INSTRUMENTATION AND CONTROLS DIVISION
ANNUAL PROGRESS REPORT
FOR PERIOD ENDING SEPTEMBER 1, 1966

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INSTRUMENTATION AND CONTROLS DIVISION

ANNUAL PROGRESS REPORT

For Period Ending September 1, 1966

C. J. Borkowski, Director
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JUNE 1967

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
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1. Nanosecond Circuitry and Techniques

1.1 OPTIMUM DESIGN OF SENSITIVE TUNNEL DIODE DISCRIMINATORS

Ronald Nutt

A new and useful theory was developed to characterize switching properties of the tunnel diode. Expressions for time delay and time resolution for small signals in the presence of amplitude noise were developed for the tunnel diode operating in the discriminator mode. The expression for time resolution is used to determine the parameters of the tunnel diode, the bias stability, and the necessary tunnel diode isolation to obtain the optimum time resolution for a specified signal-to-noise ratio.

This theory was developed after the author had discovered experimentally that the positive resistance region of the tunnel diode could be represented very accurately by a sine function in voltage,

$$I_e = I_p \sin ke \quad (0 \leq e \leq e_p),$$

(1)

where $I_p$ is the tunnel diode peak current and $e_p$ is the voltage at the peak current. This relationship is shown experimentally for several diodes in Fig. 1.1.1. Since the positive resistance region is responsible for the significant delay and time variance, Eq. (1) is sufficient to describe these properties of the tunnel diode. The usual equivalent circuit is used to represent the tunnel diode, which is characterized by the nonlinear differential equation

$$I_s = I_p \sin ke + C \frac{de}{dt} \quad (0 \leq e \leq e_p),$$

(2)

where $I_s$ is the signal current and $C$ is the total diode capacitance. The time $T_{sp}$ for the tunnel diode to switch to the negative region is

$$T_{sp} = D \int_{e_s}^{e_p} \frac{de}{I_s - I_p \sin ke},$$

(3)

---

Fig. 1.1.1 Tunnel Diode Positive Resistance Region.

where $e_a$ is the bias voltage before the signal is applied. The time variance is then determined by

$$\Delta T^{2}_{sp} = \left( \frac{\partial T}{\partial I_g} \right)^2 \Delta I_g^2.$$  \hspace{1cm} (4)

When the prescribed mathematical steps are carried out, the result is

$$\Delta T = \frac{1.27 e_p C_T}{I_p^2 \left[ (I_g/I_p) - 1 \right]} \tan^{-1} \left\{ \left[ \frac{2}{(I_g/I_p) - 1} \right]^{1/2} \frac{n}{2} \left( 1 - \frac{e_0}{e_p} \right) \right\} \Delta I_g.$$ \hspace{1cm} (5)

This equation is plotted in Fig. 1.1.2 for three bias voltages. From Eq. (5) the ratio of $C/I_p^2$ should be a minimum when a tunnel diode is selected to obtain the best time resolution. Good agreement between the calculated variance and the measured variance for the TD252A diode is shown by the points along the center curve of Fig. 1.1.2.

1.2 FEEDBACK-STABILIZED TUNNEL DIODE DISCRIMINATOR

Ronald Nutt \hspace{1cm} J. A. Biggerstaff\(^1\)

A discriminator was developed which adjusts its sensitivity to a predetermined noise level of the detector. The sensitivity of the discriminator is essentially independent of drift as-

\(^1\)Physics Division.
Fig. 1.1.2 Calculated vs Measured Variance for TD252A Diode.

associated with the tunnel diode sensing element or of gain changes between the noise source and the discriminator.

The system, as shown in Fig. 1.2.1, is composed of two tunnel diode discriminators. The more sensitive discriminator has pulse-rate feedback which adjusts the sensing tunnel diode so that it is triggered at a preset noise count rate. The second discriminator has a fixed sensitivity, and it is triggered by essentially nothing but signal pulses. Since the output pulses from the two discriminators are subtracted at the input of the pulse-rate feedback network, the sensitivity of
the first discriminator is not affected by signal pulses. A delayed fast coincidence is performed between the two discriminators so that a pulse which is time coherent with the sensitive discriminator pulse appears at the output for all true signal pulses.

The system has been designed and constructed, and preliminary indications are that it is superior to existing discriminators when used with an NaI(Tl) scintillator and photomultiplier arrangement.

1.3 PICOSECOND PEAK CURRENT METER USING TUNNEL DIODES

Ronald Nutt J. A. Biggerstaff

A system was developed to measure the peak current of pulses with pulse widths ranging from microseconds to picoseconds. The instrument was developed to measure the current pulse amplitude from a fast beam pulse pickoff system on the 3-Mv Van de Graaff accelerator.

The sensing device of the instrument is a low-capacitance tunnel diode biased in a bistable state. The bias current of the tunnel diode is adjusted by means of a pulse-rate feedback network.

\[^{1}\] Physics Division.
The feedback forces the sum of the peak signal current and the tunnel diode bias current to trigger the tunnel diode at some minimum rate. This condition results in a bias current linearly related to the peak signal current; a signal proportional to this current is the instrument output.

The limitations have been theoretically and experimentally investigated. The instrument can measure peak currents down to 400 psec with an absolute accuracy of 5% for the current range of 250 to 5 ma. The instrument is insensitive to pulse repetition rates above 10 kc. The system diagram is shown in Fig. 1.3.1.

![Diagram of Peak Current Meter](https://example.com/diagram.png)

**Fig. 1.3.1 Diagram of Peak Current Meter.**

### 1.4 DESIGN OF ELECTRONIC DISCRIMINATOR FOR FAST BEAM PULSE PICKOFF SYSTEM

Ronald Nutt

An amplifier and fast discriminator (Fig. 1.4.1) was designed to detect the zero crossover of the bipolar pulses from the beam pulse pickoff systems of 3- and 5-Mv Van de Graaff accelerators. Electronic circuitry was installed on both accelerators and is operating satisfactorily.

The amplifier was designed similar to the Rush amplifier.\(^1\) Modifications were made to improve the gain-bandwidth product so that it would satisfactorily amplify 1-nsec pulses from the

---

pickoff system. The tunnel diode discriminator was designed to trigger on the negative pulse and as near the zero crossover from the fast amplifier as possible.

The time resolution of the electronics was 10 psec rms for the normal operating current of 5 ma, and 200 psec for signal currents two orders of magnitude below the normal pulse current from the pickoff system.

1.5 NEW SHUNT-SERIES NANOSECOND PULSE AMPLIFIER

J. K. Millard

A new shunt-series amplifier section was developed for fast rise-time pulse amplifiers intended primarily for use with accelerator beam probes, solid-state detectors, and fast ionization chambers. Design equations for the gain section were derived from a high-frequency model and were validated by computer analysis and experimental results. Two amplifiers were built, with three gain sections cascaded in each. The gain of these amplifiers was 270 and 135, and the rise time was 1 and 0.9 nsec respectively.

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1.6 SIMULTANEOUS CONNECTION OF FAST- AND SLOW-AMPLIFIER SYSTEMS TO SEMICONDUCTOR SYSTEMS

N. W. Hill R. W. Peele

Experiment designs often require the time information contained in the signals from semiconductor detectors as well as the customary information on the amount of deposited energy.

1 Work funded by the National Aeronautics and Space Administration under NASA order R-104(1).
2 Neutron Physics Division.
Measurements of deposited energy in semiconductors usually depend on observation of the total charge released by the event, using charge-sensitive preamplifiers designed for stability and low noise rather than for rapid response. Since the time interval required for full collection of the charge carriers depends on the position of an event in the detector, the least ambiguous timing information lies in the first movement of charge carriers in the semiconductor. Sensing this first voltage change across the diode requires amplifiers and signal connections which allow fast transient response with minimum noise, although stability and linearity need not be perfect.

We have attempted to determine which amplifier and signal connection configurations give good overall performance for the various types of semiconductor detectors in use. Most of this work has been concerned with either thin (40 to 200 μ) totally depleted silicon surface-barrier diodes or thick (6 mm, 20 pf) lithium-drifted germanium diodes. The criteria for system design have been clean, fast signals with minimum noise for the signal rise time, slow amplifier resolution and stability essentially unhampered by the presence of the fast system, and the ability to operate at least some of the amplifiers at a distance from the detector and in vacuum.

No satisfactory approach for good time and energy resolution is readily apparent without a fast- and a slow-amplifier channel. Though other design choices are possible, we have employed charge-sensitive amplifier circuits derived from conventional design, current-mode fast amplifiers with low input impedance, and connection schemes in which each amplifier is connected to the diode without intervening active elements.

Figure 1.6.1 illustrates a fairly successful arrangement for thin silicon detectors, assuming that both sides of the mount are accessible and that the slow amplifier (which cannot terminate any cable) can be mounted very close to the detector. The transformer coupling to the fast amplifier, which has an input impedance of about 10 ohms, is arranged to provide proper damping of the series resonant circuit of the diode and its connections, to give the maximum current into the fast amplifier, and to reduce noise fed into the slow system. If a cable connects the slow amplifier to the diode, the ratio of primary to secondary transformer turns must be chosen to match this cable impedance for the fast rise-time portion of the pulse. Minimum rise times were observed when the transformer could be omitted. The fast signal in Fig. 1.6.1 appears across the slow amplifier input capacity and the stray capacity C_s in series with the diode capacity; so the fast signal can be augmented by increasing C_s until the energy resolution seen by the slow

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system is compromised. A more desirable way to accomplish this is to use parallel field-effect transistors at the slow-amplifier input. This increases the effective capacity without appreciably increasing the noise in the slow amplifier. Though we have referred to the charge-sensitive amplifier as slow, the system benefits from having fast response so that the feedback charge does not unduly lengthen the pulse seen in the fast amplifier. With the use of a room-temperature, 40-µ 100-pf diode in an arrangement such as that shown in Fig. 1.6.1, but with no transformer, clean fast signals (2.2 nsec rise time, 3.5 nsec wide) were obtained without measurable broadening of the slow-amplifier resolution.

In the case of lithium-drifted germanium detectors, only one side of the diode is readily available for signal connection, and some lead length is required because the detector must rest in a cryostat at liquid-nitrogen temperature. The most successful dual connection seems to involve transformer coupling located adjacent to the slow-amplifier input, as in Fig. 1.6.2, with parallel field-effect input transistors on the slow amplifier to increase its effective input capacity. If the cable between the pickoff transformer and the slow preamplifier is made very short in the system of Williams and Biggerstaff, their system is similar to the one described here except that the fast amplifier and the coupling transformers are of different types. A fast threshold below 200 kev and above noise has been reached with a fast-amplifier rise time of 12 nsec, over twice that allowed by the detector. The slow preamplifier, cut for proper operation with random 60-Mev input, has a gamma-ray resolution of about 13 kev (which includes the effect of the stray transformer capacity), not definitely changed by turning on the fast amplifier. Thus, the effect of the fast

amplifier was to introduce a noise component of less than 5 kev. On the other hand, the slow preamplifier can make an important noise contribution to the fast system via high-frequency noise components from the field-effect transistor.

In all cases fast-signal performance can be improved if no slow signal is required or if experiment requirements permit the energy resolution of the slow amplifier to be degraded appreciably. Of these criteria the most difficult one has been the remote location of the slow amplifier from the detector, although the systems are degraded only slightly by remote location of the fast amplifiers.

1.7 FAST FISSION CHAMBER AMPLIFIER-DISCRIMINATOR SYSTEM

R. W. Ingle F. E. Gillespie L. W. Weston

In measurements of the neutron capture cross section and the fission cross section of fissile isotopes with relatively high alpha activity, such as $^{233}$U, standard amplifiers cannot be used, because the pileup of alpha pulses greatly reduces the system detection efficiency. Less material could be placed in the fission chamber, but this would mean a poor ratio of signal to background, and more experimental machine time would be necessary to acquire statistically significant data.

A system was developed to detect a fission pulse from a chamber containing 1 g of $^{233}$U. This system (Fig. 1.7.1) consists of a ten-section fission chamber, ten separate current amplifier-discriminators, and ten pulse shapers with common output.

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1Neutron Physics Division.
Fig. 1.7.1 Amplifier Fission-Chamber Assembly.
The detector is a parallel-plate fission fragment ionization chamber. Each section contains 100 mg of $^{233}$U plated to 0.5 mg/cm$^2$ thickness and a diameter of 3 in. A single section contains four plated sides. The capacitance per section is 130 pf, and plate spacing is 1.6 mm. The chamber, designed for fast electron collection time, contains a gas mixture of 90% Ar–10% CO$_2$. For a chamber voltage of 500 V the electron collection time is approximately 30 nsec.

Figure 1.7.2 is a diagram of the system. The fission chamber, placed in the neutron beam, is connected to the amplifier by 8 ft of RG-174/U cable, which is terminated with 50 ohms at the amplifier input. The induced current pulse from a fission fragment has a rise time and amplitude limited by the RC time constant of chamber capacity and cable impedance, in this case 6.5 nsec. (Previous work had been done in observing the fast-rising current pulse from a fission detector using a wide-band amplifier.) Each amplifier-discriminator is packaged in a single-width module and consists of a three-stage Rush$^3$ configuration and a single tunnel diode discriminator. The amplifier total gain is approximately 1000, and rise time is 7 nsec. An average of 15 Mev of fragment energy is deposited between the plates of the fission chamber, and this produces a pulse at the output of the amplifier of approximately 1 ma peak, 30 nsec wide. The equivalent noise measured at the output is approximately 1.8 Mev. Alpha particles deposit a maximum of 4 Mev between the plates, but the average is less than 2 Mev.


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**Fig. 1.7.2 Amplifier-Discriminator System.**
The discriminator pulse is amplified and used to trigger a 0.5-μsec-wide pulse shaper. All ten pulse shapers are packaged in a double-width module. The outputs of all shapers are mixed to provide a common output. This pulse is used in coincidence with a fission gamma pulse to store fission data in a time-interval measuring device.

This system was used in experiments at the Rensselaer Polytechnic Institute linear electron accelerator. From a preliminary analysis of the data it appears that the results are satisfactory in the neutron energy range of 0.5 to 100 ev. The use of this technique for measurement of materials containing much higher alpha activity is being studied. It is anticipated that a factor of 4 in alpha activity per section can be tolerated without greatly reducing the detection efficiency.

1.8 INSTRUMENTATION TO MEASURE THE RATIO OF NEUTRON CAPTURE TO FISSION CROSS SECTION AT KILO-ELECTRON-VOLT NEUTRON ENERGIES

J. H. Todd  L. W. Weston

Measurements of α (the ratio of neutron-capture cross section to neutron-fission cross section) were made for $^{239}\text{Pu}$, $^{233}\text{U}$, and $^{235}\text{U}$ at neutron energies from 10 to 600 kev.

The detector consisted of eight photomultiplier tubes located around the periphery of a 210-gal tank of gadolinium-loaded liquid scintillator. The time resolution of the combined signals from the eight photomultiplier tubes was better than 5.7 nsec.

Neutron energies were measured by time-of-flight techniques using a flight path of 1 m. Fission events were distinguished from capture events by the detection of thermalized fission neutrons captured, in the scintillator, in a time interval following the initial event. The background and foreground pulse-height spectra associated with both capture and fission events were measured simultaneously with the time-of-flight spectra. An error, introduced by the basic method of measurement, was also measured simultaneously with the basic data.

1 Neutron Physics Division.

1.9 NEUTRON TIME-OF-FLIGHT SPECTROMETER

J. W. McConnell  J. H. Todd

Requirements for neutron elastic and inelastic scattering cross sections have prompted development of a neutron time-of-flight spectrometer for use on pulsed Van de Graaff accelerators. The spectrometer has also been utilized for measurements of neutrons between 0.5 and 10 Mev produced by $(p,n)$ and $(d,n)$ reactions.

The system block diagram is shown in Fig. 1.9.1. Neutrons are detected by a 1-in.-thick 5-in.-diam liquid scintillator (NE-213). Pulse shape discrimination is used to reduce gamma-ray background. Data are recorded by a two-parameter analyzer in a 256 × 16 array (flight time ×
Fig. 1.9.1 Neutron Time-of-Flight Spectrometer.
pulse height). Recording data in this manner permits use of a digital computer to correct for
time "walk" of leading-edge discriminators. The system time resolution is 1.6 nsec for 8-Mev
neutrons.

To reduce the time required to obtain a complete angular distribution, use of multiple detectors is planned. A digital computer was purchased for on-line data collection and data reduction.

1.10 COMBINED ENERGY AND MASS SPECTROMETER CONTROL

J. W. Reynolds       M. O. Krause

An instrument system was required to measure the time of flight of dissociated atoms over
two fixed flight paths to determine the energy and mass of the atoms. The system requirements
were (1) two electron-gun pulses, each 50 to 200 nsec wide with an amplitude of +5 to +30 v;
and (2) start delay steps in multiples of two from 0.4 to 8 \( \mu \)sec followed by 100 channels, each
20 nsec wide. Alternative channel widths of 50 and 100 nsec with a corresponding increase in
the start delay steps were to be included. The desired stability was 0.5%/day.

The system designed consists of a multichannel analyzer as a storage device, fast scalers
for timing channels and start delays, and a synchronizing control to gate the oscillator pulses
to the scalers and to transfer the measured time intervals to the analyzer.

The system was assembled, and preliminary checking was completed.

\(^1\)Thermonuclear Division.
2. Pulse Counting and Analysis

2.1 PULSE SHAPING FOR NUCLEAR PULSEAMPLIFIERS

C. H. Nowlin    J. L. Blankenship

Now that an energy resolution of \( \sim 0.1\% \) can be obtained with semiconductor detectors, the careful control of pulse shape to discriminate against pileup distortion as well as the usual noise-power distortion has become very important. The most desirable pulse would be one which is fast, returns smoothly to the base line with no ringing or multiple peaking, and discriminates well against noise-power distortion.

With this ideal pulse in mind, we made a theoretical study of the pulse response and the signal-to-noise ratio of various transfer functions that satisfy the conditions for synthesis as lumped-element networks, and we synthesized networks that have some of the more useful transfer functions. One of these networks was tested extensively in an amplifier, and we observed the expected reduction in both pileup distortion and in noise-power distortion.\(^1\)


2.2 CALCULATION OF NETWORK SIGNAL-TO-NOISE RATIOS

C. H. Nowlin

The calculation of the signal-to-noise ratio of a transfer function prior to the design and construction of the network is important to the improvement of nuclear amplifier pulse-shaping systems. An essential part of this calculation is the evaluation of the integral

\[
N = \int_{0}^{\infty} |P(\omega)|^2 N(\omega) \, d\omega ,
\]

where \( N \) is the output noise power, \( P(\omega) \) is the network transfer function, and \( N(\omega) \) is the input noise-power spectral density.

It is relatively easy to evaluate the integral of Eq. (1) if it is assumed that the input noise-power spectral density is

\[
N(\omega) = K_n^2 \left( 1 + \frac{a^2}{\omega^2} \right) .
\]

(2)
The noise characteristics of systems using vacuum tube preamplifiers are described rather accurately by Eq. (2), but the noise characteristics of systems using field-effect transistor preamplifiers do not follow the equation. They are more nearly described by

\[ N(\omega) = K_n^2 \left( 1 + \frac{c^2}{\omega^2} + \frac{b^2}{\omega^n} + \frac{a^2}{\omega^2} \right), \]

where \( 1 < n < 2 \), and \( a \), \( b \), and \( c \) are constants determined from the preamplifier characteristics.

We have recently developed a technique for computing the signal-to-noise ratio of any arbitrary lumped-element transfer function in combination with the latter noise-power spectral density. This technique will be used to optimize transfer functions for use with transistorized charge-sensitive preamplifiers.

### 2.3 NEW CONCEPTS IN NUCLEAR PULSE AMPLEIFIER DESIGN

**J. L. Blankenship**  
**C. H. Nowlin**

Network analysis and synthesis techniques were applied to design a new experimental nuclear pulse amplifier whose performance is superior to any other similar type of amplifier. The amplifier is designed to closely approximate desirable overall transfer functions. The instrument consists of broad-band fixed-feedback amplifiers and a novel passive, linear lumped-element network. The gain of the amplifier is adjusted by passive, constant-impedance attenuators. The variation of crossover time with attenuator position (for both fine and coarse controls) is less than \( \pm 0.5 \) nsec, and it is not necessary to make separate trimming adjustments for each attenuator setting.

The pulse-shaping network yields a unipolar output pulse having a monotonic return to the base line and a theoretical signal-to-noise ratio superior to that of any published lumped-element network, and minimum pileup distortion for a given noise-corner time constant. The bipolar pulse has nearly equal-amplitude positive and negative peaks, but with no tertiary overshoot. No delay lines are used. Minimum pileup distortion and excellent recovery from overload are achieved by the use of pole-zero cancellation techniques throughout the system. This amplifier was evaluated for overload recovery, crossover walk, pileup distortion, common mode rejection, and noise-to-signal ratio.

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### 2.4 PRECISION MERCURY PULSE GENERATOR

**J. K. Millard**

A highly stable, linear pulse generator was designed for evaluating multichannel analyzers having as many as 4000 channels. Because high stability and linearity and only low-frequency
operation were required (1 to 60 cps), a mercury-wetted relay was used as the basic pulse-forming device. The relay charges a capacitor from a highly stable, continuously variable dc reference supply and discharges the capacitor through a 50-ohm resistor in series with the 50-ohm load (Fig. 2.4.1). A frequency from 1.2 to 60 cps can be selected in seven steps. The continuously variable dc reference was obtained from the wiper of a 100-ohm Fluke precision decade potentiometer supplied by a stable 10-v regulated source.

Fig. 2.4.1 Precision Pulse Generator.

Since an absolute accuracy check of the pulse output of the instrument was not possible with existing means, the performance was established from specifications of the dc reference. The Fluke potentiometer has an integral nonlinearity of 0.0025%; however, a constant error of 2.25 mv, due probably to contact potential of the wiper, prevented the pulse output from reaching zero volts. The measured temperature stability of the dc reference with the potentiometer at mid-position (5 v dc) was 6 ppm/°C. The pulser supplies essentially a 0- to 5-v pulse into a 50-ohm load with a decay time constant of 500 μsec and a rise time of 1 to 3 nsec.

2.5 CONSTRUCTION, EVALUATION, AND DESIGN CHANGES OF THE ARGONNE ANALOG PULSE-HEIGHT COMPUTER

Ronald Nutt

The analog pulse-height computer designed at Argonne National Laboratory was packaged in the standard AEC-NIM modules (Fig. 2.5.1). After the system had been constructed, it was
evaluated for four weeks and used to calculate the position from the pulse signals of an energy-
position-sensitive detector and an energy-sensitive detector.

Printed circuit layouts were made for each of the modules of the computer. Nonstandard
supply voltages were changed to conform to standard AEC voltages. The computer, operating in a
dividing mode, was tested for linearity and long-term stability.

The computer was very useful for calculating ratios of pulses from solid-state detectors. It
will be used in other experiments to utilize its multiplying and logarithmic capabilities.

2.6 MODULAR POWER SUPPLY

W. E. Lingar
R. S. Hensley        G. A. Holt

A low-current modular power supply (ORNL model Q-2894) that provides ±12 and ±24 v was
designed to furnish power to modular instrumentation. The supply conforms to AEC-NIM stand-
ards for physical dimensions and was packaged in a single-width module 5 1/4 in. high.¹

Two of these supplies were built, tested, and used with good results to power modular in-
strument systems. (The supply will be stocked in ORNL Electronic Stores.²)

Typical power supply specifications are:

²Item No. 06-054-1640.
Input voltage 103–129 v, 60 hertz, 1 phase
Output voltages ±12 v at 0–50 ma and ±24 v at 0–50 ma, simultaneously
Line regulation 0.005% for a ±14-v line change from nominal 117 v ac
Load regulation 0.01% for a load change of 0 to 50 ma
Temperature coefficient 0.001%/°C over an ambient temperature range of 0 to 50°C
Noise and ripple <1 mv peak to peak observed on a 50-megahertz bandwidth oscilloscope
Short-circuit protection Each output voltage is independently current limited at approximately 55 ma

2.7 NIM SYSTEM TYPE III POWER SUPPLY
W. E. Lingar
C. C. Courtney G. A. Holt E. E. Waugh

A power supply (ORNL model Q-2832) was designed to be mounted on the rear of bins built to AEC-NIM standards and to provide power for any standard nuclear instrument module or modules mounted in the instrument bin.\(^1\) The supply will fit either the 5\(\frac{1}{4}\)- or the 8\(\frac{3}{4}\)-in. instrument bin. Remote sensing of the output voltage is accomplished at a laminated copper bus located directly behind the bin connectors.

Several of these power supplies were built and are presently in use at ORNL. (The supply will be stocked at ORNL Electronic Stores.\(^2\))

Some typical power supply specifications are:

Input voltage 103–129 v ac, 60 hertz, 1 phase
Output voltages ±12 v at 0–1 amp and ±24 v at 0–1 amp, simultaneously
Line regulation 0.001% for ±14-v line change from nominal 117 v ac
Load regulation 0.005% for a load change of 0 to 1 amp
Temperature coefficient 0.001%/°C over an ambient temperature range of 0 to 55°C
Noise and ripple <1 mv peak to peak observed on a 50-megahertz bandwidth oscilloscope
Short-circuit protection Each output voltage is independently current limited at approximately 1.2 amp
Thermal protection A front panel light is actuated when the ambient temperature exceeds 55°C; the supply is thermostatically turned off, and a front panel light is actuated when the heat sink temperature exceeds 95°C

\(^2\)Stores Item 06-054-1650.
2.8 TIME-TO-PULSE-HEIGHT CONVERTER

D. D. Bates

A time-to-pulse-height converter (TPHC), ORNL model Q-2520-10, was designed to convert flight times in a mass spectrometer system to corresponding pulse heights that could be fed to the direct input of a multichannel analyzer. A constant current is used to generate a linear ramp (switchable in three ranges) to provide time information up to 80 μsec.

The need for strobing the analyzer was eliminated by making the linear ramp compatible with the direct input of the analyzer analog-to-digital converter (ADC). This was accomplished by adding a delay multivibrator in the TPHC to stretch the linear ramp after it had reached the amplitude corresponding to the interval between the “start” and “stop” pulses. This 1-μsec stretch enabled the peak detector in the analyzer ADC to respond properly to the linear ramp.

Integral linearity of the TPHC and the 512-channel nuclear data analyzer was checked by using a double pulser to start and stop the TPHC. The double pulser was also fed to a precise time interval meter. The results of this measurement are shown graphically in Fig. 2.8.1.

Fig. 2.8.1 Linearity of Time-to-Pulse-Height Converter with 512-Channel Analyzer.
2.9 FIELD-EFFECT TRANSISTOR PREAMPLIFIER FOR BF$_3$ DETECTOR

J. K. Millard       J. T. De Lorenzo

The intense rf radiation environment created by high-voltage discharges accompanying thermonuclear experiments can create false neutron count rates if proper shielding is not provided for the BF$_3$ detector tube and preamplifier. To overcome this interference problem, a preamplifier and BF$_3$ detector tube were housed together in a thick copper container. Only the preamplifier output coaxial cable (RG-71/U) and the high-voltage cable supplying the detector (RG-59/U) enter the housing. Power is supplied to the preamplifier through the output cable to make the shielding efficient and interconnection simpler.

To obtain a high signal-to-noise ratio, a field-effect transistor preamplifier was designed (Fig. 2.9.1). This voltage-sensitive preamplifier provides a signal gain of 17. Since the detector capacitance is approximately 15 pf, the voltage gain is approximately 8.4, measured from the test input to output. Direct coupling prevents bias-level shifts at high count rates. The equivalent noise voltage for the preamplifier is approximately 4 nv/cycle$^{1/2}$, and the bandwidth is 3.5 megahertz.

![Circuit Diagram]

Fig. 2.9.1 Circuit for the Field-Effect Transistor Preamplifier, ORNL Model Q-2876-1.
3. Miscellaneous Electronics Development

3.1 NEW DIRECT-CURRENT INTEGRATOR
F. M. Glass
C. C. Courtney E. J. Kennedy H. N. Wilson

A new all-solid-state direct-current integrator (ORN model Q-2895) that integrates currents as low as $10^{-11}$ amp with an accuracy of 1% was designed for measuring accelerator beam currents and ionization chamber currents. The operating principle is similar to that of more conventional current integrators in that the voltage across a storage capacitor in the input circuit (Fig. 3.1.1) is monitored by an electrometer-type operational amplifier, the output of which triggers a discriminator at a given voltage level. The discriminator generates a reset pulse which dumps a fixed charge from the integrating capacitor. This is where the similarity ends. The diode pump circuit, which has long been recognized as an ideal circuit for removing precise quantities of charge from the integrating capacitor, was replaced by complementary silicon planar transistors that serve as current switches. These transistors normally have both their base-emitter and base-collector junctions reverse biased and look like open switches with leakage resistances in the range of $10^{12}$ to $10^{13}$ ohms. Reset pulses switch these transistors from the reverse-biased state to the active state for a precise time, during which a constant current flows to or from the integrating capacitor. Therefore, each reset pulse removes from the integrating capacitor a precise charge that is the product of the current and the period of the active state. By employing sufficient gain in the operational amplifier to maintain small voltage excursions at the input, the total effective leakage may be kept as low as $10^{-14}$ amp. A scaler output provides a means of reading the integrated charge; a built-in duty cycle meter, which is calibrated in units of current, provides a means of reading the instantaneous current.

The integrator has the following specifications:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Integrator current range</td>
<td>$10^{-11}$ to $10^{-4}$ amp</td>
</tr>
<tr>
<td>Charge-cycle range</td>
<td>$10^{-10}$ and $10^{-7}$ coulomb</td>
</tr>
<tr>
<td>Full-scale current meter ranges</td>
<td>$10^{-9}$, $10^{-8}$, $10^{-7}$, $10^{-6}$, $10^{-5}$, $10^{-4}$, and $2 \times 10^{-4}$</td>
</tr>
<tr>
<td>Leakage</td>
<td>Typically $10^{-13}$ amp</td>
</tr>
<tr>
<td>Integrator repeatability</td>
<td>1 part in 2000 when used in an air-conditioned building</td>
</tr>
</tbody>
</table>
Temperature coefficient
Linearity
Voltage excursion at input
Scaler signal
Built-in calibration check currents
Provisions for external 50-μA meter and 10-mv recorder

+0.025%/°C
Departure from linearity less than 0.1% over six decades starting at $10^{-10}$
$\pm 5$ mv in reference to ground
12 v positive, 4 μsec wide
$10^{-7}$ and $10^{-5}$ amp

This instrument has not been in use long enough to have a meaningful service record.

Fig. 3.1.1 Direct-Current Integrator, ORNL Model Q-2895.
3.2 HERBAGE PROBE

F. M. Glass
H. B. Adams R. S. Hensley

The Ecological Research Group of the Health Physics Division has a need for measuring the growth of grass without harvesting it. The measurements must be made quickly to avoid excessive exposure to radiation in fields that have been contaminated with radioactive isotopes. An instrument for measuring the mass of plant fibers and the water contained by the fibers, quickly and without disturbing the plant growth, was designed and put into service.

The instrument, an herbage probe, ORNL model Q-2838, consists of a capacitance probe made up of 36 insulated rods mounted on a Fiberglas board, and a heterodyne frequency meter that will measure small changes in capacitance (Fig. 3.2.1). The probe covers 450 in. of ground and will accommodate plants 36 in. high. The stability of the meter is excellent, with no perceptible drift in zero over periods of several hours and large changes in temperature. Although this does not imply that the oscillators have no perceptible drift, it does indicate that the maximum beat frequency resulting from drift is less than the beat frequency at which the two oscillators phase lock. Phase locking occurs at less than 0.2% of full scale on the meter. A single 14- or 15-v mercury battery having a 1-amp-hr rating will power the instrument for an entire growing season, since there is no need for turning the instrument on except during actual measurements.

3.3 ECHO SELECTOR SYSTEM FOR ULTRASONIC ANALYSIS OF METAL SAMPLES

J. K. Millard

A system was needed to select any two of a series of ultrasonic reflections created by a pulse induced into a metal sample by a transducer and to record two dc voltage levels proportional to the amplitude of the selected pulses. As the metal sample is stretched to the breaking point, the magnitude of the reflections varies. The nature of these variations is noted on a strip-chart recorder. The basic technique of accomplishing the echo selection has been described for vacuum tube circuitry.¹

The system is illustrated in Fig. 3.3.1. The pulse generator produces a burst of rf frequency (in this case from about 5 to 30 megahertz), lasting for a selectable time of from 5 to 30 μsec. At the same instant that the burst starts, a trigger pulse begins. The rf burst is induced into the metal sample, and echoes are produced as the ultrasonic pulses strike the sample boundaries. The echoes are sensed by another transducer, and an rf detector transforms them into unipolar pulses which are routed to a gate circuit and also to an oscilloscope input. The trigger pulse given off by the generator triggers a monostable multivibrator with a continuously variable pulse width. The trailing edge of the pulse from this multivibrator triggers another monostable circuit with a continuously variable pulse width. The output of the second multivibrator causes intensification of the oscilloscope trace and opens a linear diode gate to let the unipolar pulse associated with the echo of interest pass on to the pulse-stretching circuit which creates a dc

¹H. D. Guberman, private communication.
Fig. 3.2.1 Herbage Probe, ORNL Model Q-2838.
Fig. 3.3.1 Echo Selector System.

voltage level for the strip-chart recorder. By adjustment of the pulse width of the two multivibrators, the gating comes at the proper time (determined by the first multivibrator) and remains for the desired time (determined by the second multivibrator). The circuitry was modified by using all solid-state components. FET transistors were used in the multivibrators and in the pulse stretcher.

The instrument is presently being evaluated, and no performance data are available at this time.

3.4 DESIGN OF STATISTICAL PULSE DISPLAY SYSTEM

Ronald Nutt

A system was developed to display the average pulse shape and the pulse-height distribution as a function of time of statistical pulses. The system was developed to observe the detailed shape of pulses from an NaI(Tl) scintillator and photomultiplier arrangement.
A Tektronix 661 sampling scope was adjusted to take a single sample at a fixed time after an applied trigger signal. The signal at the vertical amplifier output of the scope was strobed, shaped, and amplified. The amplified signal was then displayed on a multichannel analyzer. The time with reference to the trigger signal was changed, and a second pulse-height distribution was displayed on the analyzer. This was repeated until a sufficient number of distributions was obtained to describe the entire curve.

The system diagram is shown in Fig. 3.4.1. A positive gate signal is derived from the cathode of the output tube of the CRT blanking circuit. The blanking signal triggers a monostable multivibrator (Q₂ and Q₃) which closes the linear gate (Q₅ and Q₆) for approximately 1 µsec. The output pulse then is a ramp in voltage which has an amplitude equal to the input signal to the 4SI sampling unit. If the horizontal display selector switch is set on "manual scan," one sample will be taken for each horizontal trace. The data for one sample will then appear at the output of the strobe circuit in the form of a ramp in voltage. The manual scan allows selection of the time at which the sample is taken.

The output of the strobe circuit is followed by a linear amplifier and shape in a manner suitable for the analyzer to be used.

The system has not been used for the original purpose, but it has been useful for studying the time variance of electronic discriminators and the detailed noise spectrum of fast pulses.

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**Fig. 3.4.1** Strobe Circuit for Displaying Sampling Scope Trace on Analyzer.
3.5 TRANSISTORIZED PULSE-GATING AND EMISSION-REGULATING CIRCUIT FOR A 2-Mev ELECTRON ACCELERATOR

J. L. Lovvorn

A variable-width, pulse-gating and emission-regulating circuit was designed to replace a vacuum-tube emission regulator for a 2-Mev Van de Graaff electron accelerator. Pulse width and repetition rate information were transmitted from the low- to the high-voltage terminal by light pulses through a plastic rod. The light source was a modulated high-intensity neon lamp. The optical receiver was a photo field-effect transistor. The received signal was amplified sufficiently to gate a transistor in series with the drift tube filament emitter.

