-chamber current preamplifier (Q-5097) was also fabricated for neutron physics service (Sect. 2.2).

Orbital weld programmers (Q-5021)³ for an automatic welding system were constructed for the Reactor Division. These units contain additional and improved circuits compared with the first unit constructed in this shop.

All etched wiring boards for construction of electronic instruments were fabricated in the etched wiring facility. In addition, miniature vaporization masks were fabricated for vacuum evaporation of thin films on ceramic substrates, and special parts were fabricated for research purposes. The facility is also being used to assist the Regional Modeling Group of the Environmental Study Project in digitizing map information.

1. F. M. Glass and E. E. Waugh, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 24.
2. C. C. Courtney and T. R. Mueller, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, p. 11.
3. R. L. Moore, W. A. Bird, and C. C. Courtney, *Ibid.*, p. 71.

9.17 CONTAINERS FOR LUNAR MATERIALS

V. A. McKay T. F. Slinki

Several containers for lunar material containers¹ were designed. In Fig. 9.17.1, the volumes of eight new stainless steel containers (reading from left to right in the rear) are as follows (in liters): 3.3, 1.2, 0.5, 0.25, and 25. In the front row there is a 0.24-liter, a 0.12-liter insert for the 0.24-liter container, and a 0.5-liter container sealed with a Teflon gasket.

These containers, except the 0.12-liter insert, can be sealed with either a disk or a ring gasket made from Alcoa alloy 1199-0. A ring and a disk gasket for each container are shown in Fig. 9.17.1.

Since the 0.2% yield values of 1199-0 alloy are low, 2500 to 3000 psi, the seals could be designed with thin flanges and low bolt loadings. Use of other metal seals in a series joint normally requires large bolts and thick flanges to prevent overstressing the flanges and bolts.

PHOTO 1306-71

Fig. 9.17.1. Containers for lunar materials.

A circular-lay, 16- μ in.-finish sealing area and a 0.055-in.-wide gasket requires a sealing load of only 218 lb/in. of seal circumference to achieve a $\leq$ rate of less than 10^{-10} std cc/sec. Subsequent resealing can be achieved at least twice by a 35% increase in sealing load.

I. V. A. McKay, T. F. Sliki, and H. J. Stripling, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, CRNL-4620, pp. 17-21.

9.18 QUALITY CONTROL

G. A. Holt

To ensure that vacuum tubes of satisfactory quality are obtained for maintenance of electronic instrumentation at ORNL, the Quality Control Group of the Instrumentation and Controls Division began acceptance testing of all vacuum tubes purchased by the ORNL Electronic Stores to replenish its stock or by the UCC-ND Purchasing Division for use at ORNL. An initial trial inspection of the present stock of vacuum tubes showed a high rejection rate. This program will also cover inspection and acceptance testing of all as-received materials for construction and maintenance of electronic instrumentation, a requirement of the ORNL Quality Assurance Program.

The acceptance tests of vacuum tubes will be carried out in three phases: (1) 100% inspection for acceptance or rejection of the present stock in the ORNL Electronic Stores, (2) 100% inspection of all vacuum tubes as received from commercial suppliers and purchased by ORNL Stores, and (3) 100% inspection of all vacuum tubes as received from commercial suppliers and purchased by the UCC-ND Purchasing Division for use at ORNL.

The accepted tubes will be marked, properly packaged, and delivered to ORNL Stores or to the requesting user. The rejected tubes, that is, those that fail to meet the manufacturer's or EIA specifications, show evidence of being rebranded or remanufactured, or appear to be used or surplus tubes, will be returned to the seller at his cost and for reimbursement to ORNL. Only new tubes from an original manufacturer in the original manufacturer's carton will be permitted in ORNL Stores.

9.19 QUALITY CONTROL AND STANDARDS

G. A. Holt

The Product Design Group of the Electronics Section continued to give consideration to the selection and quality assurance of standard components and materials. A recent accomplishment was a comprehensive selection of standard ac power plugs and receptacles for general Laboratory use and for specific use in specification, construction, and maintenance of new instruments.

In 1961, the National Electrical Manufacturers Association (NEMA) published two sets of standards for wiring devices: one for specific-purpose plugs and receptacles, and one for general-purpose plugs and receptacles. The standards of specific interest to this Division were for two-pole, three-wire, 125-V, 15-A grounding service. The electrical safety guides of the ORNL Safety Manual require specification and use of these devices in instrument construction.

Manufacturers began to produce these devices to NEMA standards about 1968. The Product Design Group purchased, as a generally specified ac power connecting device, several types of plug and receptacles made to NEMA standards from several manufacturers. The quality, usefulness, and cost of each manufacturer's product were evaluated, and the devices for use at ORNL were selected from this evaluation.

The ORNL Electronic Stores and General Stores now have in stock midget and standard size, locking and nonlocking plugs, connectors, receptacles, inlets, and outlets for two-pole, three-wire, 125-V, 15-A grounding service that conform to the latest NEMA standards.

Some plugs, receptacles, connectors, inlets, and outlets – both locking and nonlocking – were removed from the Stores. These included dual-voltage-rated devices, such as crowfoot blade devices and dual- or multivoltage-rated locking devices.

9.20 DIVISION QUALITY ASSURANCE PROGRAM

A. E. G. Bates L. F. Lieber¹

The quality assurance (QA) program of the Instrumentation and Controls Division began in September 1970 with the issuance of a quality assurance statement. Since then, the QA activity has increased appreciably. The coverage of Division-level QA procedures was well established, and six procedures of this type were issued for trial use. Activity was extended to the section level of the Division, but, with a few exceptions, these efforts were in planning. Four section-level procedures were issued, and work was started on others. Three sections of the Division are preparing documents that identify existing section standards and procedures and relate them to the QA program.

A number of QA program plans were prepared for programs funded by the AEC RDT according to their requirements.

¹. On loan from the General Engineering Division.

10. Reactor Instrumentation and Controls

ANALYSIS

10.1 HYBRID MODEL OF HEAT TRANSFER FROM A REACTOR FUEL PIN

F. H. Clark R. S. Stone

Safety considerations have sparked new interest in loss-of-coolant studies of reactor cores, with the greatest current emphasis on the water reactors. At issue are the temperatures reached in the fuel and its cladding under the loss-of-pressure and loss-of-flow contingency. Calculation of the resulting temperature distributions in the fuel is a spatially dependent kinetics problem of the type that is most conveniently handled by a hybrid computer. For these reasons, part of the hybrid software development program was to adapt the content of the THETA I digital code to the hybrid computer for the solution of the heat transfer equations in a water-cooled oxide fuel pin. The immediate incentives for this adaptation were the long computing times required by the digital program and the prospective need for an interactive program. The program development is now complete, and is intended to be used in a current water-cooled reactor safety study. In addition, the program is adaptable to liquid metals or other coolants.

The hybrid implementation puts one complete radial slice of the fuel, gas gap, clad, and coolant on the analog computer; it uses the digital machine to set and reset the coefficients of this analog "subroutine." This stratagem enables the same set of analog hardware to simulate the temperature behavior at sequential axial stations along the fuel pin. In addition, the digital machine makes a number of logical decisions concerning which heat transfer correlation to use and generates certain complex functions.

10.2 NUCLEAR DESALINATION PLANT CONTROL STUDIES

S. J. Ball N. E. Clapp, Jr. J. G. Delene¹

The problems of the control of large nuclear desalting plants were studied, with particular emphasis on the control of multistage flash (MSF) evaporators. The major objective is to develop a capability for predicting the performance characteristics, both static and dynamic, of plants with various design features, such as the Office of Saline Water (OSW) nine-stage MSF module at San Diego and the proposed OSW-California 40-Mgd prototype plant.

An important aspect of the design of large seawater distillation plants is the determination of their dynamic characteristics, stability, and controllability. As an aid to understanding and predicting the response of large multistage flash (MSF) evaporator plants, a digital simulator was developed. This simulator can calculate the response of the evaporator to various types of perturbations, accurately predicting levels, temperatures, flow rates, etc., in each stage within a reasonable computer running time. Typical system perturbations currently accommodated by the code are changes in steam flow to the brine heater and recycle flow to the evaporator. Presently, two versions of the simulator are available: a general-purpose unit

for the study of large evaporator designs and a second designed especially for the MSF module at San Diego.

Although both of the codes are operable, they are continually being improved. These improvements include changes both in the representation of the evaporator components and in the mathematical models used for describing heat transfer and flashing flow. Where possible, attempts are made to match experimental results and simulator calculations.

In the code development, a special goal was to reduce the computer running time while at the same time maintaining sufficient detail and accuracy. The running times on the ORNL IBM 390/91 computer for the two computer code versions are about 13 and 40 times real time for the general-purpose simulator (50-stage problem) and the module simulator, respectively.

Under development, but not yet operable, is an extension of the simulator to include a reactor, steam generator, and turbine-generator plant. This simulation is being developed as an aid to investigating the dynamics and possible control problems of large dual-purpose plants.

The MSF simulator is being used to determine areas in which evaporator experimentation is needed and to aid in the design of experiments on the nine-stage test module. The results of such experiments will further improve the mathematical models used in the simulator.

Studies with the ORNL MSF digital simulator showed areas where more detailed experimental data are required. For example, the predictions of overall MSF plant behavior were shown to be very sensitive to what is assumed to be the correlations for interstage orifice brine flow rate. In particular, models for stage hydraulic behavior near or in the blow-through condition (in which tray brine levels fall below the height of the orifice, allowing vapor to "blow through") were found to be crucial. More accurate expressions were also required for tray brine dynamics and nonequilibrium loss behavior.

In a series of tests run on the OSW/BLH three-stage evaporator, operated by Baldwin-Lima-Hamilton for the OSW, at Wrightsville Beach, N.C., in August 1970, several empirical correlations were obtained for a reference stage design. The test stage configuration was a 7-ft-long, 21-in.-wide empty chamber with rectangular orifices at either end. Several new test and analysis procedures were developed that improved the quality of data and correlations obtained. The "controlled-trend" test method was shown to enhance the output rate of useful information and to provide reproducible results (which checked with the data taken in conventional steady-state tests). Observation of evaporator behavior during the trend tests often made the forms of good correlating equations readily apparent.

The test results showed that the hydraulic and nonequilibrium loss behavior had an important combined effect on the operational stability of a single stage. Also, surprisingly good stage efficiency and stability characteristics were noted in experiments in which there was blow through.

In addition to the trend tests, dynamic tests on the evaporator were performed to obtain useful data for development of a dynamic model that would predict the performance of a stage in a multistage flash evaporator. The tests included both frequency response and pulse tests. The frequency response tests consisted of varying one or more of the stage inputs in a coded sequence, known as a pseudorandom binary n -sequence (PRBS), which contained a large number of odd harmonics. Three PRBS tests were performed: (1) the recycle brine flow rate was varied about a steady-state operating point, (2) the steam flow rate into the brine heater was varied, and (3) both the recycle brine flow rate and steam flow rate were varied simultaneously. In pulse tests the recycle brine flow rate or the steam flow rate was varied with a single pulse or a doublet (i.e., a positive pulse followed by a negative pulse) signal.

The method of frequency response analysis was to fit the frequency response data to theoretical models, obtaining the coefficients of the models by an optimization routine. First, the parameters of a standard distributed-parameter model for the test stage condenser were varied to obtain good agreement

with test data. From this, the flashing (or vaporization) rate was calculated, and the value was used in the flashing tray brine dynamic model development. This method of analysis yielded good results over a reasonably wide frequency range.

The pulse test data were analyzed using the ORNL hybrid computer. A model of the evaporator stage was set up on the analog computer, and digitized temperature, flow, and level data recorded during the pulse tests were stored in the digital computer. Input signal perturbations corresponding to the measured signals were sent to the analog model, and the measured outlet signals were compared with the outlet signals of the analog model. The hybrid program was prepared so that parameters could be varied manually, or automatically using a gradient search algorithm, to minimize differences between the model response and measured response.

The use of coded sequences, such as the PRBS, as input signals was an efficient means of obtaining frequency response data over a wide frequency range. The use of pulse signals as input signals was an effective way of obtaining time response data. Similar results were obtained from both frequency response and time response data; however, the analysis procedures are different. An example of the results obtained from dynamic analysis is the disclosure that there was a transport delay in the tray brine temperature frequency response, caused by channeling of brine along the bottom of and through the stage. As a result of channeling, stage performance was poorer because the measured nonequilibrium loss is larger than expected. The instability of the brine level was also dependent on the degree of channeling.

1. Reactor Division.

10.3 CONTROLLED-TREND PARAMETER VARIATION TESTS ON THE WRIGHTSVILLE BEACH THREE-STAGE FLASH EVAPORATOR, AUGUST 1970¹

S. J. Ball N. E. Ciapp, Jr. J. G. Delene²

A series of tests were run at the Office of Saline Water, Wrightsville Beach, North Carolina, Test Station on a three-stage experimental flash evaporator in August 1970. The purpose of the tests was to provide correlations to be used in dynamics and control studies of large-scale multistage flash (MSF) desalting plants using nuclear reactor heat sources.

Results of controlled-trend tests for determining nonequilibrium losses and interstage orifice brine flow behavior were analyzed, and correlations are presented. The trend test method was shown to greatly enhance the output rate of useful information. Special consideration was given to measurement and data-acquisition problems, resulting in internally consistent and reproducible results.

Observations are made regarding the combined effects of nonequilibrium loss and hydraulic behavior on stage and overall plant stability and operability. Comparisons of the resulting data and correlations with the currently used design correlations are made, and recommendations are given for future tests.

1. Abstract of published report ORNL-TM-3393 (November 1971).

2. Reactor Division.

10.4 MOLTEN-SALT BREEDER REACTOR

O. W. Burke P. G. Herndon
J. L. Anderson R. L. Moore
S. J. Ditto W. H. Sides

Participation in the conceptual design of the MSBR was continued with development of a model of the plant. The new model, an extension of work reported earlier,¹⁻³ is essentially the same for the reactor,

primary heat exchanger, and piping, but employs a digital-analog hybrid simulation of the steam generator. This hybrid model is a further development of work reported by Sanathanan.⁴

The mathematical model of the steam generator consists of equations of conservation of mass, momentum, and energy of the salt and water, written in one-space dimension (direction of water flow) and time. It was determined in previous work that a continuous-space, discrete-time model is most satisfactory for this type simulation.

The analog computer performs the integrations, and the digital computer calculates the variable coefficients of the differential equations, controls for the calculations, and stores the information. The thermodynamic properties of water are stored in the digital computers as two-dimensional tables. The steam generator model, coupled with the continuous-time analog model of the remaining parts of the system, is slowed in time by a factor of 10 or 100 to facilitate interfacing. Because first-order lags are used on the discrete outputs from the hybrid model to the analog model, the entire system is fairly smooth in time.

The entire system was programmed and operated. Initial problems of convergence and stability are being resolved, and it is expected that transient studies of plant behavior will be started soon.

A report was prepared (Sect. 10.33) which describes the updated instrumentation development needs for molten-salt reactors. Work was started to detail the instrument requirements for the Molten-Salt Breeder Experiment and to develop a set of instrument application diagrams. Assistance was given to preparation of documents that describe design bases for industrial participation in the development of molten-salt steam generators.

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1. W. H. Sides, Jr., *Control Studies of a 1000 Mw(e) MSBR*, ORNL-TM-2927 (May 18, 1970).
 2. W. H. Sides, Jr., *MSBR Control Studies: Analog Simulation Program*, ORNL-TM-3102 (May 1971).
 3. W. H. Sides, Jr., et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 118.
 4. C. K. Sanathanan and A. A. Sandberg, University of Illinois, Chicago, and F. H. Clark, O. W. Burke, and R. S. Stone, ORNL, "Dynamic Modeling of a Large Once-Through Steam Generator," *Nuclear Engineering and Design* (to be published).

10.5 DISPERSION OF FAST NEUTRON PULSES IN IRON ASSEMBLIES

R. S. Booth R. B. Perez¹

The propagation of a fast neutron pulse in iron was calculated for comparison with recent experiments at the University of Florida.² The transport kinetics program TASK³ was used in a P_3 - S_4 formalism with 11 neutron groups between 1 and 2.6 MeV derived from the recent tabulations of Penny and Kinney.⁴ To simulate the experiment, an impulse of neutrons was introduced into the highest neutron group (2.4 → 2.6 MeV) at the external boundary of the system. The attenuation and phase shift, as a function of distance from the source, were calculated for several frequency components of the impulse source. The theoretical dispersion law for the system was derived from the attenuation and phase shift predictions and the detector characteristics, and compared to the experimental dispersion law.

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1. Neutron Physics Division.
 2. C. M. Napolitano, E. E. Carroll, and M. J. Onanian, "Quasi-Monoenergetic Fast-Neutron Pulse Propagation in Iron," *Trans. Amer. Nucl. Soc.* 13, 275 (1970).
 3. H. L. Dobbs, Jr., *A New Computational Method for Space-Energy-Angular Dependent Reactor Kinetics*, ORNL-TM-3136 (1967).
 4. S. K. Penny and W. E. Kinney, *A Re-evaluation of Natural Iron Neutron and Gamma-Ray Production Cross Sections-ENDF/B Material 1124*, ORNL-4617 (1971).

10.6 A COMPARISON OF CALCULATED AND MEASURED NEUTRON ENERGY-DEPENDENT CAPTURE GAMMA-RAY YIELDS IN ^{238}U

R. S. Booth J. E. White² S. K. Penny² K. J. Vost³

The gamma-ray energy spectra resulting from neutron capture in ^{238}U were calculated using the gamma-ray cascade code DUCAL for incident neutrons in the energy range $0.0 \leq E \leq 1.1$ MeV. The overall spectral shapes generated for thermal and epithermal neutron capture agree quite favorably with an integral measurement. Absolute comparisons of the generated spectra with differential capture yield measurements exhibit general agreement. Variations in the spectral shape with neutron energy are noticeable above 3.0 MeV.

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1. Abstract of paper submitted to *Nuclear Science and Engineering*.
 2. Mathematics Division.
 3. Purdue University, Lafayette, Indiana.

10.7 HYBRID SUPPORT ACTIVITIES

F. H. Clark C. E. Murphy R. E. Wintenberg

Several software and hardware tasks were undertaken to upgrade the hybrid computer system.

A program was prepared to graph on the x-y plotter (an analog device) an array of data stored in the digital computer.

A line printer, formerly a part of a CDC-1604 system, was interfaced to the hybrid system. Implementation of software was virtually completed. The magnetic tapes with controller from the CDC-1604 were also interfaced but not software implemented.

Since this hybrid system was acquired Digital Equipment Corp. has substantially altered its monitor systems and has ceased to prepare them for single-user installations (such as the hybrid). All new DEC monitor developments are for multiuser time-share systems containing disks. Since the hardware requirements of these monitors exceed the complement of the ORNL hybrid system, this hybrid system would have been faced with a loss of new DEC software developments that would have been compatible with the new monitor systems but not with the ORNL monitor. For various reasons this situation was not acceptable. With substantial help and guidance from DEC, the ORNL monitor was modified to make it, in all respects of importance to ORNL, compatible with current DEC monitor systems and software.

DEVELOPMENT

Program for Measurement of Subcriticality in LMFBR

10.8 RESULTS OF FTR-3, ZPR-9 SUBCRITICALITY STUDIES

R. C. Kryter N. J. Ackermann, Jr. A. R. Buhl

As a part of the Liquid-Metal Fast Breeder Reactor (LMFBR) subcriticality measurement development program, extensive experiments were performed at ANL on the Zero Power Reactor, ZPR-9, mock-up (FTR-3) of the future Fast Test Reactor. The major purposes of these tests were: (1) to evaluate and intercompare a number of subcriticality measurement techniques under the realistic conditions of gamma-tolerant detectors in a large-volume, fast-spectrum reactor; (2) to test associated theoretical concepts, such as the dependencies of the various techniques on the neutron detection efficiency; and (3)

to ascertain the accuracy of available kinetic and static calculational methods in realistic complex-geometry situations, such as the prediction of neutron detection efficiencies, prompt neutron lifetime, and localized flux tilts introduced by control rods or external neutron sources. The techniques investigated were neutron noise analysis by means of both cross-power spectral density (CPSD) and polarity spectral coherence (PSC), neutron source multiplication (NSM), introduction of an asymmetrically placed neutron source (AS), and inverse kinetics (IK); all except the last (which was investigated by ANL personnel) are discussed separately below. Measurements were made from critical to -30 dollars shutdown.

Neutron Noise Analysis

In accordance with the first objective, fission counters capable of operation in a gamma flux of 10^4 R/hr (as opposed to much more sensitive ^3He or ^{10}B ionization chambers, for example) were used and placed in the middle of the reflector. The detector signals were processed in the frequency domain by an extended dynamic range CPSD analyzer system (Sect. 10.9) to yield the reactor transfer function and, hence simultaneous experimental estimates of the neutron detection efficiency W and the subcriticality ρ . Condensed conclusions (see also ref. 1) from the noise analysis portion of the experiment are: (1) subcriticality can be determined with adequate precision under realistic power reactor conditions to -2 or -3 dollars with a 30-min measurement; (2) as anticipated, the subcriticality derived from the transfer function breakfrequency is not affected by alterations in W ; (3) reactivity, as customarily defined, is a meaningful quantity in the range from 0 to -3 dollars because the measured transfer function obeys the point kinetics model in this range; (4) even under perturbed circumstances, two-dimensional transport theory calculations of W agree well with measured values; (5) good agreement was obtained between calculated and experimental values for the prompt neutron lifetime at critical; and (6) as anticipated, reactivity derived by PSC depends systematically on W , but, if W changes are known quantitatively, PSC results can be corrected by application of a simple closed formula.²

Neutron Source Multiplication

With the same fission counters as used during noise analysis, static count rates were measured at each subcritical configuration, and the ρ values thus derived¹ were corrected for changes of W as necessary. For 0 to -3 dollars subcritical, these W 's were derived from CPSD measurements; at greater subcriticalities, from transport theory calculations. Condensed conclusions (see also ref. 1) from this portion of the experiment are: (1) subcriticalities inferred from static count rates (NSM) agree with those measured by other techniques, even for severely perturbed W 's, so long as W changes are properly accounted for; (2) as expected, NSM is the only workable technique at subcriticalities greater than about -7 dollars; and (3) even in the far shutdown range, nominal agreement is obtained between subcriticalities measured by W -corrected NSM and those predicted by static eigenvalue calculations.

Asymmetric Neutron Source

The essence of this technique is that an asymmetrically positioned neutron source in a reactor causes flux tilts whose magnitudes are reactivity dependent. This tilt-to-subcriticality relationship is not simple nor easy to calculate, so to test the validity of presently available calculational techniques and to judge the utility of this AS method, static count rates from the same fission counters used previously were observed following the introduction of a $410\text{-}\mu\text{g}$ ^{252}Cf neutron source, which overrode the inherent spontaneous fission source of the reactor by about a factor of 10. The observed count rate ratios were compared with those predicted by the two-dimensional transport theory calculations, and values of ρ were thus inferred.³

Condensed conclusions (see also ref. 3) from this portion of the experiment are: (1) the AS method has high sensitivity to reactivity changes even at far subcriticalities and, therefore, might have promise for monitoring fuel reloading operations; (2) for optimum results the extraneous source should override the inherent distributed neutron sources by a factor of 5 or more; (3) the AS method is not promising for the detection of anomalous reactivity, because its use presupposes knowledge of the exact reactor loading and shutdown configuration at all times so that precalculated results can be utilized; (4) the difficult and highly detailed detector response calculations required for the AS method can be handled by two-dimensional multigroup transport theory.

In conclusion, the results of this experiment demonstrate the feasibility and practicality of the ORNL-proposed scheme for measuring subcriticality in LMFBR's, wherein a kinetics technique (for calibration of the NSM) and a static method (NSM) are combined to cover the entire range of subcriticalities. The neutron noise analysis proved to be suitable for this calibration if fission detectors were placed in the reactor reflector or inner shield; inverse kinetics was also shown to be an adequate calibration technique under these same conditions and could be used as an alternative to or a backup for the neutron noise analysis.

1. R. C. Kryter, N. J. Ackermann, Jr., and A. R. Buhl, "Measurement of Subcriticality in Large Fast Reactors by Combining Noise and Multiplication Techniques," *Trans. Amer. Nucl. Soc.* 14(1), 42 (June 1971).

2. N. J. Ackermann, Jr., A. R. Buhl, and R. C. Kryter, "An Analytical and Experimental Evaluation of Detection Efficiency Dependence of Subcriticality Measurements by the Polarity Spectral Coherence Method," *Ibid.*, p. 44.

3. A. R. Buhl, N. J. Ackermann, Jr., and R. C. Kryter, "An Evaluation of the Asymmetric Source Technique for Determining Subcritical Reactivity in Fast Reactors," *Ibid.*, p. 43.

10.9 CROSS-POWER SPECTRAL DENSITY ANALYZER FOR SUBCRITICALITY MEASUREMENT IN AN LMFBR

R. C. Kryter

Construction was completed on a neutron-noise data reduction system¹ (Q-4305) capable of efficiently extracting small amounts of coherent signal buried in uncorrelated noise, and extensive performance tests were carried out to ascertain proper performance for planned fast-reactor subcriticality experiments (Sect. 10.8). The data analysis system computes the copower spectral density of two signal inputs by the analog method of bandpass filtration, cross multiplication, and subsequent exponentially weighted integration of the resulting instantaneous signal products.

The two third-octave bandpass filters used are General Radio model 1925, which are active six-pole Butterworth designs yielding 30 filtered outputs in parallel, with center frequencies ranging from 100 to 80 kHz. Any 10 of these outputs can be selected by a patchboard for simultaneous analysis by specially developed multiplier-time averager NIM modules (Q-3128), based on the Burr-Brown model 4098/25 variable transconductance four-quadrant analog multiplier (oven controlled for stability). Time-averaged (20- or 100-sec RC) answers are read out periodically by a data logging system employing a Dymec sequential input scanner and a Teletype. Two other special NIM modules provide input signal buffering and gain control (Q-3130) and statistically independent white noise signals (Q-3129) for system checkout.

Performance of the completed system was adequate for the intended application. Frequency response is "flat" over the range from 100 to 25 kHz, with about a 7% correction for multiplier roll-off required at 80 kHz. System stability for the duration of a typical experiment is about 2%, although long-term drift of the filter banks necessitates periodic tuneup for top performance. The system signal-processing dynamic range

of about 4×10^3 enables accurate information extraction from data having a signal-to-noise ratio as low as 0.001.

1. R. C. Kryter, C. C. Courtney, and D. N. Fry, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 105.

10.10 PREPARATIONS FOR THE SEFOR SUBCRITICALITY MEASUREMENT EXPERIMENT

N. J. Ackermann, Jr.	G. C. Guerrant
A. R. Buhl	R. C. Kryter
W. T. Clay	D. P. Roux

As part of the Liquid-Metal Fast Breeder Reactor (LMFBR) subcriticality measurement program, an experiment will be performed by ORNL personnel in the Southwest Experimental Fast Oxide Reactor (SEFOR) of the General Electric Co. in the fall of 1971. The purpose of this experiment will be to demonstrate that subcriticality measurements can be made in an LMFBR-type environment (e.g., high temperature, gamma level, and background noise level). The neutron source multiplication technique will be used to determine the subcriticality over the full range of shutdown; neutron noise analysis and inverse kinetics methods will be used to calibrate the neutron source multiplication technique in the 0 to -5 dollar range. Preparations for this experiment comprise: (1) preparation of the experiment design and procedure; (2) qualification of the detector at the expected temperature (400°F) and gamma (10^7 R/hr) levels, and design, fabrication, and testing of the detector housing; (3) modification and qualification of the data processing equipment; and (4) development of data interpretational algorithms.

10.11 MODIFIED INVERSE KINETICS TECHNIQUE FOR DETERMINING REACTIVITY

J. C. Robinson¹

The inverse kinetics technique for the determination of reactivity is being considered as a calibration measurement for the neutron source multiplication technique.² As envisioned, the reactor would be changed from the critical state (nominally at 10 W) to approximately 3 dollars subcritical by the rapid insertion of control rods. The specific subcritical state would be determined using inverse kinetics.

In the classical inverse kinetics techniques,^{3,4} it is assumed (usually implicitly) that the detector efficiency remains constant throughout the observation time (before, during, and after the rod drop). In the Fast Flux Test Facility (FFTF), the neutron detectors will be fission chambers operated in the pulse mode; therefore, the detection efficiency will change owing to counting losses and perhaps to rod shadowing. Accordingly, the inverse kinetics technique was modified to explicitly allow for detector efficiency changes. Results from simulated transients following a rod drop are encouraging. For example, the correct value of reactivity can be inferred for significant changes in detector efficiency; however, there are limitations such as the dynamic range associated with the transient, the shutdown state, and the statistical uncertainty associated with the observed data. These limitations are being explored by studying simulated transients. The modified inverse kinetics algorithm will be applied to experimental data from the Southwest Experimental Fast Oxide Reactor (SEFOR) experiment.

1. Consultant from the Department of Nuclear Engineering, the University of Tennessee, Knoxville.

2. N. J. Ackermann, Jr., and A. R. Buhl, "Preparations for Subcriticality Measurements in ZPR-9 and SEFOR," *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 103-4.

3. C. A. Sastre, "The Measurement of Reactivity," *Nucl. Sci. Eng.* 8(5), 443-97 (1970).

4. S. G. Carpenter, "Reactivity Measurements in the Advanced Epithermal Thorium Reactor (AETR) Critical Experiments," *Nucl. Sci. Eng.* 21(4), 429-40 (1965).

10.12 EFFECT OF GAMMA RADIATION ON LMFBR SUBCRITICALITY MEASUREMENTS USING NOISE ANALYSIS¹

D. P. ROY A. R. Buhl

As a result of the effect of residual gamma radiation on neutron detectors in shutdown reactors, the precision of subcriticality measurements by noise analysis is degraded. An equation for this gamma degradation effect was developed for application to fast reactors. The gamma degradation factor D and the detection efficiency W_n were evaluated for ^{10}B , ^3He , and ^{235}U detectors for application in the Fast Flux Test Facility (FFTF), and it was concluded that the ^{235}U , the least sensitive of the three detectors, is the best choice. The ^{235}U detector is 40 times less efficient than the ^3He detector, but it should experience only a slight degradation in the FFTF. By contrast, degradation factors varying between 100 and a few thousand are anticipated for the ^3He detector through the shutdown range of -1 to -10 dollars. Furthermore, D is unity up to 10^6 R/hr and is independent of ρ for the fission chamber when used as a counter.

1. Abstract of article published in *Nucl. Technol.* 12, 137-40 (September 1971).

10.13 RESPONSE OF THE FFTF EX-VESSEL DETECTORS TO LARGE ^{252}Cf SOURCES

A. R. Buhl

The response of the Fast Flux Test Facility (FFTF) ex-vessel detector to large ^{252}Cf sources was evaluated to determine the feasibility of eliminating the in-vessel low-level flux monitor (LLFM) from the FFTF design. The LLFM consists of three cooled in-vessel assemblies, each of which contains a movable fission counter. The elimination of the LLFM is desirable because of mechanical complexities, the extreme fission counter environment, and mechanical interference of the LLFM with other systems in the FFTF.

Two-dimensional transport theory calculations were made to determine the response of the ex-vessel detector to a ^{252}Cf source located at the center of the core and then to three sources in the seventh reflector row. These calculations were made in R - θ geometry, using 50 energy groups, 30 angles, and a P_3 expansion of the scattering cross sections. Reflector source locations proved unsatisfactory because the large direct source contribution to the ex-vessel detector masked the core information.

The effect of placing fresh, core-zone 1 fuel in the three in-vessel stored fuel baskets was calculated for the inherent core source and the inherent core source plus 25 mg of ^{252}Cf at the core midplane and axis. These calculations were made at a subcriticality of 25 dollars. The effect of small reactivity changes was evaluated by repeating several of the calculations at 30 dollars subcritical. A summary of some of the results for 25 dollars subcritical is shown in Table 1.

The major uncertainties in this evaluation are the effects of stored fuel and, hence, the amount of ^{252}Cf required. Without stored fuel, the calculations (and, in principle, the measurements) are straightforward. However, when fuel is stored in the three baskets, the amount and isotopic content must be known precisely to determine the fraction of the detector response that is core information (signal) and the fraction that is due to the stored fuel (noise).