The original adjustable constant-current mode of operation was retained. A transistor is used as a current source, and the mode is switched from constant current to pulse by a solenoid-actuated push-rod-switch arrangement.

Discharges down the drift tube shortened transistor life. Transistors that will carry higher current without damage were obtained and will be installed with the pulse-gating modification when machine usage permits.

3.6 DYNAMIC RANGE EXPANDER AND PHASE SHIFT CONTROL

J. T. De Lorenzo

The closed-loop anelasticity equipment is limited in the measurement of sample strain and decrement by the dynamic range of its control amplifier. This amplifier senses the oscillation of the sample and automatically adjusts its gain to maintain its input level (and thus sample amplitude) constant in spite of changes in sample decrement or other disturbances.

The dynamic range can be expanded by adjusting either or both gain and attenuation before and after the control amplifier and by keeping the overall gain constant to retain the system calibration. This instrument, ORNL model Q-2897, is designed to provide this adjustment. Further, it can provide precise phase shifts of +45 or -45° of the frequency of oscillation (approximately 20 kilohertz), which will force the sample to operate at its half-power points both above and below its resonant frequency. The frequency difference between these two points will permit the calculation of the sample decrement.

In Fig. 3.6.1 switches S1A and S1B are ganged attenuators with 37 positions which adjust the attenuation before and after the control amplifier in a way that the product of the two is always constant. All amplifiers have a Philbrick P65AHU (gain-bandwidth equal to 30 megahertz) and a P66A (power booster) in cascade with the combination connected as an inverter.
3.7 ALPHA MONITOR FOR HEAVY-ELEMENT CHEMISTRY

F. M. Glass

The previously reported\(^1\) ORNL model Q-2809 alpha monitor will quickly determine elution peak positions during the separation of transplutonium elements such as americium and curium. A silicon surface-barrier diode detector mounted near the tip of the column counts the alpha emission rate in liquid drops which form just \(\frac{1}{4}\) in. from the surface of the detector. The advantages of this monitoring system over drop-by-drop counting in remote counting rooms are that it eliminates the hazard of additional handling of high-level radioactive materials and gives an immediate indication of elution peaks.

To improve the audible signal of the alpha count rate, a new model Q-2809A was developed (Fig. 3.7.1). The older model gave a single "pop" for each alpha particle counted up to the limit of human hearing. This was good for alerting personnel at the beginning of the alpha buildup, but the count rate soon passed through the frequency range that could be heard. The new model has a gated tone-modulated audio oscillator that starts oscillating at a low frequency when a given count rate is reached and increases in frequency as the counting rate increases. The frequency always stays well within the aural range of the operator, thereby providing a continuous audible indication of the changing alpha level.

This model is identical in appearance to the model Q-2809, and both have very good service records.

3.8 RECORDING FLUOROMETER

J. T. De Lorenzo

Instrument components were assembled into a system for measuring the fluorescence of materials in the red region up to 8000 A after excitation by ultraviolet light.

The detector is an EMI/US, 2-in., 11-stage photomultiplier tube, type 9558Q. The dc output current is measured with a Keithley 413A logarithmic electrometer and displayed on one axis of an x-y recorder. The output of the monochromator is displayed on the other axis.

To obtain the correct direction of current flow for the electrometer (i.e., electron current flow out of ground), the current flow to the 11th dynode is measured. The anode is then biased at a positive potential of 100 v for proper operation of the photomultiplier tube.

3.9 DOUBLE-BEAM PHOTOMETER

E. Madden
G. W. Allin M. L. Picklesimer

A double-beam, differential null-balancing photometer system (Fig. 3.9.1) was built for examining zirconium weld test specimens.

---

1 Metals and Ceramics Division.
The mechanical stage of a microscope, upon which the sample holder is mounted, rotates through 360° without changing the configuration of the light beam, sample surface, and detector. One photomultiplier tube monitors the incoming monochromatic beam from a zirconium arc lamp, and a second photomultiplier tube monitors reflected light from the test specimen mounted on the microscope stage. The signal from the second photomultiplier tube is amplified and applied to the normal pen (y) axis input of an x-y recorder. The normal reference voltage for the x-y recorder pen axis servo-positioning loop is replaced by the amplified phototube voltage derived from the incoming monochromatic beam. This allows a cancellation of the fluctuations caused by the instability of the zirconium arc lamp. The carriage (x) axis input of the x-y recorder is supplied from an angular position sensor attached to the rotary mechanical stage of the microscope.

Two 14-stage model 7265 photomultiplier tubes provide high sensitivity and an S-20 spectral-sensitivity characteristic response.

This system is being assembled for initial testing.

Fig. 3.9.1 Double-Beam Photometer System.
3.10 BETA-EXCITED LIGHT SOURCE PHOTOMETER

G. W. Allin  W. E. Lingar  V. A. McKay

A beta-excited light source photometer was designed and fabricated for the Analytical Chemistry Division for measuring light absorption of liquid samples.

The light source consists of a liquid scintillating material mixed with a small amount of a beta-emitting radioisotope in a standard absorption cell (Fig. 3.10.1). Visible light is emitted from the source as pulses, not as the continuous emission by a standard light source. Also, the intensity of the pulses is not constant; it varies from zero to some maximum value depending on the energy of the beta particle causing the pulse. These two properties of the source allow photometric measurements having a high level of sensitivity and precision.

The detector for the system is a selected photomultiplier tube with an S-11 spectral response. A preamplifier, linear amplifier, high-voltage power supply, timer, discriminator, and high-speed scaler complete the system. These electronic units are commercially available except for the preamplifier.

The photometer head (Fig. 3.10.1) houses the detector and its associated mechanical components, which are arranged in the following order (Fig. 3.10.2): light source, primary collimator, sample absorption cell holder, filter holder, detector chamber, mechanical interlock, shutter knob, sample carrier knob, sample absorption cell, source absorption cell, sample absorption cell holder, collimator knob, light-tight door, door latch.
filter holder, sample absorption cell holder, light-tight shutter, secondary collimator, and detector.

The light-tight door at the top of the photometer head permits entry to the light source, filter holder, and sample absorption cell holder. The door latch is mechanically interlocked to prevent its release except when the light-tight shutter to the detector chamber is closed. This interlock also prevents accidental opening of the shutter whenever the door is unlatched. The combination of shutter and interlock protects the detector from light damage.

A standard, commercial, four-compartment absorption cell holder can be inserted through the top door opening into the sample carrier. The motion of the carrier is detented so that any one of the four absorption cells containing the samples can be placed in the collimated light beam by means of an external positioning knob.

The light beam is defined by the primary and secondary collimators. These consist of matched pairs of openings machined in two disks which are mounted in parallel planes on a common shaft. One of eight different collimator sizes can be selected by rotating an external knob on the collimator shaft, which is detented to simplify positioning.

Data collection with this photometer has not yet begun, since the electronic components are being tested. The basic concepts have been confirmed, however, in an experimental setup.
3.11 DESCRIPTION OF HIGH-VOLTAGE SUPPLY, ORNL MODEL Q-2057

J. T. De Lorenzo

The performance characteristics of an ORNL-designed high-voltage supply, ORNL model Q-2057, are described.


3.12 ±32 v POWER SUPPLY, ORNL MODEL RC11-4-2E

J. T. De Lorenzo

A power supply which delivers positive 32 v and negative 32 v was designed as a substitute for ±32 v batteries normally used to provide power for the regulator supply modules of the ORNL modular reactor instrumentation series. The power supply is described, and acceptance test procedures are contained in this report.


3.13 SPECIFICATIONS FOR G-M TUBES

J. M. Rochelle

The Office of Civil Defense has experienced a high failure rate with its large inventory of a 0- to 50-mr/hr G-M tube portable survey meter (type CD-V-700). A major cause of instrument failure was determined to be incompatibility between G-M tube performance and instrument circuit design. In many cases the pulse produced by the tube had insufficient amplitude to trigger the monostable multivibrator which drives the count-rate meter. ORNL was requested to make recommendations for the revision of specifications used by the Office of Civil Defense for purchasing G-M tubes to ensure that replacement tubes purchased in the future would be compatible with all CD-V-700 instruments now in existence.

Since the CD-V-700 survey meters have low and variable input impedances, the pulse amplitude produced by a given tube at a given voltage may vary from instrument to instrument. Extensive experimental studies were made of each circuit to determine the worst-case conditions on pulse amplitude and trigger threshold of the monostable multivibrator. These conditions were then incorporated in a special test circuit (ORNL model Q-2903) which was made an integral part of the revised specifications. The use of such a circuit eliminated the need for a complicated and often meaningless pulse amplitude requirement in the tube specifications.

Instead of the usual plateau slope requirements which necessitate the plotting of a continuous plateau curve, the revised specifications require only that the count rate at the upper and lower voltage limits equal the count rate at the mean voltage within a given tolerance. The revised specifications also include requirements on absolute gamma efficiency, count-rate linearity, and pulse amplitude reduction at high count rates.
3.14 HIGH-COUNT-RATE NEUTRON COUNTING CHANNEL

J. T. De Lorenzo

Circuits were built and purchased to provide a neutron counting channel with a count-rate capability of nearly 100 megahertz for subcritical reactivity measurements. The equipment was used with a Reuter-Stokes boron-coated proportional detector with a 30-nsec collection time.

LeCroy Research Systems dual-pulse amplifiers (model 107F), discriminators (models 108D and 121), and prescalers were purchased as AEC-NIM modules. A preamplifier with a voltage gain of 10 and a rise time of 2 nsec was built to raise the signal level above the noise environment.

A block diagram is shown in Fig. 3.14.1. A 30-ft-long section of RG-214/U cable connects the detector to the preamplifier, which terminates the cable in 50 ohms. The voltage pulse developed across this termination is shaped like the detector current pulse. Two 15-ft cables (detector high voltage, preamplifier output signal, and power) connect the preamplifier to the rack containing the LeCroy modules. The output cable is terminated by the input impedance of the amplifier.

One of the current outputs of the LeCroy discriminator drives an RC integrating network and provides a highly accurate and stable count-rate meter from 10 kilohertz to 1 megahertz in five ranges with no more than 2.5% dead-time loss.

Fig. 3.14.1 High-Speed Neutron Pulse Counting Channel.

3.15 CHARGE-SENSITIVE PREAMPLIFIER, ORNL MODEL RC11-4-2X\(^1\)

J. T. De Lorenzo

The charge-sensitive preamplifier, ORNL model RC11-4-2X, was designed to amplify pulses from a Reuter-Stokes BF\(_3\) detector (RSN 42A). The preamplifier output drives a pulse amplifier and count-rate meter module, ORNL model Q-2614. This report describes the preamplifier and contains acceptance test procedures.

4. Instruments for Biomedical Research

4.1 DETECTION SYSTEM FOR NEUTRON DIFFRACTOMETER

J. B. Davidson

Neutron diffraction systems are usually equipped with a single detector having a small solid angle of acceptance for the reflected neutrons to obtain adequate spatial resolution. As a result most of the neutrons reflected in a given time interval are not detected, and the collection of crystal structure data is very time consuming, particularly for organic crystals.

An improved detection system for more rapidly recording the diffraction patterns is being investigated. The system consists of a large (~100 cm$^2$) neutron-sensitive phosphor screen viewed by an image intensifier. The intensified output is focused on the target of a TV camera tube. The camera tube is raster scanned, and the scintillations occurring in the phosphor are detected at the output of the video amplifier. A computer memory is synchronized with the raster scan, and each neutron count is stored in a memory cell assigned to the corresponding elemental area of the detector screen. The diffraction pattern is thus accumulated in the computer memory. Figure 4.1.1 shows the system in schematic form.

Various combinations of phosphors, intensifiers, and camera tubes are being considered. The goal is to achieve single-neutron detection capability, adequate counting rate, and maximum solid

Fig. 4.1.1 Detection System for Neutron Diffractometer.
angle of sensitivity with the simplest system capable of long, unattended runs. An improvement of orders of magnitude in data collection rate is believed feasible.

A partial mockup of the system made from readily available components was assembled. Sensitivity, resolution, and system noise are being evaluated.

4.2 CHROMOSOME ANALYSIS

M. A. Bender\(^2\)  J. B. Davidson  M. A. Kastenbaum\(^3\)

The problem of using computers as a means of speeding up chromosome analysis and making it completely objective is discussed. Ways in which programs might operate on simple lists of chromosome arm lengths are described. An approach to automating scoring for chromosomal aberrations which uses only arm length lists is also discussed briefly. The possibility of automating only some parts of the process of chromosome analysis is emphasized, and a simple aid to manual chromosome measurement is described as an example.

\(^1\)Abstract of paper presented at a seminar on "Use of Computers in Analysis of Experimental Data and Control of Nuclear Facilities, Argonne National Laboratory, May 4–6, 1966."

\(^2\)Biology Division.

\(^3\)Mathematics Division.
5. Detectors of Ionizing Particles and Radiation

5.1 GERMANIUM PURIFICATION

C. H. Nowlin   J. L. Blankenship

State-of-the-art lithium-drifted germanium detectors can be made with a 1-cm depletion depth at a bias of 1000 v; but several weeks are required to drift the lithium into the germanium, and the finished detectors must be stored and used at cryogenic temperatures. Germanium with an impurity concentration of $10^{10}$ impurity atoms per cm$^3$, but without lithium compensation, could also be used to produce detectors with a 1-cm depletion depth at a bias of 1000 v. Furthermore, these uncompensated detectors would not be destroyed by storage or operation at room temperature.

The crucible-free, vertical floating-zone technique is being used to purify 1-cm-diam germanium rods by either of two methods of heating: electron beam heating in a hard vacuum or induction heating in a hard vacuum or in a cover gas. The concentration and type of electrically active impurities in the produced material will be determined by Hall coefficient measurements. If impurities having an unfavorable segregation coefficient (e.g., boron) are present, the fractional distillation of GeCl$_4$ may be used prior to zone refining to reduce their concentration.

5.2 LITHIUM DRIFT RATES AND OXYGEN CONTAMINATION IN GERMANIUM

R. J. Fox

The unpredictable variations in lithium drift rates of various commercially available germanium crystals have made the production of germanium gamma-ray detectors rather difficult. Some as-received germanium ingots have shown diffusion constants $D$ reduced by nearly three decades. Because drift time varies inversely with $D$, the time required to drift such germanium to make large-volume detectors can become too long to be practicable. The drift rates and lithium precipitation kinetics of such germanium were investigated to determine if they were correlated.

We have examined the lithium precipitation kinetics in 24 samples cut from 13 different germanium crystals covering a wide range of drift rates. These samples were cut from both zone-leveled and pulled crystals from three vendors.

---

5.3 MATERIALS FOR SEMICONDUCTOR RADIATION DETECTORS

R. O. Chester

In a search to find materials suitable for radiation detectors, the physical properties of many semiconducting elements and compounds were tabulated under three classifications.

Table 5.3.1 lists materials having an average $Z$ at least as high as the average $Z$ of germanium ($\gtrsim 32$) and a gap energy $E_g$ at least as great as that of silicon ($\lesssim 1.1$). Theoretically, materials with a higher $Z$ should be responsive to gamma rays, and materials with a greater $E_g$ might make operation at room temperature possible.

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<th>Compound</th>
<th>$Z$ (av)</th>
<th>$E_g$ (ev)</th>
<th>$\mu_e$ (cm$^2$ sec$^{-1}$ v$^{-1}$)</th>
<th>$\mu_p$ (cm$^2$ sec$^{-1}$ v$^{-1}$)</th>
<th>Melting Point (°K)</th>
<th>Refractive Index</th>
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$^a$At room temperature.  
$^b$Indirect measurement.  
$^c$Direct measurement.

Table 5.3.2 lists materials having an average Z of $\geq 32$ but a small $E_g$ ($\lesssim 0.67$). Although detectors made from these materials would have to be operated at liquid-nitrogen or -helium temperature, the small band gap is attractive because the small average energy required to produce electron-hole pairs could make the resolution of detectors made from these materials very good.

Table 5.3.3 lists materials that have a high melting point ($\approx 2600^\circ$K) and retain their semiconducting characteristics considerably above room temperature.

5.4 LITHIUM-DRIFTED GERMANIUM DETECTOR DEVELOPMENT

R. L. Shipp

Part of the continuing need for improved spectral resolution in nuclear particle and gamma-ray spectroscopy is met through improvement of semiconductor detectors. The main goal of this work is to make better lithium-drifted germanium detectors and to improve the associated production techniques. The detectors now being made have a sensitive volume of 6 cm$^3$ and a resolution of 3.5 kev full width at half maximum (fwhm) for 1.33-Mev gamma rays compared with a sensitive volume of 2 cm$^3$ and resolution of 6 kev for detectors made a year ago with older techniques.
### Table 5.3.2. Semiconductor Compounds with $Z \geq 32$ (Ge) and $E_g \lesssim 0.67$ (Si)

<table>
<thead>
<tr>
<th>Compound</th>
<th>$Z$ (av)</th>
<th>$E_g$ (ev)</th>
<th>$\mu_e$ (cm$^2$ sec$^{-1}$ v$^{-1}$)</th>
<th>$\mu_p$ (cm$^2$ sec$^{-1}$ v$^{-1}$)</th>
<th>Melting Point ($^\circ$K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>At Room Temperature</td>
<td>At 4$^\circ$K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd$_3$P$_2$</td>
<td>34.8</td>
<td>0.5</td>
<td>3,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg$_2$Pb</td>
<td>35.3</td>
<td>&lt;0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZnPb</td>
<td>40.5</td>
<td>0.50</td>
<td>0.56</td>
<td>10</td>
<td>340</td>
</tr>
<tr>
<td>GaSb</td>
<td>41</td>
<td>0.67</td>
<td>0.78</td>
<td>4,000</td>
<td>1,400</td>
</tr>
<tr>
<td>InAs</td>
<td>41</td>
<td>0.36</td>
<td>0.43</td>
<td>33,000</td>
<td>460</td>
</tr>
<tr>
<td>GeTe</td>
<td>42</td>
<td></td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd$_3$As$_2$</td>
<td>42</td>
<td>0.13</td>
<td>15,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HgS</td>
<td>48</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PbS</td>
<td>49</td>
<td>0.41</td>
<td>0.29</td>
<td>70,000</td>
<td>90,000</td>
</tr>
<tr>
<td>CdSb</td>
<td>49.5</td>
<td>0.45</td>
<td>0.57</td>
<td>300</td>
<td>2,000</td>
</tr>
<tr>
<td>InSb</td>
<td>50</td>
<td>0.17</td>
<td>0.23</td>
<td>78,000</td>
<td>750</td>
</tr>
<tr>
<td>SnTe</td>
<td>51</td>
<td></td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sb$_2$Te$_3$</td>
<td>51.6</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Te</td>
<td>52</td>
<td>0.33</td>
<td>1,100</td>
<td>560</td>
<td>1000</td>
</tr>
<tr>
<td>Bi$_2$Se$_3$</td>
<td>53.6</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HgSe</td>
<td>57</td>
<td>0.30</td>
<td>18,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PbSe</td>
<td>58</td>
<td>0.29</td>
<td>0.17</td>
<td>500,000</td>
<td>200,000</td>
</tr>
<tr>
<td>Bi$_2$Te$_3$</td>
<td>64.4</td>
<td>0.13</td>
<td></td>
<td>1,200</td>
<td>510</td>
</tr>
<tr>
<td>HgTe</td>
<td>66</td>
<td>0.15</td>
<td>25,000</td>
<td></td>
<td>160</td>
</tr>
<tr>
<td>PbTe</td>
<td>67</td>
<td>0.32</td>
<td>0.18</td>
<td>4,000,000</td>
<td>400,000</td>
</tr>
</tbody>
</table>

*a* At room temperature.

### Table 5.3.3. Semiconductor Compounds for High Temperatures

<table>
<thead>
<tr>
<th>Compound</th>
<th>$Z$ (av)</th>
<th>$E_g$ (ev)*</th>
<th>$\mu_e$ (cm$^2$ sec$^{-1}$ v$^{-1}$)*</th>
<th>$\mu_p$ (cm$^2$ sec$^{-1}$ v$^{-1}$)*</th>
<th>Melting Point ($^\circ$K)</th>
<th>Refractive Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$-SiC(6H)</td>
<td>10</td>
<td>~2.9</td>
<td>~500</td>
<td>~50</td>
<td>3073</td>
<td>2.6</td>
</tr>
<tr>
<td>$\beta$-SiC</td>
<td>10</td>
<td>~2.5</td>
<td></td>
<td></td>
<td>3073</td>
<td>2.6</td>
</tr>
<tr>
<td>BN</td>
<td>6</td>
<td>7-10</td>
<td>~300–500</td>
<td></td>
<td>&gt;3000</td>
<td></td>
</tr>
<tr>
<td>BP</td>
<td>10</td>
<td>2.1</td>
<td>~500</td>
<td></td>
<td>&gt;3000</td>
<td></td>
</tr>
<tr>
<td>$\beta$-B</td>
<td>5</td>
<td>1.5</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>2600</td>
<td></td>
</tr>
<tr>
<td>C (dia.)</td>
<td>6</td>
<td>5.4</td>
<td>1800</td>
<td>1200</td>
<td>&gt;3500</td>
<td>2.4</td>
</tr>
</tbody>
</table>

*a* At room temperature.
One of the major problems during the past year was a shortage of germanium crystals with satisfactory properties for lithium drifting. During this period process equipment and techniques were revised, and assistance was given to the Solid State Division and to Fox (Sect. 5.2) in investigating the cause of low lithium drift rate. After satisfactory germanium crystals were again received, seven high-resolution detectors were made having sensitive volumes of about 6 cm³.

A technique was developed for producing a detector with a large, flat intrinsic area for use in charged-particle and low-energy gamma-ray spectroscopy (Fig. 5.4.1). This technique has other features: by simultaneous drifting from three surfaces the drift time is decreased; and by initially locating the n and p contacts on the proper surfaces, detectors with lower than normal capacitance-to-sensitive-volume ratios are produced.

Fig. 5.4.1 Steps in the Production of a New Lithium-Drifted Germanium Detector.

Future efforts will be made in three main areas:

1. detector improvements to include increased size, better resolution, and virtual elimination of dead layers at n or p surfaces;
2. development of improved detector mounts and associate cryogenic equipment;
3. improvement in process reliability.
5.5 TOTAL-ABSORPTION DETECTOR FOR 60-Mev PROTONS USING LITHIUM-DRIFTED GERMANIUM

F. E. Bertrand\textsuperscript{2}   R. W. Peelle\textsuperscript{2}   T. A. Love\textsuperscript{2}
R. J. Fox   N. W. Hill   H. A. Todd

A lithium-drifted germanium diode has been used for total-absorption detection of 59-Mev protons from the Oak Ridge Isochronous Cyclotron. The detector is 1.9 cm in diameter, has a depletion depth of 6 mm, is cooled to less than 85 K, and is sealed in an aluminum can with a 0.0026-in.-thick window. The diode was oriented so that the protons entered in a direction parallel to the detector junction.

The energy resolution attained for 59-Mev protons was 150 kev fwhm, uncorrected for energy straggling in windows of 76 kev, for approximately 60 kev beam resolution, and for electronic noise. The peak-to-total ratio, determined by using an anticoincidence collimator, was as high as 0.94, which is comparable to 0.96 observed elsewhere for NaI. When the collimator was moved along a line parallel to the junction and perpendicular to the beam, the energy resolution and peak-to-total ratios remained constant within the experimental accuracy over a 10-mm scanned distance. As the collimator was moved in a direction perpendicular to the junction and toward the depleted material, the peak-to-total ratio decreased, as was expected from multiple scattering calculations.

When the diode was connected by a 125-ohm terminated coaxial cable to a fast amplifier, a rise time of 4 to 5 nsec was observed. Since the protons entered the detector parallel to the junction, pictures obtained show the superposition of nearly rectangular current pulses arising from hole and electron collection. The length of the pulses is correlated with the point of incidence of the collimated beam. The mobilities of the charge carriers as calculated from the measured collection times and a knowledge of the location of proton incidence are 13,000 cm\textsuperscript{2} v\textsuperscript{-1} sec\textsuperscript{-1} for the electrons and 9800 cm\textsuperscript{2} v\textsuperscript{-1} sec\textsuperscript{-1} for holes for a detector bias of 500 v. With detector biases of 200 and 700 v, the mobilities are 60% higher and 30% lower respectively.

\textsuperscript{1} Abstract of published report, ORNL-TM-1462 (March 1966).
\textsuperscript{2} Neutron Physics Division.

5.6 SIMPLE COOLER FOR LITHIUM-DRIFTED SILICON DETECTORS

J. W. Johnson   J. A. Biggerstaff\textsuperscript{1}

Many semiconductor radiation detectors of the lithium-drifted type must be cooled to a temperature range of \(-25\) to \(-100^\circ\text{C}\) to obtain good resolution and low noise levels. The cooling techniques used most often are thermoelectric coolers and conduction cooling from a dry-ice bath

\textsuperscript{1} Physics Division.
or from liquid nitrogen. Thermoelectric coolers are expensive and usually require an elaborate mounting arrangement, and their low heat removal rate leads to long cooling times.

In this application a lithium-drifted detector is mounted from the movable top of a scattering chamber, and cold trichloroethylene is circulated through the detector mount. A pump circulates trichloroethylene through either a coil of copper tubing immersed in a Dewar containing dry ice and trichloroethylene or through a warmup coil warmed by air or hot water. The trichloroethylene is piped to and from the detector mount through polyethylene tubing insulated with Vascocel foam rubber insulation. A reservoir, connected to the return line to the pump, allows for filling the system with trichloroethylene, removal of air or vapor from the line, and contraction and expansion of the trichloroethylene in the system as it becomes cooler or warmer.

A 12-v negative-ground Bendix electric automotive fuel pump type 476087 fitted the application for flow rate and pressure drop. It ran well at the operating temperature of about \(-70^\circ\text{C}\) and cost only $15.00.

This system was used for two different experiments using the beam from the Tandem Van de Graaff accelerator. Operation was reliable, with the only problem being the dry-ice–trichloroethylene bath. Chipped or flaked dry ice must be used, thereby increasing the surface area of the ice to freeze atmospheric moisture. The water-ice causes the dry ice in the Dewar to clog, requiring frequent tamping. The size of the Dewar limits the time between refills to approximately 2 hr. To reduce the water-ice trouble and to increase the time between refilling, plans were made to install an insulated container in place of the Dewar which will be large enough to hold a standard size block of dry ice.

### 5.7 SPHERICAL BF₃ PROPORTIONAL COUNTER

W. T. Clay

Two 3-in.-diam spherical BF₃ proportional counters,¹ ORNL model Q-2804, were tested to determine their directional response as a function of the anode configuration. The anode of one counter consisted of two perpendicular 0.5-in.-diam loops fabricated from 0.002-in.-diam tungsten wire. The loops were held concentric with the spherical copper cathode by a 0.050-in.-diam stainless steel capillary tube. The other counter was identical, except that it contained only one anode loop.

Since it was difficult to obtain a small-diameter, intense thermal-neutron beam for the test, other types of beams were considered. Fluorescent x rays (38 keV) from a $^{147}\text{Pr}$ source (about 80 curies) were used. The diameter of the x-ray beam was $\frac{1}{3}$ in. where it entered the sphere and $1\frac{1}{8}$ in. at the other side. The directional response of the counter for thermal neutrons is believed to be better, but never worse, than the response obtained with x rays because of the smaller amount of scatter resulting from the $(n, \alpha)$ reaction.

---

Figure 5.7.1 illustrates the counter with two loops and the orientation of the loops with respect to the incident x-ray beam. Only loop “A” is present in a single-loop counter.

The double loops are superior to the single loop (Fig. 5.7.2). The directional response for the double-loop counter was within ±3%, whereas it was greater than ±10% for the single-loop counter.

![Diagram of Spherical BF$_3$ Proportional Counter Containing Two Loops]

**Fig. 5.7.1 Spherical BF$_3$ Proportional Counter Containing Two Loops.**

### 5.8 INVESTIGATION OF FACTORS AFFECTING LOW-ENERGY X-RAY PROPORTIONAL COUNTER RESOLUTION

R. E. Zedler

An experimental investigation of the parameters affecting low-energy (<25-kev) x-ray proportional counter performance was undertaken to achieve optimum resolution. Detectors presently in use at ORNL have resolutions of about 0.94 kev at 5.9 kev (55Fe) and 1.80 kev at 22.16 kev (109Cd).

To date, resolutions of 0.76 kev at 5.9 kev and 1.42 kev at 22.16 kev have been measured. The intrinsic detector resolutions determined by correcting for amplifier noise contribution were 0.72 kev and 1.40 kev. These values are approximately 20% better than those predicted for the gas mixture used when the usual assumption is made that the Fano factor and gas multiplication statistics negate each other. By comparison, the best resolutions achieved by the more costly and elaborate lithium-drifted silicon detector systems are approximately 0.65 kev at 5.9 kev and 0.78 kev at 22.16 kev.

An investigation was begun to determine the effects on resolution of the following counter parameters: cathode diameter, anode diameter, gas composition and gas pressure, gas purity,
operating voltage, amplifier time constants and noise contribution, and counting rate. In general, the results to date show that alteration of parameters to shorten the rise time of the pulse results in improved detector resolution. The pulse shape in low-energy x-ray proportional counters is formed principally by the motion of the localized positive-ion sheath away from the wire, the velocity of this sheath being largely determined by the potential gradient at the wire and the gas pressure. Thus, as the anode and cathode diameters are decreased, other parameters being held constant, the pulse rise time increases and resolution improves. Operation at a total pressure less than the usual 76 cm makes additional improvement. The resolution improved 6% with argon-cyclopropane and 8% with argon-acetylene relative to the resolution achieved with argon-methane at the same total pressures and organic vapor concentrations. This possibility was anticipated
because the $W$ value\(^1\) (22 ev/ion pair) for argon-acetylene is lower than that of argon-cyclopropane (23 ev/ion pair) or argon-methane (26.2 ev/ion pair) at the same organic vapor concentration, that is, 7.5%. Preliminary gas-purity studies indicate that 50 ppm of O$_2$ can cause a resolution loss of approximately 5% and that water vapor is even more detrimental. The best values of measured resolutions were obtained at operating voltages equivalent to a gas amplification of approximately 80 (dependent on amplifier noise), and the best values of intrinsic resolutions were obtained at a somewhat lower gas amplification.

The detector being used has the following parameters: a 1.5-in.-ID by 8-in.-long aluminum cathode with field tube construction, an accurately centered 0.5-mil-diam stainless steel anode wire, a $\frac{3}{8}$-in.-diam by 5-mil-thick beryllium window mounted to minimize field distortion, and a detector capacity of 4.7 pf. The gas mixture with which the preceding results were obtained was high-purity argon–7.5% purified acetylene at a total pressure of 54 cm. All measurements were made with a Tennelec TC-200 amplifier, a Tennelec TC-13 FET preamplifier, a Nuclear Data 512-channel analyzer, and an RCL 400-channel analyzer.

Further improvement in resolution can be achieved through additional efforts to optimize gas pressure and composition, gas purity, counter construction technique, and associated electronics.

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\(^1\)T. E. Bortner et al., Alpha Particle Ionization of Argon Mixtures — Further Study of the Role of Excited States, ORNL-3422 (May 1963).

### 5.9 SELECTION OF SIGNAL RESISTOR FOR TYPE 303 G-M TUBE USED IN A 1-r/hr PROBE, Q-1916-22

M. M. Chiles \quad H. R. Brashear

For proper performance of the ORNL model Q-1916-22 probe, the value of the signal resistor ($R_0$) to be used with each type 303 G-M tube must be determined for each tube. In making this determination, the capacitance of the circuit, the anode voltage, and the gamma radiation intensity are critical. A test circuit was devised, and the proper values of these three parameters were established for determining $R_0$ for these tubes.

The capacitance criterion was met by selecting and arranging components for the test circuit (Fig. 5.9.1) such that the capacitance of the test circuit was equal to the capacitance of the radiation monitor circuit.

Tests of several type 303 tubes in the integrated current mode of operation showed that the recommended anode voltage of 700 v for these tubes is not suitable for best operational stability and reproducibility. The integrated current as a function of voltage at constant gamma-radiation intensity was measured for several tubes, and from these results an anode voltage of 680 v was chosen to be the proper operating voltage.

Since the radiation monitor is designed to operate in radiation intensities from 1 to 1000 mr/hr, several type 303 G-M tubes were tested over this range. These measurements of integrated cur-
rent vs radiation intensity show that these tubes are not linear to 1000 mR/hr. (This is compensated for in the electronic instrument for a linear monitoring system with ±20% accuracy.) A radiation intensity of 600 mR/hr from $^{60}$Co was chosen for determining the value of $R_0$. A type 303 G-M tube is placed in the test circuit, and a 1-megohm potentiometer is adjusted until an indication of 6 V (equivalent to 600 mR/hr) is obtained on the VTVM (Fig. 5.9.1). A resistor equal to $R_0$ indicated by the potentiometer is then installed in the probe.

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6. Radiation Monitoring

OPERATION AND MAINTENANCE OF SYSTEMS

6.1 MODERNIZATION AND EXPANSION OF ORNL RADIATION WARNING AND COMMUNICATION SYSTEMS

D. J. Knowles       J. H. Holladay
H. P. Danforth      J. E. Inman
C. C. Hall          J. A. Russell

The radiation warning and communication system has been previously reported.\(^1\)\(^-\)\(^5\) The project is complete as originally planned in that 12 existing facilities were equipped with the new modular systems. Each facility now has a central monitoring point where the alarms from gamma, particulate, and neutron monitors and from inoperative instruments are displayed. When desirable, coincidence alarms will perform control functions such as actuating containment and evacuation alarms with remote readout of the condition at the Laboratory Emergency Control Center. A technical report that describes the systems and gives operation and checkout procedures is being written for each building. Four such reports were issued, and three more are being prepared.

Five new facilities, not part of the original plan, were equipped with these systems. The systems were designed with the facilities rather than as an addition. Four facilities are complete, and the fifth is on schedule. Two reports were issued, and one is being prepared.

Routine checkout and preventive maintenance of all operating systems were instituted. Weekly and monthly inspection procedures will be similar to those for the waste effluent systems previously reported.\(^5\)

6.2 WASTE EFFLUENT MONITORING SYSTEMS

D. J. Knowles        L. H. Chase
H. P. Danforth       C. C. Hall
J. H. Holladay

Waste effluent handling by the Operations Division is instrumented in part by four monitoring systems which send the data to the Waste Monitoring Control Center. These systems were reported previously.\textsuperscript{1–5} Liquid waste in the process waste water system is monitored and automatically sampled proportionally by stations at manholes. Selected stations are instrumented for automatic diversion of contaminated waste to holding ponds. Intermediate-level waste flows in a separate system to holding tanks which are monitored continuously for liquid level. Flow and radioactivity in the disposal stacks are also monitored continuously, and samples of the effluent are collected on filters and charcoal cartridges. Certain ducts are also monitored for particulates. A summary of systems in operation and systems planned is shown in Fig. 6.2.1. All waste effluent systems shown were in operation and on scheduled checkout during the report period. The addition of a special high-range monitor to the HFIR stack is reported in this chapter (Sect. 6.6).


6.3 ENVIRONMENTAL MONITORING SYSTEMS

L. H. Chase        D. J. Knowles

Of the 22 local air monitoring stations to be modified for the Health Physics Division, 11 were completed. A fixed-filter inventory sampler is being installed outside each cabinet, and a flow control valve is being added to each air sampling system. Flow is controlled at 2.5 cfm through the tape-deck filter and also through the fixed-filter inventory sampler. Performance of the modified monitors was satisfactory.

Telemetering of information from perimeter air monitoring stations to a slave recorder at the EGCR is no longer required. Installation of the radio telemetry system from the two newest stations\textsuperscript{1} was completed and they are operating.

Fig. 6.2.1 Existing and Proposed Laboratory Radiation Monitoring and Control Systems.
6.4 ORNL RADIO COMMUNICATION SYSTEM

J. E. Inman

Radio net 4, used by the Plant and Equipment Division, is being changed from 34-megahertz wide-band FM equipment to a more modern and efficient system because the range was inadequate, there was occasional interference, and the maintenance cost was too high. The new system being installed is a 150-megahertz narrow-band FM repeater system. Most of the new equipment was obtained from other AEC installations. The new frequency will eliminate the interference, and the repeater system will give reliable coverage over a greater range.

A 60-w base station and forty-eight 25-w units that may be used either as a fixed base station or as a mobile unit were acquired. The 60-w station was modified to a repeater station, and the rest of the equipment was altered to narrow band to conform to Interdepartment Radio Advisory Committee (IRAC) regulations.

An 80-ft steel tower was erected on Melton Hill, and two 6-db gain antennas were installed on the tower, one for receiving and one for transmitting. Two antennas are used for improved efficiency, since in the duplex (or repeater) system the transmitting and receiving frequencies are separated by approximately 5 Mc.

Conversion to the new system and installation of mobile units are being done unit by unit, with the old and the new systems connected together by carrier-operated relays which will allow a smooth transition from one system to the other without interruption of communications.

The 60-w main base repeater station is located in the radio building on Melton Hill. Foam-Helix cable is used as the transmission line to the two antennas. The main base station is controlled by three remote-control consoles located in the Laboratory area. The main repeater will be backed up by a standby unit located in Building 3015. The main station may be switched off and the standby station on by a switch located in the Laboratory Emergency Control Center. The new repeater system will consist of the two 60-w main base stations, seven 25-w auxiliary stations, fifteen remote control consoles, thirty-one 25-w mobile stations, and thirty 1-w portable units.

6.5 RADIATION MONITORING AND CONTAINMENT INSTRUMENTATION IN BUILDING 3028

J. H. Holladay

In 1963 a central panel for radiation monitoring and automatic containment actuation instrumentation was installed in Building 3028. Due to enlargement of the building operation, a larger central radiation monitoring panel was needed. An updated panel was installed utilizing the new solid-state modular design now standard for the facility radiation and contamination system in many other buildings.

The radiation monitoring instruments throughout the building are used to provide health physics monitoring information, local alarms when abnormal conditions occur, and remote alarms on a
central monitoring panel located in the central personnel air lock. Six alpha air monitors and three beta-gamma air monitors continuously sample the air in the building for radioactive particulate matter. Signals from six alpha constant air monitors and two of the three beta-gamma constant air monitors are used to actuate the automatic containment system. Five monitrons are used in the system to monitor gamma radiation. Four neutron monitors continuously monitor the area. All the monitors, however, annunciate at the central monitoring panel.

The building containment system operates automatically when two or more selected alpha air monitors or two selected beta-gamma air monitors detect a "high level" of air contamination. In addition to the central monitoring panel, there are four slave panels to indicate by pilot lights the alarm condition of any radiation monitor in the building. These slave panels are located on the second, third, and fourth levels, and in the iodine operating area. Since there are five areas in the building operating somewhat independently of each other, the slave panels will assist in determining which exits should be used if a building evacuation radiation alarm is sounded.

6.6 HIGH-LEVEL RADIATION MONITORING SYSTEM AT THE HFIR

C. C. Hall W. T. Clay T. F. Sliski

A gamma-radiation monitoring system was installed in the HFIR stack at a height of 50 ft to measure a wide range of gamma dose rates in the event of a major reactor accident. Such an accident could release large amounts of radioactive materials to the stack, mainly radioactive noble gases and possibly radioactive iodine. The system will sound an alarm when a preset radiation level is reached. The radiation level will be recorded throughout the rise and fall of the radiation level in the stack.

An inert-gas monitor was added to the existing stack monitoring system, and a wide-range monitor was added at the 50-ft level in the stack stream. The inert-gas monitor will indicate normal radiation levels up to approximately 25 mrem/hr, and the wide-range monitor will indicate from 25 mrem/hr to $2.5 \times 10^6$ r/hr. At a level of 5 r/hr, alarms will be sounded in the HFIR control room and at the Waste Disposal Control Center, Building 3105. The main recorder is located in the HFIR auxiliary control room, and slave recorders are located in the main control room and at Building 3105. A recorder and alarm will be installed at the Emergency Control Center, Building 2500.

The inert-gas monitor consists of an ORNL model Q-2325-31 inert-gas detector$^1$ and a model Q-2191 count rate meter. The gas sample is pumped from the stack at the 50-ft level and passed through filter paper in a constant air monitor, through a charcoal trap in an iodine monitor, through an ORNL model Q-2351-62 charcoal trap, and then through the gas detector. The second charcoal trap removes iodine from the gas sample when the iodine monitor charcoal trap becomes saturated.

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This will allow the gas monitor to operate again when the radiation level decreases into its range even if large quantities of iodine have been present.

The gamma radiation monitor in the stack consists of an ORNL model Q-2318 ionization chamber, a model Q-2057 high-voltage power supply, a Keithley model 413AC eight-decade logarithmic electrometer, and a Leeds & Northrup type "W" recorder. A stainless steel thimble was designed and installed in the HFIR stack at the 50-ft level. The ionization chamber, a source holder, a 0.97-mc cesium source, and a source positioning device were installed in the thimble; these can be removed for servicing without opening the stack penetration. The source positioning device is operated remotely to move the source to either one of two preset positions with respect to the ion chamber which are indicated on a remote panel by two lamps labeled "normal" and "calibrate." When the source is in the "normal" position, the gamma dose rate at the ion chamber is such that the electrometer reads upscale about 75% of the lowest meter decade. Should the system become inoperative, the electrometer will drift downside to the low set point and give an inoperative signal which is telemetered to Building 3105. A system check can be made by placing the source in the "calibrate" position, thus giving a reading which is approximately one decade higher than the "normal" level. Any change in the system response can be observed.

6.7 GAMMA-NEUTRON RADIATION MONITORING SYSTEM FOR THE 5-MV VAN DE GRAAFF ACCELERATOR

J. H. Holladay

Gamma and neutron radiation are present in various areas of the 5-Mv Van de Graaff accelerator facility, depending upon whether the accelerator is turned on and to which room the beam is directed. A radiation monitoring system was designed to permit personnel to enter areas where low levels of either or both types of radiation are present and to provide warning indications if predetermined levels of radiation are exceeded. The monitoring system provides a continuous indication of radiation levels from 0 to 100 millirems/hr. A caution alarm, indicated by rotating amber beacons in the experimental area, is actuated when the radiation level exceeds 30 millirems/hr; a high-level alarm, indicated by rotating magenta beacons, is actuated when the radiation level exceeds 100 millirems/hr.

Ionization chambers (ORNL model Q-2289) sensitive to gamma and neutron radiation were installed in five areas. Each chamber is connected to an individual electrometer (ORNL model Q-2873) located in the control room. A remote input head located at each chamber permits a long cable run between the chamber and the associated electrometer. Alarm signals are fed from each electrometer to indicator lamps at the control console which display the radiation condition of each monitored area and from the console to the amber and magenta beacons in the monitored area. In addition to the readout on each electrometer, meters are located at the control console and at each area doorway to indicate the radiation level in that particular room. Switches at the instrument rack in the control room are for manual operation of the magenta beacon.
6.8 RADIATION PROTECTION INTERLOCKS FOR THE 3-MV VAN DE GRAAFF ACCELERATOR

J. P. Judish

Depending on the type of experiment underway, all operating areas of the 3-Mv Van de Graaff accelerator are sometimes radiation hazards. When no hazard exists, free access to these areas is very desirable. The combination of free access and protection from accidental exposure to radiation was achieved by the construction of a central panel and installation of interlock switches at all operation area entrance doors.

The system operates in the following manner. The user of the Van de Graaff must evaluate the extent of the hazard in each area and then set switches at the control panel that determine what effect an open interlock will have. An alarm light is always turned on for each open interlock, but otherwise the switch positions determine whether an audible alarm is to be sounded, a beam stop is to be actuated, the Van de Graaff voltage is to be turned off, or any combination or none of these when an interlock is opened.

The circuit of the control panel was designed to minimize the chance of exposure to radiation if some part of the system should fail to work properly. For example, if the power to the interlock control panel is lost, the Van de Graaff voltage is turned off (visual inspection of the operating area is almost ensured since each interlock can be reset only at the entrance it guards); if electricity or compressed air to this electromechanical device is lost, spring loading plus atmospheric pressure force the beam stop into the beam path; if the user of the Van de Graaff or the interlock system sends a signal for the beam stop to be actuated, and if within 2 sec the beam stop is not in the closed position as sensed by a microswitch, the circuit turns off the Van de Graaff voltage.

The system has been in use since its installation (December 1965) with satisfactory results.

6.9 DESCRIPTION OF THE CELL VENTILATION MONITOR FOR THE FISSION PRODUCTS DEVELOPMENT LABORATORY, BUILDING 3517

D. J. Knowles     H. P. Danforth     L. H. Chase

The exhaust ventilation air from the Fission Products Development Laboratory (FPDL), Building 3517, is filtered before it flows to the 3039 stack. The air is monitored for radioactive particulates after being filtered at Building 3517 and again at the 3039 stack. This report describes the intended function and details of the components in the FPDL duct monitor at Building 3517. A checkout procedure is attached.

\[1\text{Abstract of published report, ORNL-TM-1384 (Dec. 15, 1965).} \]
DEVELOPMENT OF INSTRUMENTS AND COMPONENTS

6.10 NUCLEAR INSTRUMENT MODULES FOR RADIATION MONITORING SYSTEMS

E. E. Waugh  F. M. Glass  G. A. Holt

A modular (conforming to standards for AEC nuclear instrument modules) transistorized alpha or beta-gamma radiation monitoring system (series Q-2890) was developed to supersede a vacuum tube instrument, ORNL model Q-2191B.

This system, which conforms to AEC-NIM standards,\(^1\) is contained in a single \(5\frac{1}{4}\)-in. NIM bin and consists of three linear count-rate modules, three alarm modules, one 50-\(\mu\)a meter module or one 1-ma recorder module, one audio module, and one 900-v detector high-voltage supply module (Fig. 6.10.1).

The count-rate module provides eight full-scale calibration ranges from 500 to 100,000 counts/min and three integrating time constants of 1, 11, and 21 sec. The 1-ma recorder module


Fig. 6.10.1  Nuclear Instrument Modules for Monitoring Systems.
and the 50-μa meter module have a selector switch for monitoring either of the three count-rate modules.

The system provides output signals for 10-mv recorders, 50-μa meters, and 1-ma recorders; remote range indicator signals for 50-μa meters; and relay contacts for remote indication of high radiation level, low radiation level, and instrument inoperative conditions (Fig. 6.10.2). The high- and low-level alarm points are adjustable over 100% of calibration range. Colored lights on the panel of the alarm module give visible indications of alarm conditions.

The system utilizes either an ORNL model Q-2101 alpha detector or an ORNL model Q-2152 G-M probe.

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Fig. 6.10.2 Nuclear Instrument Modules for Monitoring Systems, ORNL Series Q-2890.

6.11 ELECTRICAL SAFETY OF HEALTH PHYSICS INSTRUMENTS IN USE AT ORNL

R. E. Wintenberg

Radiation monitoring instruments used by the Health Physics Division were investigated to determine their potential shock hazard. Commonly used line-operated instruments with high-voltage connectors were tested by measuring the transient and steady-state voltages when the voltage source was connected to a 50-ohm load. High-voltage characteristics of portable instru-

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ments and of instruments not widely used were calculated using "worst case" values. Instruments with connectors having exposed voltages of over 50 v were noted.

In general, instruments used for measuring or monitoring radioactivity had less than 0.01 j of stored energy and 1.0 ma of steady-state current, whereas the high-voltage power supplies had as high as 3.6 j of stored energy and 180 ma of steady-state current. No instrument in common use had more than 2000 v on a connector.

6.12 SOLID-STATE ALPHA AND NEUTRON MONITOR FOR THE TRANSURANIUM PROCESSING PLANT

F. M. Glass    R. S. Hensley    G. A. Holt
E. E. Waugh    R. E. Zedler

A solid-state alpha and neutron monitor, ORNL model Q-2831, was designed to monitor the position of elution peaks of transplutonium elements separated by ion exchange. This instrument, unlike the laboratory-type ORNL model Q-2809 and Q-2809A monitors (Sect. 3.7), was designed specifically for process control in the Transuranium Processing Plant. It is packaged in a standard NIM module\(^1\) which allows six monitors to be placed in a single 5\(\frac{1}{4}\)-in. NIM bin (Fig. 6.12.1). This monitor employs two different silicon surface-barrier diodes. One, having an active area of 20 mm\(^2\), is used for alpha detection; the other, having an active area of 80 mm\(^2\), is used with a polyethylene radiator to detect neutrons in \(^{252}\)Cf elution peaks. The preamplifier is packaged in a cylindrical container, and the input and output connectors are on the same end. This simplifies the design of the lead shield and manipulation of the preamplifier in the hot cell.

The performance specifications for the monitor are identical to the performance specification for the model Q-2809A monitor. However, in keeping with process control requirements, the gated audio oscillator was replaced with an alarm circuit. The alarm circuit is adjustable over the entire range of the rate meter, thereby producing a signal that can be used to control the process or to alert the operator at any desired level of radiation. The accuracy and repeatability of the alarm circuit is better than 1% in air-conditioned buildings.

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6.13 AIR PROPORTIONAL ALPHA SURVEY METER

F. M. Glass    G. A. Holt    E. E. Waugh

Alpha survey meters employing air proportional counter probes are preferred by some users because the size, shape, and weight of these probes make them more attractive than the heavier and more bulky scintillation probes. A commercial instrument was purchased and thoroughly tested and evaluated. The performance and reliability of this instrument was found to be inadequate for the needs of the Laboratory. A new design was worked out for use with an air proportional probe designed by the Lawrence Radiation Laboratory.
The ORNL design (model Q-2912) features a highly efficient well-regulated 1725-v power supply, a stable charge-sensitive amplifier and rate meter, a rechargeable battery, and a built-in charger. The full-scale ranges are 5, 50, and 500 counts/sec. The linearity for random spaced pulses is just as good as the Weston panel meter used, since the duty cycle is the same for all ranges and a compensating circuit compensates for counting losses. The battery drain is only 10 mA, making it possible for the instrument to be operated continuously for 50 hr on one charge. No troubles have been encountered with this instrument other than those normally associated with air proportional probes in a humid climate.

6.14 ALPHA SOURCE ASSEMBLY FOR EVALUATING ALPHA SURVEY PROBES

M. M. Chiles

An alpha source assembly was designed for testing and evaluating alpha survey probes, ORNL model Q-2101,1 for uniformity of the phosphor layer and quality of the optical coupling

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between the light pipe and photomultiplier tube. It also aids in making adjustments of the electronic sensitivity and photomultiplier tube voltage to achieve a desired efficiency near the edges of the sensitive face of the probe.

Since the alpha probe is required to have uniform efficiency over the entire sensitive area of 100 cm², the source assembly is designed to have a consistent alpha radiation intensity and constant geometry when placed on each probe to be tested. The source assembly, ORNL model Q-2839 (Fig. 6.14.1), fits on the 4.5-in.-square protective grill of the alpha probe. Five positions on the sensitive face of the probe are tested. The bottom plate, which positions the assembly on the grill, has a 1-in.-diam hole in the center and one near each corner located $2\frac{1}{16}$ in. from the center of the probe. Another plate immediately back of the positioning plate contains two 1-in.-diam alpha sources. One source, located at center of the plate, is aligned with the center hole in bottom plate at all times; the second, located $2\frac{1}{16}$ in. from the center, can be aligned with any of the four corner holes by rotating the source plate in either direction. For testing only the center of a probe, the outer source is masked when positioned between two corner holes.

The disintegration rates of the two alpha sources were selected to contribute equal count rates when a probe having proper efficiency is tested. Therefore, the count rate from both sources will be twice the rate when only the center source is counted.

![Photo 85025](image)

Fig. 6.14.1 Bottom View of Alpha Source Assembly.
6.15 STEAM CONDENSATE BETA-GAMMA MONITOR AT THE FISSION PRODUCTS DEVELOPMENT LABORATORY, BUILDING 3517

L. H. Chase D. J. Knowles

Steam condensate from the Fission Products Development Laboratory is stored in a 2000-gal underground tank and monitored continuously for beta-gamma radiation and at intervals is drained into the ORNL Process Waste System. The pumping system for withdrawing samples and the associated radiation monitoring system are described, and a checkout procedure is included.

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6.16 END-WINDOW G-M SURVEY METER

F. M. Glass G. A. Holt
E. E. Waugh

The ever-increasing quantities of low-energy beta emitters (such as $^{147}$Pm) used in research at ORNL have made it necessary for health physics surveyors to be equipped with end-window G-M survey meters. About 40 commercial instruments manufactured by four of the more reliable companies were procured and put into service. The results obtained with these instruments were very disappointing. The major weakness was poor calibration agreement from instrument to instrument; discrepancies of factors of 3 and 4 were common. As a result the development of a more reliable instrument was requested.

The new instrument, ORNL model Q-2826 (Fig. 6.16.1), was designed to work with the Amperex 500V series radiation counter tubes. The instrument features low battery consumption ($\approx 100$ mw) and light weight. The calibration shifts less than 2% over the entire life of the rechargeable battery. A dc lock-in circuit ensures a full-scale indication in a strong radiation field that could paralyze or jam the pulse circuitry. The largest observed spread in calibration resulting from changing the G-M tubes has been 10%. A single calibration control allows the instrument to be recalibrated after the counter tubes are changed.

6.17 TRANSISTORIZED IONIZATION CHAMBER SURVEY METER

E. J. Kennedy F. M. Glass

A transistorized survey meter, ORNL model Q-2898, was developed to replace a vacuum tube instrument, ORNL model Q-2299. The new instrument has full-scale sensitivity ranges of $10$ r/hr, $1$ r/hr, $100$ mR/hr, and $10$ mR/hr. The basic circuit comprises a 500-cm$^3$ ionization chamber coupled to a transistorized current-feedback differential amplifier having an open-loop gain between 30 and 50. The input current to the amplifier from the ion chamber corresponds to $0.46 \times 10^{-12}$ amp/10 mR.
Fig. 6.16.1 End Window G-M Survey Meter, ORNL Model Q-2826.

A schematic diagram of the survey meter is shown in Fig. 6.17.1. The transistorized amplifier has an input differential stage utilizing a 2N3609 dual matched-pair metal-oxide-semiconductor field-effect transistor (MOSFET). The input leakage current for the MOSFET is less than $1 \times 10^{-14}$ amp. The second stage of the amplifier is another differential unit, using 2N3645 p-n-p bipolar transistors. Negative feedback to the input is provided from the appropriate collector terminal of the second stage to the input gate of the 2N3609 MOSFET. The sensitivity range is selected by switching to the desired high-megohm resistor in the feedback loop. The source terminals of the input 2N3609 stage are fed by a bipolar transistor current source. This current source has common-mode feedback from the emitters of the 2N3645 transistors in the second stage.

The survey meter has a dc-to-dc converter to supply the required potentials of $+15$ v and $-10$ v for the amplifier stage and $+110$ v for the saturation potential of the ionization chamber. A
schematic diagram of the converter is shown in Fig. 6.17.2. The dc-to-dc converter has an efficiency of approximately 60%. The power for the input to the converter is obtained from two 1.5-v standard "D" cell batteries. The operating life of this survey meter on one pair of batteries is typically greater than 300 hr, as indicated in Fig. 6.17.3. From Fig. 6.17.3 it is evident that the zero drift of the instrument due to a battery voltage change is less than 5% of full scale over the useful life of the batteries.

In Fig. 6.17.4 the zero drift of the survey meter as a function of temperature is shown. Over a temperature range from −10 to +55°C, the zero drift is within the limits of −6 to +3% of full scale.

6.18 EXPERIMENTAL GAMMA-SENSITIVE PERSONAL RADIATION MONITOR

P. R. Kirk

An experimental personal radiation monitor (PRM) was developed to detect low-energy (0.52-Mev) gamma rays, which cannot be detected by the ORNL PRM model Q-2041A (ref. 1). The size of this PRM is about the same as the model Q-2041A PRM (Fig. 6.18.1). Five instruments tested for about three months gave satisfactory performance.
Fig. 6.17.2 DC-to-DC Converter for Ionization Chamber Survey Meter.

Fig. 6.17.3 Survey Meter Drift as a Function of Battery Voltage.
**Fig. 6.17.4** Survey Meter Drift as a Function of Temperature.

**Fig. 6.18.1** Experimental Gamma-Sensitive Personal Radiation Monitor.
The circuit is a conventional low-current circuit.\textsuperscript{1} However, the detector is an Amperex 18503 gamma radiation counter tube with a gas volume about 22 times greater than that of the Amperex 18509 tube used in the Q-2041A PRM. Thus, by virtue of the greater gas volume, the sensitivity of the experimental PRM is greater.

The electronic components are encapsulated in epoxy resin to prevent leakage current. The completed assembly is housed in a polyvinyl chloride case machined from $\frac{3}{4}$-in.-diam stock tubing which provides high impact resistance.

An Amperex 18504 counter tube having a mica end-window thickness of 2 to 3 mg/cm$^2$ and which is sensitive to alpha, soft beta, and gamma radiation is interchangeable with minor modification.

\begin{footnotesize}
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\section*{6.19 PROCESS MONITOR GAMMA PROBE}

\begin{center}
H. R. Brashear \hspace{1cm} F. E. Gillespie
\end{center}

A gamma probe using an Amperex 18509 G-M tube was designed and built for use with the ORNL model Q-2814 process monitor.\textsuperscript{1} The probe differs from its predecessor (ORNL model Q-1916) in that it operates in the pulse mode, has a single captive coaxial cable and a drawn stainless steel shell sealed with a heat-shrinkable molded boot,\textsuperscript{2} and is smaller. The useful range of the probe is 1 mR/hr to 1 r/hr. The cost of the probe is approximately one-third that of its predecessor.

The pulse mode of operation eliminates tedious individual probe calibration problems. Before assembly the G-M tubes are aged under radiation, and a sensitivity check of $92 \pm 8$ counts/min per mR/hr ($^{60}$Co) is made. Of the 70 tubes checked, all operative tubes met the sensitivity requirements. An alpha source ($^{232}$Th) is attached to the cathode of the tube to prevent "circuit inoperative" alarms in the absence of external backgrounds.

Construction details are shown in Fig. 6.19.1. The drawn shell and heat-shrinkable boot eliminate costly machining plus allowing the use of a standard, low-cost, coaxial connector on the captive cable. The smaller physical size will greatly reduce the shielding mass in most installations.

\begin{footnotesize}
\begin{enumerate}
\item Ray Clad Tubes, Inc., Redwood City, Calif.
\end{enumerate}
\end{footnotesize}
Fig. 6.19.1 Process Monitor Gamma Probe.
7. Instrumentation for Automatic Control and Data Acquisition

COMPUTER SYSTEMS

7.1 COMPUTER-CONTROLLED NEUTRON DIFFRACTOMETER

R. T. Roseberry W. R. Busing

A computer control for a neutron diffractometer was designed for the Chemistry Division on the principle of the computer-controlled x-ray diffractometer. An interface for a Digital Equipment Corporation model PDP-8 computer was designed to perform the same control functions available in the model PDP-5 interface used for controlling the x-ray diffractometer. The computer provides on-line control for crystal orientation, neutron beam monitoring, data counting, and data output in hard copy, perforated paper-tape, and an x-y histogram plot.

The computer interface includes (1) circuits for driving four Superior Electric Co. Slo-Syn motors, (2) a scaler for the neutron beam monitor, (3) a data prescaler, (4) a digital-to-analog converter for driving the histogram plotter, and (5) input-output control functions previously reported. The complete interface is included in the computer cabinet, and all interconnection cables connect to a single panel.

The neutron diffractometer will be installed at the HFIR and used by the Chemistry Division for analysis of crystal structures.

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1Chemistry Division.

7.2 TRIPLE-AXIS NEUTRON SPECTROMETER CONTROL

J. W. Reynolds W. C. Koehler

A triple-axis neutron spectrometer control was designed for use in polarized neutron experiments. A PDP-8 general-purpose computer provides flexibility of experiment control by use of a software program. Crystal and axis positioning, rf oscillator control, data taking, and histogram plotting are functions to be performed by the program through an interface.

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1Solid State Division.
The interface provides drive capability for 8 stepping motors with limit switches, 12 on-off signals to external equipment, 4 analog outputs via digital-to-analog converters, 4 analog inputs via a four-channel multiplexer, and 4 on-off signals from external equipment. Each motor has a photoelectric degree marker for computer checking of its position. Space is available for the addition of a parallel transfer of a 12-bit word to an external device. A magnetic tape deck is included to be used for program storage. Output data are recorded on paper tape and as printed copy.

The interface is complete except for cabling to the computer, installation of the interface, cabling to the external equipment, and system checkout. The system is to be installed in late December 1966.

7.3 COMPUTER CONTROL OF TRIPLE-AXIS NEUTRON SPECTROMETER

E. Madden       H. G. Smith

A Digital Equipment Corporation PDP-8 general-purpose computer is the principal component in a system to provide automatic control of a triple-axis spectrometer in experiments involving the inelastic scattering of neutrons. The computer will control the angular position of the detectors and all axes of rotation of the crystal-positioning goniometer and will operate all the detectors and monitors. Six independent axes must be positioned automatically for maximum experiment efficiency. The interface is being fabricated.

Features of the control system and computer-spectrometer interface are as follows:

1. magnetic tape system for program storage;
2. computer interrupt from three monitor scalers, a 300-cps clock, and two 12-bit interrupt registers;
3. maximum of eight stepping motors;
4. five digital-to-analog converters (one for a histogram plotter);
5. multiplexing of four analog inputs to one analog-to-digital converter;
6. control of register to provide twelve external on-off functions such as magnet power, rf oscillator, and energy selection;
7. histogram plotter.

The Slo-Syn synchronous motors are operated at a maximum stepping speed of 300 steps/sec. One motor shaft revolution, which requires 200 stepping pulses, is translated to 1° of goniometer angle motion. Since the Slo-Syn motor steps are delivered in pairs, the resulting crystal angle resolution is 0.01°. A photodiode causes a computer interrupt for every complete revolution of the Slo-Syn motor shaft, and this interrupt enables the computer software to accurately track the actual angular position of the Slo-Syn driving rotor.

1 Solid State Division.
7.4 COMPUTER-CONTROLLED X-RAY DIFFRACTION SYSTEM

T. A. Lewis J. Ralph Einstein

A system using a PDP-8 general-purpose computer was designed to provide automatic control of a four-axis x-ray diffractometer used by the Biology Division for experiments on large-molecule crystals such as protein crystals. In addition to controlling the diffractometer, the computer system automatically collects, records, and presents data from the experiment.

The control functions include positioning the sample in the diffractometer by four stepping motors whose shaft positions can be monitored by counting the electrical impulses to the motor, as is done in other systems used at ORNL. 2

Data are handled and presented by use of the computer's basic core memory. A standard ASR-33 teletype unit punches paper tape and prints copy. In addition, a strip-chart recorder plots histograms. The data system can be expanded to include magnetic tape recording facilities.

1Biology Division.

7.5 COMPUTER CONTROL SYSTEM FOR AN X-RAY DIFFRACTOMETER

F. W. Snodgrass J. H. Burns

A four-axis x-ray diffraction system will utilize a Digital Equipment Corporation PDP-8 computer as the controlling device. The basic interface design philosophy, which has proven successful in a PDP-5-controlled system, 2 was carried over and expanded for this and other x-ray and neutron diffractometer control systems currently under development. The similarity of the various interface units makes possible the use of common library program routines with, perhaps, minor modifications in some cases. Completion of the system is scheduled for December 1966.

The system will be used by the Chemistry Division in the study of crystals containing the transuranium elements. Through the use and versatility of stored programs the computer will control the diffractometer and collect and process data. Since the crystals will be radioactive, the computer will be remote from the diffractometer to ensure a safe environment for operating personnel. The computer will provide efficient, continuous data collection, and in the study of short-lived elements the computer speed will be of great importance.

Functions to be performed by the computer via the interface include: driving four stepping motors at 200 steps per degree for crystal orientation and detector positioning, operating up to

1Chemistry Division.
six solenoid actuated devices, accepting detector count data, monitoring degree marking signals from each motor to ensure that the motors are tracking with the program, monitoring up to seven safety limit switches, and operating a histogram plotter.

7.6 MULTIANALYZER STORED-PROGRAM DATA ACQUISITION SYSTEM INTERFACE

E. Madden       R. W. Peelé\textsuperscript{1}

In collaboration with the Neutron Physics Division, a multianalyzer stored-program data acquisition system (Fig. 7.6.1) is being developed. For each nuclear event accepted by ex-

\textsuperscript{1}Neutron Physics Division.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig761.png}
\caption{Stored Program Data Acquisition System.}
\end{figure}
ternal coincidence circuits, a Digital Equipment Corporation PDP-8 general-purpose digital computer will accept digital information from two Victoreen 2048-channel analog-to-digital converters and from two RIDL 400-channel pulse-height analyzers. Upon receipt of an incoming pulse and the coincident external trigger, each of the selected converters and/or analyzers must deliver, to the interface, either an upper-level discriminator pulse, an overflow pulse, or a conversion complete pulse. After the last pulse has been received, the interface signals the computer to take the data. Forty-eight bits are multiplexed into four successive 12-bit words and transferred into a computer buffer store. The computer then resets the interface in preparation for the next coincidence.

Since billions of memory channels are required for such a four-parameter data acquisition system, all the information concerning each selected event is written on magnetic tape, to be sorted and totaled by the Laboratory main computer at a later time. Computer buffer storage must be utilized to mesh the incoming data transfer rate with the magnetic tape write rate and thus decrease the systemdeadtime.

The system will display selected information concerning the nuclear events and exert some control on the external equipment sensing the nuclear events. The control is to be expanded to handle up to 32 external scalers.

### 7.7 Modification of Multichannel Analyzers for Data Center Use

E. Madden    J. W. Reynolds

Three multichannel analyzers and one analog-to-digital converter (ADC) unit were modified for use with the data center of the High-Voltage Laboratory. A Victoreen model 800 and two Nuclear Data 160M, 4096-channel arithmetic units were modified to allow either standard punched paper-tape output or access to the existing CDC 160-A computer through the data center. A Nuclear Data 160F dual ADC was modified for direct access to the computer in a single or dual mode. The interface of the ND-160F was combined with the interface of one of the ND-160M units.

A multiposition “tape-computer” switch was added to the Victoreen SC-2 serial converter to perform the following functions:

1. disable the 60-character/sec paper-tape punch channel and enable a modified magnetic-tape channel which was used for the 2000-character/sec computer mode;
2. allow the computer data center to exert control over the data transmission;
3. remove power supply voltage from the paper-tape punch solenoid drivers and isolate the drivers by placing rectifiers in all the punch solenoid leads;
4. use the punch solenoid driver transistors to drive the data lines to the computer data center.

Interface units were added to the existing ORNL model Q-2752 punch control-readout units so as to connect the ND-160M units to the computer. A multiposition switch routes the data lines to either the paper-tape punch control or to the data center. Additional control logic al-
allows the analyzer stored data to be transmitted to the computer at the rate at which the paper
tape punch operates, namely 110 characters/sec. Two minutes is required to dump 4096
channels.

The modifications to the ND-160F consist of an interface unit controlled by the dual ADC
and inspected for data by the computer program. The ADC was modified by adding three wires
to the experiment configuration plug. Ten data bits and a flag bit are parallel transferred to the
computer in the single mode, while the dual mode transfers two words of 11 bits, with a flag bit
in the second word.

Approximately 50% of all accumulated pulse-height analyzer data at the High-Voltage Labo-
ratory is transferred to the computer through the data center.

7.8 COMPUTER-CONTROLLED COMMUNICATION SYSTEM FOR THE
DEXTIR DATA LOGGING SYSTEM

R. T. Roseberry

A study was made of the complexity of applying a small general-purpose computer to process
on-line data acquired by the Dextir data system so that experimenters would be provided with
real time information on the status or condition of their experiments. Details were worked out
for the hardware interface necessary to connect a Digital Equipment Corporation model PDP-8
computer to the Dextir system and provide up to 32 teletype units at remote experiment stations.

Programming details were developed to permit use of one remote station initially. Expanding
the system to 32 stations at a later date will require a minimum of program alterations.

The basic 4096-word memory of the computer will be sufficiently large to handle the data
conversion for any one data-gathering box configuration on the Dextir party line. Memory re-
quirements for the PDP-8–Dextir system have been estimated, and of the 4096 words available
on the basic PDP-8 computer memory, about 3000 words will be required for the system executive
program. This leaves about 1000 words available for programming routines peculiar to a
specific data-gathering box configuration and the read-back requirements of the experimenters
for that particular box. Programming routines for all box configurations can be stored on mag-
netic tape and transferred into memory on request.
HARD-WIRED SYSTEMS

7.9 DATA ACQUISITION SYSTEM FOR REACTOR DIVISION AND THERMONUCLEAR DIVISION EXPERIMENTS


Operating experience on a Beckman Dextir data acquisition system\(^1\) was accumulated for 15 months. This data system is unique in that a single central cable (Fig. 7.9.1) up to 5000 ft long carries the low-level analog signal and control signals required to take data from experiments located in two buildings 2700 ft apart. The data are recorded on magnetic tape, and the tape is processed daily in the ORNL central computer.

Approximately 21 Reactor Division experiments have been connected to the system since it was installed. The system was recently extended to building 9201-2, where it will service Thermonuclear Division experiments. The data system was used effectively for automatic processing.


Fig. 7.9.1 Dextir Data Acquisition System.
of experimental data as indicated by the user summary in Table 7.9.1. The services of a full-
time programmer were required to perform the work indicated in this table. Interface programming
was provided by the Instrumentation and Controls Division Data Processing and Analysis Sec-
tion.

System availability to the users was 98.4%. Availability is defined as the system being in
the "record" mode and capable of recording accurate experimental data. If only electronics
problems are considered, the availability was 99.4%.

A significant achievement during the year was the conversion of the main Dextir computer
program so that it could be run on the IBM 360, model 75 computer at ORNL.

Several interfaces were completed. The most significant was a design (Sect. 7.8) that will
interface the Dextir system with a small on-line computer such that feedback of data to experi-
ments in engineering units could be accomplished in something close to real time. An expand-
able system is envisioned which initially will consist of the computer main frame with extended
arithmetic unit, 4096 words of fast core memory, and one input-output typewriter with paper-tape
punch and paper-tape reader.

An interface was designed that, by use of commercial "peak pickers" to store six peaks
from a chromatograph, gates the peaks into the proper Dextir channels after the sixth peak has
been received. The system is then reset, and the cycle is repeated.

The standard Dextir system can accept digital inputs of decimal or BCD contact closures
only. A logic interface circuit was designed which will enable Dextir to accept BCD logic
levels (voltages) from a commercial scaler. The circuit will also allow an automatic accumu-
lation of counts in the scaler for an adjustable period; then the Dextir data box will be started,
the data recorded, and the counter will be reset for another cycle, all automatically.

The Dextir system has an alarm feature that allows either high- or low-alarm checking on
any channel. An audible, visible alarm is obtained at the central processor when any channel
is out of limit. A logic circuit was designed to provide control (a relay action) on an individual
channel basis by requiring a coincidence of the standard alarm with a contact closure from the
channel being monitored.