We conclude that the ^{252}Cf source monitor is feasible for source level flux monitoring *only if* the uncertainties associated with the stored fuel can be resolved. From the information in Table 1 and a criterion which states that a signal-to-noise ratio of 1:1 is an acceptable response for an ex-vessel detector, an 8.2-mg ^{252}Cf source is sufficient for the source monitor at 25 dollars subcritical. However, burnup and decay considerations over a one-year period will double the quantity required.

Table 1. Response of ex-vessel detectors in the FFTF
at 25 dollars subcritical

Reactor-source configuration	Response (fissions $\text{sec}^{-1} \text{ g}^{-1}$ of ^{235}U)
Spontaneous fission + oxide source with no stored fuel	1.8
Spontaneous fission + oxide source with stored fuel	276
25 mg of ^{252}Cf at core center with no stored fuel	1332
25 mg of ^{252}Cf at core center with stored fuel	2098

10.14 STATUS OF THE FAST REACTOR KINETICS CODE TASK

A. R. Buhl J. C. Robinson¹

TASK (Transfer And Scattering Kinetics), a spinoff from the ORNL Liquid-Metal Fast Breeder Reactor (LMFBR) subcriticality measurement program, was developed for use as a tool for the interpretation of several planned kinetic experiments.

TASK is a one-dimensional kinetics code that has both transport theory and diffusion theory capability. It is based on an algorithm that combines the transfer matrix formulation which has been used for solution of initial value problems and the scattering matrix formulation which has been used for solution of problems in transmission line theory and shielding and criticality studies.

A well-tested version of TASK is running on the IBM 360/91, /75, and /65 computers. This version was used to analyze data from neutron wave experiments,² neutron noise experiments in thermal reactors,³ and fast kinetics experiments.⁴ Typical applications included five energy groups, four angles, and computations for static eigenvalues, as well as kinetics calculations. These applications also utilized the arbitrary space-energy-distributed source option in TASK.

The group-angle limitation is due to the size of the coefficient matrices. This limitation is being eliminated by introducing source iteration into TASK.

The TASK development program is as follows:

1. TASK will be made user oriented by attachment of standard I/O interface packages.
2. The addition of the source iteration scheme will be completed within a few months.
3. Spherical and cylindrical geometry packages will be added.
4. The programming will be optimized to decrease both computation time and computer core requirements.
5. Linear feedback options will be incorporated.
6. The direct time solution algorithm will be included as an option.
7. Nonlinear feedback capabilities will be provided.
8. TASK II D, a two-dimensional version of TASK, will be made available.

Steps 1 to 4 are straightforward, and their completion will produce a generalized reactor kinetics code based on transport theory. Such a code will fulfill two purposes: (1) for evaluation of kinetic parameters for and analysis of data from experiments on fast reactors; and (2) for evaluation of various approximate models such as diffusion theory, spectral synthesis, and low quadrature models, since the basic solution algorithm is model independent.

Steps 5 to 8 are conceptually more difficult than the preceding steps. Work will be started on step 6 in late 1971.

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1. Consultant from the Department of Nuclear Engineering, the University of Tennessee, Knoxville.
 2. H. L. Dodds, Jr., *A New Computational Method for Space-Energy-Angular Dependent Reactor Kinetics*, ORNL-TM-3136 (January 1971).
 3. J. C. Robinson and M. L. Alexander, "Calculation of Reactor Noise Spectra Using a Space-Energy Dependent Model: Comparison with Experiment," *Trans. Amer. Nucl. Soc.* 14(2), 856-57 (October 1971).
 4. A. R. Buhl, N. J. Ackermann, Jr., and J. C. Robinson, "Application of Transport Theory Kinetics to the Interpretation of Experimental Neutron Noise Spectra in Large Fast Reactors," *Ibid.*, pp. 857-58.

10.15 APPLICATION OF TRANSPORT THEORY KINETICS TO THE FAST TEST REACTOR-3

A. R. Buhl N. J. Ackermann, Jr. J. C. Robinson¹

A major problem in using kinetics measurement techniques to infer reactor parameters is that the quantities directly observable in kinetics experiments are often difficult to calculate. Hence, the ability to establish conditions under which parameter inferences can be made is diminished. In the application of noise analysis to fast reactors, space and energy effects often mask the desired reactor parameters.

To improve the ability to infer parameters from noise measurements, the directly observable noise data were calculated with transport theory, using TASK (Sect. 10.14). This code eliminates truncation and round-off errors that have severely restricted previous attempts to compute directly observable results. The calculated results were applied to interpret experimental neutron noise spectra² (NNS) for the FTR-3 loading of the Zero Power Reactor, ZPR-9. These calculations were made to establish the conditions under which NNS can be interpreted in terms of reactor parameters, in particular, the neutron generation time Λ and the reactivity ρ . These are the first NNS calculated using transport theory that compare favorably with experimental data.

The measured and calculated cross-power spectral densities (CPSD) of two ²³⁵U detectors in the reflector were in excellent agreement for the critical configuration. The calculated and experimental results agreed with point reactor model predictions. The same CPSD was calculated for two identical detectors in the center of the core. Except for an amplitude normalization, these results were identical to those for detectors in the reflector, indicating that identical values of the prompt frequency break would be obtained in the reflector or in the core at critical.

The generation time obtained from the calculated NNS was 0.787 μ sec; this value agrees with the experimental value of 0.728 μ sec. For further comparison, 0.889 was calculated using the adjoint weighted definition of generation time,³ the same neutronic model, and multigroup constants in ANISN.

In contrast to the critical NNS, at a nominal subcriticality of 7 dollars the calculated NNS deviated from point model behavior, indicating space and energy effects. These effects were different in the core than in the reflector. However, a forced fit of the point model to these data predicted a reactivity of -6.44 dollars. A lambda mode eigenvalue calculation of reactivity was -7.04 dollars.

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1. Consultant from the Department of Nuclear Engineering, the University of Tennessee, Knoxville.
 2. R. C. Kryter, N. J. Ackermann, Jr., and A. R. Buhl, "Measurement of Subcriticality in Large Fast Reactors by Combining Noise and Multiplication Techniques," *Trans. Amer. Nucl. Soc.* 14(1), 42-43 (June 1971).
 3. A. F. Henry, "The Application of Reactor Kinetics to the Analysis of Experiments," *Nucl. Sci. Eng.* 3, 52-70 (1958).

OTHER DEVELOPMENT

10.16 CALCULATION OF REACTOR NOISE SPECTRA USING A SPACE-ENERGY
DEPENDENT MODEL: COMPARISON WITH EXPERIMENTJ. C. Robinson¹ M. L. Alexander²

The transfer and scattering kinetics (TASK) algorithm³ was extended to permit the calculation of reactor noise spectra based on the Langevin conjecture, that is, the introduction of a noise equivalent source (NES). The NES was assumed to be white and to have a mean fission-density spatial distribution and a fission-neutron-energy spectrum.

The physical model in this study was a one-dimensional slab geometry mock-up of the Pool Critical Assembly (PCA). The neutronic model was a three-energy group diffusion theory model. The computed quantities were the auto-power spectral density (APSD) and cross-power spectral density (CPSD) for a fast- and a thermal-neutron detector located in the reactor core and in the reactor reflector. The computed APSD and CPSD for various detectors were compared with similar experimental APSD and CPSD obtained by Ackermann⁴ and Penland.⁵ Spatial and energy effects were evident in the calculated and experimental spectra; furthermore, the calculated spatial and energy effects agreed well with the observed spatial and energy effects. From these observations, the calculational procedure for the spectral density calculations was judged to be valid. Therefore this same procedure can aid the interpretation and design of future spectral density measurements.

1. Consultant from the Department of Nuclear Engineering, the University of Tennessee, Knoxville.

2. Graduate student in nuclear engineering, University of Tennessee, presently with Virginia Power Co.

3. H. L. Dodds, Jr., *A New Calculational Method for Space-Energy-Angular Dependent Reactor Kinetics*, ORNL-TM-3136 (January 1971).

4. N. J. Ackermann, Jr., *An Analytical and Experimental Investigation of the Neutron Energy Effects on Reactor Fluctuation Spectra*, ORNL-TM-3245 (February 1971).

5. J. R. Penland, *Space and Energy Dependence of Reactor Fluctuation Spectra*, ORNL-TM-3372 (to be published).

10.17 NOISE ANALYSIS INVESTIGATIONS AT THE FUEL-FAILURE MOCK-UP

D. N. Fry R. F. Saxe¹ C. B. Stokes

Noise analysis techniques are being applied to the Fuel-Failure Mock-up (FFM) to (1) diagnose instrumentation malfunctions or failures, (2) investigate and develop methods of sodium boiling detection, and (3) monitor flow stability during intentional flow blockage tests. Noise signals being investigated are acoustic noise signals from hydrophones mounted on the test section, magnetic flow meter noise, and thermocouple noise.

Frequency analysis of background (no boiling) acoustic noise shows that peaks at 325, 2650, 4400, and 10,000 Hz are strongly dependent on the sodium flow rate. In the frequency range from 20 to 600 kHz, the main cause of acoustic noise is compressed air that cools an exit seal at the top of a thermocouple test section.

An experiment was conducted to determine whether pulses due to bubbles formed by boiling could be detected above the background noise. A hydrophone was pulsed with pulses similar to those produced by boiling bubbles, and these pulses were detected by a second hydrophone in the presence of the background noise. The detection of boiling in the FFM is, therefore, possible, and the detection sensitivity might be increased by decreasing the background noise due to the flow of compressed air.

Noise from the inlet magnetic flow meter on the test section was measured at flow rates from 6 to 40 gpm to determine the change in the flow noise spectrum as a function of flow. The results show that: (1) the noise bandwidth is 1.4 Hz at 40 gpm, and (2) the bandwidth is approximately proportional to flow in the range of flow rates investigated. The amplitude of flow noise varied from $0.02 \text{ rms-gpm (Hz)}^{1/2}$ at 5.8 gpm to $0.075 \text{ rms-gpm (Hz)}^{1/2}$ at 40 gpm. These results will be used as reference data for future flow noise investigations during flow blockage tests at the FFM.

Thermocouple noise analysis was investigated at the FFM heater test facility to determine if noise analysis diagnostic methods can be used to detect thermocouple failures and monitor the response time of installed thermocouples.

The time response of a spacer-wire thermocouple in flowing sodium at 1000°F was estimated from the observed frequency spectrum of the noise on the thermocouple signal. To do this, the frequency spectrum of the true sodium temperature fluctuation was assumed to be constant (white) over the bandwidth of the thermocouple response (these temperature fluctuations are caused by turbulent heat transfer from the heated pin to the sodium coolant). Thus, the shape of the observed temperature noise spectrum represents the gain-frequency response of the thermocouple. The thermocouple time response inferred from its frequency response was 145 msec. This agrees with independent measurements² (by insertion of similar thermocouples into boiling water) of 146 to 652 msec.

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1. Consultant from the Department of Nuclear Engineering, North Carolina State University, Raleigh.
 2. Personal communication from M. B. Hershkovitz, ORNL.

10.18 METHOD FOR VERIFYING REACTIVITY FEEDBACK TIME RESPONSE IN POWER REACTORS

D. N. Fry

An experimental method was tested for verifying the reactivity feedback time constants used in safety analysis of reactors. The main objective of this investigation was to determine whether the reactor power-to-temperature transfer function could be measured and, thereby, whether the time response of the reactivity feedback from different reactor core regions could be inferred. Other objectives of this study were to thoroughly test and improve the experimental procedure, equipment, and data reduction techniques and to determine the feasibility of this method with an analog computer without consuming reactor operating time.

The frequency response of an analog model of the High-Flux Isotope Reactor (HFIR) was obtained by supplying an external reactivity input from a white noise generator, recording simultaneously the reactivity fluctuations and the resulting power and temperature fluctuations of the model, and computing the cross-power spectral density (CPSD) of the input and output signals by using the fast Fourier transform code CROSSPOW.^{1,2} The transfer function was computed as

$$G(f) = \frac{\text{CPSD}(f)}{\text{APSD}(f)}, \quad (1)$$

where $\text{APSD}(f)$ is the power spectral density of the input driving function.

These experiments were conducted using the analog model to determine the sensitivity of the power-to-reactivity transfer function to changes of the overall positive or negative temperature reactivity feedback, temperature coefficients of reactivity, and core coolant flow. The temperature-to-power transfer functions were also determined, and, from these, the time constants of reactivity feedback were inferred

from core, target, and control-rod regions. The sensitivity of temperature-to-power transfer functions to changes of the coolant flow rate was also studied.

The conclusions from this study were as follows:

1. Positive reactivity feedback has a negligible effect on the HFIR power-to-reactivity transfer function at frequencies above 0.1 Hz. As expected, all positive feedback time constants in the HFIR are longer than the negative feedback time constants.
2. Because of the different effects caused by changes in the fuel and core-coolant temperature coefficients, it might be possible to diagnose which coefficient has changed by monitoring the gain and phase functions.
3. Thermal response time constants can be inferred by perturbing the reactor power and computing the CPSD of power and temperature signals.
4. Real-time analog models of a reactor, developed for safety or control studies, can be used for planning a dynamic experiment with little additional effort.
5. Since temperature-to-power transfer functions are sensitive to changes of coolant flow rates, it might be possible that partially blocked flow channels in reactor subassemblies could be detected by cross correlating the reactor power and subassembly outlet temperature.

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1. R. C. Kryter, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1968*, ORNL-4335, p. 80.
 2. R. C. Kryter, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, p. 92.

10.19 STUDIES OF PARTIAL COOLANT-FLOW BLOCKAGE AT THE HFIR

W. H. Sides, Jr. J. B. Bullock

The detection of a partial coolant flow blockage was investigated by measuring the power coefficient at the High-Flux Isotope Reactor (HFIR). An experiment was conducted to measure the reactivity decrement associated with a power increase from 1 to 10 MW (1 to 10% of full power). The measurement was made at full primary coolant flow and at partial flow with three, two, and one pump operating, and finally with all three pumps on emergency power (approximately 12% of full flow). The on-line HFIR computer was used to calculate the reactivity change from measured neutron flux using the inverse kinetics method. A reactivity decrement (power coefficient) of -2.2 cents/MW was measured at 12% flow. Full-flow measurements of the reactivity decrement associated with a power increase from 10 to 100 MW indicated a value of approximately -0.4 cent/MW at the beginning of core life.

An analog computer simulation model of the nuclear and thermal behavior of the HFIR was used to confirm these results. The analog model exhibited a reactivity decrement of -0.45 cent/MW at full flow and -2.9 cents/MW at 12% flow, which were in agreement with the experimental results from the HFIR. A variation in the flow rate of only 4.5% was required to account for the 0.7 cent/MW difference at 12% flow.

An analog model, which included only temperature effects on reactivity, indicated that the power coefficient was constant at all power levels for a given flow rate. The variation in this coefficient between full flow (three pumps) and 56% flow (one pump) was about 0.23 cent/MW. The variation between 56 and 12% flow (three pumps at emergency flow) was 2.2 cents/MW. Therefore, during the escalation of power at the beginning of core life, an abnormal core flow rate would be detectable by a power coefficient measurement before sufficient power would be reached to induce boiling and core damage. Further, partial flow blockage in various regions of the core or target might produce measurable differences in the power coefficient while affecting the total-flow measurement only slightly. Further investigations are being carried out.

REACTOR SAFETY AND EVALUATION

10.20 NUCLEAR SAFETY JOURNAL

E. W. Hagen

Publication of *Nuclear Safety* under the auspices of the Nuclear Safety Information Center (NSIC) was continued.¹ Responsibility was continued for the preparation and editing of material related to instrumentation and control,² and members of the Instrumentation and Controls Division wrote four of the six articles (Sects. 10.21–10.23 and 10.39) contained in the "Control and Instrumentation" section of *Nuclear Safety* during the past year.

1. C. S. Walker and E. W. Hagen, *Instrumentation and Controls Div. Annu. Prog. Rep. Sept. 1, 1970*, ORNL-4620, p. 114.

2. E. W. Hagen (ed.), *Nucl. Safety* 11(5), 375–78 (Sept.–Oct. 1970); 11(6), 468–74 (Nov.–Dec. 1970); 12(2), 90–99 (March–Apr. 1971); 12(3), 217–33 (May–June 1971); and 12(4), 310–25 (July–Aug. 1971).

10.21 INSTRUMENTATION FOR MONITORING THE HYPOTHETICAL LOSS-OF-COOLANT ACCIDENT IN LARGE LIGHT-WATER POWER REACTORS¹

T. G. Robinson² B. C. Duggins

Various engineered safety features available in nuclear-fueled commercial power stations would be called upon to cope with the consequences of a loss-of-coolant accident. These safety features are provided with instruments to initiate operation and to monitor continued operation. When the safety features were called upon, the plant operator would need information regarding both the operation of these emergency systems and equipment and the continuing success of their mission.