A number of other modifications were made to the standard Dextir system to increase its
flexibility and usefulness. It is now possible to (1) start scanning by means of a contact clo-
sure, record any number of records desired, and stop scanning, all automatically; (2) automatic-
ically record one set of data in a continuously recurring sequence which is adjustable from 1
to 24 hr; and (3) disconnect a load when scanning one channel, read a second channel with
the load disconnected, and reconnect the load when scanning a third channel, all on one data
input unit scan (3 sec duration).

Also being operated is an ORNL-designed and -built version of a digital switch panel which
eliminates many of the shortcomings of the commercial product.
<table>
<thead>
<tr>
<th>Experiment</th>
<th>Computer Program</th>
<th>Computer Plot (Calcomp)</th>
<th>Digital Data Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molten-Salt Reactor Prototype Pump Test</td>
<td>Plot program only</td>
<td>Pump head, flow, speed, power, and temperature vs time</td>
<td></td>
</tr>
<tr>
<td>Magnetic Flowmeter Calibration Facility (liquid metal)</td>
<td>Solve equations for weight, flow, and flowmeter temperature correction</td>
<td>Magnetic flowmeter output vs calibration standard</td>
<td></td>
</tr>
<tr>
<td>Liquid Metal Jet Pump Test</td>
<td>Solve equations for weight flow, pump flow coefficient, pump head coefficient, flowmeter temperature correction, and fluid density correction</td>
<td>Jet pump head coefficient vs jet pump flow coefficient</td>
<td></td>
</tr>
<tr>
<td>Small Potassium System No. 1</td>
<td>Plot program only</td>
<td>Firerod heater ground currents and temperature vs time</td>
<td>Test number entered digitally</td>
</tr>
<tr>
<td>Small Potassium System No. 2</td>
<td>Plot program only</td>
<td>Daily series of seven summary plots of 48-loop parameters vs time</td>
<td>Test number, firerod heater ground currents, and number of heaters entered digitally</td>
</tr>
<tr>
<td>Intermediate Potassium System</td>
<td>This is a very large program involving 22 loop and component performance computations on each set of data plus special data sorting and formatting to produce listings in engineering units</td>
<td>Loop temperature profiles, pressure profiles, and turbopump performance curves; these curves were produced from data which were taken and stored on tapes many months previously</td>
<td>Inlet air temperature, number of heaters in test, and level element potentiometer settings are all entered digitally</td>
</tr>
<tr>
<td>Intermediate Water System</td>
<td>Similar to the Intermediate Potassium System program, but also least-squares data fits to $Y = a \sqrt{x} + bx + c$ are done</td>
<td></td>
<td>Many variables such as flows, speeds, pressures, etc., are entered into the system as digital data</td>
</tr>
<tr>
<td>Firerod Heater Capsule Tests</td>
<td>Temperature averaging and selection of the maximum test specimen temperature</td>
<td>Plot of 12 variables vs time</td>
<td>Heater voltage and current read from panel meters and recorded digitally</td>
</tr>
</tbody>
</table>
Table 7.9.1 (continued)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Computer Program</th>
<th>Computer Plot (Calcomp)</th>
<th>Digital Data Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop No. 7 Stand &quot;A,&quot; Phase 3</td>
<td></td>
<td></td>
<td>Important loop control settings are entered into the system digitally as an aid to reproducing important loop parameters at a later date</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>All data are entered into system digitally; digital switches are also used as computer flags</td>
</tr>
<tr>
<td>Saline Water Research Loop No. 1</td>
<td>Performance calculations for various desalination evaporators under test</td>
<td></td>
<td>Test number, barometer pressure, instrument scale factors, rotometer readings, and computer flags are all entered digitally; digital switches are used for analog alarm set points</td>
</tr>
<tr>
<td>Saline Water Research Loop No. 2</td>
<td>Performance calculations for various desalination evaporators under test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphite Mechanics Test</td>
<td>Axial strain × scale factor; stress × scale factor; lateral strain (with grain) × scale factor; lateral strain (across grain) × scale factor</td>
<td>Stress vs strain plot; strain ratio vs strain plot</td>
<td>Strain gage &quot;K&quot; factor, specimen numbers, type of test, type of graphite, program parameters, computer flags, and orientation of specimen axis are entered digitally</td>
</tr>
<tr>
<td>Data Acquisition System Self-Monitoring System</td>
<td>Plot program only</td>
<td>Dextrir system internal temperature vs time (for troubleshooting purposes)</td>
<td>Alarm patches are used in conjunction with voltage standards to automatically monitor the Dextrir system analog accuracy once an hour</td>
</tr>
</tbody>
</table>
7.10 SINGLE-AXIS X-RAY DIFFRAC TOMETER PROGRAMMER

R. T. Roseberry        R. W. Hendricks

The x-ray diffraction group of the Metals and Ceramics Division was provided engineering assistance in purchasing a programmable step-scanner control for a single-axis x-ray diffractometer. Specifications were written for the system, which is programmable by both perforated paper tape and patchboard and which automatically collects and outputs data in both hard copy and perforated papertape.

The programmer contains six patchboard blocks, each of which can be programmed for a starting angle, the number and size of steps to be taken or the size of the angle to scan, and whether or not data should be taken with each of two balanced filters. Operations programmed on any patchboard block can be executed individually, or programs on all six blocks can be executed sequentially. The input paper tape can be programmed to cause any operation programmable by patchboard, or the paper tape can be programmed to request the program contained in any patchboard block to be executed.

Types of data collected are: counts from a photomultiplier tube; elapsed time of counting, which of the two balanced filters was used; month of year; day of month; and time of day. The data scanner also accepts the output from a digital voltmeter which might be indirectly measuring temperature or resistivity of the sample.

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1Metals and Ceramics Division.

7.11 DATA COLLECTION SYSTEM FOR THE LIQUID-SAMPLE X-RAY DIFFRAC TOMETER

R. T. Roseberry

The data collection system of the Chemistry Division liquid-sample x-ray diffractometer was replaced. The new system can be preset to count for given number of counts or for a given time, whichever comes first, and the data are recorded as typed copy and perforated paper tape. The control interface between the diffractometer and the counting instrumentation was designed as a part of, and built into, the counting system.

Count data were collected by the original system for a preset number of counts (with a preset count scaler), and the counting time was measured by a Clary printing timer. The elapsed time required to collect the preset number of counts — an operation repeated successively as the sample was moved — was printed on narrow papertape. Before the data could be processed at the central computing facility, the data recorded on perforated tape had to be recorded on punched cards and the cards added to a program deck.

The new system consists of a preset timer and a preset scaler. The outputs from these two units are scanned serially by character and transferred serially by bit to a Teletype Corporation
model TC33 automatic send-receive unit. This unit prints the data for visual inspection and punches paper tape for transfer to the computer.

7.12 DIGITAL DATA ACQUISITION SYSTEM UTILIZING A TELETYPewriter ASR 33

E. Madden

A control system was fabricated to provide punched paper tape and printed copy of digitized scanned analog voltage inputs obtained from experimental studies of reactor noise. Using a Teletype ASR 33 Teletypewriter as the output device, the system scans and records 42 analog lines per minute.

A commercial scanner serializes up to 25 analog voltage input lines. The scanner also provides a binary coded decimal (BCD) identification number. The specific input lines to be scanned may be selected by pushbuttons.

A digital voltmeter equipped with a high-gain auto-range unit digitizes each analog input and provides 4-digit BCD data, polarity, and automatic range information. The digital voltmeter provides a voltage accuracy of ±0.1% of the reading ±1 digit on the 99.99 mv range, which is the lowest range of four available.

The control provides the following features:
1. pinboard programming of the word format, which can consist of from 1 to 12 characters, such as SPACE, PERIOD, POLARITY SIGNS, DATA DIGITS, and END-OF-WORD;
2. switch selection of the number of words per line of printed copy;
3. switch selection of the number of lines per field of printed copy, with double spacing between fields;
4. automatic line feed and carriage return;
5. preset scan interval time, total number of scans, and warmup time.

7.13 DIFFRACTOMETER EQUIPMENT

G. W. Allin

Several pieces of equipment were designed and fabricated for use in diffractometer research programs.

A multiple filter mechanism was designed and fabricated for the Chemistry Division for use with a Picker x-ray diffractometer. This unit contains five filters which are independently actuated by solenoids on command from the computer controller. All or any combination of these filters may be inserted into the x-ray beam at any time. Four of these are fixed-thickness filters mounted in removable frames for easy changeout. The fifth, a variable-thickness (or balance) filter, is made such that the filter can be tilted in the x-ray beam so that the apparent thickness, as seen by the x-ray beam, is changed. Tilting is accomplished by rotating the filter in its
holder. The angle of incidence with the beam is continuously adjustable through a range of 20°. This mechanism was installed, and it has performed satisfactorily under operating conditions.

A similar filter mechanism was designed and fabricated for the Metals and Ceramics Division. This unit contains two fixed-thickness filters which are independently actuated by solenoids on command from the computer controller. A third solenoid actuator operates a dual-filter holder containing a fixed-thickness and a variable-thickness (or balance) filter. In this case, either one or the other of the filters is always in the x-ray beam. Attached to this filter mechanism is a monochromator housing for use with this system. It contains a gimbal mounting arrangement for the accurate multidirectional positioning of a contoured crystal in the x-ray beam. This permits the focusing of monochromatic x rays from this crystal onto the specimen being examined. This unit has been tested under simulated conditions, but actual installation is being delayed until a suitable crystal for the monochromator has been produced.

An existing stepper-motor synchronization device (Fig. 7.13.1) was redesigned in order to reduce fabrication costs. One of these devices is coupled to each stepper motor that drives the various angle modes of the diffractometer goniometer head. This device maintains synchronization between the angular position of the drive and the computer-controller readout system. The cost of this unit was reduced by approximately 40%. Twenty of these units have been fabricated for installation on four new diffractometers now on order. This device has been checked
out for satisfactory operation with a stepper motor under simulated conditions. Installation
awaits the receipt of the new diffractometers.

A computer-controlled operator was designed and fabricated for driving the beam-stop mecha-
nism, which is an integral part of the Picker x-ray tube housing. An electrical safety system
complete with indicator lights and interlocks continuously shows the position of the beam stop
to avoid any accidental exposure of personnel to the x-ray beam. In addition to this system, a
mechanical indicator also shows the position of the beam stop. One of these units was installed
on the Chemistry Division diffractometer and is performing satisfactorily.
8. Data Collection and Analysis

8.1 ACTIVITIES OF THE DATA PROCESSING AND ANALYSIS GROUP

R. K. Adams

R. R. Gaddis       R. F. Hyland
C. D. Martin       R. L. Simpson

The activities of the Data Processing and Analysis Group were continued in four basic areas: (1) interface programming, (2) data systems application, (3) data acquisition services, and (4) development of mathematical techniques in support of these activities.

In the area of interface programming (in addition to MSRE computer programming support reported in Sect. 8.3) work was done in data editing and error correction for data taken on the Millisadic data system and on data systems for the Solid State Division. Since these systems take data on punched paper tape, programs were written to convert data from paper tape to magnetic tape for the CDC 160-A computer, and editing was done on the magnetic tape data. One of these conversion programs is a little unusual in that it accommodates a format change in the body of the data tape.

In the application of data systems, three data systems were installed or modified for various research divisions. A chart reading head was designed and built for use with the low-speed data system reported previously, and this system is also being used by the Solid State Division. A microphotometer data system (formerly used for the Health Physics Division tissue analysis project) was modified to digitize data from recorder charts in a feasibility study for the Reactor Division. To improve reliability and maintainability, a paper-tape converter modification to the Millisadic data system is being built, and a design for subsequently replacing the paper-tape punch with an incremental tape recorder for producing magnetic tape in computer format is in progress. In the past year the Millisadic data system was used to collect some 400,000 cards of data for three experimenters, two of whom have continuing need for the service. The paper-tape output will facilitate the processing of Millisadic acquired data by eliminating many of the errors which now result from the magnetic tape to card conversion and will greatly improve the maintainability of the system. The applications support for the Dextir data system in the Reactor Division is reported in Sect. 7.9.

Work on the development and application of techniques for thermocouple table smoothing and calibration programs for the Standards Laboratory is reported in more detail in Sect. 8.4. A mathematical technique which has been applied by the group is of particular interest. It includes a least-squares-fitting and extrapolation procedure that is extremely simple and results in a very fast running data-editing program.

8.2 DATA COLLECTION AND ANALYSIS SYSTEM FOR THE MSRE

G. H. Burger
C. D. Martin J. E. Schmith

Acceptance tests of the MSRE data collection and analysis system\textsuperscript{2-4} were completed on October 1, 1965, and the system was accepted and placed in operation. Since then the system has been on line continuously except for sporadic failures and one long shutdown for modifications. The system has met all objectives and is a valuable tool for reactor operations. The use of the system was expanded by adding more input signals, more-refined calculations, and extensive data retrieval and processing programs. An additional benefit has been realized by using the data system as a closed-loop controller to control and match the temperatures of material specimens to the reactor core temperature profile, which is calculated by the computer.

For the first 11 months of operation the on-line availability of the system, based on 24-hr/day operation, was 97.31\%, exclusive of scheduled downtime. The total downtime was 221.7 hr. Although this record is short of the 99\% reliability and 1500 hr mean free time to failure required in the specification, the reliability did improve. For the last five months the availability was greater than 99.5\% (Fig. 8.2.1). More downtime was experienced during the first four months. Most of the system shutdowns were caused by failures in the analog-input components, which include input relays, four input amplifiers, an analog-to-digital converter, and associated control circuitry. Failures of these components, aside from normal shakedown failures, were due to poor quality control and inadequate design and testing of the specially built analog input units. Other causes were failure of components within the computer itself, errors in the design and fabrication of the system, and failures of transistors and diodes usually expected during the first few months of operation.

Programming problems were virtually nonexistent, since the programs were checked at the manufacturer's plant in April 1965. A number of programs were added and others altered to meet the changing requirements of the reactor operators and analysts as they gained more experience in the use of the data system.

\textsuperscript{1}General Electric Co., Atlanta, Ga.
Fig. 8.2.1 MSRE Computer Time Available.

The entire operation of the data system is routine. Most of the program additions and revisions and changes in system functions were completed. The retrieval and processing of previously stored data by use of the system and the facilities at the ORNL Computing Center is approaching a routine operating task.

8.3 MSRE COMPUTER PROGRAMMING

C. D. Martin     G. H. Burger

Programming responsibilities of the Instrumentation and Controls Division for the MSRE on-line computer include (1) on-line calculations, (2) data retrieval and utility programs, and (3) maintenance and improvement of the on-line programming system (executive or monitor system). A discussion of some of the work in these categories follows.

On-Line Calculation

Many calculations are automatically performed by the on-line computer at the MSRE to determine the states of the systems and reactor components. The use of the computer to make these
calculations saves many man-hours which would otherwise be required for manual calculation and provides the operators with “instant data” for guidance in operating the reactor. Most of these calculations were based on original reactor design assumptions, but as more experimental data were collected, many changes in the programs were made to achieve agreement between calculated and experimental results.

The computer was also programmed to control a test apparatus which subjects material specimens to the reactor core temperature profile. The computer calculates the temperature profile and adjusts controller set points to conform to the calculated profile. A digital model of the conventional three-mode controller is used to set heater power, and feedback signals are read by the computer from thermocouples in the test apparatus.

Data Retrieval and Utility Programs

Every 5 min all 350 input signals from the reactor to the computer are converted to engineering units and recorded on magnetic tape. In the past year approximately 45 data retrieval programs were written to print out and sometimes to make calculations using this recorded data. A utility program to calculate the machine comparator word for high and low limits for analog input signals was written and used extensively.

On-Line System

Of considerable significance were programs written to automatically restart the system in the event of an intermittent system failure. All code words and tables containing information concerning the status of the operating system are updated on the magnetic drum every minute. If an intermittent failure stops the system for as much as half a second, the executive (system control) program is reloaded from the drum; the updated code words and tables last written on the drum are reloaded in the core memory; tasks are scheduled to the current clock time; and the system proceeds as if nothing unusual had happened. This restart program facilitated the isolation of hardware failures from program problems and, thereby, greatly improved both the maintenance diagnosis and on-line availability. Since the incorporation of the automatic restart program, system availability has risen from 96 to 99.5%.

Several changes in the symbolic language on-line assembler resulted in reducing the drum memory needed by more than 16% and in speeding up the assembly process by using magnetic tape listing. Programs are now assembled more than 200 times faster than when they were assembled with the previous on-line typewriter listing. This allows long assemblies to be run on line with a minimum of interference with other background (data retrieval, etc.) operations. The magnetic tape output of the assembler might be listed on line at a later time when the system demands are less or it may be sent to the ORNL Computing Center for listing on the line printer, using a special program written for the CDC 160-A computer.
8.4 THERMOCouple TABLE STATUS REPORT

R. L. Simpson   R. K. Adams

Work in smoothing new thermocouple tables and intercomparison of tables continued during the year. Ten new cryogenic thermocouple tables from the National Bureau of Standards at Boulder, Colorado, were smoothed and compared with the old cryogenic tables \(^1\) (Fig. 8.4.1). The differences between the old and new smoothed tables were insignificant, which indicates that the NBS work to correct and smooth their data had no appreciable effect on the results after our smoothing techniques were applied to the original tables.

A new tungsten-rhenium table from the Englehard Company and the Hoskins Company in 10°C increments was interpolated to 1°C increments and smoothed. When compared with the old Englehard table \(^2\) (Fig. 8.4.2), a number of inconsistencies became apparent, and one manufacturer has since submitted some new data for analysis.

Some of the °C tables previously published were converted to °F tables; they were more consistent with their °C counterparts than the NBS °F tables (Fig. 8.4.3) published in NBS circular 561 (ref. 3).

A computer program was written to plot the thermoelectric power of a thermocouple \((de/dt)\) vs temperature, and all the rough and smooth (Fig. 8.4.4) tables were so plotted to make them available to researchers and as a check on the "reasonableness" of several new tables.

Because of the many requests for the smoothed tables from industrial establishments and research laboratories, the thermocouple tables are being shipped on a 6-in. reel of magnetic tape in place of two large boxes of computer cards. The magnetic tape is more convenient and costs less.

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\(^2\) Ibid., sect. 2.9.


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![Figure 8.4.1 Deviation of the Old Cryogenic Table from the New Table](image)

*Fig. 8.4.1 Deviation of the Old Cryogenic Table from the New Table. If the difference were zero, the plot would be a straight line along the zero axis. The maximum deviation of 0.2 \(\mu\)V represents about 0.00001°C.*
Fig. 8.4.2 Deviation of Original Englehard Table from New Hoskins Table. A thermocouple table is not expected to follow a curve as shown in the plot. The number of peaks and valleys show the inconsistencies between the two tables.

Fig. 8.4.3 Difference in Microvolts Between Values in the Table Converted from °C to °F and Those in the NBS 561 Fahrenheit Table. The shift of the plot from zero and the variation between 0 and 500°F show the inconsistencies in a few of the NBS 561 Fahrenheit tables.

The thermocouple tables in smoothed form (Table 8.4.1) are on file at ORNL and are available on request. Some tables are not considered standard, because they were made for materials not readily available in this country or because another table is considered to be a better fit to the curve of the thermocouple.
**8.5 WORK ORDER AND LABOR SUMMARY COMPUTER PROGRAM**

R. L. Simpson

A new computer program for preparing work order summaries was written to improve the method of processing work orders in the Division, to help in scheduling the work loads in each section in the Division, and to give the engineer the current status of the work orders assigned to him.

All work orders and associated information are stored on magnetic tape. The program (Fig. 8.5.1) is updated each month by entering new work orders, deleting work orders where the final cost has been received, entering new estimates from the engineer, entering the costs received from central accounting, and adding the time spent on the work order taken from the magnetic tape received from central accounting to the time spent on work orders and accounts by Division personnel.
## Table 8.4.1. Smoothed Thermocouple Tables

<table>
<thead>
<tr>
<th>Thermocouple Type</th>
<th>Source</th>
<th>Temperature*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>From</td>
</tr>
<tr>
<td>Pt vs Pt—10% Rh</td>
<td>NBS 561</td>
<td>0 C</td>
</tr>
<tr>
<td>Pt vs Pt—10% Rh&lt;sup&gt;b&lt;/sup&gt;</td>
<td>NPL</td>
<td>0 C</td>
</tr>
<tr>
<td>Pt vs Pt—13% Rh</td>
<td>NBS 561</td>
<td>0 C</td>
</tr>
<tr>
<td>Pt—6% Rh vs Pt—30% Rh&lt;sup&gt;b&lt;/sup&gt;</td>
<td>NBS</td>
<td>0 C</td>
</tr>
<tr>
<td>Chromel vs Alumel</td>
<td>NBS 561</td>
<td>—200 C</td>
</tr>
<tr>
<td>Chromel vs Alumel&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Potts-McElroy</td>
<td>0 C</td>
</tr>
<tr>
<td>Fe vs constantan</td>
<td>NBS 561</td>
<td>—190 C</td>
</tr>
<tr>
<td>Cu vs constantan</td>
<td>NBS 561</td>
<td>—190 C</td>
</tr>
<tr>
<td>Chromel vs constantan</td>
<td>NBS 561</td>
<td>—200 C</td>
</tr>
<tr>
<td>W vs W—26% Re&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Hoskins</td>
<td>0 C</td>
</tr>
<tr>
<td>W—5% Re vs W—26% Re&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Hoskins</td>
<td>0 C</td>
</tr>
<tr>
<td>W—3% Re vs W—25% Re&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Hoskins (11/65)</td>
<td>0 C</td>
</tr>
<tr>
<td>W—3% Re vs W—25% Re&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Englishard</td>
<td>0 C</td>
</tr>
<tr>
<td>W—3% Re vs W—25% Re</td>
<td>Englishard (11/65)</td>
<td>0 C</td>
</tr>
<tr>
<td>Au-Co vs Cu</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Cu vs constantan</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Normal Ag vs constantan</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Fe (Y) vs constantan</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Fe (J) vs constantan</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Chromel vs Au-Co</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Cu vs normal Ag</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Chromel vs constantan</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Normal Ag vs Au-Co</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Chromel vs Alumel</td>
<td>NBS Boulder</td>
<td>0 K</td>
</tr>
<tr>
<td>Pt vs Pt—10% Rh</td>
<td>°C Tables</td>
<td>32 F</td>
</tr>
<tr>
<td>Pt vs Pt—13% Rh</td>
<td>°C Tables</td>
<td>32 F</td>
</tr>
<tr>
<td>Chromel vs Alumel</td>
<td>°C Tables</td>
<td>—329 F</td>
</tr>
<tr>
<td>Fe vs constantan</td>
<td>°C Tables</td>
<td>—311 F</td>
</tr>
<tr>
<td>Cu vs constantan</td>
<td>°C Tables</td>
<td>—311 F</td>
</tr>
<tr>
<td>Chromel vs constantan</td>
<td>°C Tables</td>
<td>—329 F</td>
</tr>
</tbody>
</table>

*All table entries are in 1°C increments.

<sup>b</sup>These tables are not considered standard.
Fig. 8.5.1 Work Order and Labor Summary Programs.

Each month an engineer receives a printed list of all work orders assigned to him. All cross orders prepared by the engineer for the work order are listed below the work order. This list gives the engineer the current status of the work order and the total time in man-weeks that has been spent on the order by Division personnel. When the cost exceeds 75% of the estimate, a message is printed below the work order.

A list of all work orders in the system is printed in numerical order for management use. This list shows the group or section and engineer working on the work order, and the current estimates and costs.

A work order backlog is computed and printed, giving the engineering backlog in each section or group and the total work order backlog for the Division.

A separate computer program for preparing labor summaries was also written. The same magnetic tape used by the work order summary program is used to print a summary that gives for each department the time spent by each payroll (monthly, weekly, hourly) on other Division work orders and department work orders and charges.

9.1 THORIUM UTILIZATION PROGRAM

C. S. Lisser
G. W. Allin H. R. Brashear
F. M. Glass C. C. Hall
A. H. Malone W. R. Miller

The Thorium Utilization Program schedule,\textsuperscript{1} slowed down in 1965, has reverted to its earlier target date for operation of the Thorium-Uranium Fuel Cycle Development Facility (TUFcdf). However, the sol-gel fuel fabrication process was changed from production of powder to production of fuel microspheres from 200 to 600 \( \mu \) in diameter. This change multiplied the number of experiments and required additional test and development work in instrumentation.

Construction of the facility is in an advanced stage, although much of the cell structure and interior finishing has not been completed. Installation of building services instrumentation was begun, and the building control panel was fabricated by a subcontractor. Standard ORNL radiation and contamination system instrumentation for TUFcdf was designed, procured, and tested.

All parts of the microsphere production process are being tested in the laboratory as well as on an engineering scale. About eight tests are now in progress, with instrumentation measuring and controlling the important variables; these experiments are also used to test instrument concepts and developments intended for in-cell installation. Typical of the latter is a device for controlling the quality of microspheres produced from sol in the forming column. An electromagnetic driver vibrates a drop-forming attachment which controls the size of the spherical drops by selected combinations of frequency, amplitude, and sol flow rate (Sect. 10.11).

Originally, the equipment for fuel element fabrication had been designed to accommodate powder-filled metal tubes. Two machines, the vibratory compactor and the alpha monitor, were built. Instrumentation for the compactor includes the first ORNL application of solid-state industrial logic modules to production control. The alpha monitor was developed to replace the smear-taking technique of inspection, and tests show that it can detect 400 dis/min in the pres-

ence of up to 20 r/hr of gamma radiation from $^{60}$Co. A scan of 5 min is required for a sufficiently high confidence level.

Some of the equipment which might be used in the revised solids handling line was operated in scaled-down tests; of these, a rotary furnace and a fluid bed coater were instrumented. Final design of instrumentation for this phase of the TUFCDF has to await the selection of in-cell equipment.

### 9.2 NUCLEAR SAFETY PILOT PLANT

C. Brashear B. C. Thompson

The equipment and instrumentation in the Nuclear Safety Pilot Plant\(^1\),\(^2\) was modified to provide more efficient and safer operation and to improve data acquisition facilities for studies of transportation and fallout of fission products from the meltdown of fuel samples of greatly increased radioactivity in a steam atmosphere.

Some of the modifications and additions were as follows:

1. The capacity for measurement and control was more than doubled by adding a new penetration plug in the wall of cell B which contained 150 electrical circuits and 44 pneumatic lines. All electrical penetrations were sealed inside and outside the cell. The same fittings and sealing compounds recommended by the electrical industry for explosive atmosphere installations were used.

2. Radiation detectors and automatic cutoff valves were installed at each major process penetration.

3. A scintillation counter was installed to monitor radioactivity in the containment vessel. A new preamplifier and detector assembly was designed to provide sufficient signal to drive the remote monitor.

4. Twelve flow control systems were fabricated and installed in cell B. With these systems small flow rates through sequential air sampling devices located in the containment vessel can be regulated remotely at the control room.

5. A fog-density monitor for the containment vessel (Sect. 10.9) was installed. Three more will be installed in the future.

6. An emergency lighting and evacuation alarm system was designed and installed throughout the plant.

7. The cooling system for the sampler off-gas cold trap was redesigned to provide flow of liquid rather than slurry to the traps, thus eliminating the problem of plugged lines.

8. A system was designed and installed to provide automatic regulation of the differential pressure between the boat drive stuffing box and the containment vessel. The system senses the variable pressure of the model containment vessel and maintains the pressure of the stuffing box at a fixed positive pressure with respect to the vessel pressure.

9. A panelboard was added to the control room for new instrumentation, and the existing panelboard was rearranged to increase operating efficiency. A small console was added to the control room desk as a further convenience for the operator.


Many of the time-dependent samplers require the use of a stepping motor to precisely index a particular sample window or sample tube. A special motor designed by the Energy Conversion Systems Corporation was tested. The motor worked very reliably in a dry atmosphere at low ambient temperatures; however, in a moist atmosphere at 350°F the motor was unsatisfactory. The motor was redesigned; a new larger magnet and a new high-temperature coil were added, and greater clearances were used. Certain parts were chrome or nickel plated and sprayed with Formula 2-26 by Corrosion Reaction Consultants, Inc., to provide a protective barrier between the motor parts and moisture.

9.3 TRANSURANIUM PROCESSING PLANT

H. E. Cochran

The Transuranium Processing Plant is being operated full scale to produce gram quantities of $^{252}$Cf and varying amounts of other transuranium elements. Since the last report\(^1\) a complete shakedown of the instrument systems was completed; 1800 major components in over 300 separate instrumentation systems for chemical, metallurgical, and analytical processing were calibrated and checked for correct operation. A centrifuge and controls, and instrumentation for a second dissolver were installed. Additional controls were installed in the air compressor system to provide greater safety.

A Beckman Dextir data acquisition system is being installed. The system will initially scan 100 electrical signals and 128 pneumatic signals and record their values in computer-compatible format on seven-level magnetic tape. Because it has a "party line" cable, the system can be expanded to scan 100 data input units each having a capacity of 25 low-level analog channels and 25 digital channels. The data will be processed the same day they are gathered. At 8:00 AM on the following day, the processed data in a form desired by the experimenter will be available for his use in planning the operation for that day.

Trouble-free operation of the instrumentation systems has been the general case. However, during the process runs some problems did arise, as follows:

1. The nonbleed relays in the pulse-column interface-level control loops (Fig. 9.3.1) continued to fail. The seats in the relays were badly damaged. It was concluded that a low bleed rate provided in the process (forcing the relay plugs to operate near their seats) and close coupling of these relays with a pulsing pressure system caused the damage. Properly sized control valves were installed in place of the relays to overcome this problem.

2. Low-liquid-level alarms (Fig. 9.3.2) had been installed originally in the nonradioactive chemical feed tanks to the first- and second-cycle pulse-column sets. During the initial test runs of the plant, these systems were unreliable. A mockup revealed that air bubbles had accumulated

on the detector surface and reduced the coupling between the element and the liquid to produce a low-level alarm. All these elements were removed and replaced by glass gages.

3. Erratic drive of the charts of approximately 50 miniature recorders was caused by a faulty slip clutch in the drive assembly. The trouble was eliminated by the installation of a redesigned clutch assembly.

4. Solenoid valves actuated by an electric timer are used to alternately pressurize (with air) and evacuate all of the diaphragm transfer and pulser pumps in the chemical process system at rates up to 60 cpm. The solenoid valves selected for this application failed after a relatively short period of time. Life tests were run on the solenoid valves, and those with a greater life expectancy are being installed as the old valves fail.

5. A centrifuge tachometer had indicated that the centrifuge had stalled during one of the initial hot runs. Because of the cost of decontamination and removal of this piece of equipment, it was necessary to prove conclusively that the controls were not at fault. A spare centrifuge
motor with a squirrel-cage fan as a load was mocked up and wired to the terminal box at the cell penetration. A combination of checks to determine continuity of wiring from the terminal box to the motor in the cell and testing of the mocked-up centrifuge proved that the controls were not at fault.

9.4 PROJECT SALT VAULT

M. B. Herskovitz C. C. Hall

Instrumentation for the Project Salt Vault Experiment, reported previously,¹ was designed, fabricated, and placed in operation. The purpose of the experiment, located at the Carey salt mine in Lyons, Kansas, is to evaluate salt mines as long-term storage locations for high-level radiation wastes.

One of the major concerns at the beginning of the design in 1964 was the corrosive effect of salt on thermocouple sensors and interconnecting wires. These sensors were buried in the salt at strategic locations about the radioactive waste containers at distances up to 300 ft from the readout point (Fig. 9.4.1). For temperatures up to 100°C, high-density polyethylene thermocouple wells were used. For thermocouples in the range from 100 to 250°C, Teflon wells were used. In a few cases, where the temperature would be 250 to 800°C, type 304L stainless-steel-sheathed MgO-insulated thermocouples were buried directly in the salt. Interconnecting wiring consisted of polyvinyl chloride (PVC) jacketed multiconductor cable buried in the salt. To date, salt corrosion of these materials has been negligible.

Another problem anticipated during the initial stages of design concerned the use of persons not having instrument experience to install the instrument components and the associated interconnecting wires. The design plan was to (1) cut all cables to length and terminate all cable

Fig. 9.4.1 Layout of Experimental Area.
wires in multipin disconnects; (2) prewire all junction boxes and provide multipin disconnects mounted on these boxes (Fig. 9.4.2); and (3) provide all temperature sensors and readout instruments with multipin disconnects. After all subassemblies were received from instrument companies, the installation was completed ahead of schedule.

Difficulties experienced during installation were mostly due to crossed polarities in the multiconductor thermocouple cable assemblies and poor electrical terminations of 20 of 300 thermocouple sensor assemblies. A polypropylene radiation-gas sampling bottle is to be replaced by one fabricated from stainless steel.

The only remaining problem is being experienced with instrumentation for detecting off-gas gamma radiation. When the high-voltage lead is disconnected from the count rate meter, the cable must be shorted to dissipate the charge stored on the 200-ft length of cable. If the cable is not discharged before being reconnected, the transistors in the count rate meter receive an over-voltage, and the preamplifier is made inoperative. Correct operational procedure should alleviate this problem.

The experiment was placed in operation in November 1965 for two years. An annual maintenance contract was issued for maintenance of the temperature recorders.

Future activity is to be limited to engineering assistance on an as-requested basis.

Fig. 9.4.2 Prefabricated Multiconductor Cable, Junction Box, and Extension Pairs in Place.
9.5 FIXATION OF RADIOACTIVE WASTE IN ASPHALT

R. E. Toucey  T. F. Sliski

A small-scale pilot plant to test the feasibility of combining low-level radioactive liquid waste with asphalt was constructed in Building 4505. Liquid waste will be mixed with emulsified asphalt; then the mixture will be heated until the water is evaporated, leaving the solid waste contained in the asphalt. The pilot plant will be operated with nonradioactive liquid waste to test the process and system components.

Air-purged dip tubes and differential pressure transmitters were installed for measuring the level and density in the storage tanks. On tanks containing emulsified asphalt, a float-type level indicator was installed as a backup in case the dip tubes become plugged with congealed asphalt. Temperature control was required in the tanks and transfer lines to keep the emulsified asphalt from hardening. A proximity switch operates an impulse counter to measure the speed of the wiper blades in the wiped film evaporator vessel. Other instrumentation required included two multipoint temperature recorders for monitoring temperatures in the system.

Design of the instrumentation was completed, and the instruments were installed and tested. The initial shakedown runs were completed, and the pilot plant is ready for operation.

9.6 CONTAINMENT RESEARCH INSTALLATION

E. H. Bell

The installation of all the instrument systems was completed for the Containment Research Installation in a hot cell in Building 4501. 1 Figure 9.6.1 shows a control panelboard. All components were calibrated, and the pneumatic and electrical systems were checked for continuity and function.

Design modifications required the following additional instrumentation:

1. controllers to regulate the pressure on the sampler filters, furnace tube, and the annulus between the containment vessel and its liner;
2. controllers to regulate the temperature of the primary vessel and various sections of interconnecting piping;
3. seven flow controllers for the special ("LOFT") sampling system being operated for evaluation by Phillips Petroleum Company personnel.

During initial shakedown some of the remotely operated ball-type valves did not fully open or close when actuated, thereby aborting the run. To avoid this occurrence in the future, limit position switches coupled to indicating lights on the panelboard were installed on the shafts of the control valves located in critical lines of the process.

Two low-level runs were completed to determine the validity of the design.

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9.7 PLANNING IN THE PROCESS CONTROL AND INSTRUMENTATION SECTION

C. S. Lisser
P. M. Reyling R. L. Simpson

The volume and type of work handled by the Process Control and Instrumentation Section of the Instrumentation and Controls Division requires organization and planning to oversee and efficiently manage the work, to anticipate and schedule manpower requirements, and to utilize personnel to best advantage. For such planning, the following aids to better management, engineering, and maintenance methods were developed.

Management

Scheduling of manpower\(^1\) was continued. Engineering manpower allocations for the next year are being anticipated by summing the requirements for existing work orders and adding the ex-

pected blanket work order load and any additional work proposed by "customer" divisions. Control of work is aided by an internal cross-order system through which an engineer or foreman can subcontract work to others and be informed of its general progress by a monthly work order summary. This summary has been improved by three features:

1. Work orders are grouped and printed out under the name of the assigned engineer or foreman for easier access and distribution.
2. When a listed work order reaches 75% of the estimates in any of four categories, a warning is printed under the work order.
3. Instrumentation and Controls Division labor charges are automatically retrieved from time-keeping records and are printed out with each work order in the monthly work order summary, thus providing a check of estimated man-weeks vs actual man-weeks to date.

Engineering Methods

A manual for engineers was updated and reissued to a wider distribution and is being kept current. Included are some 46 instrument specifications for instruments bought on a repetitive basis. Use of these specifications not only materially reduces the time required for procurement but also ensures the purchase of quality instruments. The manual also contains test reports, instructions, standards, installation details, drawing symbols, and estimating rates, thus giving each engineer a compendium of details he need not reinvent or search out.

Along with others at ORNL, this Section began using microfilmed drawings, thereby reducing storage space and eliminating much travel between field and central print facilities.

The Section is also using a simplified system of incorporating instrumentation activities in large project critical paths in order to find the best balance between the need to show all time-consuming activities and the need to keep the number of charge codes to an acceptable level.

Planned Maintenance

The number of instruments at ORNL continues to increase, and each installed instrument adds to the demand for maintenance services. It is important to know where instruments are located by type and range, to record maintenance requirements, and to provide preventive maintenance where needed. A program and data cards were designed to identify each instrument by an assigned sequential number and type and to record its location and service history. The information retrieved from the program can be tabulated under many classifications, among which are:

1. location,
2. type,
3. range or size,

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4. manufacturer,
5. service date,
6. cumulative service hours,
7. type of service,
8. combinations of the above.

Some of the field-installed instruments are being tagged with identification numbers, and data cards are being completed for them. The system, now in use on a trial group of instruments, is being expanded.
10. Process Instrumentation Development

10.1 POWER-PROPORTIONING DEVICE

W. R. Miller

An inexpensive device to proportion power to a heater in a cryogenic experiment was designed and built (Fig. 10.1.1). Absolute input to output isolation is achieved by coupling of the light beam.

Small dc current signals (0 to 5 ma) from a temperature controller are amplified by a single transistor (Fig. 10.1.2) and fed to a No. 47 incandescent lamp mounted in the center of a heat-sink and light-shield assembly. Four power photocells mounted on the sides of the heat-sink assembly

Fig. 10.1.1 Power Proportioning Device.
Fig. 10.1.2 Schematic Circuit for Power Proportioning Device. (a) Control circuit, (b) heat sink wiring detail.

change resistance as the light intensity is varied. Three of the photocells are connected in parallel and serve as a series control element between the ac power line and a 40-w heater located in the experiment. A fourth photocell is utilized as a feedback element in the amplifier circuit to compensate for the nonlinear characteristics of the incandescent lamp. The greatly improved characteristic is shown in Fig. 10.1.3.

Essentially, the system forms an inexpensive (yet isolated) final control element which can often replace a more costly and complex magnetic amplifier or controlled rectifier unit. The unit also is free from the ripple and/or radio-frequency interference effects of the latter devices.

10.2 BASIC CONTROL UNIT

W. R. Miller     L. H. Thacker

A process or furnace controller was designed and built (Fig. 10.2.1) which for economic and reliability reasons was designed as a basically simple unit. Many such units were applied to small experiment needs at ORNL with excellent results.

The process variable signal, derived from either a thermocouple, an automatic optical pyrometer, or a power-sensing transducer, is compared directly to the set-point signal at the summing
Fig. 10.1.3 Power Proportioning Device Characteristics.

Fig. 10.2.1 Basic Control Unit.
junction of an economy-grade (cost less than $50) operational amplifier. The resulting difference (error signal) is amplified and modified by the components in the negative feedback network of the amplifier to provide proportional (gain), reset, and rate response. Interaction between these functions was minimized in the design of the feedback network.

Bumpless transfer from automatic to manual mode is accomplished by artificially loading the unused mode. A dual-function meter indicates the difference between automatic and manual output signals during transfer operations and provides an indication of output signal during normal automatic operation.

The operational amplifier is protected from accidental input signal overloads by protective diodes. Electrolytic capacitors in the feedback network operate back to back in the nonpolar configuration, since the output signal goes both positive and negative 10 V.

A commercial silicon controlled rectifier power-proportioning device is used with this unit for furnace operation.

10.3 PROGRAM GENERATORS

W. R. Miller    L. H. Thacker

Six program generators were designed and built to control furnaces used in chemical and metallurgical studies. Although there were some variations in detail among the six units built, all automatically change the controlled furnace temperature at a preselected linear rate (i.e., a "ramp" rate) between preselected upper and lower reference temperatures. The generators accept and control on the basis of signals from thermocouples, optical pyrometers, or power transducers; the programmed output is tailored to the specific requirements of the individual experimenter. All program parameters are selected by appropriate settings on ten-turn potentiometers. No equivalent commercial program generators are known to be available.

A sample temperature program is shown in Fig. 10.3.1. In the case illustrated the linear temperature change, or ramp, is reversed at each reference limit; thus the temperature automatically cycles between limits. Other programs provide ramping between limits without subsequent cycling and the option of independent up-ramp and down-ramp times.

![Diagram of sample temperature program]

Fig. 10.3.1 Sample Temperature Program.
Fig. 10.3.2 Schematic Circuit for Linear Program Generator.

A simplified schematic of a representative linear program generator is shown in Fig. 10.3.2. The ramp signal generated by amplifier 1 and limited by the Zener diode across the feedback capacitor is adjusted to a standard 0- to 10-v signal in conditioning amplifier 2. This signal is applied to the bottom of the low-reference potentiometer and is inverted by amplifier 4 and applied to the top of the high-reference potentiometer.

Initially (with the ramp signal at zero), the wiper of the low-reference potentiometer can be adjusted to any value between 0 and 10 v. There is no signal from the wiper of the high-reference potentiometer, because the output signal from the inverting amplifier (4) is zero.

As the ramp progresses (Fig. 10.3.3), the signal from the low-reference potentiometer goes to +10 v (regardless of setting), and the signal from the wiper of the high-reference potentiometer goes from 0 to a percentage of the -10 v signal (depending on the setting).

The summation of these signals by amplifier 5 yields a program demand signal that conforms to the low- and high-reference settings. The ramp time period is independent of the reference values selected.

Amplifier 3 detects when the ramp signal crosses either 0 or +10 v and actuates relay K1 to reverse the direction of the ramp signal and to change the reference input to amplifier 3.

Bumpless transfer between the programmed demand signal and a manual control mode is accomplished by isolation amplifier 6, which allows precise balancing before switching between modes. The controller output assumes whatever value may be required to maintain a null between the demand and feedback signals.
10.4 CONSTANT-POWER POWER SUPPLY

G. W. Greene

A small power supply capable of maintaining constant power input to a variable resistive load (a calorimetric flowmeter) was required. Figure 10.4.1 shows a circuit designed for this purpose. Only a preliminary bench test was made because the project for which the circuit was developed was canceled. Results of the test are shown in Fig. 10.4.2.

A description of the circuit follows. A voltage $V_1$ from the constant-voltage power supply is impressed across the load $R$ in parallel with the slide wire $S$, causing current $I$ to flow. A small millivolt signal, proportional to current $I$, is developed across the series resistor marked "shunt" in Fig. 10.4.1. This signal is amplified by the servo amplifier which, in turn, causes the servomotor to position the wiper on the slide wire $S$. Now, since the voltage impressed across the slide wire $S$ is identical to the voltage across load $R$ and the position of the wiper on the slide wire is proportional to current $I$, then voltage $V_2$ is proportional to $V_1 \times I$, or to the power dissipated in load $R$ (neglect the millivolts dropped across the shunt, the transistor base to emitter voltage, and the small current through the slide wire). Since $V_2$ is fed back to the control circuit

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Footnote: Patent applied for.
of the supply through $Q_1$, the voltage $V_1$ across the load $R$ is caused to vary in a manner that maintains $V_2$ constant as the resistance of load $R$ varies.

Transistor $Q_1$ acts as an emitter-follower isolation amplifier to reduce the loading of slide wire $S$ by the remote sensing terminals of the constant-voltage power supply.

Although this circuit was designed for use in a system requiring only a small amount of power, there is no apparent reason why it could not be modified to control any size power supply having the remote sensing feature.

The load $R$ was varied by a factor of almost 5 to 1 in the test, but it is not likely that this much variation would ever be encountered in actual practice.
10.5 FURNACE BURNOUT MONITOR

J. T. Hutton

Graphite helix high-temperature furnaces used in extended tests of materials at elevated temperatures are subject to unexpected burnout. If this occurs overnight or over the weekend, the time of furnace burnout and the total time at temperature for the specimens cannot be determined. For this reason, a furnace burnout monitor was developed.

The circuit shown in Fig. 10.5.1 was designed and placed in service. Since the furnaces operate on ac power, the current-carrying power line to the heater element is used as a single-turn primary in a stepup, clamp-on transformer (constructed from a small high-voltage inverter transformer). The transistor switch circuits from several furnaces being monitored control pen solenoids of an inexpensive event recorder to give an indication of furnace burnout. With the component values shown, the switches are on for heater currents of less than 10 amp and actuate pen solenoids drawing up to 100 ma at 24 v dc. The monitor circuit was designed so that current flowing to the heater element keeps the pen solenoid deenergized.

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Fig. 10.5.1 Furnace Burnout Monitor.
10.6 MULTIPONT RECORDER PROGRAMMABLE RANGE CONVERTER

J. T. Hutton

A versatile range converter was designed to provide signal conditioning for as many as 12 low-level inputs. The converter is used with a multipoint strip-chart recorder and will change ranges in step with the recorder point-selector switch. Both linear and logarithmic ranges are provided.

The range converter was designed primarily for use with a Beckman DB uv spectrophotometer which has an output of 0 to 100 mv proportional to transmittance. Since the experimenter was interested in determining the concentrations of various components in test specimens, the spectrophotometer output was converted from transmittance to absorbance. Several different absorbance ranges were made available so that both weak and strong concentrations could be handled. The converter will also record linear signals such as pH, temperature, and control settings.

A block diagram of the range converter is shown in Fig. 10.6.1. The logarithmic conversion is accomplished in the first operational amplifier stage which has an output of 2 to 0 v for an input of 1 to 100 mv. Since the recorder has a 100-mv range, the first-stage output must be attenuated in the second amplifier stage; different second-stage attenuations provide the required absorbance ranges. Linear inputs are fed through the first amplifier stage (with linear feedback elements switched in instead of the logarithmic element). The switching of feedback elements

![Block diagram of the range converter](image)

Fig. 10.6.1 Programmable Range Converter.
in the operational amplifier circuits is done with relays that are energized in step with the recorder input selector switch; front-panel range switches are used to select the required relays to give the desired range for each input. Linear ranges of 1, 10, 50, and 100 mv full scale and absorbance ranges of 2, 0.5, and 0.1 full scale are provided. Accuracy of the range converter is better than ±0.5% for all ranges.

10.7 TANTALUM PROCESS VALVE

G. W. Allin    Bernard Lieberman
H. J. Stripling, Jr.

A pneumatically operated two-way diaphragm valve was developed for the californium recovery system of the Transuranium Processing Plant (TRU). Tantalum and tantalum-tungsten alloys were used in the construction of the process-wetted region of the valve to minimize contamination of process materials with corrosion products. This valve is similar in most respects to one previously developed for TRU.¹

The valve requirements are as follows:
1. packless helium-tight construction to be used, with helium leakage not to exceed 10⁻⁸ cm³/sec at standard conditions,
2. seat leakage not to exceed 1 cm³/min of air at a differential pressure of 50 psi,
3. radiation-resistant materials to be used throughout,
4. maximum actuator operating pressure to be 80 psi,
5. minimum flow coefficient to be 0.13 at a differential pressure of 20 in. H₂O with 1 psig at the inlet,
6. process-wetted parts to be made of tantalum or a suitable substitute,
7. tapered quick-disconnect ports to facilitate remote installation and removal.

The upper body, which is the process-wetted region of these valves, is 2½ in. square and 3/4 in. thick and is sandwiched between the lower body and the operator, whose parts are made of stainless steel (Fig. 10.7.1). The diaphragm is 0.005-in.-thick tantalum–10% tungsten.

The upper body of the prototype valve was made of tantalum. When tested, the tantalum seat deformed excessively after very few operating cycles, resulting in excessive seat leakage. The design of the valve was changed to accommodate a seat insert (Fig. 10.7.2). Seat inserts of Zircaloy-2, tantalum–5% tungsten, and tantalum–10% tungsten were cycled under test conditions. Tantalum–5% tungsten was chosen as the insert material because it did not deform under load, it provided slightly better seat leakage results than the tantalum–10% tungsten, and it is more corrosion resistant than Zircaloy-2. Several insert designs were tried before a satisfactory one was developed.

Fig. 10.7.1 Tantalum Process Valve.

Fig. 10.7.2 Typical Section Through Tantalum Process Valve Upper Body with Insert.
Since solid tantalum–10% tungsten had been ordered for fabrication of upper bodies if insert troubles had persisted, the upper bodies of some valves were made from tantalum–10% tungsten. Other valves have tantalum upper bodies and tantalum–5% tungsten seat inserts.

The sealing surface in contact with the diaphragm of the solid tantalum–10% tungsten bodies was grooved to achieve a helium-tight seal at this joint.

The lift (distance above the seat that the diaphragm moves) was increased from 0.008 in. (lift of previously developed valves) to 0.012 in. This is the maximum lift that the pneumatic operator can handle when operated at 80 psi.

Fourteen valves were fabricated and are presently in service; six more are being fabricated.

10.8 GRAPHITE EVALUATION PROGRAM

L. H. Thacker W. F. Johnson

The Reactor Division is carrying out a program to evaluate the relative thermal rupture resistance of various types of graphite under intense differential heating. The heat is supplied by an electric welding torch applied to the center of one surface of a disk-shaped specimen, and temperatures above 3000° C at the center of the specimen are sometimes obtained.

Instrumentation (Fig. 10.8.1) was provided for measuring and recording the following test parameters: (1) torch current and voltage, (2) temperature at up to ten points on a radius of the specimen disk, and (3) time at which cracking of the specimen occurs. All parameters are

![Graphite Evaluation Instrumentation](ORNL-DWG-66-8184R)
recorded on a multichannel oscillograph for easier cross correlation; all inputs to the oscillograph are conditioned by commercial galvanometer-driver amplifiers.

The torch voltage is measured directly. The current is measured by the voltage drop across a 50-mv 1000-amp shunt and conditioned by an operational amplifier used as a preamplifier.

To obtain the surface temperature distribution of a specimen, a studio camera is used to focus an image of the specimen disk on a special ground-glass plate upon which is mounted a ten-element linear array silicon photovoltaic detector. The image can be oriented on the detector as desired by the operator. The detectors are utilized in the short-circuit current-operating mode to improve linearity and to decrease the sensitivity to ambient temperature changes; the short-circuit mode of operation is obtained by using operational preamplifiers as current-to-voltage converters. The silicon detector outputs are calibrated by using an automatic two-color optical pyrometer with narrow-angle optics to measure the temperature at each of the silicon detector image points. To obtain additional correlations, a thermocouple is used for measuring lower temperatures near the rim of the specimen.

A commercially available moving-coil stethoscope detector was modified by attaching an 8-in. steel probe to the diaphragm and potting the detector in RTV silicone compound. The probe was mounted in a bushing and spring loaded against the side of each graphite specimen; the device very clearly detects the mechanical disturbance associated with cracking of the disk.

10.9 NUCLEAR SAFETY PILOT PLANT FOG DETECTOR

L. H. Thacker

A prototype instrument for measuring the optical density of fog and/or smoke concentrations in the NSPP model containment vessel was built and then tested during plant operation (Fig. 10.9.1),

Fig. 10.9.1 Aerosol Density Monitor.
The instrument detects the attenuation of unpolarized broadband radiation from a tungsten filament lamp. The light beam is projected diametrically across the vessel and impinges on a photoconductor in the input circuit of an operational amplifier used as a current-to-voltage converter. Zero suppression is provided to cancel out the input current from the photodetector and give zero output to the recorder when no light-scattering material is in the beam; total extinction of the beam is established as 100% span by adjusting the span potentiometer. Amplifier outputs up to 10 v dc at 2 ma are available.

The results obtained during operation are qualitative in that no attempt was made to analytically or empirically relate the observed optical densities to the mechanical densities of material suspended in the model containment vessel atmosphere. However, the measured optical density can be correlated with events known to be happening in the vessel, and the instrument is expected to provide an effective new channel of test information.

10.10 PNEUMATIC SCANNING SYSTEM

W. R. Miller

A system to sequentially scan 24 pneumatic signals and convert them to electrical signals was designed and built as part of an on-line process computer system. A commercial product to satisfy this requirement was not available at the time. Economic considerations dictated the use of a minimum number of costly transducers ($200 each).

Two 12-point rotary pneumatic selector switches, each driven by a separate solenoid stepper, are operated in unison. The common port of each pneumatic selector is connected through very low volume tubing and fittings to a flush-diaphragm pressure transducer. The computer is programmed to alternately read signals from the two transducers between stepping pulses.

Short-duration power pulses to prevent stepper coil overheating are generated by a one-shot power driver (Fig. 10.10.1). The driver is triggered by a contact in the computer that closes for 1 msec every 116 msec. This action shorts out a 1-v signal at the driver input, causing the circuit to fire and advance the steppers one position. The timing sequence for the entire system is shown in Fig. 10.10.2.

A dual-channel amplifier and power supply that also furnishes excitation for the transducers is shown in Fig. 10.10.3. Volume limiting throughout the pneumatic system and the use of undamped solid-state operational amplifiers provide a stable signal to the computer 10 msec after a step pressure change from 0 to 15 psi.

The entire system is diagrammed in Fig. 10.10.4. Although designed for a specific application, the pressure system is capable of much faster operation as evidenced by the 10-msec pressure signal stabilization time.
Fig. 10.10.1 One-Shot Power Driver – Ledex Steppers.

Fig. 10.10.2 Signal Timing Sequence.
TRANSDUCER F.S. SIGNAL OUT = 8 mv
AMPLIFIER F.S. SIGNAL OUT = 0—120 mv
AMPLIFIER GAIN = 15

Fig. 10.10.3 Transducer Excitation and Signal Amplification.

Fig. 10.10.4 Pneumatic Scanning System.
10.11 MICROSPHERE PRODUCTION

W. R. Miller

Reactor fuel in spherical form offers optimum cooling area and is an ideal form for uniform density packaging. Fuel spheres, 200- to 500-μ range, are produced from a colloidal suspension of thoria in an alcohol drying column by using various dispersing methods. The dispersing devices currently in use produce 80 to 90% uniform spheres but do not provide sufficient latitude in the control of sphere diameter for production purposes.

A new dispersing device, designed and built for Chemical Technology Division, can be remotely adjusted to provide a wide selection of sphere diameters. In test runs with this device, production quantities are being made with a uniformity as high as 99%.

A developmental dispersing device (Fig. 10.11.1) has a 12-in. loudspeaker as a transducer to drive four hypodermic nozzles whose tips project just below the surface of the alcohol in the drying column. Thoria gel, fed through the nozzles at a specific flow rate, is converted to spherical droplets by the reciprocating motion of the transducer (Fig. 10.11.2).

Fig. 10.11.1 Dispersing Device.
The loudspeaker is driven by a commercial 30-w audio amplifier; a conventional sine-wave audio generator is the signal source. The sphere diameter is remotely controlled by selected combinations of frequency and amplitude at specific flow rates.

Selection of a nozzle type to eliminate the production of fines, the method of attaching the nozzles to the transducer to minimize harmonic motion, and the reduction of mass to permit operation at full amplitude above 200 cps were problems overcome during development.

10.12 PRESENT STATUS OF RESISTANCE-TYPE LIQUID-METAL LEVEL DETECTORS

G. W. Greene  C. M. Burton
N. H. Briggs  E. G. Meyer

The development of resistance-type liquid-metal level sensors has gone through a series of evolutionary designs, which started with the J-tube,\(^1\) progressed to the I-probe,\(^2\) and has presently culminated in a design called the Twin-I-probe.\(^3\)

J-tubes are no longer being used in new installations at ORNL; some are still in use in earlier loops. J-tubes have been used because they can be installed through the top of a vessel when the bottom of a vessel is not accessible or when a weld below the surface of the liquid metal is not wanted. The J-tube is difficult to fabricate.

The I-probe (Fig. 10.12.1) has the following advantages over the J-tube: it is of much simpler construction, it requires less space, and its output signal is linear over more of its active length.

Both the J-tube and the I-probe require ac excitation (hence, ac readout) for satisfactory operation when there is a temperature gradient along the probe. As shown in the equivalent circuit in Fig. 10.12.1, a thermal emf is generated between the liquid metal and the level element sheath. This thermal emf has been measured and found to be as much as \(\pm 15\%\) of the output signal from the transducer. Thus, there was a definite need to develop a level transducer which could be dc excited without producing thermal emf in its output. This would allow the simpler, more readily available dc millivolt readout instruments to be used.

Such a transducer is shown in Fig. 10.12.2. It is essentially two identical I-probes (hence, the name Twin-I-probe) connected in a manner that results in complete cancellation of the thermal emf generated and a doubling of the level signal (assuming equal exciting currents) generated in each sheath.

Figures 10.12.3 and 10.12.4 show the results of tests made on an I-probe and a Twin-I-probe, respectively, both of which were dc excited. Although the relative sensitivities of the two transducers were different, preventing direct comparison of the two curves, it is apparent that


considerable improvement in the data was effected by use of the Twin-I-probe. (The test of the Twin-I-probe covered a temperature range of 400 to 1400°F vs 600 to 1200°F for the I-probe.)

An additional advantage of the Twin-I-probe (Figs. 10.12.3 and 10.12.4) is that its millivolt output goes to zero at full level, thus eliminating the need for a suppressed-range readout instrument.

10.13 DEVELOPMENT OF RESISTANCE-TYPE LIQUID-METAL LEVEL ELEMENTS

N. H. Briggs  G. W. Greene  R. F. Hyland

The continuous and accurate measurement of liquid-metal level at temperatures up to 2200°F is required in many experiments now being conducted at ORNL. We have designed and tested and are using resistance-type continuous liquid-metal level indicators, which we call "I" tubes, that are inserted through the bottom of process vessels containing liquid metal. This device, first suggested by others,\(^2\) will be described in detail in a forthcoming report.\(^3\)

Fig. 10.12.2 Twin I-Probe and Its Equivalent Circuit.

Fig. 10.12.3 I-Probe Level Element Output with DC Excitation.
A typical installation of an "I" tube in a process vessel and its equivalent electrical circuit is shown in Fig. 10.12.1. An "I" tube for operation up to 1500°F is comprised of a swaged stainless steel sheath containing two stainless steel wires insulated with MgO. For higher temperatures and in vacuum environments, refractory metal "I" tubes were made using Cb–1% Zr wires and tubes and hard-fired Al₂O₃ insulation.

The wire resistance $R_w$ of the "I" tube is made approximately 100 times the sum of the resistances of the tube wall ($R_{Ta} + R_{Ti}$), where $R_{Ta}$ designates the active portion and $R_{Ti}$ designates the inactive portion of the sheath-wall resistance. Thus, the output of the "I" tube is given approximately by $E_{out} = E_{in} (R_{Ti} + R_{Ta})/R_w$. With $E_{in}$ held constant or with any variations of $E_{in}$ compensated for in the readout instrument, the output voltage $E_{out}$ is a linear function of the liquid-metal level; it decreases as the liquid-metal level increases, from 100% of the maximum signal to a minimum that depends on the inactive resistance of the "I" tube below the process vessel (the minimum signal is about 20% of the maximum signal for the design shown in Fig. 10.12.1). With the sheath and the internal wires made of the same material, the ratio of
resistances \( \left( R_{T_1} + R_{T_2} \right)/R_w \) remains unchanged with temperature; thus, temperature compensation at thermal equilibrium is inherently achieved.

The emf range of the "I" tube can be predicted to within ±10% or better by use of resistance values measured at room temperature. With an in situ calibration with liquid metal, this range can be determined to within ±2% or better at operating temperatures.

The level elements can be excited by either ac or dc power supplies. With the low electrical signals being measured, dc excitation is preferred because less-complex instrumentation is used. However, with dc excitation, the output voltage \( E_{ou1} \) may contain large errors owing to thermoelectric emf's. These are generated between the sheath and the liquid metal by temperature gradients existing either along the "I" tube or between the "I" tube and the vessel wall.

In several large potassium experiments being conducted at ORNL, the range of differential pressures is too low to be measured accurately with differential pressure transmitters available for use in high-temperature liquid-metal systems. An important application of the "I" tube level element is its use as a manometer for determining such small differential pressures in liquid-metal systems. The longest liquid-metal manometer used to date in a potassium experiment was 48 in. long (a \( \frac{3}{8} \)-in.-OD "I" tube installed within a 1-in. sched-40 pipe). The accuracy of such a 48-in.-long manometer was determined to be ±2% of the active length over the temperature range 400 to 1400°F with ac excitation. The same accuracy was achieved with dc excitation when correction was made for the thermoelectric emf.

10.14 INSTRUMENT DEVELOPMENT AIDS

W. R. Miller L. H. Thacker

The greatly increased use of operational amplifiers in special instrumentation has led to the development of several pieces of auxiliary equipment to facilitate breadboarding of complex systems efficiently and economically.

The simplest of these development aids is a printed-circuit, single-amplifier breadboard with accommodations for input and feedback components in either the single-ended or differential input modes (Fig. 10.14.1). Plug-in input and output terminals, power supply terminals, and output meter terminals are provided on each board. As an aid to the designer the printed-circuit wiring is on the top side of the board, showing immediately the relationships among plug-in components.

Although the single-amplifier boards can be assembled in complex arrays using only patch cords, it has been found convenient to produce a five-amplifier board (instrument simulator) with an integral ±15 v dc power supply and ten 10-turn potentiometers for establishing coefficients, zero suppression, constant inputs, etc. (Fig. 10.14.2). The five amplifiers plug into sockets on the board, and any ±15 v dc amplifier that meets the specific requirements of the problem at hand can be adapted for service by using a small printed-circuit adapter board produced for this purpose. This assembly has proved very useful, both in developing special systems and as a temporary component in research instrumentation systems.
Fig. 10.14.1 Single Amplifier Breadboard.
10.15 NOZZLE FLOW STABILITY IN PNEUMATIC TEMPERATURE MEASUREMENTS

E. W. Hagen

The ORNL study of pneumatic gas thermometry using sonic flow nozzles\textsuperscript{1} was terminated. The last series of tests for long-term stability of typical EGCR nozzles showed that nozzle flow coefficients varied considerably during 614 days of operation in a test loop. The variations caused an error four times that specified for the whole EGCR-PTM system.

With respect to nozzle material performance, there was no significant differences between Inconel and nitried type 304 stainless steel nozzles; however, the Inconel nozzle conformed to a more predictable pattern and was rated the best of all materials tested. If this work is carried further, we suggest that sapphire be considered as throat construction material, provided that such sapphire liner can be mounted satisfactorily. Another recommendation is that the nozzles be temperature conditioned before in-system use. This recommendation is based on the observation that major changes in stability occurred during the first few hours of a nozzle test and that these changes did not recur.

In general, we conclude that a pneumatic temperature measuring technique may have advantages over the use of thermocouples in high-temperature applications requiring long-term reliability.

10.16 SYSTEM FOR MEASURING THE THERMAL DIFFUSIVITY OF SOLIDS BY THE LASER FLASH TECHNIQUE

J. W. Krewson    R. E. Wintenberg

The Heat Transfer—Fluid Mechanics Group of the Reactor Division was assisted in selecting and developing electronic equipment for measuring the thermal diffusivity of solids by the laser flash technique (Fig. 10.16.1).

The thermal diffusivity of a material is the rate of heat flow through the material and is a function of specific heat, density, thermal conductivity, and initial temperature of the material. The measurement method is to expose a thin disk of material to a very short (50 to 500 μsec) and powerful (5 to 10 J) pulse of energy from a laser and to measure the rate of change of temperature of the back, or unexposed face, of the disk. The specimen is mounted in a furnace so that its initial temperature can be varied by the experimenter. In this experiment the initial temperature of the specimen will be varied from room temperature to 5000°F. The temperature

![Diagram]

Fig. 10.16.1 Flash Diffusivity Control and Data Recording System.
increase of the specimen resulting from the laser pulse is expected to be about 10°F. The change in temperature of the specimen will be detected by a thermocouple at room temperature to 2000°F and by photovoltaic detectors at 1000 to 5000°F. All data will be displayed on an oscilloscope and photographed. The time sequence is described in Table 10.16.1.

Table 10.16.1. Time Sequence of Laser System for Measuring Thermal Diffusivity of Solids

1. Trigger pushbutton is pressed momentarily and then released. The capacitor in use is charged, and the laser is ready to fire.
   a. “B” time base is started.
   b. Camera shutter solenoid is energized.
   c. Ground is removed from SCR trigger pulse generator in remote control box.

2. Camera shutter opens (the delay is due to solenoid and shutter inertia) and remains open for the preset exposure time, which normally is 1 sec.

3. “B” time base ends; “A” sweep starts.

4. At approximately 1 cm of “A” sweep, a delayed low-level pulse from the oscilloscope fires the SCR trigger pulse generator in the remote-control box. This generates a high-level pulse that actuates the high-voltage control circuit in the laser cabinet, which in turn discharges the energy storage condenser through the xenon flash lamp and ruby laser.

5. The flash of the xenon flash tube is detected by a photodiode, the output of which produces a marker pip on the oscilloscope trace.

6. The laser pulse has heated the sample, causing its temperature to change. The amplitude and rate of this temperature change are detected either by attached thermocouples or an infrared detector (or both) and displayed on the oscilloscope. The trace is photographed.

7. The camera shutter closes.

The laser is a pulsed, water-cooled, ruby laser. The laser pulse length and pulse power are controlled by the capacity of the energy storage condenser in the flash lamp circuit and by the voltage to which this condenser is charged. The cooling water pump, heat exchanger, water supply, and deionizer for this system are contained in a small cabinet separate from the main control cabinet. The laser head, together with its associated reflectors and lens support, is mounted on a rigid aluminum bed. It is electrically connected to the laser control cabinet by high-voltage cables.

To date, this system has had limited operation. A new, higher-temperature furnace is being installed; work is proceeding on eliminating noise problems; and the design of a suitable specimen mount is being investigated.

10.17 AUTOMATIC DIFFERENTIAL THERMAL ANALYZER

L. H. Thacker W. R. Miller

An automatic differential thermal analyzer (DTA) was designed and built for use in Reactor Chemistry Division studies of molten fluoride salt systems at temperatures to 1200°C. The system (Fig. 10.17.1) includes signal conditioning and recording equipment and equipment to control and program the DTA furnace temperature.
Differential thermal analysis is a technique by which the thermal properties of a material specimen are compared with those of a reference material at the same temperature. The specimens being studied are contained in two crucibles (A and B in Fig. 10.17.1), each with a thermocouple in a tube reentrant from the bottom. The thermocouples are referenced to an ice bath and are so connected that two outputs are provided: the reference specimen (B) temperature and the difference in temperature (∆T) between the two specimens. The ∆T signal is amplified as required and can be recorded directly or the derivative with respect to time can be taken and recorded; the reference specimen temperature is fed through the analyzer unit and provides the horizontal x-y recorder input.

The system is controlled by a program generator (Sect. 10.3) which automatically varies the sample temperature at a preselected linear rate between preselected upper and lower temperature limits. The furnace temperature signal is provided by a third thermocouple in the DTA furnace, and the program generator controls the furnace temperature through a 2.3-kw silicon controlled rectifier power-proportioning device. The program generator also provides automatic offset of the data trace on the x-y recorder; up to 24 traverses across a given temperature range can be made without operator attention.
10.18 ELECTROLYTIC POLISHING CONTROLLER FOR ELECTRON MICROSCOPE SPECIMENS

T. M. Gayle J. T. Hutton

Development work was continued on the electrolytic polishing controller for electron microscope specimens. The preliminary model previously reported1 was redesigned with major improvements in the light source and detector system.

The improved light source was built around the type DAH high-intensity projection lamp rated at 10,000 lumens output at a color temperature of 3200°K. The lamp is force cooled with a medium-sized centrifugal blower, and a vacuum tube heat shield is used on the envelope to break down the film coefficient of the cooling air and to provide increased heat dissipation area in the air stream. Normally the lamp has a rated life of 200 hr; this is extended considerably by bringing the lamp filament up to rated current with a full-wave unijunction transistor, triac power control circuit. The usual potentiometer for controlling the triac firing angle is replaced with a thermistor heated by a power resistor (Fig. 10.18.1). When the lamp is first switched on, the firing angle of the triac is very narrow, and lamp current is close to zero. As the power resistor heats up, the thermistor resistance drops, gradually increasing the firing angle and resultant lamp current. A 60-sec time-delay relay shorts out the triac circuit after the lamp is at essentially full current. The power circuits are interlocked so that the lamp cannot be turned on until the blower is started.

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The light beam is coupled to a fiber optic bundle through a clad glass rod (American Optical No. CR-2-12) which absorbs a portion of the infrared component of the beam. This keeps the temperature at the face of the epoxy-bonded fiber optic bundle at an acceptable level. The glass rod is cooled along its length with a small-sized blower.

The flexible fiber optic bundle transmits the light beam to a special electropolishing cell. Focusing lenses on both the input and the output side of the cell concentrate the light beam and reduce stray light pickup. A second fiber optic bundle picks up the transmitted light beam as a hole is polished through the specimen. The second fiber optic bundle couples the light beam to the photo field-effect transistor light detector.

The detector circuit was modified to be compatible with both a single transistor sensor, which is used for most processing, and with a dual transistor sensor, used with high-optical-density electrolytes requiring extra sensitivity. The second transistor balances out the effects of temperature drifts in the photo transistor. Crystalonics FF600 photo transistors are now being used as the photosensors.

10.19 PRECISION OPTICAL EXTENSOMETER

G. W. Allin       J. T. De Lorenzo

An automatic, recording optical extensometer (Figs. 10.19.1 and 10.19.2) designed by Southern Research Institute, Birmingham, Alabama, was fabricated with certain modifications by ORNL for the Reactor Division Stress Laboratory. This instrument is designed for making precision strain measurements on test specimens at elevated temperatures, where direct contact with the specimens would not be practicable. It has a null-balance servo system coupled to an x-y plotter to produce stress-strain diagrams.

Small-diameter graphite pins, herein referred to as flags, are attached to each end of the specimen to serve as gage marks. At specimen temperatures above 2000°F, the flags are self-illuminating. An image of each flag is projected by separate telescopes (Fig. 10.19.3) to an aperture subassembly containing two edge-defining apertures for each image. The distance between the two apertures is adjusted so that each edge of the image is coincident with one edge of each of the apertures. In this null position no light reaches the photoresistor cell (Fig. 10.19.4a).

A light-beam chopper whose axis intersects and is perpendicular to the axis of the telescope is located immediately behind the secondary lens of each of the telescopes. The chopper is a round opaque bar machined so that only a small sector of the circular cross section of the bar remains. As this bar is rotated about its own axis by a 3600-rpm synchronous motor, the sector continuously chops the entire viewing field of the telescope.