A brief study was conducted to determine the types and extent of instrumentation available in the designs of representative nuclear power plants of the latest generation for monitoring the course of a loss-of-coolant accident. The four plants surveyed appeared to have adequate and sufficient instrumentation for monitoring the operation of the equipment in the engineered safety system for the case of a successfully contained loss-of-coolant accident; however, instruments for directly detecting unexpected damage to the reactor core appear to be lacking.

1. Abstract of published journal article: *Nucl. Safety* 11(6), 468–74 (November–December 1970).

2. Present address: Tennessee Valley Authority, Knoxville.

10.22 THE USE OF ACTUATORS AS LOGIC ELEMENTS IN RELATION TO FAIL-SAFE DESIGN¹

E. P. Epler² S. J. Ditto

Some of the principles governing current designs of electrical or electronic voting logic systems can be applied to the design of control and protection systems where the voting logic is at the level of the large electromechanical devices that act directly to control a process. This application is of particular benefit in systems for which there may be a significant penalty for failure in the so-called safe mode as well as in the unsafe mode. Such systems have frequently made use of "failure-to-danger" techniques, which in some areas might lead to a compromise of safety objectives. The use of actuators as logic elements allows the design of simpler systems, with more complete testability, and can provide an ultimate gain in safety.

1. Abstract of published journal article: *Nucl. Safety* 12(3), 216–33 (May–June 1971).

2. Consultant to the Instrumentation and Controls Division.

10.23 JOINT ANNUAL SYMPOSIUM OF IEEE POWER AND NUCLEAR SCIENCE GROUPS -- 1970¹

Compiled and Edited by E. W. Hagen²

The second joint symposium by the IEEE Power and Nuclear Science Groups on the general topic of nuclear power, control, and instrumentation was held in New York City, November 3-6, 1970. The talks and papers presented totaled 121 at 15 sessions, of which two were tutorial. Environmental considerations were the subject of the general meeting, and the luncheon speaker defended technology. The technical sessions covered some operating experiences, reliability analyses, and standards for nuclear power stations. There were also papers on nuclear instrumentation for research and development in nuclear physics, biomedicine, space exploration, and data collecting.

1. Abstract of published journal article: *Nucl. Safety* 12(4) (July-August 1971).

2. Contributing authors are Session Chairmen H. C. Barnes, American Electric Power Service Corp.; D. G. Fitzgerald, NUS Corp.; P. F. Gustafson, ANL; J. M. Harrer, ANL; I. M. Jacobs, General Electric Co.; R. R. Mehler, University of Oklahoma; and V. A. Moore, USAEC-DKL.

10.24 RELIABILITY CONSIDERATIONS FOR NUCLEAR REACTOR PROTECTION SYSTEMS

P. Rubel

The final draft of a topical report on the theoretical and practical aspects of achieving reliability in reactor protection systems was completed. The report is based on survey studies performed during the last period,¹ sponsored by the ORNL NSIC. The material is intended to promote understanding of the methods available to assure the required performance of vital protective functions and to assess the extent to which the methods are currently being applied.

1. P. Rubel, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 114.

10.25 RELIABILITY STUDIES OF PROPOSED UNDERSEA REACTOR

P. Rubel

As a part of a U.S. Navy-sponsored ORNL program to review small reactor concepts for possible undersea application, evaluation of the reliability aspects of several proposed plant designs was begun. Development of reliability profiles, mainly qualitative, was started for the principal systems of each plant. The information will be assembled on a comparison basis so as to form broad estimates of what could be accomplished and to identify critical areas requiring special quality assurance measures.

10.26 NUCLEAR SAFETY INFORMATION CENTER

E. W. Hagen

The program of collecting, evaluating, indexing, storing, and disseminating information related to instrumentation and electric power associated with nuclear safety was continued.¹ This material pertains to the safety of nuclear plants in the categories of protection systems, operation systems, plant instrumentation, and plant electric power systems. Approximately 1233 documents were reviewed and abstracted for the computerized information retrieval system at the NSIC, and 54 direct requests for special

tabulations of references or information were processed for the national and international nuclear community during the past year.

1. E. W. Hagen, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 114.

10.27 REACTOR AVAILABILITY AND STATION RELIABILITY FOR CONTINUITY OF SERVICE

E. W. Hagen

Section 4.2, entitled "Heat Source Reliability," of a project summary report, *Use of Steam-Electric Power Plants to Provide Thermal Energy to Urban Areas* ORNL-HUD-14, was revised, and the report was published. This material summarized a portion of a more comprehensive study¹ that examined reactor availability and reliability from the reported experiences of seven commercially operated, nuclear-powered generating stations: Big Rock Point, Connecticut Yankee, Dresden 1, Humboldt Bay, Indian Point 1, Shippingport 2, and Yankee-Rowe.

1. E. W. Hagen, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 114.

REACTOR PROJECTS

10.28 PBF CONTROL AND SAFETY INSTRUMENTATION

J. L. Anderson S. J. Ditto

The reactor control and protection system, which was designed and fabricated at ORNL, for the Power Burst Facility at the National Reactor Testing Station (NRTS) was shipped to the site as previously reported¹ and was installed and checked out. Meanwhile, the program of experiments planned for the facility was substantially altered by AEC directive. The new experiments require different modes of operation than previously planned, and, as a result, some modifications of the protection system are necessary. Some new instruments are being designed at ORNL to replace or supplement those in the installed system to achieve the new protection requirements. Additional analyses are being carried out in cooperation with Idaho Nuclear Corp. to specify or verify the new protective functions. Initial operation of the facility will be delayed as a result of these program changes until late 1971.

1. J. L. Anderson et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 119.

10.29 BSR PROTECTION SYSTEM IMPROVEMENT

J. L. Anderson

C. C. Courtney S. J. Ditto J. B. Ruble K. W. West

A solid-state magnet control system was developed for the ORNL 2-MW Bulk Shielding Reactor protection system. The system replaces vintage vacuum-tube magnet amplifiers that have been in service 20 years. The change was made to reduce the failure rate of the scram electromagnets which were required to operate at high voltage, under water, in a moderately high radiation environment. In the new system some improvements in magnet design were incorporated as well.

In the old system the magnets were operated in the anode circuit of a vacuum tube at 300 to 400 V, necessitating a watertight seal in the magnet assembly. In the radiation environment it was difficult to

maintain such a seal, and minute leaks resulted in frequent electrical breakdown of the magnet coils. In addition, the electronic components required excessive maintenance to reduce the spurious scram rate and frequent tuning to maintain performance within acceptable limits.

The new system was designed to operate the magnets at only a few volts above ground potential. In addition, fewer turns of the magnet coils operate at high current, which results in very low inductive surge voltage when turned off. With additional electronic surge limiting, the flyback voltage is held to less than 50 V without detrimental effect on the magnet release time. With these operating conditions, it was no longer necessary to make the housing waterproof. The coils were wound on ceramic bobbins, epoxy potted, and operated directly in the demineralized pool water. The magnet core structures and armatures were made of a nickel-iron alloy and nickel plated to eliminate corrosion. The new electronics circuits were based on designs previously produced for other reactors.^{1,2} Pulse testing replaced the continuous circuit monitors previously used. Although only a portion of the reactor protection system was affected by this change, the design is such that later replacement of the remainder of the vacuum tube system will be easier. The new system was packaged in NiM bins.

A notable aspect of this design is that it was used as a test of the newly established ORNL quality assurance procedures, with limited success. The system operated satisfactorily for several months.

1. L. C. Oakes, *A Second Generation of Reactor Control Systems as Applied to the HFIR*, ORNL-TM-1259 (September 1965).

2. J. L. Anderson, S. J. Ditto, and T. L. McLean, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 119.

10.30 CONTINUOUS AUTOMATIC CALIBRATION SYSTEM FOR REACTOR FLUX INSTRUMENTATION

J. L. Anderson

In most reactors the ionization chambers for protection and control measure leakage flux, which is not linearly proportional to power because of control rod shading, experiment interference, changes in flux distribution, etc. Heat power measurements (typically flow times differential temperature) are accurate, but too slow to use directly for protection or automatic control. By slowly adjusting the gain of the flux signal to agree with the heat power computation, one can retain the fast response of the flux signal and achieve the accuracy of the heat power measurement.

Servo-driven electromechanical systems that automatically adjust the gain were operated in the High-Flux Isotope Reactor (HFIR) since its start-up.^{1,2} The reset rate was tailored so that the gain is not changed significantly during fast transients that require protective action. However, wear of the motor-driven potentiometers caused noise.

To eliminate the problems of mechanical systems, an all-electronic system was developed to adjust the gain. The electronic system was made practicable by the availability of low-cost electronic multipliers. A prototype electronic unit was tested in the HFIR in 1969, but fabrication of units to replace the mechanical systems was delayed.

The scheme³ was recently used by the Allis-Chalmers and Foxboro Companies and put in service in the LaCrosse Boiling Water Reactor.⁴ ORNL personnel assisted in the conceptual stages of the commercial design.

1. L. C. Oakes, *A Second Generation of Reactor Control Systems as Applied to the HFIR*, ORNL-TM-1259 (September 1965).

2. *The High-Flux Isotope Reactor, A Functional Description*, ORNL-3572 (May 1964).

3. Originally conceived by the late E. R. Mann in 1960, and patent applied for by ORNL.

4. *LACBWR Nuclear Instrumentation - Automatic Gain Control System*, Allis-Chalmers Atomic Energy Division, ACNP-70503 (October 1970).

10.31 PROCESS INSTRUMENTATION FOR OPERATING REACTORS

B. C. Duggins B. G. Eads

To meet new requirements and improve system performance, minor modifications were made to reactor process instrumentation at the High-Flux Isotope Reactor (HFIR) and the Oak Ridge Research Reactor (ORR).

At the HFIR, a system was installed to monitor the concentration of dissolved oxygen in the primary water coolant. The span of the primary-coolant flow transmitters was increased to accommodate the flow increase due to elimination of the combs in the fuel elements. A flow monitor was installed on the instrument air-supply line to the Transuranium Processing Plant (TRU), Building 7920. Additional filters were recommended for the instrument air system to remove desiccant dust, which originated in the air dryers, after examination of the internal parts of pneumatic instruments revealed that dust was being deposited inside the instrument in sufficient quantities to shift the output calibration of the instruments.

At the ORR, ten resistance thermometers, which had been installed in 1962 in the reactor coolant inlet and exit lines as components of the reactor protection system, were replaced with new but identical thermometers, even though they had operated without maintenance since then. This was done to preclude damage of the cables due to embrittlement of the Neoprene insulation.

A quality assurance program consistent with AEC requirements was prepared and executed for the replacement thermometers. Important features of this program were: (1) that the manufacturer had certified that the replacement thermometers were identical to those furnished under the original instrument specifications, and (2) that the replacement thermometers were calibrated to better than the manufacturer's tolerances by the Standards Laboratory of the Instrumentation and Controls Division. In addition, the calibrations of all channels before and after the thermometer change were compared by operating the reactor at various power levels and comparing data from the resistance thermometers with data from thermocouples that had been left in the reactor throughout the change. The differences in the calibration data from the resistance-thermometer channels before and after the change were within the accuracy of the thermometers in all channels and at all operating powers.

10.32 MSRE DESIGN AND OPERATIONS REPORT, PART IIB: NUCLEAR AND PROCESS INSTRUMENTATION¹

R. L. Moore P. G. Herridon

This report is the second of two parts describing Molten-Salt Reactor Experiment nuclear and process instrumentation. In first part,² Chaps. 1 and 2 provide broad and quite general descriptions which are intended to convey the criteria and philosophy used as the basis for the design of the MSRE instrumentation and control systems. Chapter 2 also contains detailed descriptions of the nuclear instrumentation; the health physics, process, and stack radiation monitoring systems; the data logger computer; and the beryllium monitoring system. Chapters 3 through 7, which are contained in this volume, provide detailed descriptions of the MSRE process instrumentation and electrical control and alarm circuitry.

1. Abstract of published report ORNL-TM-729, Part IIB (to be published).

2. J. K. Tallackson, *MSRE Design and Operations Report, Part IIA, Nuclear and Process Instrumentation*, ORNL-TM-729 (February 1968).

10.33 FURTHER DISCUSSION OF INSTRUMENTATION AND CONTROLS DEVELOPMENT NEEDED FOR THE MOLTEN-SALT BREEDER REACTOR¹

R. L. Moore

Previously published information (J. R. Tallackson, R. L. Moore, and S. J. Ditto, *Instrumentation and Controls Development for Molten-Salt Breeder Reactors*, ORNL-TM-1856, May 1967) concerning the development and evaluation of process instrumentation applicable to molten-salt breeder reactors (MSBR) was updated. Areas where instrumentation techniques and components tested during operation of the Molten-Salt Breeder Experiment may be applicable to the MSBR are described and recommendations for further development are stated. ... this study to date, no problems are foreseen that are beyond the present state of the art.

1. Abstract of published report ORNL-TM-3303 (August 5, 1971).

10.34 MSRE POSTOPERATIVE EXAMINATIONS

P. G. Herndon

Selected thermocouple elements were retrieved from the MSRE salt-circulating systems and stored at the reactor site where they will be available for postoperative examinations. All of these elements were exposed to high temperatures (900 to 1200°C) for six years, and a few were exposed to both high temperatures and high radiation levels.

10.35 REVIEW OF ORNL REACTOR PROTECTION SYSTEMS

E. P. Epler¹ S. J. Ditto

The review² of ORNL reactor protection systems was continued to determine their status with respect to RDT Standard C16-1T, "Supplementary Criteria and Requirements for RLT Reactor Plant Protection Systems (December 1969)." Reports of the review findings for the HFIR, ORR, BSR, PCA, TSF, and HPRR were submitted to the AEC Division of Reactor Development and Technology. Although, as expected, the review did disclose areas in which ORNL systems do not meet requirements of the standard, it was apparent that the practices in effect at ORNL when these systems were designed are in substantial agreement with the intent of C16-1T (Sect. 0.39). Inasmuch as ORNL was a major contributor in the preparation of C16-1T, this agreement is not surprising.

1. Consultant to the Instrumentation and Controls Division.

2. E. P. Epler and S. J. Ditto, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 119.

10.36 REVIEW OF FFTF DESIGN PROPOSAL FOR RDT

J. L. Anderson B. C. Duggins S. J. Ditto

A proposal for a newly developed logic system for use in the protection system of the Fast Flux Test Facility was reviewed for the AEC Division of Reactor Development and Technology (RDT). A report of the review was submitted to RDT to help them evaluate the proposal.

Subsequent to the review, the designers of the system prepared a document for issuance as an RDT standard for procurement of such a system. Parts of that document, in particular the design requirements, were also reviewed and the comments were reported informally to RDT. Similar tasks in support of RDT programs will be continued.

STANDARDS

10.37 USAEC STANDARDS PROGRAM

A. E. G. Bates

The standards program sponsored by the RDT was continued through the year. Its purpose is to generate general criteria, definitions of terms, general and detailed specifications, procedures, and other standards documents suitable for application to the design, construction, and maintenance of RDT nuclear reactors.

Documents covering both nuclear and process instruments were completed, and others were processed to various stages of completion during the year. Comments from users of a few of these standards were received and studied. Indicated changes were incorporated in some of the documents.

In addition to the preparation of standards documents, an appreciable number of documents prepared by other AEC contractors were reviewed, such as ANL, Idaho Nuclear Corp., LMEC, and PNL.

10.38 AEC STANDARDS FOR REACTOR AUXILIARY ELECTRIC POWER SYSTEMS

P. Rubel

General design criteria were prepared¹ for auxiliary electric power systems in AEC-sponsored reactors. These criteria emphasize features that will assure an uninterrupted supply of energy to the vital protective functions. They also cover electric supplies to loads whose interruption could result in substantial economic loss. The proposed criteria were assembled in a review draft.