When the specimen is stressed, there is a corresponding strain produced that causes the flags to move. As a flag image moves from its null position, chopped light passes through one of the two apertures onto the cell and produces a 60-cycle voltage. This signal voltage is amplified and imposed across the control phase winding of an ac servomotor which repositions the aperture subassembly to regain null conditions. If the flag moves in the opposite direction, the chopped
light passes through the other aperture onto the cell and produces a 60-cycle voltage which is approximately $180^\circ$ out of phase with the voltage produced when the flag moved in the previous direction. This causes the motor to drive the aperture subassembly in the proper direction to regain null conditions. The direction of movement depends on whether the signal voltage leads or lags the line voltage on the fixed phase winding.

This extensometer may also be used at temperatures below $2000^\circ$F by placing an iodine-quartz lamp with a tungsten filament behind the specimen and projecting a dark image through the telescopes. The spacing of the defining apertures must be changed (Fig. 10.19.46) and certain phase reversals made by switches on the control panel to accommodate this mode of operation.

High-precision multiple-turn potentiometers are mechanically coupled to the servo-driven components in such a manner that the signal or combination of signals produced is proportional to the relative movement occurring between the two specimen flags, which is the specimen strain.
Fig. 10.19.2 Precision Optical Extensometer Control Panel Assembly.
Fig. 10.19.3 Precision Optical Extensometer Servomechanism.

This signal is then used to produce strain coordinates on the x-y plotter. The signal used to produce stress coordinates on the x-y plotter can be derived from a conventional load cell on the strain machine.

This system can be operated in any one of three different strain modes which are optimized mechanically for fine, intermediate, or coarse strain conditions. For fine strain measurements of less than 0.050 in., both aperture subassemblies are servo driven. This produces the most accurate data available from this instrument. For intermediate strain measurements of greater than 0.050 in. and less than 0.5 in., the primary lens of one telescope and one aperture subassembly are driven. Each time the range of the aperture subassembly drive is exceeded, the distance between primary lenses of the telescopes must be manually adjusted by an increment of 0.050 in. This causes the servo-driven aperture subassembly to reposition by an equal amount. This repositioning produces a “saw-toothed” curve on the x-y plotter but extends the range with some slight sacrifice in accuracy. For coarse strain measurements up to 1 in., the primary lenses of both telescopes are servo driven. This eliminates the need for the manual repositioning procedure used in the intermediate mode, but it also produces somewhat less accurate data.

A number of refinements in mechanical design, in packaging, and in electronics were made to produce an improved version of the design by Southern Research Institute.

The complete system has been checked out and operated under simulated conditions, but no actual strain data have been taken. Strain data accurate to within 0.000030 in. are anticipated.
Fig. 10.19.4 Projected Images as Seen at Aperture Subassembly of the Precision Optical Extensometer. (a) At temperatures above 2000°F, (b) at temperatures below 2000°F.
11. Reactor Instrumentation and Controls

ANALYSIS

11.1 REACTOR STUDIES AND EVALUATIONS

C. S. Walker

The purpose of the reactor studies and evaluations program is to assist the AEC and ORNL management in evaluating long-term objectives of the reactor development program. This work includes an examination of the principal instrumentation, control, and safety problems of proposed large power reactors and an assessment of the effectiveness of technical developments in solving these problems.

Three proposed large reactors were examined, namely, a 3000-Mw (thermal) Heavy-Water-Moderated Organic-Cooled Reactor (HWOCR), a 10,000-Mw (thermal) High-Temperature Gas-Cooled Reactor (HTGR), and a 10,000-Mw (thermal) Very Large Fast Breeder Reactor (VLFBR). Extensive analog computer studies of the behavior of the HWOCR concept were carried out (Sect. 11.2), and the instrumentation, control, and safety evaluations for the reactor were reported.\(^1\) Reports on the evaluations of the HTGR and VLFBR are in preparation.

\(^{1}\) P. R. Kasten \textit{et al.}, \textit{An Evaluation of Heavy-Water-Moderated Organic-Cooled Reactors}, ORNL-3921 (in preparation).

11.2 ANALYSIS OF HEAVY-WATER-MODERATED ORGANIC-COOLED REACTOR

R. S. Stone

As part of an ORNL evaluation of the reactor, an analog simulation of the 3000-Mw (thermal) HWOCR was used to investigate some moderately severe control system requirements. Because the HWOCR has a generally positive power coefficient of reactivity, perturbations in its flux level tend to extend themselves. It is important, therefore, to determine the adequacy of the control system for prevention of positive or negative excursions. An adequate control system must keep unavoidable perturbations of moderate size from producing or forcing a plant shutdown and should minimize the disturbance seen by the load. The large physical dimensions of
the HWOCR make spatial effects potentially important, and the positive coolant temperature coefficient will emphasize local temperature variations.

It seemed apparent that the usual point-reactor simulation was inadequate for the HWOCR; so, to include the necessary spatial effects, the reactor was divided into five axial sections. The separation was made axially because this is the direction of the coolant flow and of the gradient in fuel burnup. Each of the five sections has different temperature coefficients of reactivity and different heat transfer characteristics across the fuel gas gap. Radial discontinuities will ultimately be of concern in the overall control problem, but these were judged to be of secondary importance in the initial investigation. A choice was necessary, since the size of the analog installation limited the present model to five sections.

In the simulation developed, each of the five axial sections of the core was considered to be a subcritical assembly, with a source consisting of leakage neutrons from the adjoining sections. A typical fuel pin was simulated in each of the five axial sections and was divided into four radial shells for finding the temperature profile. The heat transfer simulation also included the gas gap between fuel and cladding, and the film coefficient (variable with coolant flow) between the cladding and coolant. A complete description of the model developed and the results obtained are given in the ORNL evaluation report.\(^1\) Basic data on the reactor were supplied by Combustion Engineering, Inc., and Atomics International.

Results of the simulation indicate that the reactor can be held on line in the face of most of the perturbations which must be expected in an operating reactor. One such incident is the failure of one coolant pump, assumed to drop the flow to 78% on a 10-sec time constant. A control system designed to keep power proportional to flow, and given a reactivity rate of ±0.010%/sec, can in such a situation match power to flow with hardly a ripple in the outlet temperature. For a reactivity step of −0.10%, representing an accidentally dropped safety rod, the same control system would control the reactor back to design conditions in 23 sec with a maximum drop of 40°F in outlet temperature. The rod rate necessary in each of these cases is twice the design rate of ±0.005%/sec. The maximum amount of control rod travel required was +0.15% for the dropped rod and −0.10% for the pump failure. These are within the range of the present design. With the control system inactivated, the simulated reactor was allowed to drift into positive excursions, and the adequacy of various safety system response times was similarly assayed.

This study, the evaluation of HWOCR level control and safety action, is thus complete. Additional analysis is needed on spatial control of reactivity in similar reactors, and the model development reported here can serve as a basis for such a study. Running realistic multidimensional simulations will require a considerable expansion of the present capabilities of the computer, however.

\(^{1}\) P. R. Kasten et al., An Evaluation of Heavy-Water-Moderated Organic-Cooled Reactors, ORNL-3921 (in preparation).
11.3 MULTISTAGE FLASH EVAPORATOR PLANT DYNAMICS STUDY

S. J. Ball

For the ORNL Nuclear Desalination Program a preliminary study was made of the dynamic behavior of large multistage flash (MSF) evaporators to be used in nuclear desalination plants. The major effort in the study was the development of a flexible digital computer code for calculating the frequency response characteristics of various MSF plant designs. Since apparently no analyses of this type have been published, this work provides new information on overall studies of plant dynamics and control incorporating a reactor, turbine, and MSF evaporator.

A mathematical model for a single evaporator stage was developed, the model was linearized, and the Laplace transformed equations for the entire plant were solved. Figure 11.3.1, a diagram of a typical MSF evaporator, indicates some of the responses calculated by the transfer function code. A typical plant analysis involves the solution of about a 425th-order equation. Since there are many uncertainties, both in the mathematical models and in the parameter values used in any given plant study, the sensitivity of the dynamic behavior to variations in models and parameters was determined for a reference plant.

The MSF transfer function code is being continually refined to include new features and more sophisticated models. Future analytical work will include a thorough investigation of MSF plant

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1S. J. Ball, Nuclear Desalination Dual-Purpose Plant Control Study — Interim Report, ORNL-TM-1618, part 1 (October 1966).

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Fig. 11.3.1 MSF Plant Showing Inputs and Outputs Calculated by MSF Transfer Function Code.
stability characteristics and a dynamics study for a nonlinear model of the plant. Future experimental work includes a dynamics testing program on existing evaporators for the purpose of verifying the theoretical results.

The analytical results indicate several significant features of MSF plant designs that have a strong influence on the inherent stability characteristics. It is also shown that a rather detailed and complex model is required to obtain results that would be sufficiently accurate for plant control and optimization studies.

11.4 ANALYSIS OF POWER SOURCE CONTRIBUTION TO EVAPORATOR PLANT DYNAMICS

R. S. Stone

The multistage flash evaporator plant dynamics study (Sect. 11.3) requires a simplified representation of the interaction between the evaporator plant and its source of heat. The initial investigation assumes a 3220-Mw (thermal) pressurized-water reactor plus a vertical U-tube steam generator. A simple behavioristic model of the reactor plus steam generator combination is sought for inclusion as one of many transfer functions in later evaporator analyses. To this end the reactor and its control system, as well as the steam generator, were simulated, and the response of this system to steps and ramps in its load was determined. A simple transfer function was then fitted to the response obtained for later use in representing power source behavior in the model of the overall evaporator plant. A possible extension of this work would be to include the back-pressure turbine in the reactor-plus-boiler simulation so as to obtain a simplified transfer-function model for everything external to the flash evaporator plant.

In setting up the model, the nuclear characteristics of the reactor itself were not treated in detail; the reactor was considered simply as a source of heat with specified limitations as to the rate at which its control system could change power level. This approach was permissible, since fast reactor transients were not considered, and the model is thus applicable to almost any reactor type. The reactor control system produces variable ramp rates in power in response to deviations in reactor coolant temperature or as changes in steam flow reflect variations in the load. Pressure and temperature of the steam and water in the boiler were generated by performing mass and energy balances using a linear relation for saturation temperature as a function of steam density. Steam generation (or condensation) was assumed to proceed at a rate linearly related to the difference between water (or steam) temperature and the saturation temperature. With this model an approximate transfer function for the reactor-plus-boiler system was obtained, that is,

\[ \Delta T = [(0.312 \exp - 0.112t) - (0.346 \exp - 0.0133t) - 0.106] \Delta L. \]

Here \( \Delta T \) is change in boiler outlet temperature (°F), \( \Delta L \) is change in boiler load (% of full load), and \( t \) is time since load change (sec). This function can be used to close the loop in analog or digital analyses of evaporator plant plus turbine behavior.
11.5 MEASUREMENT OF THE INHERENT DYNAMIC CHARACTERISTICS OF THE MSRE

S. J. Ball T. W. Kerlin

Frequency response tests were made on the MSRE during its approach to full power to investigate the inherent stability of the system and to evaluate the mathematical models and the parameters used to predict the dynamic behavior. Future tests will be made periodically to determine any changes in the reactor characteristics that may not be evident from steady-state measurements. Three different types of input disturbances were used to obtain the nuclear power to reactivity frequency response: pulse, step, and pseudorandom binary reactivity inputs. An on-line hybrid computer (Fig. 11.5.1), consisting of the MSRE digital computer and a portable analog computer, was used to control the pseudorandom binary inputs by precise regulating rod positioning and to amplify, filter, and digitize the test signals.

The results of the tests were consistent with previous theoretical predictions both in the shape of the frequency response curves and the inherent period of oscillation over two decades of power operation, 75 kw to 7.5 Mw. A comparison of the periods is shown in Fig. 11.5.2. Although the experimental and theoretical phase characteristics were in good agreement and the

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1 Reactor Division.

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Fig. 11.5.1 MSRE Rod Jogging and Data Logging System for Pseudorandom Binary Reactivity Input Tests.
Fig. 11.5.2 Comparison of Predicted and Measured Inherent Periods of Oscillation for the MSRE from 75 kw to 7.5 Mw.

shapes of the magnitude ratio curves were consistent, there were inconsistencies in the absolute magnitudes for different tests at the same conditions. This is attributed to equipment limitations. The conclusions are that the dynamic characteristics of the system are satisfactory and in agreement with predictions within the accuracy of the test equipment.


11.6 ANALYSIS OF FILLING ACCIDENTS IN MSRE

J. R. Engel P. N. Haubenreich S. J. Ball

Whenever the MSRE is shut down, the fuel salt is drained from the core. Then, during a normal startup, the graphite and the fuel are preheated, and the control rods are positioned so that the reactor remains subcritical while it is being filled. Certain abnormal circumstances could result in criticality and a power excursion in the partially filled core. Various postulated incidents were surveyed, and the worst case was analyzed in detail. This case involved selective freezing in the drain tanks to concentrate the uranium in the molten-salt fraction. Physical

restrictions on the fill rate and safety actions of control rods and gas control valves limited the calculated power and temperature excursions so that any damage to the reactor would be prevented.

11.7 POWER BURST FACILITY ANALOG COMPUTER STUDIES

O. W. Burke

An analog computer model of the Power Burst Facility Reactor (PBFR) was developed. This model will be used in the design of the safety and control system which is to be furnished by ORNL.

The PBFR, to be built and operated by the Phillips Petroleum Co., will be part of a test facility capable of operating in five modes as follows:

1. free-running power bursts with reactor periods as short as 1 msec (the burst will be limited by the Doppler effect),
2. shaped power bursts with reactor periods as short as 10 msec (the power will be held up near its peak until a prescribed quantity of energy has been produced),
3. an extended burst with reactor power at about 100 Mw (the power will be held until a prescribed quantity of energy has been produced),
4. steady-state operation of up to 20 Mw,
5. a power burst following steady-state operation at some power level.

The second mode of operation, which is quite different from that of previous reactors, is very difficult to attain. The difficulty lies in maintaining the proper reactivity to accomplish the desired shaped power burst. For short, initial period-shaped bursts, the required rates of changes of reactivity are very high, meaning that the required control-rod accelerating forces must be very high.

The analog computer was used to determine the required reactivity as a function of time for some shaped bursts. This information will be used in the design of the control system.

11.8 ANALOG COMPUTER MODEL OF THE BOILER HOT TEST RIG

O. W. Burke A. R. Barbin\textsuperscript{1} M. M. Yarosh\textsuperscript{2}

An analog computer model of the Boiler Hot Test Rig was developed. This test rig, built by the Reactor Division, was used to obtain design information for the MPRE.

The response of the computer model to input perturbations was compared with the test rig response to the same perturbations. Since the responses were quite similar, the computer model can be used to obtain system responses to design changes without building them into the test rig.

\textsuperscript{1}Summer participant from Auburn University.
\textsuperscript{2}Reactor Division.
11.9 AN ANALOG COMPUTER STUDY OF THE CONTROL CHARACTERISTICS OF THE MEDIUM-POWER REACTOR EXPERIMENT SYSTEM INCLUDING THE TURBINE GENERATOR\(^1\)

O. W. Burke S. J. Ditto C. S. Walker

The stability and control characteristics of the Medium-Power Reactor Experiment (MPRE), including the turbine-generator unit and the reactor system, were investigated by means of an analog computer. The generator terminal voltage and frequency were controlled for two types of electrical loads. One load was entirely resistive, and the other was similar to that imposed by induction motors driving pumps.

With a simple resistive load the system was found to be stable and controllable when using either control scheme; however, the response characteristics were much better for scheme 1. With the simulated induction motor load, scheme 2 gave acceptable results; however, the results for this load were not as good as those for the resistive load. Stable plant operation was not achieved when using control scheme 1 with the motor load.

\(^1\)Unclassified abstract of published report, ORNL-TM-1494 (May 6, 1966) (Confidential).

11.10 ANALOG COMPUTER ANALYSIS OF BIMETALLIC LOOP

R. S. Stone

A control study was made for a proposed boiling-potassium heat-exchange loop designed to serve as a mockup of the power train of a space reactor. The mockup will consist of a preheater and boiler (with heat input from a separate sodium loop), a simulated turbine (consisting of an orifice plus heat exchanger), a condenser, a liquid reservoir, and a pump. It was feared that instabilities might develop in this system, and an analog simulation was proposed as an aid in designing a control system. A model of the proposed system was developed, and an analog computer study was made. The loop was found to be inherently unstable; but by use of the analog model, a control scheme having good stability characteristics was developed. The study is considered complete unless operational problems which dictate additional analog work are found in the completed mockup.

To create a computer model, mass and energy balances were written for each section of the loop.\(^1\) A constant power input and a constant vapor volume were assumed at the boiler. Given the (variable) liquid flow rate into the boiler, the energy necessary to vaporize this liquid when subtracted from the total heat flux yields the heat left for raising the vapor temperature. A mass balance for the boiler vapor yields the mass of vapor present, and for known temperature, volume, and mass, the pressure can be calculated. This pressure is used to help calculate the

\(^1\)Much of this material was supplied by G. T. Colwell, Reactor Division.
flow rate into the turbine. This type of analysis was continued, section by section, until the final model was developed. Two mechanically driven capacitor-storage transport lag devices were used to simulate the rather long time delays involved in the liquid reservoir and in the pump plus preheater. To shorten the solution time, the simulation was run at ten times the actual rate.

The system tended to develop divergent pressure oscillations, with the instability particularly evident in the liquid reservoir. Changing the pump rate could give temporary control through increasing or holding back the liquid flow from the reservoir. However, when the abnormal flow rates thus generated made a complete circuit of the system and came back into the reservoir from the other side, the original excursion was intensified. The best control was obtained by altering the secondary temperature in either the turbine heat exchanger or in the condenser as a function of pressure deviations in the reservoir. With such a system, a 3% change in rate of heat removal by the "turbine" will counter a 100% change in reservoir pressure.

11.11 ANALYSIS OF OPERATIONS PROCEDURES FOR THE HFIR

O. W. Burke

Sticking of the HFIR control rods during restart could lead to a power excursion. The circumstances that might allow a power excursion to develop are as follows:

1. the reactor has been operating at some power level and this level has been reduced,
2. a power recovery is in progress such that the xenon poison burnout rate exceeds the buildup rate,
3. the control rods become immobilized.

For these circumstances, the reactor would go on a power excursion because the xenon concentration would be decreasing with time. A time lapse of 2.5 min was deemed reasonable for the operator to discover that the rods are stuck and to make the reactor subcritical by means of the liquid-poison system. This establishes a criterion that the restart procedure must be such that if the rods should stick, at least 2.5 min will elapse before the onset of nucleate boiling. The severity of a power excursion in these circumstances is a function of the xenon concentration, the iodine concentration, and the power level at the instant that the rods stick. The xenon and iodine concentrations are a function of the power operating history of the core prior to the time at which the rods stick. The restart power must be programmed to meet the stated criterion.

The analog computer was used to develop safe restart power programs as a function of time in core life at which the scram occurred. The power programs consisted of a series of increasing power steps and operating times at each power. These power steps progressed from the low power to the desired operating power.

These restart power programs have been followed in all HFIR restarts.
11.12 EFFECT OF DESTRUCTIVE EXCURSIONS ON HFIR CONTAINMENT

R. S. Stone  O. W. Burke

To investigate operational hazards of the HFIR, analyses of a number of accident situations were required. One of these situations involved the termination of a severe reactor excursion wherein no safety system action is taken. Since such an excursion can only end in the violent destruction of the reactor core, the objective was to determine the total energy release to be expected before dispersal of the core would stop the reaction. With the total energy release known, the challenge to the containment system could then be assessed. A simplified one-dimensional analog model was developed, and by use of this model, reactor excursions were simulated for a number of initial conditions. From these simulated excursions, the required total energy releases were obtained.

1By W. K. Ergen, ORNL.

DEVELOPMENT

11.13 SUBCRITICAL REACTIVITY MEASUREMENT USING FLUCTUATIONS FROM A PULSE-TYPE DETECTOR

D. P. Roux  J. T. De Lorenzo
S. H. Hanauer1  J. R. Trinko1

The potential advantages of using neutron population fluctuations to measure the reactivity of subcritical power reactors have not yet been realized, partially because of the large gamma-ray intensities associated with these systems after a period of operation at power. To overcome this obstacle, we investigated the use of pulse-type detectors in place of the integrating current-type detectors previously used. Pulse-type detectors had been used previously by Rajagopal, but only one measurement was reported. The advantage of detecting discrete pulses lies in the possibility of distinguishing between neutron- and gamma-ray-induced detector events. A reactivity measurement could then be based wholly on the neutron-induced portion of the detector signal, and the undesirable portion due to the gamma rays could, in principle, be eliminated.

As a feasibility experiment, subcriticality measurements were made on the Pool Critical Assembly (PCA) core previously studied. A current-type BF ionization chamber channel was installed adjacent to the counting channel for comparison purposes. The counting channel con-

1University of Tennessee.
sisted of a BF$_3$ proportional counter and a vacuum tube 1-megahertz amplifier with discriminator and pulse shaper; the resulting pulses were fed into a linear counting rate meter with an integrating time constant of $10^{-4}$ sec which created a fluctuating signal similar to that generated by the ionization chamber and its associated amplifier. Simultaneous recordings were made of the fluctuating output signals from both channels. The subcriticalities inferred from both channels agreed satisfactorily, but some unexplained effects related to counting loss in the pulse channel were observed.

In light of this pulse resolution deficiency experienced in the preliminary experiment, a new 100-megahertz pulse-counting channel was designed (Sect. 3.14) to cope with the high counting rate obtained. The new detector was a boron-lined proportional counter (RSN 251) having a 30-nsec collection time and designed to operate in gamma fluxes up to $10^5$ r/hr without severe performance degradation by gamma rays (pulse pileup and space charge).

To evaluate this system a new series of experiments was performed at the PCA to (1) demonstrate the equivalence of the pulse and current modes when negligible counting loss is experienced, (2) determine the extent to which gamma rays detected in the counter influence the shutdown reactivity measurements, and (3) determine the effect of counting loss upon neutron power spectral density measurements. The pulse-height discrimination level was chosen so as to eliminate gamma pileup pulses in gamma fluxes up to $10^5$ r/hr; this setting was retained for all phases of the experiment.

Results from the first phase of the experiment ("clean" reactor) show that for pulse channel counting losses of less than 1%, the reactivities predicted by analysis of both channels are in agreement for subcritical reactivity conditions of 1, 2, and 4 dollars. In the second phase of the experiment, the reactor was maintained at 1 dollar subcritical, and a $^{60}$Co source was used to vary the gamma flux at the counter from 0 to $1.4 \times 10^5$ r/hr. Results indicated that higher gamma fluxes caused reduced neutron detection efficiency via space-charge effect: the intense ionization caused by the gamma rays negatively charged the space surrounding the anode of the proportional counter, thus reducing the effective electric field and hence the neutron pulse size. However, the values of the measured reactivity did not vary appreciably for gamma fluxes up to $\sim 10^5$ r/hr. In the third phase of the experiment the reactor was kept critical, and the counting loss was controlled by adjusting the reactor power level. For counting losses up to 20% (obtained at a counting rate of $10^6$ counts/sec), the ratio of reactor-correlated to uncorrelated pulses decreased linearly with increased counting loss, but the power spectral density distribution of the reactor-correlated neutrons remained the same.

We conclude from this investigation that measurement of reactor subcritical reactivity using count-rate fluctuations from a pulse-type detector yields the same information as measurement using current fluctuations from an ionization chamber. With the equipment used, the usefulness of the pulse mode is limited to gamma fluxes of approximately $10^5$ r/hr and maximum counting rates of $10^6$ counts/sec.
11.14 PRELIMINARY INVESTIGATION OF CROSS-SPECTRAL DENSITY TECHNIQUES

R. C. Kryter        D. N. Fry        D. P. Roux

Although the usefulness and accuracy of determining shutdown margin in nuclear reactors devoid of fission products through neutron fluctuation analysis are now well established,\(^1\) the extension of the method to measurements in power reactors with gamma-decaying fission products is not straightforward. If, under such adverse conditions, one attempts to deduce reactivity in the customary manner from the shape of the autospectral density function, measured with a single neutron-sensitive detector viewing the reactor, one often finds the spectrum dominated by a "white" component resulting from the intense gamma field and, hence, almost uninterpretable. This masking of signal with noise may be alleviated to a degree at its source by detector optimization (Sect. 11.15) or by pulse-height gamma discrimination (Sect. 11.13), but the present state of the art often proves a limitation in practice. We thought a useful adjunct to these refinements would be the measurement of the cospectral density function characteristic of two neutron-sensitive detectors\(^2\) (both viewing the reactor) as opposed to the autospectrum; one would anticipate that the portion of the signal which is highly correlated between the two detectors (resulting from chain-linked reactor neutrons) would be reinforced, but that the remaining, completely uncorrelated portion of the signal (resulting mostly from statistically independent gamma rays) would be effectively canceled. To our knowledge, this conjecture had not been previously tested.

Accordingly, both the relative merits and inherent limitations of the autospectra and cospectra approaches to shutdown measurement were investigated more thoroughly under high-gamma-flux conditions. A shutdown power reactor was simulated under controlled conditions at the Pool Critical Assembly by using a strong \(^{60}\)Co gamma source placed close to the detectors to represent fission product gamma rays. The relative values of the neutron and gamma fluxes at the detectors were chosen to yield an autospectral density function essentially independent of frequency, and were about \(0.85 \times 10^4\) \(\text{nv}\) and \(4 \times 10^4\) \(\text{r/hr}\) respectively. Simultaneous recordings were made of the outputs from two separate ionization chambers positioned in adjacent vacant fuel positions at the core edge with the reactor at 3 dollars subcritical (this value was measured with the gamma source removed). The results of analyzing a pair of detector signals, both by autospectra and cospectra approaches with equal analysis times, are shown in Fig. 11.14.1. Curve A is typical of the autospectrum of either detector, and curve B displays the cospectrum of the two detectors jointly. The discrete points in these plots are the experimental data, and the solid lines represent a least-squares fit to appropriate theory (a point-reactor model for curve B and a point-reactor model with an additive term independent of frequency for curve A). Curve C is derived from curve A by subtracting from both theory and experiment the least-squares-determined constant-spectrum component caused by the gamma rays.


Fig. 11.14.1 Comparison of Auto- and Co-Spectral Density Analyses for Gamma-Contaminated Detector Signals. The curves have been arbitrarily spaced for clarity.

thereby allowing valid comparison with curve B. While the estimates of subcritical reactivity derived from both the autospectra and cospectra analyses of the same records are in agreement with the correct value of minus 3 dollars within the rather large standard deviations assigned them by the least-squares fitting code (±20% for the autospectra and ±8% for the cospectrum), it is clear that cospectral analysis is the superior method under conditions of this simulation.

Although this work is not yet complete, we can conclude presently that (1) the undesirable background of uncorrelated detector events prevalent under adverse gamma conditions can indeed be canceled by two-detector measurements, and (2) the precision of the reactivity estimates thus obtained can be equal or superior to the precision which can be obtained with the simpler single-detector measurements. In addition, our results indicate qualitatively that the spatial separation of the two detectors is not a critical factor for reactivity measurement, at least for the small system dealt with here; this aspect of the technique will be explored more carefully in the future.
11.15 MEASUREMENT OF REACTOR SHUTDOWN MARGIN IN HIGH GAMMA FLUXES

D. P. Roux  E. N. Ford  S. H. Hanauer

Since the quality of reactor shutdown margin measurements made by neutron noise analysis is degraded by high gamma-ray intensities produced by residual fission products, an analytical study was made to derive an equation that can be used to predict quantitatively this degrading effect. This equation indicates the significant parameters controlling the ratio of the signal to background. With this information, ionization chamber characteristics were optimized. The results predicted by this analysis were experimentally verified.

By use of a point reactor model approximation, the measured power spectral density (PSD) associated with the fluctuating current of a neutron-sensitive ionization chamber can be derived. Because of the statistical nature of the detection process, an uncorrelated detector neutron noise is superimposed upon the correlated neutron population fluctuations. The ratio of the correlated to uncorrelated PSD as a function of the reactivity \( \rho \) (in dollar units) and other reactor parameters was approximated as follows:

\[
\frac{C}{U}(\rho, \omega_A) \approx \frac{E_{\text{meas}}}{(1 - \rho)^2}.
\]

In this equation \( E_{\text{meas}} \) represents the measured \( C/U \) ratio for the reactor at critical and at an angular frequency \( \omega_A \) such that \( \lambda^2 < \omega_A^2 << \beta/\Lambda \), where \( \lambda \) is the averaged delayed neutron precursor decay constant, \( \beta \) is the effective fraction of delayed neutrons, and \( \Lambda \) is the prompt-neutron generation time.

In the presence of a gamma flux background, an additional frequency-independent background, also due to the statistical nature of the gamma detection process, occurs. Since at shutdown this gamma flux background is uncorrelated to the neutron population fluctuations, it can be taken into account in Eq. (2) as follows:

\[
\frac{C}{U}(\rho, \omega_A) \approx \frac{E_{\text{meas}}}{(1 - \rho)^2 \left[ 1 + (\Phi_{\gamma}Z/\Phi_n) \right]},
\]

where \( Z \) in nv-hr/r units is a value characteristic of the chamber used. The term \( [1 + (\Phi_{\gamma}Z/\Phi_n)] \) represents the degradation resulting from the gamma background. The value of \( Z \) can be as low as 2 for optimized chambers, and if it is no, \( C/U \) is not appreciably degraded as long as \( \Phi_{\gamma} < \Phi_n \) (this emphasizes the need for a strong reactor neutron source). When \( \Phi_{\gamma} > \Phi_n \), the degradation factor approaches \( \Phi_{\gamma}Z/\Phi_n \), and the ratio \( C/U \) becomes nearly proportional to \((1 - \rho)^{-2} \cdot |\rho|^{-1}\) or \(|\rho|^{-3} \) if \( |\rho| > 1 \), \( \Phi_n \) being proportional to \(|\rho|^{-1}\).

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1 ORGDP, K-25.
2 University of Tennessee.
Table 11.15.1. Chamber Characteristics for Shutdown Margin Measurements in High Gamma Fluxes

<table>
<thead>
<tr>
<th>Chamber Type</th>
<th>Sensitive Volume Length&lt;sup&gt;a&lt;/sup&gt;</th>
<th>$S_n$&lt;sup&gt;b&lt;/sup&gt; $\times 10^{-14}$ amp/ny</th>
<th>$S_\gamma$&lt;sup&gt;b&lt;/sup&gt; $\times 10^{-11}$ amp-hr/r</th>
<th>$Z$ (nv-hr/r)</th>
<th>$E_{meas}$</th>
<th>$E/Z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSN-81A</td>
<td>7&lt;sup&gt;3/4&lt;/sup&gt;</td>
<td>7.2</td>
<td>3.3</td>
<td>6.5</td>
<td>30</td>
<td>4.5</td>
</tr>
<tr>
<td>1 atm BF&lt;sub&gt;3&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSN-81A</td>
<td>7&lt;sup&gt;3/4&lt;/sup&gt;</td>
<td>4.2</td>
<td>1.65</td>
<td>9</td>
<td>70</td>
<td>8</td>
</tr>
<tr>
<td>5 atm $^3$He</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSN-76A</td>
<td>7&lt;sup&gt;3/4&lt;/sup&gt;</td>
<td>4.5</td>
<td>2.45</td>
<td>11</td>
<td>34</td>
<td>3</td>
</tr>
<tr>
<td>$^{10}$B coated, 1 atm Ar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSN 76A Mod.</td>
<td>7&lt;sup&gt;3/4&lt;/sup&gt;</td>
<td>2.7</td>
<td>0.6</td>
<td>2.0</td>
<td>34</td>
<td>17</td>
</tr>
<tr>
<td>$^{10}$B coated, 2 atm $^4$He</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSN 252</td>
<td>9&lt;sup&gt;1/2&lt;/sup&gt;</td>
<td>~2.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>~40&lt;sup&gt;c&lt;/sup&gt;</td>
<td>~15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{10}$B coated, 0.26 atm Ar + CO&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

<sup>a</sup>Every chamber has a 2 in. OD.
<sup>b</sup>Measured at the PCA.
<sup>c</sup>Estimated.

As a result of this analysis, an effort was made to obtain an ionization chamber with maximum $E/Z$ ratio. Chamber characteristics for shutdown margin measurements in high gamma fluxes, including predicted $Z$ and $E$ values, are listed in Table 11.15.1 for five ionization chambers. The chamber with maximum $E/Z$ ratio was determined to be an RSN-76A boron-lined chamber filled with $^4$He at a pressure of 2 atm. The $E/Z$ ratio obtained for this chamber was slightly better than that obtained for an RSN-252 chamber that consisted of 34 individual $\frac{1}{4}$-in.-OD elements and was designed especially for measurement of reactor shutdown margin in a high gamma flux. The three other chambers and their characteristics are merely listed for reference to indicate the range in which $Z$ and $E/Z$ values vary for different neutron-sensitive gases and coatings; in particular, the improvement obtained by filling the RSN-76A chamber with a more appropriate ionizing gas should be noted.

An experiment was performed at the PCA to verify the validity of Eq. (2). The reactor was maintained in a known static subcritical condition. The gamma flux was varied from 0 to $4 \times 10^4$ r/hr at the detector by changing the separation distance between the detector and a 42,000-curie $^{60}$Co gamma source. For each condition the degradation factor was measured, and the value of $Z$, inferred from the measured neutron and gamma fluxes, was nearly constant and therefore independent of the gamma flux. Four types of ionization chambers were tested, and for each detector, the observed value of $Z$ agreed well with the predicted values listed in Table 11.15.1.

11.16 ANALOG SIMULATION OF NEUTRON FLUCTUATIONS IN A ZERO-POWER REACTOR

D. N. Fry

The use of neutron fluctuations to measure shutdown margin in a zero-power reactor is an established technique. However, there are many pitfalls that an experimenter may encounter if he does not understand thoroughly how data acquisition and analysis methods might influence the results. If a known system were available having known parameters and emitting a noise spectrum similar to what is expected from the reactor, the experimenter could analyze the system output and obtain a reliable check of his apparatus and techniques. To provide such a system, the output of an ionization chamber placed near a subcritical reactor was simulated on an analog computer. The model allows changes to be made in reactor parameters and in ionization-chamber detection efficiency.

The model consists of two parts: a reactor, simulated by using a point kinetics model, and a simulation of the neutron detection process in an ionization chamber. The input to the reactor model is a white-noise source, representing the neutron source in a subcritical reactor. A separate white-noise source is used to represent the detector background noise generated by the random neutron detection process. The model can be extended to include additional ionization chambers, but each chamber must have its own independent white-noise background. In this way two-detector cross-correlation experiments (Sect. 11.14) can be simulated.

By performing checkout of data analysis techniques on the analog computer, where experiment conditions can be controlled, the experimenter will not have to spend valuable reactor time understanding his equipment. In addition, the simulated experiment can be used to plan reactor experiments and to perform certain neutron noise experiments when a reactor is not available.

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11.17 MEASUREMENT OF DELAYED NEUTRON FRACTION IN THE MSRE
BY NEUTRON FLUCTUATION ANALYSIS

D. N. Fry D. P. Roux

The effective delayed-neutron fraction $\beta_e$ is less in a circulating-fuel reactor, because the precursors decay while the fuel is outside the core. Neutron power spectral density (NPSD) measurements made with the MSRE at zero power are used to determine the difference in $\beta_e$ when the fuel is circulating and not circulating in the primary loop.

The MSRE is a single-region, unclad graphite-moderated fluid-fuel reactor with a design heat-generation rate of 10 Mw. The reactor heat is transferred from the circulating fuel to a

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similar coolant salt and is dissipated to the atmosphere. The circulating fuel is in the core approximately 9 sec and outside the core in the external loop about 16 sec.

A Reuter-Stokes type 81A ionization chamber filled with 2 atm BF₃ was installed in a vertical penetration of the thermal shield at the midplane of the core. With the reactor at a power of 10 w, the current fluctuations from the chamber were amplified by a low-noise wide-band ac amplifier and recorded for 1 hr on magnetic tape using a frequency-modulated tape recorder. The recorder signals for two reactor conditions (fuel circulating and not circulating) were analyzed using a multichannel spectral density analyzer. A digital least-squares program was used to fit the parameters of a theoretical model to the observed spectra. The model assumes an infinite homogeneous one-speed reactor with one group of delayed neutrons, plus an additional term representing the detection-noise component of the observed NPSD.

Figure 11.17.1 shows the results of the MSRE measurements. The standard deviation for a data point is smaller than the size of the point representing the data, unless otherwise shown. In fitting the model to the measured spectra, the neutron generation time λ was held constant at the design value, and the least-squares program was allowed to fit βₑ, the one-group effective delayed neutron decay constant λ, the detection noise component, and the overall amplitude of the reactor neutron noise. Figure 11.17.1a illustrates the effect of fuel circulation on the NPSD. The decrease in βₑ due to fuel circulation results in an increased reactor gain, and thus the NPSD is greater in the frequency range where delayed neutrons affect the reactor dynamics (below 5 cps).

Figures 11.17.1b and 11.17.1c show the measured spectra with the frequency-independent detection noise component as determined by the computer subtracted, and also show the least-squares fit of the data to the theoretical model. The large standard deviation of data taken at higher frequencies is due to the subtraction of one number from another of nearly equal magnitude. The least-squares fit indicates that βₑ is increased by a factor of 1.58 ± 0.21 when circulation of the fuel is stopped. Independent measurements (using control rod calibration) yielded a corresponding increase of 1.47. This agreement is good considering that the neutron detection efficiency was low because of the unfavorable detector location that was available. This resulted in a small ratio of reactor-correlated neutron fluctuations to the detection noise as made evident in Fig. 11.17.1a.

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Fig. 11.17.1 Measured Neutron Spectra for the MSRE at a Power of 10 w.  (a) Spectra before subtraction of detection noise, (b) spectrum minus detection noise with fuel circulating, (c) spectrum minus detection noise with fuel stagnant.
11.18 HFIR CORE EVALUATION USING NEUTRON FLUCTUATION ANALYSIS

D. N. Fry

Since the reactivity worth of HFIR cores can vary depending on the amount of burnable poison and $^{235}\text{U}$ in the core, some check of the total reactivity worth is desired before the cores are placed in the reactor. Neutron fluctuation analysis was used to measure the worth of three cores when they were submerged in water at the Critical Facility. The results of these measurements were in agreement with independent tests made by the Critical Facility personnel.

To measure the core reactivity worths using neutron fluctuation analysis, the cores were placed in a tank of water, along with a neutron source, and the fluctuating current signals from an ionization chamber were amplified and recorded on magnetic tape. The taped signals were later analyzed using a ten-channel spectral density analyzer. Data obtained from the spectral density analysis were least-squares fitted to a one-group point reactor model to obtain the core reactivity worth. The results showed that the three cores had worths of $-1.68$, $-1.61$, and $-1.60$ dollars, while the independent Critical Facility measurements yielded values of $-2.01$, $-1.90$, and $-1.92$ dollars respectively. These results indicate that both methods yield about the same differences in core worth, although the absolute magnitudes predicted by the methods systematically differ by about 30 cents. This difference is most likely due to the large and different neutron flux perturbations introduced by each method: the neutron fluctuation method requires that a neutron absorber in the form of an ionization chamber be placed directly adjacent to the core, but the method used by the Critical Facility personnel necessitates that additional fuel be placed in the trap region of the core to make it critical.

Since the primary purpose of the measurements is to detect differences in core worth, both methods seem to perform this function equally well. However, the neutron fluctuation method is faster and does not require the core to be taken critical. Moreover, the amount of core handling and transportation would be reduced since, in principle, the neutron fluctuation measurements could be made at the HFIR site in a pool of water. One drawback is that some assurance must be given that the core would not become critical when placed in water. This problem is currently being reviewed.

11.19 MEASUREMENT OF NEUTRON POWER SPECTRAL DENSITY IN POWER REACTORS

D. N. Fry    R. C. Kryter    D. P. Roux
S. E. Stephenson$^1$    J. C. Robinson$^2$

There are mechanisms in a nuclear reactor that produce reactivity fluctuations, thereby indirectly causing neutron population (reactor power) fluctuations. In most reactors these reactivity perturbations are introduced by such things as control rod or fuel element vibrations, coolant pressure, or flow fluctuations. It is important that these sources of reactivity perturba-

$^1$Summer research participant from the University of Arkansas, Fayetteville.
$^2$Summer research participant from the University of Tennessee, Knoxville.
tion be identified so that corrective measures may be taken if necessary. We are currently developing reactor neutron noise analysis techniques which can serve as a sensitive nonperturbing means for detecting anomalous conditions of the type mentioned above. During the past year data were taken at the ORR, the HFIR, and the MSRE to (1) provide reference data for comparison with future measurements and (2) supply experimental results for comparison with theoretical predictions concerning the probable sources and mechanisms of reactor power fluctuations.

Concurrent with these reactor measurements, we are attempting to understand the causes of neutron population fluctuations from a theoretical standpoint. We made considerable progress in constructing a theoretical model of the fluctuation generation process. The theory has been revised several times in an attempt to obtain agreement with the experimental data.

Measurements made at the ORR\textsuperscript{3} showed that the reactor power fluctuations are strongly dependent upon coolant flow rate, thus suggesting flow-induced control rod vibrations or coolant temperature fluctuations in the core as sources of fluctuating reactivity. The scant amount of data obtained thus far on the MSRE has not allowed isolation of the noise sources, but measurements to date indicate that the magnitude of the percent power fluctuations in this reactor is only about 0.01 of that in the ORR. We have analyzed the neutron noise from three HFIR cores, each of which was run to burnup at a chosen, steady thermal-power level (50, 75, and 90 Mw); in each case data were taken periodically over the span of core life. Data from a fourth core, the first of the series to be operated at the 100-Mw design limit of the HFIR, are currently being analyzed. Analysis of data from the three lower power conditions shows a strong correspondence between control rod positions and the presence or absence of certain peaks in the observed spectrum of power fluctuations in the range of 10 to 20 cps.

From this year's experience we conclude that noise analysis is a sensitive tool in the diagnosis of anomalous power reactor performance but that considerable theoretical work remains to be done in relating observed changes in the fluctuation spectrum with specific physical mechanisms responsible for power fluctuations in reactors.


### 11.20 STUDY OF REACTOR ACOUSTICAL NOISE\textsuperscript{1}

\textbf{R. F. Saxe}\textsuperscript{2}

L. W. Lau\textsuperscript{2} \hspace{1em} W. H. Sides, Jr.\textsuperscript{2}

The study of acoustical radiations from reactors was prompted by the possibility that boiling in a reactor could be determined by detection of the acoustical emission from boiling bubbles. The emissions from boiling bubbles depend considerably on the condition of the medium, but

\textsuperscript{1}Work performed under subcontract with the North Carolina State University.

\textsuperscript{2}North Carolina State University.
for boiling in most water-moderated and water-cooled reactors, the frequencies of emission will fall in the lower kilocycle range.

To make an assessment of the smallest amount of boiling which might be detected, it is necessary to know the acoustical background against which the boiling noise must be measured. Therefore, some experiments were made to measure the background noise of the ORR. The results show that this reactor emits a large amount of noise in the range 1 to 6 kc with peaks at 1.5, 2.2, and 5.25 kc. This information, coupled with other observations, suggests that the origin of the noise is flow-induced cavitation. An extra-reactor experiment was started to check this finding and to measure the behavior of such cavitation.

A transparent vessel was constructed. Transparent channels, approximating reactor coolant channels, could be inserted in the vessel and water could flow through the channels at velocities up to about 40 fps. At flow rates up to about this value in channels with cross sections of $3 \times \frac{1}{4}$ and $1 \times \frac{1}{4}$ in., the flow-induced cavitation did occur within the channel owing to the rapid change in velocity experienced by the water in entering the channel.

The cavitation emitted acoustical radiations similar to those measured at the ORR both in position of the peaks and in variations of the amplitude at any frequency.

The cavitation was photographed by a short-exposure ($\sim 10^{-7}$ sec) flash camera; the pictures of the cavities were not blurred by motion. Subsequent photographs with two light flashes separated by a known time interval will be used to determine the values of local velocity, the number of bubbles, and their size, growth, and collapse.

The object of the present experiments is to attempt to correlate the bubble numbers and sizes with the recorded acoustical radiations. To assist in this study, an on-line correlator is being built in which the autocorrelation or cross-correlation curve is built up and displayed on a multichannel analyzer. Either curve may be built up within a few minutes to an accuracy limited by the unavoidable drifts, etc., in the input detectors and amplifiers. The frequency range to be covered will range from a few tens of cycles per second down to very low frequencies.

The experiments are being performed with different sizes and shapes of channels and for different flow velocities. Subsequently, the effects of coupled channels will be studied.

11.21 DETERMINATION OF THE POWER VS REACTIVITY FREQUENCY RESPONSE FUNCTION OF A POWER REACTOR, WITH APPLICATION TO THE HIGH FLUX ISOPOE REACTOR

B. R. Lawrence

A description is given of a numerical technique for calculating the power vs reactivity frequency response function of a power reactor. The approach avoids the evaluation of transfer functions in an algebraic form. The space-independent reactor kinetics model is used in conjunction with a general set of first-order equations to represent the thermal performance of the

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reactor. Results obtained by applying the technique to the Oak Ridge High Flux Isotope Reactor indicate that the reactor operating at full power of 100 Mw with the flux controller off has a frequency response which peaks broadly at 10 cps with a \((\delta P/P^0) vs (\delta k/k^0)\) gain of 140.

### 11.22 On-line Reactivity Computation for the HFIR

B. R. Lawrence J. B. Bullock H. P. Danforth

An on-line reactivity computation technique was developed to accurately determine reactivity changes in the HFIR. The reactor control system had been designed to perform automatic shim-rod insertion and withdrawal; however, to prevent unsafe shim-rod withdrawal due to abnormal reactivity losses, a shim withdrawal permit must be provided. Currently this permit is given manually by the reactor operator, but the complexity of assessing reactivity anomalies makes it imperative that this function be carried out by an on-line computer system.

The basis for a program to calculate the core reactivity balance is a model\(^1\) of the HFIR, which was developed to keep an account of changes in reactivity associated with burnup, poisoning, and temperature variations. A computer calculation, using the proposed model with thermal cross sections as initial estimates for one-energy group averaged cross sections, showed that the model agrees well enough with the multigroup reactor physics\(^2\) calculations to merit more study. An improvement of these initial effective cross-section estimates was made by least-squares fitting\(^3\) to the values obtained from the reactor physics calculations; further adjustments are being made as more data become available from operation of the reactor.

The starting point for this reactor model is the one-energy group pseudo-steady-state diffusion equation

\[
\nabla \cdot D [x, T(x)] \nabla \phi - \Sigma_a [x, T(x)] \phi + \frac{1}{k} \nu \Sigma_f [x, T(x)] + 2 \Sigma_{n2n} [x, T(x)] \phi = 0 ,
\]

(1)

where \(D, \Sigma_a, \nu \Sigma_f, \) and \(\Sigma_{n2n}\) are constants averaged over the entire neutron energy spectrum from thermal to fission energies. \(T(x)\) is the temperature at position \(x\) in the reactor. It is convenient to write Eq. (1) in the form

\[
J \phi = \frac{1}{k} K \phi ,
\]

(2)

where \(J\) is the neutron destruction operator, and \(K\) is the neutron production operator. Applying standard first-order perturbation theory\(^4\) to Eq. (2) we obtain

\(^2\)Elliot Whitesides, MODBURN (unpublished reactor burnup computer code).
\[-\delta \rho = \delta \left( \frac{1}{k} \right) = -\frac{\delta k}{k^2} = \frac{\int dx \, \phi(x) \, \left[ \delta J - (1/k) \, \delta K \right] \, \phi(x)}{\int dx \, \phi(x) \, K \, \phi(x)} \] (3)

If it is assumed that changes in the diffusion coefficient with burnup may be neglected, then
\[\delta J = \delta \Sigma_{a} \left[ x, T(x) \right];\] and also assuming that changes in \( \Sigma_{n2n} \) for the beryllium reflector may be ignored, so that \( \delta K = \delta \nu \Sigma_{t} \left[ x, T(x) \right] \), then Eq. (3) becomes

\[\delta \rho = \frac{\int [(1/k) \, \delta \nu \Sigma_{t} \left[ x, T(x) \right] - \delta \Sigma_{a} \left[ x, T(x) \right]] \, \phi(x) \, dx}{\int \left[ \nu \Sigma_{t} \left[ x, T(x) \right] + 2 \Sigma_{n2n} \left[ x, T(x) \right] \right] \, \phi(x)^2 \, dx} \] (4)

The total reactivity change in a time interval \( \delta t \) is the sum of the contributions from all spatial regions and can be written as

\[\delta \rho = \sum_{r} \delta \rho_{r} = \frac{\sum [(1/k) \left( \frac{\partial}{\partial t} \right) \nu \Sigma_{k_0} \left( \frac{\partial}{\partial t} \right) \Sigma_{a(r)}] \, \phi_{(r)}^2 \, V_{(r)} \, \delta t}{\sum \left[ \nu \Sigma_{t(s)} \left[ x, T(x) \right] + 2 \Sigma_{n2n} \left[ x, T(x) \right] \right] \, \phi_{(s)}^2 \, V_{(s)}} \] (5)

To determine \( \left( \frac{\partial}{\partial t} \right) \nu \Sigma_{t}, \left( \frac{\partial}{\partial t} \right) \Sigma_{a}, \nu \Sigma_{t}, \) and \( \Sigma_{n2n} \), it is only necessary to calculate the time behavior of those nuclides in the region \( (r) \) which contribute appreciably to these terms. Equation (5), along with equations describing the nuclide concentrations, forms the basis for a computer program for the on-line computation of reactivity changes in the HFIR. The reactivity change \( \delta \rho \) is calculated at time intervals \( \delta t \) of 30 sec and summed over the life of the core to yield total reactivity as a function of time. These results are compared to rod position and rod-worth data to determine if an automatic shim-rod withdrawal is permissible. Calculations made on the CDC 1604 computer showed a maximum error of 80 cents reactivity during a full core cycle when compared to the multigroup, space-dependent reactor physics calculations.

An on-line computer system (Fig. 11.22.1) was purchased, with delivery scheduled in early 1967. Operating experience on the HFIR and data from future experiments will be used to fit the model more closely to the reactor once the on-line computer system is in operation. Studies are being made to determine how well the program can calculate \( \delta \rho \) during reactor transients; initial results compare favorably with the multigroup, multiregion model. Other primary applications of the on-line computer system will include:

1. control of shim-rod drive motors to correct for rod asymmetry conditions,
2. determination of the sequence of annunciator alarms,
3. calculation of optimum profiles to increase power from 10 to 100 Mw after a setback under the constraint that if all rods become immobilized the power will not exceed 130 Mw in 2.5 min,
4. on-line neutron noise analysis studies for reactor diagnosis applications.

11.23 APPLICATION OF A DIGITAL SIMULATION OF THE HFIR CONTROL SYSTEM

J. B. Bullock

A FORTRAN-63 program was written to simulate the dynamic behavior of the HFIR control system. The reactor core is described by a six-group point kinetics model and is incorporated in
the code so that neutron level and power level can be generated and used as inputs to the simulated control system. The code was written to aid in the off-line evaluation of several digital control algorithms being considered for the HFIR control computer.

This program, called TRIM, was debugged and used successfully in several applications. A problem of primary interest in the HFIR is that of recovering control rod symmetry. At power levels above 10 Mw the HFIR control rods must be maintained to within about 1 in. of each other to minimize the neutron-flux tilting caused by rod asymmetry. The operator is therefore required to manually adjust the rods after a rod drop or flow reduction before the reactor can be returned to full power. The simulation program has provisions for inserting different digital control algorithms to aid in determining suitable methods for automatic correction of rod asymmetry. Schemes which simultaneously raise the lower rods while inserting the higher rods are inherently faster than manual operations and are being investigated in detail.

The code simulates only one of the three existing control channels and does not include all of the system interlocks. However, the details necessary to simulate the system response to loss of primary coolant flow or a shim-rod drop are included. The loss of flow simulation was found to be useful in predicting the effects of minor HFIR system modifications without the necessity of performing hardware changes and experiments on the reactor. The output list includes time, rod positions, net core reactivity, flux-to-flow ratio, and reactor power level. An integration time step of 0.1 sec appears to be optimum, and the computing time required on the CDC 1604-A is approximately one-half the real-time span of the problem. A plotting option permits graphic display of the rod positions as a function of time.
11.24 AN ALGORITHM FOR CALCULATING REACTIVITY FROM NEUTRON FLUX USING AN ON-LINE DIGITAL COMPUTER

B. R. Lawrence\textsuperscript{1} \hspace{1cm} J. B. Bullock

A real-time calculation of reactivity from the reactor neutron flux signal has several potential applications. The areas of operational interest are: the determination of control rod worth by observing the reactivity change corresponding to a given change in rod position; the development of a reactor criticality meter by continually displaying the net system reactivity; and the identification of a reactivity anomaly by comparing the expected reactivity based on rod position, fuel burnup, and poison concentrations with the reactivity calculated from the neutron flux behavior. As a part of the computer control development program, an analysis was made to determine the feasibility of accurately solving the kinetics equations with an on-line digital computer.\textsuperscript{2}

The standard space-independent kinetics equations

\[
\frac{d\phi}{dt} = \frac{(1 - \beta) k - 1}{l} \phi + \sum_{i} \lambda_{i} C_{i}
\]

(1)

and

\[
\frac{dC_{i}}{dt} = \frac{\beta_{i} k \phi}{l} - \lambda_{i} C_{i}
\]

(2)

were solved for the multiplication constant \(k(t)\) when the neutron flux signal \(\phi(t)\) and \(d\phi/dt\) were given as inputs.

Calculations were made on a CDC 1604-A computer using a second-order Runge-Kutta process for the recurrence relations and a simulated noise-free neutron flux signal. The importance of the flux derivative was evaluated by running calculations both with and without the \(d\phi/dt\) term. For step changes in reactivity, it was noted that \(d\phi/dt\) must be included if solution accuracy is required in a time less than 100 prompt-neutron lifetimes following the step change.

The calculations demonstrated the accuracy of an algorithm which can be used in a small on-line computer having no library subroutines and limited data storage space. The effect of noise on the accuracy of \(d\phi/dt\), and consequently \(k(t)\), must be studied in more detail before conclusions on practical feasibility can be drawn. In noise-free applications the method has the necessary features for on-line applications.

\textsuperscript{1}Formerly on assignment from the Australian Atomic Energy Research Establishment.

REACTOR PROJECTS

11.25 CONTROL AND SAFETY SYSTEM FOR THE TSF-SNAP REACTOR

S. J. Ditto C. F. Holloway

A modified SNAP-10A reactor is being acquired for installation and operation at the Tower Shielding Facility as a radiation source for shielding experiments by the Neutron Physics Division. Although the reactor configuration is well suited to a study of shielding problems of space reactors, it was neither designed for ground operation nor for numerous startup and shutdown maneuvers. Therefore, it was necessary to have the reactor designers modify the basic SNAP-10A reactor package and for ORNL to design adequate control and safety systems for operation at ORNL.

Preliminary studies were made to determine the required modifications to the basic reactor configuration. The most significant change, from the standpoint of reactor control and safety, was the addition of scram capability. The original SNAP-10A reactor had four reflector drums for reactivity control. Two of the drums were used for regulation and were actuated by stepping motors in a control scheme that permitted only addition of reactivity. The other two drums were locked in their least reactive position until a satisfactory orbit was assured, after which they were inserted rapidly by springs to permit subsequent criticality by controlled insertion of the so-called fine control drums. None of the four drums could be withdrawn to reduce reactivity, although shutdown could be achieved by jettisoning the reflector assembly. The reactor designers were asked to modify the coarse drum actuators so that the drums could be inserted by a pneumatic piston and withdrawn by spring force for scram. In addition, the stepping-motor controllers were redesigned to permit motion in either direction for shimming and power regulation.

Concurrently with design modifications of the reactor, the ORNL Reactor Controls Department designed the control and safety circuits to be installed external to the reactor at the Tower Shielding Facility. The short time duration of the experiment led to the decision to build a facility which will use, insofar as is feasible, the instrumentation normally used in operating the Tower Shielding Reactor. To this end, the instrument rack will be prewired to accept those instruments which can be transferred readily prior to reactor startup. A few special instruments, including two dual-section ionization chambers and an operating console, were designed especially for the SNAP reactor experiments. The Instrumentation and Controls Division also established criteria for the design of equipment for the required reactor motions, a fission-chamber positioning device, and other auxiliaries.

The reactor is to be delivered to ORNL in early 1967, at which time site preparation and construction of control console, instrument racks, and the relay cabinet should be complete. Active participation by the Instrumentation and Controls Division will continue through system installation and checkout, with reactor startup scheduled for mid-1967.
11.26 INSTRUMENTATION AND CONTROL FOR THE ABERDEEN PULSE REACTOR

W. D. Brown

The instrumentation and control system for the Aberdeen Pulse Reactor was fabricated this year. This reactor is the third to use ORNL second-generation modular instrumentation. United Nuclear, Inc., was engaged as a subcontractor to carry out the work under the direction of ORNL.

The modules and drawers were built to ORNL drawings and specifications by Milletron, Inc.

After testing, the modular instrumentation was shipped to the subcontractor for incorporation into the instrumentation and control package. ORNL directed the subcontractor in fabrication of the remaining portion of the reactor control system, consisting of the relay panel, vertical (or instrument) panel, and the control console.

After completion of the fabrication work, the precritical operational checkout was performed at the subcontractor’s plant by ORNL and Aberdeen Proving Ground personnel. The inspection included wire checking of the relay logic and system testing of the instrumentation. Several vendor errors were corrected, and minor modifications were made during this period. The most significant modification consisted in shielding bulkhead coaxial connectors to reduce the noise in the counting channels.

The reactor, with the exception of the core, is scheduled to be shipped to ORNL in September 1966. The reactor will be assembled and tested in the ORNL critical facility.

11.27 MODULAR REACTOR INSTRUMENTATION OF THE HFIR AND THE MSRE

J. L. Anderson   S. J. Ditto   E. N. Fray\textsuperscript{1}
L. C. Oakes       H. G. O'Brien

A newly developed line of solid-state, modular reactor instrumentation has been in continuous operation in the High Flux Isotope Reactor (HFIR) and the Molten-Salt Reactor Experiment (MSRE) since late summer 1965. These instruments, known as the “second generation” of ORNL reactor instruments, are also being used in the Aberdeen Pulse Reactor, which is scheduled for initial operation about October 1966.

Performance has been quite satisfactory, especially considering that the systems, as well as the components, are completely new and hitherto unproven. A few problems were encountered with the electronic system, such as inadvertent ground loops resulting in electrical interference, but these were corrected in the initial phases of operation. The component failure rate was somewhat higher than anticipated because of minor design deficiencies in some circuits which are gradually being corrected as they appear. No loss of protection has resulted from component failures primarily because of the high degree of channel independence which has been achieved in the safety systems and the thoroughness of the on-line testing system.

The two-out-of-three coincidence system, which is used primarily to facilitate on-line testing, has been very beneficial during initial phases of reactor operation by permitting on-line modifi-

\textsuperscript{1}Presently employed by General Electric Corp., San Jose, Calif.
cations, adjustments, and calibrations to be made without shutting down the reactor. This ease of on-line maintenance, coupled with the on-line testing system, is certain to shorten service time during refueling shutdowns.

The HFIR control and safety systems are designed to keep the reactor operating during major power outages at the highest power commensurate with available emergency coolant flow without the necessity of scramming and restarting. This capability was tested at each new power level during the prolonged escalation from 20 to 100 Mw. Both real and simulated major power outages were initiated with the reactor at power. The control system smoothly lowered the power and held it at the allowed 13 to 15 Mw while maintaining safe ratios of power to flow during coastdown of all main coolant pumps. Some unexpected difficulties were encountered in the procedure for restoring full coolant flow and power. Because the main secondary coolant system flow is also lost during a power outage, the average primary water temperature slowly increases, and when the primary pumps are started, the rush of warm water reaching the reactor inlet temperature sensors produces a scram. This problem was solved by reprogramming the automatic process equipment starting system to restore secondary flow some time before primary flow. Successful power-outage coastdowns and restarts were then performed from 50 through 100 Mw. On one occasion an unscheduled power outage during a severe thunderstorm caused every reactor at ORNL to scram except the HFIR; it maintained control at the allowable reduced power on emergency coolant flow.

The unique triple servo system" performed well, and it has already demonstrated its worth in improved reliability by maintaining control of the reactor almost unperturbed in spite of isolated component failures.

Repeated failure of a cable in the articulated "snake" preamplifier-fission chamber assembly was traced to binding of the fission chamber in a bend in the guide tube which caused excessive strain on the cable. This trouble was eliminated by shortening the fission chamber assembly slightly to allow it to pass through the bend more easily.

The safety system and counting channels of the MSRE, which are very similar to those of the HFIR, performed very well with only minor difficulties. Two time-consuming troubles were water leaks into the fission chamber assembly and intermittent failures of a wire-wound resistor in an amplifier aggravated by poor regulation of the control room temperature.

The MSRE outlet temperature controller is a stable and reliable system. It was used for nearly all of the power operation of the reactor.

The excellent overall performance of both the HFIR and MSRE instrumentation systems, the flexibility and ease of repair of the modular arrangements, and the declining failure rate as initial design weaknesses are remedied are all evoking considerable optimism as to the continued success of the nearly complete transition to modular, solid-state electronic instrumentation represented by the "second generation."

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3. D. P. Roux et al., A Miniaturized Fission Chamber and Preamplifier Assembly (Q-2617) for High-Flux Reactors, ORNL-3699 (October 1964).
11.28 STARTUP OF THE HFIR

B. C. Duggins  D. S. Asquith  W. F. Johnson  R. E. Whitt

Many requirements of the process instrumentation for the HFIR are unusually severe due to the high performance characteristics of the reactor and the close relationship between heat power measurements and nuclear control. Approximately 2.5 engineering man-years were spent in checking, performance testing, and modifying the instrument system before reactor startup and during the escalation to design power. Written procedures for testing the various instrument systems were prepared. Problem areas discovered through use of these procedures received further analysis or design effort as required.

Most of the process instrumentation has been operating satisfactorily for several months. Two areas, however, will require further consideration: (1) several control valves have developed intolerable leaks through the seat after being operated with demineralized water and high pressure drops, and (2) the heat power computers might require redesign to improve their accuracy.

The more significant problems which have been found and solved are described in other reports (Sects. 11.29 to 11.31). In addition to these, approximately 25 changes, each requiring at least one man-week of design or analysis time, were made to the process instrument systems. Typical changes were: (1) the closing time of the 2-in. let-down block valves was reduced to 0.4 sec to lessen the probability of a loss-of-pressure accident; (2) the pH measuring system was altered to permit operation at atmospheric pressure, and the electrodes and cell blocks were replaced to provide better measurement in high-resistivity water; and (3) the special resistance thermometers used to measure reactor inlet and outlet temperatures were modified to greatly reduce the effects of thermal voltages produced by the hot water test system.

11.29 ANOMALY IN HFIR COOLANT FLOW METERING

B. C. Duggins

During the initial startup and low-power operation of the HFIR, the output of one of six almost identical flow transmitters measuring the reactor primary coolant flow varied periodically approximately 6% with a period of 20 sec. Since this flow signal is used in computing heat power for the automatic flux reset system, the reactor power controller on this instrument channel was kept in constant motion by the disturbance. This was considered an intolerable situation, and it was necessary to find and eliminate the cause of the disturbance.

Figure 11.29.1 shows the test setup and results of tests made on the flow system using fast-response transducers. The differential pressure signal from the Venturi had an average value upon which was superimposed 150-cps noise, and the noise on the disturbed channel was nonsymmetrically modulated at a very low frequency. The noise was not modulated on channel 6. The diagnosis was that resonance in the impulse lines from the Venturi to the transmitter was the cause of the trouble and, in particular, that the modulation was due to phase shift caused by
variations in the noise frequency as the three main circulating pumps shifted load among themselves. After a quarter wavelength at 150 cps was added to the length of the impulse lines (L in Fig. 11.29.1), the problem disappeared.

11.30 TEMPERATURE CONTROL FOR THE HFIR

B. C. Duggins  R. E. Whitt

Satisfactory control of the HFIR primary water temperature was dependent on the positioning of a series-connected 36-in. butterfly valve to 0.1%. In prestartup tests the valve hysteresis varied from 2 to 8%, depending on valve angle, and the valve was unstable due to cavitation at certain operating conditions. After extensive testing of this valve and its component parts, it
was concluded that high differential pressure across the valve caused bearing loads so great that a commercial valve which would meet the positioning specifications could not be obtained.

Since it was not practical to procure a special valve or to modify the flow system, the alternate temperature control system shown in Fig. 11.30.1 was designed. A 10-in. double-seat bypass valve was installed and is controlled by the conventional error control system. The 36-in. valve is positioned as required to keep the smaller valve in throttling range by an analog computing type controller which computes a signal based on heat exchanger design data and the indicated inputs. This control method eliminates the importance of hysteresis and is capable of responding quickly to large reactor power changes without causing the two valves to interact.

This control system was tested at reactor power levels up to 50 Mw; its performance was satisfactory.

![Diagram of HFIR Cooling System](ORNL-DWG-66-8909A)

**Fig. 11.30.1 HFIR Cooling System.**

### 11.31 HFIR PRIMARY FLOW SYSTEM TRANSIENT RESPONSE

**L. H. Thacker**    **D. S. Asquith**

The automatic safety and control systems of the HFIR operate on the basis of electrically calculated values of the ratio of neutron flux to primary coolant flow. The three safety channels
use electronic flow transmitters and signal conditioning equipment, while the three control channels use equivalent pneumatic equipment, with a pneumatic-to-electric converter at the input to the ratio calculator. The response time of both control and safety systems is, therefore, directly dependent upon the time response characteristics of the two types of flow measuring systems. Tests showed the characteristics of both systems to be marginal and indicated that a reduction in the response time would improve both safety and control action.

A detailed series of tests was performed to isolate the major sources of time delays in both systems. The greatest time delay in the pneumatic system (Fig. 11.31.1) was 100 ft of \( \frac{3}{4} \)-in. tubing connecting the flow transmitter in the beam room to the square-root extractor in the auxiliary control room. The response time of the pneumatic system (to 63% of final value following a step change in input) was reduced from 1.260 sec to 350 msec by moving the square-root extractor and pneumatic-to-electric converter from the auxiliary control room to the beam room. An additional square-root extractor was added in the beam room to supply the flow signal to the pneumatic heat-power calculator.

The major source of time delay in the electronic flow-measuring system (Fig. 11.31.2) was an isolation amplifier installed to permit grounding one end of the nuclear safety output resistor without interfering with the operation of the heat power multiplier. The simple expedient of shifting the isolation amplifier to isolate the heat power multiplier and allowing the nuclear safety system to operate directly from the square-root extractor reduced the flow signal response time from 475 to less than 300 msec.

### 11.32 STATUS OF INSTRUMENTATION AND CONTROLS DESIGN FOR THE MSRE

R. L. Moore       J. R. Tallackson
A. H. Anderson     D. G. Davis     P. G. Herndon

**General**

Formal design of the MSRE instrumentation and controls system was completed. Design of all systems originally planned and of all modifications and additions scheduled at the beginning of this report period were completed. Except for some revisions of specification sheets and preparation of a design report, documentation is complete. A small amount of design work remains on instrumentation and controls for an off-gas sampler system and on system modifications and additions.

**Chemical Process Sampler**

The fuel sampler-enricher system\(^1\) was redesigned for use as a chemical process sampler. This work involved some revisions to panel and field instrumentation, some changes in control

Fig. 11.31.1 Pneumatic Flow Measuring System. (a) Original system, (b) modified system.
Fig. 11.31.2 Electronic Flow Measuring System. (a) Original system, (b) modified system.
circuitry, preparation of installation and interconnection drawings required to install the system at the MSRE site, and revision of nomenclature and numbering of instruments and circuits to conform with MSRE practices.

Functionally, the instrumentation and control system of the chemical process sampler is similar to that for the fuel sampler-enricher system; however, the detailed design of the chemical process system sampler is simpler because the requirements for containment were reduced since lower radiation levels are present in the chemical processing system. The reduced containment requirements permitted the use of conventional (single-tracked) control circuitry instead of the redundant (dual-tracked) "safety-grade" circuitry used in the fuel sampler-enricher. Also, some commercial-grade components were used instead of special weld-sealed components, and some components were no longer needed.

Off-Gas Sampler

Design of instrumentation and controls for an off-gas sampler is nearing completion.

The off-gas sampler\textsuperscript{3} will be used for on-line analysis of off-gas from the reactor and for obtaining concentrated gas samples for off-site analysis. Instrumentation is being provided for on-line chromatographic and conductivity analysis; for measurement of flows, pressures, and temperatures required for proper operation of, and interpretation of data from, the chromatograph and conductivity analyzers; for control of the temperature of a molecular sieve trap and of the level of a liquid-nitrogen bath in which the molecular sieve is immersed; and for detection and annunciation of undesirable operating conditions to prevent the occurrence of hazardous conditions.

Since the sampler will be an integral part of the primary containment during sampling operations and since some components of the sampler did not meet the requirements for primary containment system components, solenoid block valves will be installed in the inlet and outlet lines that connect the sampler to the reactor system. Two valves will be installed in series in each line. These valves will automatically close and isolate the sampler from the reactor system in the event of high pressure in the reactor containment cell, high pressure in the fuel pump bowl, or high air activity in the sampler enclosure. High reactor-cell pressure will possibly indicate that the primary containment has ruptured and a maximum credible accident has occurred. High fuel-pump-bowl pressure will indicate that conditions exist that could result in a rupture of the sampler primary containment. High activity in the sampler will indicate that a rupture of the sampler primary containment has occurred. Sampler air activity will be detected by two gamma monitors (G-M tube type, ORNL model Q-1916) which will monitor two independent air samples collected from and returned to the sampler enclosure. At least two independent devices will supply input signals to the system and close the valves. One-out-of-two logic was used in the con-


control circuitry, and separation and identification were maintained in the detailed design of the wiring.

Panel-mounted instrumentation will occupy 5 lin ft of panel (6 ft high and 2 ft deep). These panels will be installed in the vent house south of the reactor building. The sampler and associated instrumentation will be installed in a trench outside the vent house. Since all major sampling operations will be carried out at the sampler, all sampling information will be displayed at the sampler panels; however, occurrence of an alarm condition at the sampler will actuate an annunciator in the main control room, and provisions are being made to permit some information to be transmitted to the computer-data logger. Also, a "permit to sample" switch will be located in the main control room. This switch, which is connected in the block valve circuits, will be used to prevent operation of the sampler without knowledge of the reactor operators.

Most of the instrument components used in the off-gas sampler were salvaged or were on hand. Reconditioning and calibration of this equipment and procurement of additional components were completed. Preparation of instrumentation application drawings was also completed. Panel design and fabrication of panels are nearing completion.

**Additions and Modifications**

During initial operation of the MSRE it became evident that additions and modifications to the instrumentation and controls system were necessary. Some changes were made to give additional protection to the system, but most were made to improve performance and give more information to the operator. A few minor design errors were corrected, and some instrumentation was added to simplify maintenance procedures. These changes were made with no major changes in instrumentation or design philosophy being necessary. A total of 275 requests for changes in instrumentation and controls (or in systems affecting instrumentation and controls) was reviewed: 188 required changes to the instrumentation or the controls, 25 were canceled, 37 did not require changes, and 25 are active requests for which design revisions are either in progress or pending. Twenty-seven of the requests required only changes in switch set points. Before any design changes were made, the requests were reviewed by persons responsible for operating the reactor and for the original design. No changes were made in the reactor system until the necessary approvals had been obtained. Some examples of these changes are:

1. To ensure proper drainage, the existing safety-grade circuits were designed to open vent valves on the fuel drain tank on a high neutron-flux (scram) signal and to hold the valves open until a manual reset is used to permit reclosing.