1. P. Rubel, *Instrumentation and Controls Div. Annu. Prog. Rep. Sept. 1, 1970*, ORNL-4626, p. 121.

10.39 CRITERIA AND REQUIREMENTS FOR RDT PLANT PROTECTION SYSTEMS¹

C. S. Walker²

A set of general design criteria and requirements for reactor protection systems has been issued as a tentative standard for application to reactors and critical assemblies under the jurisdiction of the USAEC Division of Reactor Development and Technology. This standard, C16-1T, includes within its scope all the active devices, such as instruments, actuators, and electric power supplies, necessary to prevent unacceptable release of radioactive materials or unacceptable plant damage. This standard applies to the overall behavior of the protection system rather than to the design of individual equipment items. The major sections are design basis, criteria and requirements, and quality assurance. Emphasis is given the design basis section, which prescribes the interdisciplinary information and analyses for specifying the necessary protective functions, together with the system-reliability requirements. Criteria are then given for providing defenses against various kinds of failures and for accommodating the systems and procedures required to operate the plant normally.

1. Abstract of published journal article: *Nucl. Safety* 11(5), 375-78 (September-October 1970).

2. Present address: Tennessee Valley Authority, Knoxville.

10.40 IEEE STANDARDS FOR REACTOR PROTECTION SYSTEMS

S. J. Ditto C. F. Holloway

Support was continued for the standards program¹ of the Institute of Electrical and Electronics Engineers (IEEE). A number of standards were issued by the IEEE, as were a number of guides for trial use and evaluation. The above authors are members of committees doing this work with the assistance of other members of the Division who reviewed the proposed standards and guides.

1. C. S. Walker and S. J. Ditto, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 121.

10.41 RDT STANDARD C 15-3T, "CURRENT PULSE PREAMPLIFIERS FOR USE WITH FISSION COUNTERS"

J. T. DeLorenzo

Standard C 15-3T, prepared for the AEC Division of Reactor Development and Technology (RDT), states the requirements of a preamplifier capable of sensing and amplifying the current pulses from a fission counter in reactor service where it is required to detect neutrons in an extremely high gamma radiation background. Conventional charge-sensitive preamplifiers cannot operate properly in such service and would provide misleading data because the intense gamma radiation would interfere with the ability of the instrument to discriminate neutrons from gamma pulses.

The Standard describes both single-ended and differential input designs. The differential input design is recommended for applications where high electrical interference is present.

10.42 INSTRUMENTATION AND CONTROLS DIVISION DRAFTING AND DESIGN STANDARDS PROGRAM

A. E. G. Bates

H. E. Cochran	J. A. Russell, Jr.
J. W. Cunningham	H. J. Stripling, Jr.
P. G. Herndon	O. M. Thomas ¹
C. F. Holloway	K. W. West

A number of recommendations made by its various subcommittees were considered by the Drafting and Design Standards Committee, and three of these, two dealing with handling of drawing revisions and one concerning drafting film format, were approved. Others being discussed are concerned with drafting symbols; arrangement, format, and administration of documentation; the scope of the program; and more on handling of drafting revisions. The expanding quality assurance program of the Laboratory is giving special emphasis to the work of this Committee.

1. General Engineering Division.

11. Support for In-Pile Experiments

11.1 INSTRUMENTED EXPERIMENTS IN THE HFIR

J. W. Cunningham R. L. Durall

A second experiment identical to one previously installed¹ was installed in the High-Flux Isotope Reactor. The instruments required very little attention. Assistance was given to preparation of a procedure for periodic checking of the pressure relief valves on the loop.

1. C. M. Burton, J. W. Cunningham, and R. L. Durall, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1965*, ORNL-4459, pp. 117-18.

11.2 INSTRUMENTATION FOR PM CAPSULE NO. I

B. Lieberman B. G. Eads T. F. Sliski H. J. Stripling

Temperature and leak detection instruments were supplied for PM Capsule No. I, an in-pile experiment designed for insertion into the High-Flux Isotope Reactor (HFIR) by the Metals and Ceramics Division. This experiment, under the fuel element fabrication development program, was conducted to determine if the lifetime of fuel elements in the Advanced Test Reactor can be extended.

Twelve sheathed, Chromel-Alumel thermocouples were installed for sensing temperatures in three experimental fuel plates, and from these data the temperatures of the plates were inferred. Conductivity detector electrodes were installed to detect water leaks from the reactor primary system into the thermocouple junction box located in the pool above the reactor vessel.

The tips of the thermocouples were inserted into the fuel plates with a force fit, using an air riveting gun (Fig. 11.2.1) and a jig. To enable a force fit, close dimensional units were specified for the purchased thermocouples so that they would all fit into holes of the same size. However, the thermocouples, as manufactured, failed to meet these dimensional specifications. One of these thermocouples was swaged at ORNL to reduce the sheath diameter to within specified limits, but the sheath failed.

For two reasons, that is, time limitations and a possibility that thermocouples could not be manufactured to such rigid dimensional specifications, the thermocouples were accepted at a reduction in price. The thermocouples were inserted into the plates by measuring the thermocouple sheath diameters and individually sizing the holes in the plates. Each hole was drilled undersize, and then pins of increasing size were driven into the holes to enlarge them to the desired size.

The in-pile portion of the capsule, including the thermocouples and conductivity detector, was designated to meet level II of quality assurance requirements. A quality assurance program in accordance with current AEC requirements was prepared. Procedures were prepared to assure that proper testing and fabrication techniques were used in critical portions of the apparatus. The thermocouples and the

Fig. 11.21. Insertion of thermocouples into fuel plate.

conductivity detector were tested prior to assembly of the capsule to verify that they performed satisfactorily and were checked again during fabrication of the capsule to verify that they continued to function properly.

All thermocouples and the conductivity detector functioned properly for the duration of the experiment (five reactor cycles).

11.3 UN RADIATION PROGRAM

J. W. Cunningham R. L. Durall

Chromel-Alumel thermocouples with Al_2O_3 insulation in a Nb-1% Zr sheath with a tantalum liner for operation to 1200°C were finally obtained for the UN radiation program. Six were installed to measure the fuel cladding temperature in UN-4. Three of the same type and three W-3% Re vs W-25% Re thermocouples were installed on UN-5 instead of UN-6 as previously reported.¹

UN-4 and UN-5 completed two Oak Ridge Research Reactor (ORR) seven-week reactor cycles. Unexplained temperature fluctuations occurred, and at least one thermocouple appeared to have formed a new junction. It is too early to form any conclusion on the merits of this type of sheathed thermocouple construction.

Installation drawings for all three UN capsules were completed, including a cabinet to hold the extra data boxes required to connect these experiments to the Dextir data collection system. Nonheated thermocouple cold-reference junction boxes were also installed in the cabinet.

I. J. W. Cunningham and R. L. Durall, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 127.

11.4 GAS-COOLED FAST-REACTOR FUEL IRRADIATION TEST GB-9

J. W. Cunningham R. L. Durall

The designation of this test was changed to GB-9 from P-S, under which it had been reported.¹ The capsule was operated in the Oak Ridge Research Reactor (ORR) Test Facility for 15 months; there were no troubles from any of the 12 Chromel-Alumel thermocouples or from the ground detector devices on the heater circuits. The seat and stem combination in the control valve, which regulates the helium sweep gas pressure at 1000 psi at a flow of 150 sccm, was changed three times due to "sticking." In the last change, the mating surfaces of both parts were polished with jewelers rouge. These polished parts outlasted any of the previous seats and stems by a factor of 3.

I. J. W. Cunningham and R. L. Durall, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL 4620, p. 127.

11.5 MECHANICAL INTERACTION IRRADIATION EXPERIMENTS FOR LMFBR FUEL EXPANSION MEASUREMENTS

J. W. Cunningham R. L. Durall

Numerous difficulties were encountered in assembling this capsule.¹ It is not yet ready for installation in the reactor.

The variable-permeance-type motion-sensing transducers were received and tested, and they easily sensed a change of 0.001 in. in a bench test. Since there is no way to duplicate out-of-pile the temperature profile of the various parts of the capsule, including the coil windings of the transducers, in the reactor, it is hoped that data taken as the capsule is raised to operating temperature will allow correlation of the ultimate measurements to a fixed base.

Drawings covering the installation and connection of these transducers and the pressure and temperature measuring instruments for the experiment were completed and issued.

I. J. W. Cunningham and R. L. Durall, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 133.

12. Instrumentation for Reactor Division Experiments and Test Loops

12.1 DENSITOMETER FOR MSR BUBBLE STUDIES

R. M. Burnett H. J. Metz R. L. Moore

A densitometer was developed to measure the density of flowing water containing air bubbles and installed and tested on the Molten-Salt Reactor, gas-handling water test loop. From this experience sufficient information was obtained to design the type of instrument that would be needed for service on the Molten-Salt Breeder Reactor (MSBR).

Helium bubbles will be generated in the fuel salt flowing to the MSBR. After the fuel salt passes through the reactor and the heat exchangers, the entrained helium will be separated from the fuel salt and processed to remove the fission gases from the helium. The fuel salt will be returned to the fuel salt system. The bubble generator and separator are being developed also in the MSR water-air loop along with the densitometer.

The densitometer comprises an Ohmart radiation detection cell and source, a picoammeter, and a picoampere source.

12.2 INSTRUMENTATION FOR A ZIRCALOY CLADDING FAILURE FACILITY

R. L. Moore T. M. Cate

Design, installation, and check-out of instrumentation and controls required to expand this facility for testing seven rods was completed.¹

Engineering assistance was continued during startup and operation. During the first depressurization test, most of the instrumentation performed adequately and considerable useful data were obtained. During this same test, the sensing circuits failed to detect the depressurization to actuate the control and protective actions. However, the failure was noticed in time to prevent a complete loss of the test. The system was modified to preclude a similar failure in subsequent tests. Two later tests were purposely aborted because a seal had failed in the test section. No additional tests were attempted because of insufficient funds. The loop was shut down, and its future is uncertain.

1. R. L. Moore, T. M. Cate, and C. M. Burton, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 130.

12.3 INSTRUMENTATION FOR A ROD BURNOUT FACILITY

R. L. Moore D. G. Davis J. W. Krewson

Design of instrumentation and controls for this facility,¹ which had been stopped in December 1969, was resumed in August 1970, and installation work was accelerated. Installation of instruments on the main loop was completed, and a preoperational test of all systems is nearing completion. A test section bypass line fitted with valves, venturi, and flow tubes was added to the main loop for simulating test runs and checking operational flow measuring systems. A signal conditioning cabinet was designed and assembled to house a multipoint thermocouple reference junction unit, 4 Sanborn carrier preamplifiers, and 12 low-level dc isolation amplifiers. A Dextir data gathering station was installed and made ready for connection of data acquisition input leads. Procurement of instrument components for the test section was completed except for two push-in-type resistance thermometer detectors now on order.

A control interlock and alarm system required to interface the experiment with two 10,000-A, 250-V-dc generators was designed, and installation was begun.

A circuit for instantaneous (<15 msec) power setback following an incipient burnout was developed. This circuit interfaces the rod burnout detector with the test section power system and provides setback by connecting four water-cooled shunt resistors across the test section, using two silicon-controlled rectifiers (SCR's) as the switching mechanism. In the interface circuitry, a low-power signal from the burnout detectors triggers a small SCR and discharges a condenser through the primary of a coupling transformer. This discharge produces a short-duration pulse of sufficient power to trigger large (1200-A rated) SCR's connected to the transformer secondary through a protective network. The transformer also isolates the floating dc power systems from the burnout detector circuits. The circuit enables any of the five detectors to trigger both of the large SCR's and also indicates the channel that produces a burnout and the relay contact operations required for interlocks in the test section power circuits.

1. R. L. Moore et al., *Instrumentation and Controls Div. Annual Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 130-31.

12.4 SUPPORT FOR THE ENGINEERING SCIENCE DEPARTMENT, HEAT TRANSFER AND FLUID MECHANICS SECTION

J. W. Krewson W. A. Bird P. P. Williams

The requirements for Instrumentation and Controls Division support of this section were approximately the same this year as last year¹ except that more effort was devoted to the development of new instruments.

One new experimental apparatus (deformed-rod-bundle, pressure-drop test) was built this year and none were deactivated. Several were modified considerably: the molten-salt heat transfer, molten-salt thermal conductivity, and heat transfer enhancement apparatus. Each year, the capability of the heat transfer enhancement apparatus was expanded as originally planned, and, when the present modifications are completed, it will have an electrical heat capacity of 0.5 MW at an operating pressure of 2000 psi. The molten-salt experiments were modified when accumulated data indicated that some changes were necessary. All instrument and control work on these experimental units was done by Instrumentation and Controls Division personnel.

Design of apparatus for a new experiment was started, a demonstration unit for hyperfiltration with dynamic membranes for the desalting program. Instrument application drawings for two possible processes were completed for evaluation. Control of pH in these processes is unusual in that it must be controllable at

any point over a range from 2 to 10, and it might be necessary to develop a new type of base or acid injection system to meet this requirement. A pH controller was specified and purchased, and an evaluation of injection methods was started.

As-built instrumentation drawings were completed for all the experimental units in this section regardless of whether they were on standby or operational basis. This completed an approximately six-year task to upgrade the experimental systems in this section.

Development of an infrared sensing type of burnout ("hot-spot") detector for the Rod Burnout Facility (Sect. 12.3) was completed, and installation of a system was begun. Since the infrared detector has some limitations, resistance measurement techniques to detect incipient burnout are being investigated for application as a back-up system. Methods were studied for detecting thermal transients and pressure variations on the surface of a heater immersed in liquid metal, without making attachments to or penetrations of the surface. Development of a thermal-transient measurement method was partially successful, but nothing practicable was developed. Investigation of methods of measuring pressure variations was started, and it is too soon to predict ultimate success or failure.

1. J. W. Krewson and W. A. Bird, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 131.

12.5 SUPPORT FOR THE SOLID-MECHANICS DEPARTMENT, EXPERIMENTAL MECHANICS SECTION

R. L. Moore

T. M. Cate P. G. Herndon C. D. Martin, Jr.

The Solid Mechanics Department undertakes a variety of research to determine the mechanical properties of materials and components. In support of this work, the Instrumentation and Controls Division furnished about 1.5 man-years of labor for the design, application, and maintenance of instruments for the experimental apparatus. A major effort was the procurement, installation, and acceptance testing of a computer-controlled data acquisition system (CCDAS, Sect. 7.13). Some examples of support given to these experimental programs are described in the following paragraphs.

In a thermal cylinder test, which is an experiment for the prestressed concrete reactor vessel program, the behavior of prestressed concrete will be studied under simulated reactor conditions over a period of two years. Division personnel directed the fabrication and installation of all cables for connection of 130 strain gages and 30 thermocouples to the CCDAS. A basic requirement of this test is that the base temperature and temperature gradient in a cylindrical concrete model be closely controlled over the two-year period. Division personnel designed and supervised the installation and checkout of instrumentation and controls for the circulating water system which determines the temperature of the model and assisted in setting up and operating the CCDAS in the early phases of this test.

As part of a piping technology program, structural tests are being conducted on commercial piping components to support analytical methods and code development for the design of nuclear piping systems. Division personnel assisted in the fabrication, installation, and checkout of all cables for connection of 260 strain gages, 2 load cells, and 1 pressure transducer to the CCDAS and in setting up and operating the CCDAS during startup of this test. This is a continuing program, and as many as 1000 strain gages might be installed on a single component in future tests. In anticipation of these requirements, additional equipment is being purchased to expand the input capacity of the CCDAS to 704 channels.

The objective of an elevated temperature beam test is to study the mechanical properties of a machined beam-type specimen at elevated temperatures. A temperature control system was supplied to control the

temperature of an oven over a range from 700 to 1200°F. The mechanical displacement of a specimen during loading is measured at 5 points by linear differential transformers, and its temperature is measured at 12 points by Chromel-Alumel thermocouples. All data are collected by the CCDAS, converted to engineering units, and typed by a teletypewriter.

Tests to determine the behavior of Liquid-Metal Fast Breeder Reactor (LMFBR) structural materials in simple structures under multiaxial stress conditions at elevated temperature are being conducted for development of design standards for fast reactor systems. Instrumentation and Controls Division personnel designed an electrical system to control a hydraulic supply system for a multiaxial materials testing system that had been purchased by the Solid Mechanics Department. They also assisted in constructing a system for programmed control of the temperature of a specimen heated in a high-density, infrared radiant heating chamber.

Four 11.5-kW tubular electric furnaces with automatic temperature controls were installed in a weldment creep-rupture facility to test the creep-rupture characteristics of welds on type 304 stainless steel materials to be used in the LMFBR program. A test vessel placed in each furnace is subjected to temperatures between 700 and 1300°F and internal pressures to 2600 psig. The outputs of ten thermocouples and one pressure transducer in each furnace are recorded by the Dextir data logging system.

12.6 INSTRUMENTATION FOR FISSION PRODUCTS DEPOSITION LOOP 5

A. H. Anderson, Jr. R. M. Burnett

Routine instrument maintenance and assistance for the Dextir data acquisition system were provided for this induction-heated cesium evaporator test facility during the past year.¹ The planned tests were ended, the area is being decontaminated, and the facility will be placed in standby condition.

1. A. H. Anderson, Jr., and R. M. Burnett, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1969*, ORNL-4459, p. 123.

12.7 INSTRUMENTATION FOR LMFBR FUEL FAILURE MOCK-UP FACILITY¹

A. H. Anderson, Jr. R. M. Burnett

Instrumentation for test section bundle 1 was installed and tested, and operation of the equipment was started in this high-temperature sodium facility for conducting out-of-pile Liquid-Metal Fast Breeder Reactor fuel element propagation experiments. Circuits were designed and installed to shut down the equipment if it should fail during unattended, off-shift operation. Assistance was given to preparation of a final systems design description and an operating manual.

Calibration procedures and results and instrument specification sheets were compiled for each instrument. Procedures for routine maintenance were prepared for checking each of the 74 alarm and control circuits. Design of instrumentation for test section bundle 2 was started. This unit will have 70 more thermocouple junctions than bundle 1.

1. A. H. Anderson and R. M. Burnett, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 132.

12.8 FUEL FAILURE MOCK-UP FACILITY, FINAL SYSTEM DESIGN DESCRIPTION

C. Brashear A. H. Anderson R. L. Durali

The Instrumentation and Controls Division assisted the Reactor Division in preparing a final systems design description for the fuel failure mock-up facility (Sect. 12.7).

Each system was treated as a separate subject and described in accordance with RDT instructions.

Personnel from the Instrumentation and Controls Division prepared a description of the inert gas system; the unattended operation control system; and the instruments, controls, alarms, and protective devices for the sodium circulating, cooling, and purification system, for the electric power systems, and for the test section.

A tabulation of all instrument components, listing the component manufacturer, number, type, purpose, range, error, set point, and special remarks, was compiled for the appendix. A tabulation of hand valves, listing the valve number, size, pressure rating, type, body material, end connection, location, and manufacturer, was also compiled for the appendix.

12.9 FUEL ELEMENT MACCT FACILITY

C. Brashear R. L. Durall

Owing to a change in test requirements, the instrumentation and control system in the Liquid-Metal Fast Breeder Reactor (LMFBR) fuel element, multiple assembly cask cooling test (MACCT) facility¹ was modified and expanded. Design, fabrication, installation, and checkout of the instrumentation and controls for this expansion were completed.

In the facility a shipping cask for 27 LMFBR fuel assemblies is simulated. The assemblies in the cask are arranged in a horizontal hexagonal array, typical for shipment to a reprocessing site after being removed from the reactor. The purpose of the test is to study the behavior of liquid-metal coolant surrounding the fuel assemblies and to determine the temperature distribution. The test vessel is rated for a maximum operating pressure of 5 psig at 1000°F and contains 700 gal of Na surrounding thirty-seven 5-in.-OD tubes on 7-in. centers. Each tube contains a heater with controls for adjusting the power over a 7.5-kW range. At full power, the 37 heaters generate 280 kW of heat which is transferred to the Na. When not in the test vessel, the Na is stored in a sump tank. A surge tank maintains a head pressure of Na to the test vessel. A blanket of high-purity Ar from gas bottles covers the Na in the system. The pressure in the test vessel is controlled by regulating the pressure of Ar supplied to the surge tank. The test vessel is filled with Na by regulating the pressure of Ar supplied to the sump tank.

NaK-filled, high-temperature pressure transmitters on the surge tank furnish pneumatic signals for level indicators. Temperatures of the system are measured by 66 thermocouples and read out by four multipoint recorders and a precision indicator. The recorders were modified; they were equipped with nonshorting switches and an operational amplifier for isolation so that the thermocouple signals could be received by the Dextir data acquisition system. A 9-ft-long Al probe containing eight spring-loaded thermocouples on 1-ft centers is inserted into the 37 tubes, one at a time, to obtain a temperature map. Four sets of eight temperatures are monitored by the Dextir data system at the top, bottom, and the two sides of each tube.

Shields protect personnel from being struck by molten Na from a leak, and optical smoke detectors above the shields monitor the system for leaks. A pan under the test facility will retain all Na leaks or spills; if a fire starts the pan is flooded with Ar from the building supply to blanket the Na.

The heater power circuits are monitored by voltmeters, ammeters, and thermal watt converters that are read out by a millivolt recorder. A ground-current detector monitors the heaters for short circuit or heater grounds during operation.

Alarms were installed to give warning on all critical parameters. An automatic dump control system was installed to drain the Na to the sump tank and maintain the system in a safe condition if the system should fail during unattended operation (Sect. 12.10).

All planned tests were completed, and the facility is in standby condition.

1. C. Brashear and H. J. Metz, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 135.

12.10 UNATTENDED OPERATION

C. Brashear A. H. Anderson G. W. Greene

Discontinuance of shift technician coverage of Reactor Division test facilities required equipment to automatically shut down systems being operated unattended over nights, weekends, or holidays when such systems fail to operate as intended. In addition to the design and installation of such equipment, the instrumentation and control systems in each test facility were improved to obtain more reliable safety monitoring. Whenever a shutdown control or safety monitor is actuated, an alarm is also actuated in the Laboratory Shift Superintendent's office. When this alarm sounds, the Shift Superintendent makes a personal investigation to determine if any further action should be taken.

Unattended operation systems were installed in three new test facilities, MACCT, FFM, and FCL-2 (Sect. 12.9, 12.7, and 12.13, respectively), completed during the year. A system was also designed and installed in an existing test facility. Two other test facilities being designed will include unattended operation systems.

12.11 INSTRUMENTATION FOR MSBR GAS SYSTEM TECHNOLOGY FACILITY

A. H. Anderson, Jr. P. M. Burnett

Design and procurement of instrumentation were started for this facility in which circulating molten salt will be studied for evaluating designs of a bubble generator, bubble separator, and components for off-gas purification and recycle. Side loops will be constructed for chemistry experiments. The direct costs for instrumentation and controls for the facility, not including the side loops, were estimated to be \$23,000 for design, \$29,160 for new instruments, \$40,000 for instruments on hand, and \$38,630 for craft labor.

12.12 MOLTEN-SALT FORCED-CIRCULATION LOOP 1

G. W. Greene

After over 10,000 hr at design conditions this loop¹ ruptured due to failure of a high-temperature safety instrument. Reconstruction of the loop was almost completed, and additional safety interlocks were added to prevent a similar failure.

1. G. W. Greene, C. Brashear, and R. L. Durall, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 135.

12.13 MOLTEN-SALT FORCED-CIRCULATION LOOP 2

G. W. Greene

Design and construction were completed,¹ and the loop was operated at a variety of conditions to determine heat loss data and other operating parameters. The loop is instrumented for unattended operation.

1. G. W. Greene, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 135.

12.14 ORGANIC LOOP DECOMPOSITION TEST

G. W. Greene

Installation of instrumentation for this experimental loop was nearly completed. The purpose of the experiment is to determine the effect of gamma radiation on the thermal decomposition of an organic material.

The loop consists of a reentrant boiler with electric heaters and a radioisotope source (gamma), a regenerative heat exchanger, a condenser, and a pump. Instrumentation was designed to permit unattended operation.

12.15 MOLTEN-SALT LEVEL DETECTOR

G. W. Greene

A readout device for contact-type, single-point, salt-level detectors was developed. A triac circuit energizes indicator lights or relays, and the salt-level detector is adjustable. Its main advantage is that the adjustable probe operates at ~6 V instead of 115 V as did earlier detectors of this type.

12.16 THERMAL PRECIPITATION TESTS AT THE PEACH BOTTOM REACTOR

J. W. Cunningham

R. L. Durall G. W. Greene H. J. Metz

Surveillance of particles and fission products in the coolant gas in the Peach Bottom Reactor was to be done for the HTGR fission product surveillance program. A gas flow measurement and control system and thermocouples were supplied. These components were certified for reactor containment quality integrity.

12.17 HIGH-TEMPERATURE PRESSURE TRANSMITTERS FOR MOLTEN-SALT SERVICE

H. J. Metz

Preparation of specification A 7238, "NaK Transmission High-Temperature Pressure Transmitter for Molten-Salt Service," was completed. This specification is for transmitters of a quality that is suitable for use on a molten-salt nuclear reactor. No bids were received that met the requirements of the specification. Negotiations with manufacturers are under way to determine whether the combined capabilities of both ORNL and a manufacturer can produce acceptable transmitters.

12.18 HEAVY SECTION STEEL TECHNOLOGY FACILITY

R. L. Durall H. J. Metz

To correlate pressure vessel theory with reality, vessels about 3 by 6 ft with 6-in. walls will be burst at pressures up to 50,000 psi and temperatures between -50 and 350°F. After more than half of the instrumentation for this facility had been designed, work was stopped near the end of the previous reporting period. Then the work was resumed. Drawings were completed, equipment was purchased, construction was completed, and checkout was started. The -50°F refrigeration system required about half of the design effort.

12.19 RDT STANDARDS

H. J. Metz

RDT Standard C 6-1, "Austenitic Stainless Steel High-Temperature Pressure Transmitter," was submitted for external review. The standard was discussed with LMEC engineers in Los Angeles. At that time, an agreement was reached that LMEC personnel would prepare and issue this standard because LMEC would be the first user of the standard.

RDT Standard C 6-5, "NaK Transmission High-Temperature Pressure Transmitter for Molten-Salt Service," was completed after internal reviews. The standard was sent out for official comment. RDT decided to have LMEC personnel combine this standard with C 6-1.

12.20 FURNACE CONTROL MODULES

H. J. Metz

Twenty-two furnaces operated by the Reactor Chemistry Division required temperature controllers and protection against above-limit temperatures. A prototype was designed and built, containing controls, relays, and pilot lights. When further study proved that it would be less expensive to buy solid-state controllers than to change ranges and overhaul existing millivoltmeter pyrometers, funds were made available and units were ordered. The units can be connected to the building alarm system.

12.21 ORNL LEAK DETECTION COMMITTEE

H. J. Metz

Leak detection is the only nondestructive test method that does not have national standards for certification of personnel for leak testing. Neither are there standard procedures for leak testing. There are approximately 22 methods of leak detection, and, of these, helium mass spectrometer leak detection is the best method for achieving high-quality containment.

A committee of ORNL personnel¹ was organized, and they have prepared rough drafts of a Standard for Certification of Personnel for Leak Testing, a Leak Detection Training Course Outline, and a Mass Spectrometer Leak Testing Procedure. These drafts are being reviewed internally.

1. K. K. Klindt, Chairman, C. W. Cunningham, J. R. Gibson, and H. J. Metz.

12.22 INSTRUMENTATION FOR THE VERTICAL TUBE BUNDLE TEST VEHICLE

R. L. Moore H. B. Adams D. G. Davis

Design, procurement, and installation of the test instrumentation and data acquisition package for the VTE-X was completed and has been in use since October 1971.¹ This equipment was installed by a contractor employed by the Office of Saline Water (OSW). Division personnel traveled to the installation site at San Diego to advise the contractor on installation requirements, to inspect instrument components purchased by ORNL and delivered to the installation site, and later to inspect the installed instrumentation.

1. D. G. Davis et al., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 62.

13. Ecological Sciences Studies

13.1 ECOLOGICAL SCIENCES DATA ACQUISITION SYSTEM

J. L. Redford

A signal conditioning system for 50 thermistor temperature probes was designed and fabricated for the Atmospheric Turbulence and Diffusion Laboratory (ATDL) for use in monitoring air temperature in a 100 X 160 m grid area in the ORNL Liriodendron forest. The system is a bridge circuit, with the reference half of the bridge common to all thermistors; it compensates for individual lead-wire resistance and operates with an existing data acquisition system having punched paper-tape output.

To accommodate both high-level thermistor signals and low-level signals from other types of sensors, a dual-gain amplifier with individual channel gain selection capability was engineered into the data acquisition system. Tests were conducted to ensure that remote control of the data acquisition system stepping, digitizing, and output circuits could be accomplished from a digital computer which will be incorporated into the system at a later date. During development of this system, several logic design and hardware faults were discovered in the data acquisition system which were subsequently corrected by the manufacturer.

13.2 AQUATIC LABORATORY DESIGN STATUS

B. C. Duggins J. M. Jansen, Jr.

The preliminary development and design of instruments for the aquatic laboratory has been reported.¹ Since then, three important areas of the design were studied extensively, and decisions were made concerning them: (1) computer failure philosophy, (2) blending valve control, and (3) temperature programming techniques.

In the water control system for the fish tanks (Fig. 13.2.1), either heated or cooled water will be blended with water at ambient temperature to achieve a desired temperature. The water heater and chiller will be controlled by standard pneumatic analog controllers and, thus, will be unrelated to the computer. When the computer is controlling the tank temperatures, its operation will be monitored by a "watchdog" program which will run at fixed time intervals. If the watchdog program fails to execute, a computer failure will be presumed and an automatic restart will be attempted. If the restart is unsuccessful, the blending valve signals will be automatically transferred from the computer to a preset manual signal. Since the water temperature to the valve will be held constant, as described above, no significant process upset should result from a computer failure.

Experience with direct digital control (DDC) of a prototype tank revealed a significant problem in positioning the blending valve. At first, a conventional split-phase motor was used, the acceleration and velocity characteristics of the motor-valve combination were measured, and then this information was used to position the valve as commanded by the DDC algorithm. In practice, however, the characteristics varied with valve position and packing friction. As a result, the valve position could not be determined with

Fig. 13.2.1. Fish-tank water control system.

sufficient accuracy. After further study, it was concluded that the most economical way to resolve this problem was to use a stepping motor with sufficient excess torque to ensure a precise incremental valve position for each step. Thus, the computer can determine the valve position at any time by counting the commanded number of steps.

Detailed descriptions of the computer tasks for control, logging, and operator interaction were prepared. Techniques were developed for programming tank temperatures to simulate daily, seasonal, and special variations (such as power plant cycles) which will allow the tanks to be at any point in the program at a given time and will also achieve the best utilization of the computer memory. The need for two different input scan rates was also determined, because some of the tanks will require update as often as every 100 msec and others will require update at nothing less than 30-sec intervals.

Construction of the aquatic laboratory will begin early in FY 1972, and it is expected that the facility will be in operation by the end of the year.

1. B. C. Duggins and J. M. Googe, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 43.

13.3 REGIONAL MODELING

A. H. Voelker¹

The Regional Modeling Group of the Environmental Study Program is developing a composite of separable but interacting submodels that simulate the human ecosystem. Included are submodels that simulate land use, regional socioeconomics, and ecological systems. Examples of simulation using such a model are the effect of land use zoning on regional growth and road building policy on economic development.

The Instrumentation and Controls Division provided assistance in model design, hardware design, and software programming. Regional models require very large data bases, and a significant portion of Division assistance was in the design and implementation of these data bases. Because the data bases are very large

(30 million bytes), automation in data collection is a fundamental goal. Several automated data collection techniques were investigated — many to the hardware stage and then discarded. A manual point-by-point digitizer of map data was prone to human error, and a PDP-8/I computer interfaced to a flying spot scanner was used to evaluate various automated scanning methods.

A combination of manual and automatic techniques, centered around the ORNL IBM 360 computers, was evolved in which map information was manually copied on Mylar overlays, one category at a time. For example, several overlays may have been required to describe all categories presented in a geological map (sandstone, limestone, etc.). Each overlay was photographed (Sect. 9.16), and the 35-mm film was sent to the University of Pennsylvania to be digitized on the Hough Powell flying spot scanner. The digitized information, returned to ORNL on magnetic tape, was aggregated and assigned to the proper data base locations through ORNL programs run on the IBM 360.

Information that wasn't suitable for automated scanning, such as tax map parcel data, was manually digitized with the aid of grid overlays drawn by the computer. The information was keypunched for entry into the data base. As a verification of the accuracy of these data the computer plotted a check grid containing the parcel information.

Special software was developed for other types of data, such as census information, which was received on magnetic tape, extracted, and then stored in the data bases.

Consultation to the regional modeling group is being continued on data storage and retrieval and the design of the land use simulation models, in addition to engineering support for data acquisition systems.

1. This work was done with C. R. Meyers of the Regional Modeling Group and R. C. Durfee, T. C. Tucker, and D. L. Wilson of the Mathematics Division.

13.4 SOFTWARE FOR ECOLOGICAL SCIENCES COMPUTER SYSTEM

R. L. Simpson

Because of the many problems associated with reading paper tape by the CDC 160A and the long turnaround time for running programs through the ORNL Computer Center, a paper-tape editing program was written for the Ecological Sciences Division PDP-8/I computer system.

The software (programming repertoire) was developed in the FOCAL conversational language, which was extensively modified to provide new commands and functions for reading and editing paper tape and to read from and write on magnetic tape.

The paper tape of data, punched by a multichannel pulse-height analyzer, is read into a buffer in the computer, and each character is checked for validity and correctness, depending on its position on the tape. Each group of characters is also checked to ensure that the number of characters is correct. If any errors occur, the operator's attention is flagged so that he may intervene and exercise a number of options by answering questions printed on the Teletype, by deleting, or by adding or moving characters in the computer buffer. When it is determined that a record is correct, the operator directs that it be written on IBM-compatible magnetic tape. After each input tape is edited, the computer prints the spectrum number and number of channels for that spectrum. The program enables a rerun of spectra that had been skipped due to errors and their addition to the data on the magnetic tape.

13.5 WALKER BRANCH WATERSHED DATA ACQUISITION SYSTEM

C. D. Martin, Jr. R. K. Adams

Funds were approved for the small computer-based data acquisition system to automatically monitor the Walker Branch Watershed.¹ The system will also receive data from an existing data acquisition system in

a ^{137}Cs -tagged forest (Sect. 13.1). Design of the data acquisition stations for the remote locations and preparation of application software were started. The disk-based executive program (Sect. 7.24) will be used for the software system, permitting use of the system for engineering calculations and data reduction as background operations. The total system is scheduled to be operational near the end of FY 1972.

I. C. D. Martin, Jr., and R. K. Adams, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, pp. 60-61.

13.6 INTERACTIVE FITTING OF SYSTEMS ANALYSIS MODELS TO ECOLOGICAL DATA USING THE HYBRID COMPUTER

R. S. Booth

Many modeling problems in ecology require fitting measured data to a set of first-order differential equations with adjustable coefficients (systems analysis model). Such a model is often depicted as a block diagram that shows a collection of compartments linked together by transfer coefficients, with one differential equation or balance equation for each compartment. In most cases, the data are insufficient to ensure a unique fit of the model to the data, and often the most realistic model is not known with certainty. From a mathematical point of view, model fitting of this type is at worst impossible, at best not unique, and certainly cannot be automated. The experimenter, however, knows a great deal more about the ecological system than contained in his collection of data points. He can, with an interactive fitting procedure, add constraints to the fitting process so that his model will make ecological sense, as well as fit the data.

A hybrid computer program, ECOFIT, was developed such that the model, solved on the analog computer, and the data points are displayed simultaneously on an oscilloscope screen. When transfer coefficient in the model is changed by the operator by use of a coefficient slewing device, he sees instantaneously the effect of this change on his model and his fit to the data. Also, he can easily change the model by changing the analog patching. Options in the code allow the operator to read in his data, set up initial guesses for the coefficients (if desired), perform a fit, make plots, and make statistical tests. This program is currently being used to fit a model of tritium (HTO) movement through fish to measured data and of ^{137}Cs movement through trees to several data sets.

13.7 GREEN'S FUNCTION SOLUTION OF THE TIME-DEPENDENT, DIFFUSION EQUATION WITH CONVECTION FOR A SEMI-INFINITE REGION WITH ARBITRARY, MIXED BOUNDARY CONDITIONS AT THE SOURCE PLANE

R. S. Booth

The time-dependent movement of tritium through soil was previously modeled by the one-dimensional diffusion equation with convection, caused by subsequent rainfall, simulated by translation.¹ A new study was started in which convection was included explicitly in the diffusion equation, and the equation was solved by Green's function technique for mixed boundary conditions at the source plane. With the Green's function, study can be made of the accuracy of the previous solution¹ and of the effect of various initial conditions and boundary conditions upon the solution. Solving the diffusion equation by the Green's function technique also facilitates application of the equation to other ecological problems such as the transport of waste heat and radioactivity down a stream and the movement of a radioactive cloud in the air.

1. M. J. Kelly and R. S. Booth, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL 4620, pp. 137-38.

**13.8 STUDY OF DRAFT REPORT BY H. D. DUNSTER AND E. G. STRUXNESS,
'RADIOLOGICAL SAFETY EVALUATIONS RELATED TO PLANNED AND
UNPLANNED RELEASES OF RADIOACTIVE MATERIALS
INTO THE NATURAL ENVIRONMENT'**

R. S. Booth

In a draft report, Dunster and Struxness had described an arithmetic procedures model (APM) for predicting the transfer of radioactivity to man from release to the natural environment. This APM model was analyzed¹ and compared with a systems analysis model (SAM) developed by the author (Booth). The SAM model was reduced to the APM model to determine the assumptions and limitations of the APM model that are not present in the SAM model. The results of this study were presented by Struxness at the annual meeting of the International Commission on Radiation Protection, April 15-24, 1971, London, England.

**13.9 A PRELIMINARY SYSTEMS ANALYSIS MODEL OF RADIOACTIVITY TRANSFER
TO MAN FROM DEPOSITION IN A TERRESTRIAL ENVIRONMENT¹**

R. S. Booth Stephen V. Kaye²

A mathematical model was constructed, simulating selected terrestrial pathways by which fallout radioactivity can be transferred ultimately to man. This model is intended for preliminary predictions of radionuclide intakes by man through consumption of milk, beef, and plant parts contaminated directly by fallout as well as by uptake from the soil. The intake rates and total intakes of 25 radionuclides were predicted for a "standard" man based on a hypothetical fallout of $1 \mu\text{Ci}/\text{m}^2$ of each radionuclide. In the first few days after deposition, milk and directly contaminated plant parts provided the greatest intake of radioactivity from this mixture of radionuclides. After ~ 30 days, the intake rate via beef was 2.5 times more important than that from directly contaminated plant parts. Finally by 500 days, the intake rate from plant parts contaminated by uptake from the soil was the most important source of radioactivity to man in the contaminated area. This generalized dynamic model is sufficiently versatile that it can be applied to many terrestrial environments and to all radionuclides. This first version of the model is expected to undergo future refinements.

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1. Abstract of published report ORNL-TM-3135 (October 1971).
 2. Ecological Sciences Division.

**13.10 A SYSTEMS ANALYSIS METHODOLOGY FOR PREDICTING DOSE TO MAN
FROM A RADIOACTIVELY CONTAMINATED TERRESTRIAL ENVIRONMENT¹**

R. S. Booth S. V. Kaye² P. S. Rohwer³

An environmental system was modeled comprising selected pathways by which terrestrially deposited fallout can be ultimately transferred to man. This model is intended for preliminary predictions of radionuclide intakes by man through consumption of milk and beef and plant parts contaminated directly by fallout as well as by uptake from the soil. The intake rates and total intakes of 25 radionuclides were predicted for a "standard" man based on an initial fallout of $1 \mu\text{Ci}/\text{m}^2$ of each radionuclide. In the first few days after deposition, milk and directly contaminated plant parts would furnish the greatest intake of radioactivity from this mixture of radionuclides. After ~ 30 days, the intake rate via beef would become ten

times more important than directly contaminated plant parts. Finally, by 500 days, the intake rate of plant parts contaminated by uptake from the soil would become the most important source of radioactivity to man in the area contaminated by this assumed radioactive fallout. This generalized dynamic model is sufficiently versatile that it can be applied to almost any location in the world and to all radionuclides.

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1. Abstract of paper presented at the Third National Symposium on Radioecology, May 10-12, 1971, Oak Ridge.
 2. Ecological Sciences Division.
 3. Health Physics Division.

13.11 DETAILED STUDY OF LRL MODEL FOR DOSE TO MAN FROM A NUCLEAR DETONATION THROUGH THE FORAGE-COW-MILK PATHWAY

R. S. Booth

The Lawrence Radiation Laboratory model for predicting the dose to man from milk contaminated by fallout was evaluated. A systems ecology model described by a set of linear, first-order differential equations was derived, and the assumptions needed to reduce it to the LRL model were determined. The LRL model was thereby derived with the use of a consistent set of assumptions that replaced the single assumption of instantaneous equilibrium used in the LRL derivation. This consistent set of assumptions gives greater insight into the limitations of the LRL model.

13.12 GUIDANCE FOR LIMITING ENVIRONMENTAL RELEASES OF TRITIUM¹

P. S. Rohwer² M. J. Kelly³ R. S. Booth

Permissible releases of tritium to the environment, as for all radionuclides, should be limited on the basis of radiation dose potential to the population exposed. Steps are outlined for calculating a Cumulative Exposure Index (CUEX) for tritium such that, when it is respected in the environmental exposure situation for which it is intended, it will assure that dose limits for the public, or some selected fraction thereof, will not be exceeded. The CUEX, a radionuclide concentration, may be calculated for application to the receiving environmental medium at the release point, or it may be calculated for application at locations removed from the release point. The CUEX concept includes consideration of all important modes of exposure. In the case of tritium, the following exposure modes are considered important: inhalation, ingestion, and cutaneous absorption. Although the dose contribution via the ingestion mode is often the most difficult to estimate realistically, it appears to be the most important in many cases. Recent developments concerning tritium behavior in the environment and movement through the food chain to man are discussed in relation to their influence on a CUEX for tritium.

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1. Abstract of paper to be published in the Proceedings of the Tritium Symposium Aug. 30-Sept. 2, 1971, Las Vegas, Nevada.
 2. Health Physics Division.
 3. Reactor Chemistry Division.

13.13 RADIONUCLIDES IN RIVER SYSTEMS¹

D. J. Nelson² S. V. Kaye² R. S. Booth

This survey paper includes a discussion of radionuclide releases to rivers, radionuclide transport in rivers, concentration of radioactivity in aquatic organisms, and assessments of man's potential ingestion of

radioactivity from rivers. It is intended as an introduction to the complex problem of evaluating the environmental impact of radionuclides in river systems.

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1. Abstract of paper presented at International Symposium on River Ecology and the Impact of Man, June 20-23, 1971, University of Massachusetts, Amherst.
 2. Ecological Sciences Division.

13.14 SYSTEMS ANALYSIS AS APPLIED TO ECOLOGICAL PROCESSES: A MECHANISM FOR SYNTHESIS, INTEGRATION, AND INTERPRETATION OF IBP WOODLANDS ECOSYSTEM RESEARCH¹

D. E. Reichle²

R. S. Booth S. V. Kaye²
R. V. O'Neill² Phillip Sollins²

Environmental systems analysis, or systems ecology, deals with the mathematical modeling of environmental systems as sets of coupled compartments through which the temporal passing of elements, compounds, and chemical energy may be predicted with mathematical equations. A basic premise is that environmental systems may be simulated with mathematical equations similar to the equations used to simulate engineering systems. Systems analysis techniques are used in many fields of science and engineering where the dynamic response of a system is of interest. A logical extension of this usage would be to apply these same mathematical techniques to the analysis of ecosystem functions. Ecologists have long recognized that nutrient elements and energy are cycled in the environment from one trophic level to another, but only recently have they learned to apply the well-developed mathematical techniques of systems engineering to ecological problems. This paper discusses the feasibility, techniques, and, with examples, applications of systems analysis to modeling of an entire ecosystem and ecological process. In summary, an immediate action program is proposed for international synthesis of woodlands/forests ecosystem data at the V IBP General Assembly in 1972.

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1. Abstract of paper presented Tiagi Workshop Meeting, June 14-18, 1971, Stockholm.
 2. Ecological Sciences Division.

14. Molecular Anatomy Program and Medical Applications

14.1 GeMSAEC FAST ANALYZER DEVELOPMENT FOR THE MOLECULAR ANATOMY PROGRAM

W. F. Johnson¹

Several instruments were developed this year to aid in rapid analysis of biological compounds by the GeMSAEC Fast Analyzer. An analyzer containing 42 sample cuvettes was placed in service in the clinical laboratory of the ORNL Health Division along with an earlier 15-cuvette model. The 42-cuvette model has an improved rotor temperature control system and thermistor rotor temperature sensors to give a remote temperature readout.

Modules for automatic start-up and automatic cuvette washing sequences were added to the 15-cuvette model. The automatic start-up sequence assures that solutions will be transferred from the transfer disk to the cuvettes in a precisely repeatable manner. The washing module controls the addition of water and air to the cuvettes and controls the speed of the rotor during these additions to obtain optimum cuvette cleaning and drying in the shortest possible time.

Several peripheral instruments were developed and installed in the clinical laboratory to automatically load the GeMSAEC transfer disks. One of these automatically and accurately dispenses reagents into either the 15- or the 42-cuvette transfer disks; the repeatability and loading time achieved is much improved over previous manual methods. A later model of this instrument loads reagents and picks up, dilutes, and dispenses the biological samples to be analyzed. The automatic sample dilution is accurate to 1% compared with an accuracy of 3 to 5% for manual dilution.

i. C. A. Burtis of the MAN Program and C. A. Hahs of the General Engineering Division also participated in this work.

14.2 GeMSAEC ANALYZER DEVELOPMENT FOR OPERATION IN ZERO GRAVITY

W. F. Johnson¹ W. R. Miller

A compact GeMSAEC analyzer system is being developed to operate in zero gravity for the Skylab Program for NASA. This analyzer, designated G0 for gravity zero, will perform several different analyses of a single blood sample and is intended for use by astronauts on board orbiting laboratories.

The analyzer is contained in a small (8 X 6 X 10 in.) instrument package which houses the rotor drive mechanism, cuvette and rotor synchronizing pulse circuitry, and cuvette light-transmittance circuits. The unit is compatible with existing GeMSAEC computers normally used with the 15- and 42-cuvette analyzers, and can be used with a small recording system being developed. This recorder will print the results from up to 16 end-point reactions on a single IBM-sized card. In the recorder, digital logic correlates the signals originating at the photodetector with the proper cuvette position and immediately produces a permanent record of the end-point values without the aid of the usual GeMSAEC computer.

1. This work is being done for the Molecular Anatomy (MAN) Program, and many individuals from other ORNL divisions are participating in this project.

14.3 GeMSAEC COMPUTER SYSTEM¹

J. M. Jansen, Jr. M. T. Kelley²

Both hardware and software development changes were made to the system. An improved GeMSAEC-analyzer-to-computer interface³ was installed in the system now located in the Health Division. Software changes were made to accommodate the 42-sample GeMSAEC analyzer. The system was modified and extended to improve interaction with clinical laboratory technicians using the system for routine analysis. A single hardware malfunction occurred during the year, causing a loss of 3 hr of production time.

1. J. M. Jansen and J. L. Redford, *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 54.

2. Analytical Chemistry Division.

3. Patent Application CNID 2632, Serial No. 34,783, "A Computer Interface."

14.4 BODY FLUIDS ANALYSIS COMPUTER SYSTEM¹

J. M. Jansen, Jr.

This system continued to acquire and analyze data from column chromatographic analyzers for researchers in the Chemical Technology Division. No hardware or software changes were required. The system was shut down 221 hr owing to two separate hardware malfunctions of the magnetic disk unit.

1. J. M. Jansen, Jr., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 54.

14.5 AUTOMATED ELECTROCARDIOGRAM DATA ACQUISITION SYSTEM

A. H. Voelker A. S. Garrett, Jr., M.D.¹ R. L. Simpson

A Marquette Electronics automated electrocardiogram system² was placed in operation to simplify the manual process of electrocardiogram (ECG) interpretation. The system consists of two separate pieces of hardware which communicate through a telephone line. The patient transmitter cart located in the ORNL Health Division can acquire ECG data for both classical 12-lead electrocardiograms and 3-phase orthogonal "Frank" vectorcardiograms.

The data, as three FM channels of analog data, are transmitted by a common-carrier dial phone to a batch collection unit in Building 3500, ~1/4 mil. away. This unit can collect 64 ECG's on one analog magnetic tape. Each day the collected ECG's are transferred from the analog tape by recording them in computer-compatible form on a digital tape. The digital tape is analyzed on the ORNL IBM 360/91 computer, and an interpretation is printed for review the next day.

Under the procedure formerly used, the ECG strip chart was mailed to cardiologists for analysis, requiring a week or more for analysis. Preliminary analysis of the first 100 ECG's interpreted by both the computer and cardiologist showed only ~10% disagreement in minor areas and none of clinical significance. With this system, cardiologists will analyze only a small percentage of the ECG's; the majority will be analyzed in one day by the computer.

Computer analysis of ECG's makes use of the Mayo Clinic analysis program,³ which was modified by the Instrumentation and Controls Division for compatibility with the IBM 360/91 computer. A preprocessing program was written to convert the digital tape unit output to the form required by the Mayo Program.

The system will be expanded to process up to 200 ECG's per day through the use of four additional patient transmitter carts.

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1. Health Division.
 2. R. K. Adams and T. A. Lincoln, M.D., *Instrumentation and Controls Div. Annu. Progr. Rep. Sept. 1, 1970*, ORNL-4620, p. 54.
 3. Ralph Smith, M.D., Mayo Clinic, Rochester, Minn.

14.6 HEART RATE TELEMETERING AND RECORDING SYSTEM

W. R. Miller

A system for telemetering and recording a human heart rate was developed and built for studies of the work expended by persons engaged in emergency activities, such as stretcher bearing, mouth-to-mouth resuscitation, and external cardiac massage.

The system consists of a commercial, battery-operated electrode preamplifier; a newly designed audio-modulated FM transmitter unit; and a modified commercial, battery-operated FM receiver and stereo cassette tape recorder unit.

The person wears the preamplifier and transmitter units on a belt around the waist. Each unit is approximately 3 X 4 X 1 in., and each weighs only a few ounces. The transmitting range is >500 ft.

An observer carries the receiver and recorder unit. On one stereo channel the heart rate signal from the receiver is recorded. Simultaneously, on the other stereo channel, comments spoken into a microphone by the observer concerning the activities of the person wearing the transmitter are recorded.

A unique feature of this system is that the heart beat triggers an audio oscillator that, in turn, modulates the FM transmitter. The result is a single-frequency "beep" recorded on the tape for each heart beat, rather than a low-frequency "thump" that would normally result if the transmitter were directly modulated by the preamplifier.

If background noise is high, a filter can be used during playback of the heart beat channel to eliminate all but the desired "beep" signal.

The transmitter unit (Fig. 14.6.1) has only three active components: a high-frequency transistor to generate the FM signal ~100 MHz in the commercial FM band, a unijunction transistor to generate the audio beep tone at ~2500 Hz, and a third transistor to gate the audio oscillator as each pulse is received from the preamplifier.

The preamplifier is a Quintron Instruments model QI-609; it is modified by bypassing the optical isolator.

The receiver-recorder is a commercial unit that was altered to accept the inputs previously described and to operate in a playback mode in which the heart rate signal is fed to an analyzer while the voice signal is heard through the speaker.

ORNL-DWG 72-4838

Professional Awards and Achievements and Offices and Memberships of Professional Groups Held by Instrumentation and Controls Division Personnel

AMERICAN INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE)

- R. K. Abele:** Member of Nuclear Instruments and Detectors Committee under Nuclear Science Group
- J. L. Blankenship:** Member of Nuclear Instruments and Detectors Committee, Symposium Committee, and Program Subcommittee under Symposium Committee, all of Nuclear Science Group
- S. J. Ditto:** Member of Joint Committee on Nuclear Power Standards of Nuclear Science Group and Power Group and Member of Subcommittee SC-5, Reliability, under the Joint Committee
- J. H. Holladay:** Vice-Chairman of the Oak Ridge Section
- C. F. Holloway:** Member of Subcommittee SC-4, Auxiliary Power Systems, under Joint Committee on Nuclear Power Standards of Nuclear Science Group and Power Group
- J. L. Lovvorn:** Director, and Chairman of the Educational Activities Committee of the Oak Ridge Section
- F. W. Manning:** Member of Committee for 17th Annual Symposium on Nuclear Science under Nuclear Science Group
- J. W. McConnell:** Member of Executive Committee of the Oak Ridge Section

AMERICAN NUCLEAR SOCIETY (ANS)

- C. J. Borkowski:** Fellow

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

- W. W. Johnston, Jr.:** Member of Committee E-20, Temperature Measurement, and Subcommittees and Sections under this Committee, as follows:

Chairman of Committee E20.03, Resistance Thermometers

Member of Committee E20.04, Thermocouples

Member of E20.04.01, Standardization of Standard Thermocouples and Materials, under Committee E20.04

Member of E20.04.04, Standardization of Noble Metal Thermocouples and Materials, under E20.04.01

Member of E20.04.03, Metallic Sheathed Thermocouples for Nuclear Service, under Committee E20.04

Member of E20.04.06, Thermocouple Applications, under Committee E20.04

Member of E20.04.07, Insulating Materials for Thermocouples, under Committee E20.04

Member of E20.04.10, Sheathed Electrical Heaters for Nuclear Applications, under Committee E20.04

R. L. Shepard: Secretary of Subcommittee on Acoustical Thermometry, under Committee E-20, Temperature Measurement

**FIFTH SYMPOSIUM ON TEMPERATURE—ITS MEASUREMENT AND CONTROL IN SCIENCE
AND INDUSTRY—JUNE 1971, WASHINGTON, D.C.**

W. W. Johnston, Jr.: Member of Thermocouple Committee

R. L. Shepard: Chairman of Omnibus Thermometry Committee

Member of Thermocouple Committee

Member of Editorial Committee for Proceedings Publication

INDUSTRIAL RESEARCH—IR-100 AWARD

W. F. Johnson for Body Fluids UV Analyzer

INSTRUMENT SOCIETY OF AMERICA (ISA)

H. E. Cochran, Commander: Executive Officer of Research Company 6-3 of the U.S. Naval Reserve

M. B. Herskovitz: Chairman of Utilities Committee for 17th Annual Southeastern Conference and Exhibit, Gatlinburg

B. Lieberman: Member of Honors and Awards Committee of the Oak Ridge Section

Chairman of the Liaison Committee for the 17th Annual Southeastern Conference and Exhibit, Gatlinburg

C. S. Lisser: Chairman of the Control Centers Committee

Chairman of Committee SP-60, Standards

Associate Director of Process Measurement and Controls Division

C. D. Martin, Jr.: Executive Counselor of the Oak Ridge Section

Chairman of the Program Committee of the Oak Ridge Section

J. L. Redford, Commander: Executive Officer of Research Company 6-3 of the U.S. Naval Reserve

R. E. Toucey: Member of Utilities Committee for the 17th Annual Southeastern Conference and Exhibit, Gatlinburg

INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC/TC-45)

J. L. Blankenship: Member of Detectors Working Group (WG-9)

NATIONAL COUNCIL ON RADIATION PROTECTION AND UNITS

F. H. Clark: Consultant

ORNL DIRECTOR'S REVIEW COMMITTEES

B. G. Eads: Accelerators and Radiation Sources

B. C. Duggins: Reactor Operations

B. Lieberman: Radioactive Operations

UNITED STATES OF AMERICA STANDARDS INSTITUTE (USASI)

J. W. Krewson: Member of Subcommittee on Liquid Level under Committee B-88, Calibration of Instruments

F. W. Manning: Member of Committee N-42, Nuclear Instrumentation

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.

- Ackermann, N. J., Jr., and J. C. Robinson,¹ "A Noise Technique for Measuring Reactivity Independent of β/Λ ," *Trans. Am. Nucl. Soc.* 13(2), 764-65 (November 1970).
- Ackermann, N. J., Jr., and A. R. Buhl, *LMFBR Subcriticality System Development*, ORNL-CF-70-11-67 (November 1970).
- Ackermann, N. J., Jr., *An Analytical and Experimental Investigation of the Neutron Energy Effects on Reactor Fluctuation Spectra*, ORNL-TM-3245 (February 1971).
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- Booth, R. S., *A Detailed Study of the LRL Model for the Dose to Man Caused by a Nuclear Detonation by the Forage-Cow-Milk Pathway*, ORNL CF-70-9-2 (September 1970).
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- Fry, D. N., "Experience in Reactor Malfunction Diagnosis Using On-Line Noise Analysis," *Nucl. Technol.* 10, 273-82 (March 1971).
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- Roux, D. P., and J. Max,¹⁹ "Detection and Location of a Fuel Pin Failure in Rapsodie Using Noise Analysis," *Trans. Am. Nucl. Soc.* 14(1), 304-305 (June 1971).
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- Sides, W. H., Jr., "Preliminary Control Study of a 1000-MW(e) Molten Salt Breeder Reactor," *Trans. Am. Nucl. Soc.* 13(Suppl.), 16-17 (September 1970).
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- Thacker, L. H., C. D. Scott,⁶ and W. W. Pitt, Jr.,⁶ "A Miniaturized Ultraviolet Flow Photometer for Use in Liquid Chromatographic Systems," *J. Chromatography* 51(2), 175-81 (September 1970).
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- Uziel, M.,²⁰ J. W. Starken, J. W. Eveleigh, and W. F. Johnson, "Automated Sequential Degradation of Ribonucleic Acids," pp. 740-44 in *Proc. Third Ann. Symposium High-Resolution Anal. and Advanced Concepts for the Clinical Lab.*, March 11-12, 1971, Oak Ridge, Tennessee.

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- Weston, L. W.,² R. Gwin,² G. deSaussure,² R. W. Ingle, J. H. Todd and C. W. Craven,²¹ "Neutron Fission and Capture Cross-Section Measurements for Uranium-233 in the Energy Region 0.02 to 1 eV," *Nucl. Sci. Eng.* 42, 143 (1970).
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²⁰Biology Division.

²¹Mathematics Division.

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.

*Conference on Power Reactor Systems and Components,
American Nuclear Society, Power Division, Williamsburg,
Virginia, September 1-3, 1970*

O'Brien, H. G., O. W. Burke, and C. S. Walker, "Loss-of-Cooling Accidents in a Gas-Cooled Fast Reactor."

Sides, W. H., Jr., "Preliminary Control Study of a 1000-MW(e) Molten Salt Breeder Reactor."

*Fourteenth Conference on Analytical Chemistry
Nuclear Technology, Gatlinburg, Tennessee, October
13-15, 1970*

Shipp, R. L., "A Gas Effluent Monitor for Identification of Alpha Contaminants."

*1970 Nuclear Science Symposium and Nuclear Power Systems Symposium,
New York City, November 4-6, 1970*

Buhl, A. R., and N. J. Ackermann, Jr., "Precision of Shutdown Margin Measurements Using the Two-Frequency Reactor Noise Technique in an LMFBR."

De Lorenzo, J. T., "Low-Noise, Wide-Band, Current-Pulse Preamplifiers for Neutron Counters."

Ditto, S. J., "Numerical Goals and Establishment of Test Intervals."

Fry, D. N., R. C. Kryter, and J. C. Robinson,¹ "Investigation of Boiling Detection in the HFIR Using Out-of-Core Instrumentation."

Lynnworth, L. C.,² E. P. Papadakis,² D. R. Patch,² K. A. Fowler,² and R. L. Shepard, "Nuclear Reactor Applications of New Ultrasonic Transducers."

*1970 Winter Meeting American Nuclear Society, Washington, D.C.,
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Ackermann, N. J., Jr., and J. C. Robinson,¹ "A Noise Technique for Measuring Reactivity Independent of β/Λ ."

Carr, K. R., "New Methods for Measuring Compaction of Ceramic Insulators in Sheathed Thermocouples."

Perez, R. B.,³ G. de Saussure,³ E. G. Silver,³ and R. W. Ingle, "Measurement of the Capture Cross Section of ^{238}U up to 100 keV."

*1971 Particle Accelerator Conference Accelerator Engineering
and Technology, Chicago, Illinois, March 1-3, 1971*

Millard, J. K., T. A. Lewis, and G. W. Allin, "Beam Current Monitor for the Oak Ridge Electron Linear Accelerator."

*Third Symposium on Automated High-Resolution Analyses in the Clinical
Laboratory, Oak Ridge National Laboratory, Oak Ridge, Tennessee, March 11-12, 1971*

Burtis, C. A.,⁴ W. F. Johnson, J. E. Attrill,⁵ C. D. Scott,⁶ N. Cho,⁷ and N. G. Anderson,⁴ "Increase in the Rate of Sample Throughput by Use of a 42-Cuvet GeMSAEC Fast Analyzer."

*Third Conference on Neutron Cross Sections and Technology, Knoxville,
Tennessee, March 15-17, 1971*

Silver, E. G.,³ G. de Saussure,³ R. B. Perez,³ and R. W. Ingle, "Measurement of Neutron Cross Sections in ^{238}U and ^{235}U Below 100 keV at the ORELA."

Weston, L. W.,³ and J. H. Todd, "Neutron Multiplicity for ^{239}Pu Resonance Fission."

*The Third National Symposium on Radioecology, Oak Ridge,
Tennessee, May 10-12, 1971*

Booth, R. S., S. V. Kzye,⁸ and P. S. Rohwer,⁹ "A Systems Analysis Methodology for Predicting Dose to Man from a Radioactively Contaminated Terrestrial Environment."

*1971 Annual Meeting American Nuclear Society, Boston,
Massachusetts, June 13-17, 1971*

Ackermann, N. J., Jr., A. R. Buhl, and R. C. Kryter, "An Analytical and Experimental Evaluation of Detection Efficiency Dependence of Subcriticality Measurements by the Polarity Spectral Coherence Method."

Buhl, A. R., N. J. Ackermann, Jr., and R. C. Kryter, "An Evaluation of the Asymmetric Source Technique for Determining Subcritical Reactivity in Fast Reactors."

Chen, C. H.,¹⁰ T. W. Kerlin,¹¹ and D. N. Fry, "Experiences with Binary Periodic Signals for Dynamic Testing at the HFIR."

de Saussure, G.,³ R. B. Perez,³ E. G. Silver,³ and R. W. Ingle, "Simultaneous Measurement of the Neutron Fission and Capture Cross Sections of ^{235}U for Energies up to 100 keV."

Dodds, H. L., Jr.,¹² J. C. Robinson,¹ and A. R. Buhl, "A New Technique for Controlling Numerical Errors in Transfer and Scattering Matrix Methods."

Kryter, R. C., N. J. Ackermann, Jr., and A. R. Buhl, "Measurement of Subcriticality in Large Fast Reactors by Combining Noise and Multiplication Techniques."

Roux, D. P., and J. Max,^{1,3} "Detection and Location of a Fuel Pin Failure in Rapsodie Using Noise Analysis."

Fifth Symposium on Temperature, Its Measurement and Control in Science and Industry, Washington, D. C., June 21-24, 1971

Adams, R. K., and R. L. Simpson, "Review of Techniques for Determining Thermocouple EMF-Temperature Characteristics"

Adams, R. K., J. T. Hutton, R. F. Hyland, J. M. Jansen, Jr., T. G. Kollie,^{1,4} B. C. Duggins, B. G. Eads, C. D. Martin, Jr., C. A. Mossman, J. L. Redford, R. L. Simpson, and A. H. Voelker, "Application of Small Computers as Thermometry Research Tools."

Carr, K. R., "An Evaluation of Industrial Platinum Resistance Thermometers."

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Eads, B. G., and B. C. Duggins, "Experience with Direct Digital Control of Several Temperature Processes."

Herskovitz, M. B., "Thermal Cycling Life Tests of Metal Sheathed Thermocouple Assemblies."

Johnston, W. W., Jr., and M. H. Cooper, Jr., "Traceability, What and How, Relating Temperature Measurement at ORNL."

Kollie, T. G.,^{1,4} D. L. McElroy,^{1,4} R. K. Adams, and J. M. Jansen, "Measurement Accuracy of a Computer Operated Data Acquisition System."

Martin, C. D., and C. H. Gabbard,^{1,5} "Experience With Type K Thermocouples in an Experimental Nuclear Reactor."

Shepard, R. L., R. F. Hyland, J. M. Googe,^{1,6} and J. R. McDearman,^{1,1} "Equivalent Circuit Modeling of Insulator Shunting Errors in High Temperature Sheathed Thermocouples."

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Reichle, D. E.,⁸ R. S. Booth, S. V. Kaye,⁸ R. V. O'Neill,⁸ and P. Sollins,⁸ "Systems Analysis as Applied to Ecological Processes: A Mechanism for Synthesis, Integration, and Interpretation of IBP Woodlands Ecosystem Research."

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