2. To reduce coasting of the control rod drive after power is switched off, a dynamic brake was installed on the servo-controlled rod drive motor.

3. To reduce period overshoot when the control rods operated, the settings of the "withdraw inhibit" and "reverse" interlocks were changed, and an electromechanical clutch brake was inserted in the shim-locating motor-drive train. The dynamic brake is also expected to reduce this period overshoot problem.
4. To provide the necessary counting sensitivity and ensure proper operation of the permissive "confidence" interlocks which allow filling the core vessel and withdrawal of control rods, a sensitive BF₃ counting channel was added to supplement the fission counters in the existing wide-range counting channel, and revisions were made in the electrical control circuitry.

5. To maintain the integrity of the reactor secondary containment, solenoid block valves with safety-grade wiring were installed in the fuel-drain-tank steam-dome drain piping.

6. To increase the reliability of the two containment barriers between the primary system (fuel pump bowl) and the operator, the fuel sampler-enricher "safety-grade" control circuits were revised.

7. To reduce the chances of damaging the radiator-door drive mechanism because of overtravel, cable fouling, or door jamming, the radiator-door drive control circuits were revised.

8. To prevent possible diffusion of H₂ into the HF gas supply cylinder, interlocks were installed in the fuel processing facility control circuits to close both the H₂ and HF gas supply station valves when the main gas supply valve to the fuel storage tank is closed.

9. To correct minor errors in the design or to simplify maintenance and operational procedures, a number of revisions were made in control-grade circuits. These included revising the run-mode-permissive circuit to prevent the failure of one pump-speed monitor from shutting down the reactor and replacing manual switches that allow sump-jet discharge valves in the reactor cell and drain tank cell to be operated individually.

Some revisions and additions were made to either improve performance or provide additional information to the operator. Examples of these changes are: addition of an ammeter in each control rod drive motor circuit; correction of conditions causing undesired operations of the reactor-flux scram-setpoint circuits, changing alarm and interlock-switch set points, addition of an alarm indicating the need for a change of range on the linear power recorder, addition of an alarm to indicate failure of the power supply for a health physics monitor, and reconnecting the main helium supply high- and low-pressure switches in separate annunciator circuits.

Details of these and other changes were reported previously.⁴,⁵

**Documentation**

Except for some revisions and additions to instrument specification sheets and preparation of a design report, documentation of the MSRE instrumentation and controls system design is complete. Instrument application and switch tabulations were completed and issued, and design drawings were revised to incorporate as-built revisions.

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11.33 STATUS OF INSTRUMENT DEVELOPMENT FOR THE MSRE

R. L. Moore
G. H. Burger       J. W. Krewson
D. G. Davis       R. E. Wintenberg

During the past year the MSRE attained full-power operation, and the special instruments developed for the MSRE\textsuperscript{1-8} accumulated a significant amount of time in steady-state operation under process and ambient conditions of temperature, pressure, nuclear radiation, etc., associated with full-power operation of the reactor. Some of these instruments have been operated under combined nuclear and nonnuclear conditions for as long as two years.

Observation of the performance of developmental (and standard) instrumentation was continued to determine whether modifications and repairs had satisfactorily corrected previous deficiencies in performance and whether new problems had arisen. Performance of all developmental instruments installed at the MSRE and on developmental test facilities continued to be satisfactory. No failures occurred in any of the developmental devices during the past year, and no problems arose that required major modifications in design or mode of operation. However, some minor modifications and adjustments were made, and some troublesome equipment was replaced to improve performance.

Investigation of the causes of failure of a NaK-filled differential-pressure transmitter is continuing.

**Float-Type Molten-Salt Level Transmitter**

Performance of the ball-float-type transmitter\textsuperscript{4,8} installed on the coolant-salt pump continues to be satisfactory. The calibration errors previously reported were found to be correctable by adjustment of the receiving instrumentation.

The ball-float level transmitter on the MSRE pump test loop continues to operate satisfactorily, although on one fill the float would not rise until the temperature of the heater at the

\textsuperscript{8}J. W. Krewson, *ibid.*, pp. 119–23.
bottom of the float chamber was increased. Either unmelted salt or curvature of the bottom inside the float chamber is assumed to be the cause of this sticking. A previous inspection of the core tube showed no deposits that would cause it to stick in the core chamber. The curvature of the bottom inside the float chamber coincides with the curved bottom of the float very well and may block entrance of the molten salt into the chamber. This design error had been noted prior to fabrication of the float chamber for the MSRE and was corrected on the assumption that such valving action might occur. The bottom of the float chamber was made flat so that the curved bottom of the float could not block flow of molten salt into the chamber.

One of the prototype ball-float level transmitters installed on the level test loop completed 4.5 years of operation at temperature in August 1966 and is still operating satisfactorily. The other transmitter was removed last year so that an ultrasonic single-point level indicator could be installed. The transmitter was operating satisfactorily when removed.

Except for preparing detailed drawings of the differential transformer assembly, design of a ball-float transmitter for the MK-2 MSRE fuel circulating pump has been completed.

**Conductivity-Type Single-Point Level Probe for Molten Salt**

Performance of the conductivity-type level probes\(^8\) installed in the MSRE fuel, flush, and coolant drain tanks continues to be satisfactory. There were no additional failures of excitation and signal cables on these probes.

**Ultrasonic Single-Point Level Probe for Molten Salt**

Since no fuel has been processed, the ultrasonic level probe installed in the MSRE fuel storage tank\(^8\) was not used during the past year.

To correct an excessive frequency drift present in the excitation oscillator supplying the ultrasonic level probe, a number of minor changes were made in the components and circuitry of the oscillator and detector-amplifier circuits. In general, these changes involved the replacement of a number of critical components with high-grade components having very small temperature coefficients, increasing the size of coupling capacitors so that they would have smaller reactance at the 25-kilohertz operating frequencies, and making several minor circuit revisions to increase the stability of the B\(^+\) supply. These changes resulted in considerable improvement in frequency stability. Before the changes were made, the oscillator had drifted randomly with a maximum deviation from the center, or resonant, frequency of 300 hertz. This deviation was sufficient to cause the instrument to become inoperative. After the changes were made, and after warmup, the maximum drift observed over a period of 5 hr was 5 hertz. These drifts were observed in an air-conditioned laboratory and are expected to be greater in the field; however, it is expected that the increased stability obtained will be adequate. A complete check on the operability of the ultrasonic level probe requires an actual variation of the level of molten salt in the fuel storage tank. Since no salt has been transferred to or from this tank since the probe
circuitry was modified, field checks on the effectiveness of the modifications were not made. These checks will be made when salt transfers can be made without interference with MSRE operations.

Except for a similar problem with frequency drift, the prototype ultrasonic level probe installed on the level test facility has continued to operate satisfactorily.

Temperature Scanner

Performance of the temperature scanning system\(^3\) continued to be generally satisfactory, although some problems were experienced with the oscilloscopes and mercury switches, and some system instability was noted.

The problems with the oscilloscopes were due to the age and design of the scopes, which being about 12 to 15 years old were a continuing source of trouble. Two new solid-state circuit scopes were ordered and installed. The new scopes apparently eliminated the problem. Performance of the mercury switches was excellent. It had been expected that the switches would need frequent attention and that the mean life between routine cleaning or repair would be about 1000 hr. In practice, however, the switches gave very little trouble, and their mean life was much greater than 1000 hr. Since the start of operation of this system in September 1964, there have been no bearing or other mechanical failures of the five switches installed. Four switches developed excessive noise during this period and required cleaning and replacement of the mercury. In one of these cases the switch failure was caused by a failure in the nitrogen purge-gas supply system. All five switches were cleaned and reconditioned before the start of power operations as a routine precautionary measure.

Although the mercury switches continued to give much better service than expected, some problems due to normal wear developed. When replacement parts for the switches were ordered, it was learned that the switches were no longer being manufactured. Since no spare parts existed, it was apparent that a replacement switch was needed. A solid-state multiplexer developed by the Union Carbide Corporation, Olefins Division, for use as a direct replacement for a mercury switch will be tested and evaluated to determine whether it would be a suitable replacement for the mercury switches.

Instability of the scanner was largely due to operation of the system outside its design range. Since elimination of this problem would require redesign of the discriminator, operation of the system was changed back to comply with the original design.

High-Temperature NaK-Filled Differential-Pressure Transmitter

The coolant-salt system flow transmitter that failed in service at the MSRE\(^6,8\) was refilled with silicone oil and tested. Prior to refilling, a vacuum pump was connected to the transmitter in such a manner that the pressure could be reduced on the process side of both seals and both
sides of the silicone-filled body at the same time. Liquid traps were installed in the body evacuation lines to catch any oil that might be forced out of the transmitter body by the expansion of trapped gas during evacuation. When the pressure was reduced to a 28 in. Hg vacuum (the lowest pressure attainable with the system at that time), oil was forced from the capillaries: 8.2 ml from the low-pressure side of the transmitter and 15.8 ml from the high-pressure side. This indicated that there was gas trapped in both sides of the transmitter body and that the amounts trapped were unequal.

Subsequent testing at temperatures from room temperature to 1200°F showed that although the temperature sensitivity had been significantly reduced by the refilling operation, it was still excessive. Before refilling, the zero shifts were 15 to 20 in. (water column) per °F change in ambient temperature. After refilling, the shifts were 0.1 in. of water per °F. Zero shifts of 0.1 in. of water per °F or less are required to obtain the accuracy desired in measurement of MSRE coolant-salt flow. In all cases the temperature-induced shifts were zero shifts. No shifts of span calibration were observed. Also, the transmitter did not exhibit a sensitivity to static pressure changes either before or after refilling.

The remaining shifts are believed to be due to gas bubbles in the silicone-oil-filled cavities. Attempts to eliminate these bubbles will be made by repeating the filling operations. To ensure that all remaining gas has been removed, attempts will be made to obtain a "harder" vacuum than the 28 in. Hg vacuum previously obtained. After refilling, the temperature sensitivity tests will be repeated.

**Single-Point Temperature Alarm Switches**

During initial checkout and precritical operation of the MSRE, considerable trouble was experienced with set-point drift and the occurrence of dual set points in the 110 single-point temperature alarm switch modules\(^9\) used for control of freeze valves and for actuating an alarm at certain critical temperatures. The switch modules were modified to correct these deficiencies,\(^10\)\(^11\) and tests made on randomly selected modules indicated that the problem had been corrected. However, after continued reports of set-point inaccuracy it became uncertain as to whether the modification had been 100% effective. This uncertainty was accompanied by a necessity to make frequent changes to determine the proper set point. A further uncertainty arose as to the accuracy with which the initial settings of some modules had been made. To eliminate this confusion, calibration procedures were refined, tighter administrative controls were established, and a program of routine checks and observation was initiated. Prior to power operation of the reactor, all modules were reset and the settings were recorded. Data obtained from subsequent spot checks made during reactor shutdowns indicated that a few modules had

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shifted excessively; however, these data were considered inconclusive because operations
records indicated that the modules might have been realigned. Some additional cases of dual
set points were discovered and corrected during these spot checks. Results of recent checks of
the set points of all modules indicate that no significant set-point drift has occurred during the
past six months. Also, no additional cases of dual set points were detected. Based on these
results, it is believed that the modifications made previously, together with in-service aging of
equipment, have successfully eliminated set-point drift. Further tests and observations of module
performance will be made to verify this conclusion.

Thermocouple Drift Tests

The checking of eight metal-sheathed mineral-insulated Chromel-Alumel thermocouples fabri-
cated from MSRE material for calibration drift at 1250°F was concluded. All thermocouples
continued to show some drift to the end of a 26-month test period. The final temperature equiva-
lent drift values were between the limits of +4.7 and +6.4°F.

11.34 DILATOMETER FOR MEASURING AXIAL DISPLACEMENT
OF FUEL DURING IRRADIATION

T. L. McLean V. A. DeCarlo² F. R. McQuilkin² R. L. Senn²

The axial displacement of UO₂ fuel pellets during irradiation was measured with a dilatometer
using a commercial pneumatic, linear-motion transducer.

The transducer consists of three chambers separated by two small sharp-edged orifices. A
precisely tapered pin attached to the fuel moves in one of the orifices. A thin-wall nickel bel-
lows keeps the fission gas from leaving the capsule and entering the transducer and allows the
fuel motion to move the tapered pin.

Calibration of the system is done before insertion into the reactor by moving the fuel column
and recording the transducer output.

Two capsules instrumented with these devices have performed well and have shown an ac-
curacy of ±0.001 in. and a repeatability of ±0.0005 in. The range is 0.290 in.

¹Abstract of paper presented at the 1966 Annual Meeting of the American Nuclear Society in Denver,
Colorado, June 1966, by F. R. McQuilkin.
²Reactor Division.

11.35 DIMENSIONAL GAGING INSTRUMENTATION
FOR HFIR FUEL PLATE BUCKLING TESTS

W. F. Johnson

Dimensional gaging instrumentation was provided for a series of buckling tests on individual
HFIR fuel plates. Owing to the difference in the coefficients of expansion of the fuel plates and
the side walls of assembled fuel elements, it was feared that the longitudinal expansion of the thin fuel plates might result in buckling or rippling, with a resultant effect on the distribution of cooling water flow.

Tests on individual plates were conducted in a test jig (Fig. 11.35.1) that closely simulated the restraints imposed on the plates in the actual fuel assembly. The fuel plate profile was measured by seven differential transformers mounted in a carriage assembly which could traverse the length of the plates. The transformer core and surface follower assembly was supported by means of parallel top and bottom flexures that provided precise alignment at all times. The differential transformers were excited by a carrier amplifier system; this system also amplified and demodulated the transformer output signal. Fuel plate profile data were recorded on a multi-channel direct writing oscillograph.

Actual tests were conducted in a furnace by traversing the fuel plates and recording the profile at various temperatures up to 400°F. To ensure the accuracy of the test at elevated temperatures, a calibration block was provided at one end of the fuel plate. The calibration block had three machine steps corresponding to \(-0.010\), \(0\), and \(+0.010\) in. relative to the initial plate surface.

A total of 35 fuel plates were tested, and no deflections greater than 0.020 in. were detected.

Fig. 11.35.1 HFIR Fuel Plate Test Jig.
11.36 A NEUTRON COUNTING SYSTEM WITH A FISSION DETECTOR AND A FLEXIBLE, BALANCED LINE

J. T. De Lorenzo  G. C. Guerrant  D. P. Roux

A neutron counting system containing a fission detector and a pulse transformer driving a balanced transmission cable was investigated to determine its usefulness as an instrument for reactor control. Because of the noise rejection capability of the balanced system input, all active elements can be located away from the hostile environment of the reactor, resulting in longer periods of trouble-free operation. The design criteria of Fowler\(^1\) were used as a guide.

The primary objective was to measure the response of the system to noise characteristic of the Oak Ridge Research Reactor (ORR). The results showed no noise pulses in excess of the alpha threshold after six days of operation at the ORR. A dummy fission detector (without \(^{235}\text{U}\)) was used to make this measurement.

Figure 11.36.1 shows the preamplifier circuit. A balanced line was also used between the preamplifier and the main amplifier. This has become a standard feature for reactor counting systems at ORNL. A capacitor at the detector transformer was required to retain a balanced signal source.

![Diagram of Preamplifier Circuit](image)

**Fig. 11.36.1 Preamplifier Circuit.**

The input cable, with a characteristic impedance of 250 ohms, was a 40-ft-long double-shielded twisted pair. Its outer jacket and inner dielectric were made of irradiated polyolefin compounds. The cable was enclosed in a flexible, stainless steel conduit for underwater operation.

The transfer impedance of this cable and four other types of balanced cables was measured. To determine the effect of the flexible conduit, a separate measurement was made with the cable-

conduit combination. The results are shown in Fig. 11.36.2. The improvement in shielding made by the stainless steel bellows can be seen by comparing curves A and B. Of the RG-22B/U, RG-22/U, and RG-108A/U group, only the RG-22B/U has a double thickness of shielding braid. The effect of a solid copper tube, 0.500 in. OD with 0.035 in. wall thickness, can be seen in curve F, where this tube was substituted for the double braid of the RG-22B/U cable.

Fig. 11.36.2 Transfer Impedance of Various Twin Conductor Cables.
The signal from the detector-cable combination requires a preamplifier with a low-noise input stage. A series-shunt feedback stage using two 2N2857 transistors gave an input noise of approximately 2.8 \text{nV/cycle}^{1/2} from 50 kilohertz to 30 megahertz with a terminating input resistor of 250 ohms.

The common-mode rejection of the detector, pulse transformer, cable, and preamplifier input transformer was measured from 20 kilohertz to 10 megahertz. The result is shown in curve A of Fig. 11.36.3. It was later discovered that a great improvement could be made in the common-mode rejection by the addition of a 10-kilohm resistor in series with the center tap of the detector transformer. Curve B of Fig. 11.36.3 shows this improved response, giving a value of nearly 90 db at 20 kilohertz and decreasing to slightly less than 40 db at 10 megahertz.

Fig. 11.36.3 Effective Transfer Impedance Curves with Common-Mode Rejection and RC-RC Filter Response Curves.
An overall "effective" transfer impedance was determined by correcting for the effects of common-mode rejection and the RC-RC filter of the system (50 nsec in this case). The results are shown in curves E and F of Fig. 11.36.3 for the system as tested and for the improved common-mode rejection respectively. The values for the improved common-mode rejection range from $7 \times 10^{-7}$ mv/amp-ft at 20 kilohertz to $2 \times 10^{-4}$ mv/amp-ft at 10 megahertz. Curve C of Fig. 11.36.3 represents the attenuation of the filter, and curve D is the transfer impedance of the cable-conduit combination, a repeat of curve B in Fig. 11.36.2.

11.37 NUCLEAR SAFETY INFORMATION CENTER

C. S. Walker

The Nuclear Safety Information Center serves the nuclear community by collecting, storing, evaluating, and disseminating nuclear safety information obtained from sources throughout the world. The activities of the Center include information on the design and operation of control and safety systems for various nuclear processes. Matters of interest are the performance required of safety systems; the specification of instrumentation; the concepts of redundancy, coincidence, failure modes, and reliability; the adequacy of reactor shutdown margins; and the design features of control devices in nuclear plants.

Nuclear safety information pertinent to instrumentation and control specialists is taken from material collected from all available sources. After the information to be stored in the Center has been selected, an abstract is prepared or extracted from each document, and key words are assigned for indexing purposes. The necessary reference data with the abstract and key words are then placed on file cards for storage in the manual files and on magnetic tape for computer storage. Both the manual and computer files are available for searching by means of key words, authors, subjects, etc.

Another important service of the Center is the preparation of the technical progress review journal *Nuclear Safety*, and members of the Instrumentation and Controls Division have been the principal contributors to the Control and Instrumentation Section. A state-of-the-art report on secondary shutdown systems of nuclear power plants was issued.1

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12. In-Pile Experiments

12.1 INSTRUMENT ENGINEERING SUPPORT FOR IN-PILE EXPERIMENTS

C. Brashear
A. M. Billings A. H. Malone R. E. Whitt

The in-pile research programs make it necessary to design new or to frequently modify existing instrumentation and control systems for the experimental facilities. The Instrumentation and Controls Division assists these programs by designing, procuring, installing, and testing the systems. Design and installation of four new instrumentation control systems and extensive modifications to five systems were completed. Also, the design of two new systems is nearing completion.

The in-pile irradiation facilities at the LITR, operated by the General Electric Company for studies in the high-temperature materials research program, test fuel elements under a variety of flux, temperature, and other environmental conditions. Two experiments, C-28 and C-48, are now operated from one instrument-control panelboard, which is being modified to provide instrumentation and controls for operating two additional experiments, C-42 and C-45. The panelboard was enlarged from 16 to 24 ft and reworked to group the instruments for each experiment. Design and installation of the instrument control system for experiment C-42 are complete. Design of the instrument control system for experiment C-45 is nearing completion, and the system will be installed later in 1966.

Two new irradiation facilities, C-43 and C-57, were installed at the LITR for use by the Naval Research Laboratory (NRL) to perform experiments for determining the mechanical properties of metal test specimens under irradiation at high temperatures. Each in-pile experiment assembly contains a great number of test specimens arranged in four groups, with each group having an electric heater for supplementing gamma heat to obtain the necessary high temperatures. The array is encapsulated in a double-wall containment shell. The temperature of the specimens is controlled by the combination of heaters and air pressure. A unique feature of these experiments is that air pressure is used to regulate the heat transfer rate by controlling the distance between the inner and outer containment walls and not as a direct coolant. The instrument panelboard for the C-57 facility was fabricated by NRL. The complete instrumentation and control system for the C-43 facility was fabricated by ORNL. A new instrument system is being designed for C-43 to permit the operation of two experiments simultaneously in the one facility.
A new facility was installed for performing an experiment in beam hole HB-2 at the LITR. This facility, operated by the Physics Division, will detect and measure a possible electric dipole moment of the neutron. An experiment instrumentation and control panelboard was fabricated and installed to monitor experiment temperatures. The system monitors the temperature of circulating D_2O and reduces the reactor power if the temperature of the experiment liner should exceed a preset maximum value.

A new panelboard was fabricated for the Solid State Division to be used for performing liquid-nitrogen cryostat experiments at the BSR. The panelboard and control circuits will permit future interconnection to the reactor experiment safety system. Upon completion of the new BSR, the reactor control system will incorporate a reactor experiment control system similar to the systems at the ORR and the LITR.

The Reactor Chemistry Division irradiation facility at the Engineering Test Reactor (ETR), Idaho Falls, was modified to permit irradiation of capsules containing new materials, such as other oxides, carbides, and coated fuel particles. The original instrument system\(^1\) had been designed and fabricated at ORNL to control the temperature of many beryllium oxide samples encapsulated and placed in the radiation field of the ETR. The system was modified by adding radiation monitoring equipment and changing the temperature control instruments.

Instrumentation for the Reactor Chemistry Division F-9 facility at the ORR was modified to permit the operation of a new type of experiment — a charcoal ignition test — alternately with the fuel meltdown experiment. The ignition experiments require, in addition to instrumentation used for fuel meltdown experiments, two additional temperature control systems and modifications of another one to provide an adjustable control rate of ignition by regulating the atmosphere surrounding the sample.


### 12.2 INSTRUMENTATION FOR THE MOLTEN-SALT BREEDER REACTOR

#### IN-PILE MOLTEN-SALT EXPERIMENT

H. D. Wills

To provide information on short- and long-term effects of irradiation on fuels and materials of interest to the Molten-Salt Reactor Program, an In-Pile Molten-Salt Experiment\(^1\) was fabricated and operated by personnel of the Reactor Chemistry Division. Since extensive instrumentation was required to operate the experiment and since the HN-1 beam hole of the ORR was used for the experiment, the old panelboard at the beam hole was redesigned and rebuilt to suit the purposes of the new experiment.

The old panel consisted of 26 lin ft of panel; 22 ft was removed and completely disassembled, and all instruments and wiring were removed. Twenty-six new drawings were made. The panel was refabricated from the old parts. All instruments reused were completely reworked, and the panels were rewired with new wire. The panel was then delivered to the reactor, reinstalled, and connected to the experiment. The completed panel (Fig. 12.2.1), including a 4-ft section occupied by a multichannel analyzer, is 24 ft long. The checkout and initial operation resulted in few instrumentation changes.

![Image of a control room](Photo 84975)

Fig. 12.2.1 Instrument Panel for MSRE In-Pile Experiment.

## 12.3 HIGH-BURNUP CAPSULE TEST

T. L. McLean

An instrument system was designed for the irradiation of coated-particle spheres to high burnup in the F-9 core position of the ORR.

The facility is unique in that the core position is shared with a fuel meltdown experiment conducted by the Reactor Chemistry Division. Because of this some instruments are, of necessity, common to both experiments, and the reactor safety circuits must be transferred to the

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proper instrument panels. Considerable time was given to designing a simple, relatively foolproof method of switching these critical functions.

Because the capsule assembly must be capable of being inserted into the core and then removed and stored at poolside while the meltdown experiment is in progress, the capsules were connected to the poolside junctions with stainless steel hose instead of rigid tube. Considerable engineering consultation was given to the Reactor Division designers in working out the mechanical details of this flexible assembly. Hemetic seals, thermocouples, thermocouple extension wire, thermocouple connectors and junctions, and other mechanical details were specified.

The temperature of the capsule is controlled by changing the ratio of helium to neon in an annulus surrounding the fuel. This changes the thermoconductivity by a ratio of 8 to 1, giving a wide range of operating temperatures.

The fuel, which consists of coated particles held in a graphite sleeve, is purged with high-purity helium. The gas stream is sampled for radionuclides after it leaves the capsule. This is the same system that was used on the AVR² capsules.

To date, one assembly of this design was irradiated without incident to the highest heavy metal burnup ever obtained at the ORR. Only one thermocouple was lost. The experiment was removed from the core approximately eight times.

²F. R. McQuilkin et al., An Irradiation Test of AVR Production Fuel Spheres in the ORR, ORNL-TM-1512 (June 1966).

12.4 IMPROVED TEMPERATURE CONTROL FOR THE ORR C-1 EXPERIMENT
R. E. Whitt

An improved temperature control system was designed for the ORR C-1 experiment to compensate for temperature disturbances caused by variations in flux. The experiment is designed to collect data on fission products released from a cladded-fuel sample by the diffusion process. The instrumentation sinusoidally cycles the flux level by varying the position of the sample in the lattice while the temperature is maintained constant. This continuous flux variation subjects the specimen to a variable heat input rate. Figure 12.4.1 illustrates that the heat removal rate is determined by thermal time delays associated with the thermal insulation surrounding the cladded-fuel specimen and the "containment jacket" housing the specimen. Since the heat input rate changes essentially instantaneously with changes in position and the heat removal rate lags the heat input rate by the thermal time constant determined by the barriers between the specimen and the cooling air stream, some form of anticipatory control action was needed. No adjustment of the existing temperature controller would give satisfactory regulation.

To determine what changes were needed in the temperature control scheme, the control problem was analyzed using a TR-10 analog computer. The objective was to design a compensator which, with the existing control system, would eliminate the effect of position disturbances on temperature regulation. Field testing supplied sufficient transient and steady-state data to derive
Fig. 12.4.1 Experiment and Control Systems.

analog models for the experiment and all control system components except the temperature controller and position programmer. The temperature control loop was analyzed to derive the transfer function of a compensator, and an analog circuit with this transfer function was programmed on the TR-10. With these analog circuits and the actual temperature controller and programmer, the response of the simulated system (both with and without the compensator) to load disturbances introduced by the position programmer was studied.

The compensator works as follows: the A(s) network develops a signal which, in response to a position change, adjusts the air-flow rate toward that value demanded at the new position; and the D(s) network delays the position disturbance by the amount of time required for the heat removal rate to match the heat input rate at the new position. The compensated control loop holds the temperature constant during position disturbances if (1) the gain associated with the transfer function D(s)N(s) is identical to that associated with $A_2(s)F_2(s)F_3(s)G_2(s)$, and (2) the time constants associated with these two transfer functions are identical.

Figure 12.4.2 shows the results obtained from the simulated system. For the case of a step disturbance of 1 in. in position, as indicated, the compensated system reduced the temperature
disturbance from approximately 38 to 3°C. For a continuous position disturbance of 2 in. peak to peak, the compensated system reduced the temperature disturbance from approximately 100 to 8°C.

A more complex compensator could perhaps further reduce the disturbances, but the additional complexity is not warranted since control is adequate for the present application. A compensator based on this design and employing operational amplifiers was constructed and will be installed in the experiment control system in the near future.

12.5 FEEDFORWARD COMPENSATION OF A TEMPERATURE CONTROL SYSTEM

R. E. Whitt

The closed-loop control system which regulates the temperature of a nuclear fuel specimen experiment in a nuclear reactor was simulated on an analog computer. All components of the system, except the controller, were represented by linear mathematical models determined from test data. An equivalent analog circuit was developed for each of the component models. Using these circuits and the actual temperature controller, the response of the analog system to a simulated load disturbance was determined.

A circuit which compensated the temperature control system for the load disturbance effect was developed and incorporated into the simulation. Simulated neutron flux perturbations were then introduced into the compensated model. Data recorded showed that the compensation circuit reduced the temperature deviations by a factor of 10.

1Abstract of M.S. thesis, Auburn University; published as ORNL-TM-1485 (June 1966).
12.6 BeO GRAPHITE COMPATIBILITY TEST

T. L. McLean

The BeO Graphite Compatibility Test\(^1\)\(^-\)\(^3\) was performed in the ORR core position F-1 as the first phase of a study of the reactions between BeO and graphite at high temperatures under irradiation. The test was in support of the High Temperature Gas-Cooled Reactor program and was part of a cooperative program with General Atomic.

A completely new instrument system was designed\(^4\) and built because the existing system, which had been used on the 8-Ball Test\(^5\) in the F-1 position, was inadequate for this test. The new system can continuously monitor the pressure and temperature of the test-specimen environment. Recorders are used to initiate a reactor setback when the capsule temperature becomes too high. For the first time tungsten alloy thermocouples are successfully used in a reactor power reduction system.

A gas cleanup system was designed to deliver helium and argon with less than 2 ppm total impurities. This high-purity gas is monitored for moisture and CO content as it is swept through the capsule. The capsule temperature is controlled by varying the ratio of helium to argon in an annulus between the capsule and the outer wall of the test assembly.

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\(^1\)C. A. Brandon, *An Irradiation Experiment to Study the Compatibility of BeO with Graphite at 1500\(^\circ\) C*, ORNL-TM-1255 (November 1965).


\(^4\)The detailed panel engineering was done by the ORGDP electrical and instrument engineering groups under the direction of the Instrumentation and Controls Division project engineer.


12.7 FUEL GRAPHITE COMPATIBILITY TEST

T. L. McLean

The Fuel Graphite Compatibility Test\(^1\)\(^,\)\(^2\) was performed in ORR poolside position No. 5 as the second phase of a study of the reaction of high-temperature oxides in contact with graphite. The test was in support of the High Temperature Gas-Cooled Reactor program and was part of a cooperative program with General Atomic.

The criteria for the test required that the capsule be swept with a helium stream containing 300 ppm of CO. The effluent from the capsule was periodically analyzed for radionuclides to determine the release rate to the birth rate of fission products in the fuel.

The CO was added by injecting 60 cm\(^3\)/hr of a 1% CO–helium mixture into a flowing stream of helium. A precision regulator and an 8-ft-long 0.004-in.-ID capillary were used to control the

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flow rate of the injected gas. The amounts of CO entering and leaving the capsule were measured with an infrared gas analyzer.

The design of the instrument control system\textsuperscript{3} made maximum use of available instruments by using an existing control panel and adding only the instrumentation necessary for the CO addition and monitoring and for interconnection to other existing facilities.

\textsuperscript{3}The detailed engineering for the project was done by the ORGDP electrical and instrument engineering groups under the direction of the Instrumentation and Controls Division project engineer.

12.8 FAST GAS-COOLED REACTOR CAPSULE TESTS

T. L. McLean

The Fast Gas-Cooled Reactor Capsule Tests\textsuperscript{1,2} are being performed in poolside position P4 of the ORR to irradiate, under simulated reactor operating conditions, prototype fuel elements for the Fast Gas-Cooled Reactor. The tests are being conducted under a cooperative program with General Atomic. These capsules are the highest-powered (20 kw/ft) and the highest-pressured capsules to be irradiated at poolside in the ORR to date.

Three instrument panels were designed to house the control systems for two capsules which were irradiated simultaneously. In each capsule the temperature and pressure of the environment within the test assembly are recorded. The reactor power is reduced when the capsule temperature becomes too high or the capsule pressure becomes either too high or too low.

The gas systems used to pressurize the capsule are rated for 2500-psig service. The flexible fuel can is operated at 1000 psig and is pressure cycled.


12.9 ORR HN-2 PNEUMATIC TUBE CONTROL SYSTEM

R. E. Whitt

The HN-2 high-speed pneumatic tube system transports samples between a new neutron activation analysis facility in the Graphite Reactor building and the HN-2 beam hole in the ORR approximately 300 ft away. Because the facility was designed to study the decay of short-lived isotopes, fast transfer of the sample containers (rabbits) and accurate measurement of irradiation and decay times are required. The control system allows either manual or automatic insertion and ejection of the rabbits and provides timing of the irradiation to an accuracy of ±10 msec for periods from 30 sec to 1 hr. The transit time of samples between the beam hole and the analysis facility is 6 sec. The system developed to provide the required timing and control functions requires that the position of the rabbit in the pneumatic tube be known.
The arrival of the rabbit at the beam hole entrance and at the loading station is detected by photoelectric sensors located there. Pressure-sensing tubes with their associated piezoelectric sensors\(^1\) are located at the irradiation position and at a point 18 in. back. The latter sensor is at the point where the rabbit first enters a region of any appreciable flux. A calibration coil\(^1\) is located at each sensing tube for accurate determination of the tubing delay, which is approximately 20 msec. Since the pressure sensors respond to the insert pressure turn-on pulse, this pulse would trigger the timing system falsely and signify the arrival of the rabbit. The photoelectric sensor located at the shield face prevents this by "arming" the timing circuit only after the rabbit passes that point. These four sensors provide the timing signals needed for sequential control of the steps in an irradiation cycle.

The operational features provided by the control system permit the operator to program the irradiation cycle for either automatic or manual execution in the following sequence: (1) insertion of the rabbit, (2) irradiation for a preset period, (3) ejection of the rabbit, and (4) removal of the sample for analysis. The operator can also select any of the sensors to start an auxiliary timer. This auxiliary timer can be used to measure the transit time of the rabbit between any two detection points.

The facility is now operational, and in the future a second loading station will be added. The control system already includes the logic and controls necessary for operating either of the two loading stations. Figure 12.9.1 shows a schematic of this system.

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13. Instrumentation for Reactor Division Test Loops

13.1 INSTRUMENT SERVICES FOR BOILING-LIQUID-METAL LOOP

J. W. Cunningham

Instrument services were provided to place a boiling-potassium loop in operation for heat transfer studies. The outputs from 28 thermocouples and 5 pressure sensors already connected to 3 multipoint recorders at the local panelboard were connected to record on the Dextir data collection system. Since sampling of data by the Dextir system while the recorder was unbalanced on a point being sampled or while the recorder selector switch was moving to or from the point might result in erroneous data being recorded by the Dextir system, two steps were taken to avoid this error. The step switches in the recorder were altered so that the wiper arm broke contact before making the next contact, eliminating the possibility that the Dextir system could sample a thermocouple at the instant it was bridged to another thermocouple at the recorder step switch. Also, an amplifier with a 50,000-ohm input impedance was installed in each of the recorders so that the high impedance limited the current circulating in a thermocouple during the period the recorder was achieving balance, thus minimizing any error should the Dextir system sample then.

At startup, when it was found that circulation could not be established because of several plugs within the system, all major components of the loop and the pressure transmitters on the boiler were removed and cleaned. The boiler is being replaced. Bare wire (0.010 in. diam) thermocouples, passing through the space between the boiler and the clamshell heaters that provide boiler heat, are individually welded to the boiler. For the new boilers Pt–6% Rh vs Pt–30% Rh thermocouples will be installed because their mechanical strength is greater than that of other types. Extension wires to the instruments were changed to copper conductors. The recorders were changed to a millivolt calibration, and temperature scales corresponding to the millivolt signals were prepared.

13.2 MAINTENANCE EXPERIENCE WITH INSTRUMENTATION OF THE INTERMEDIATE POTASSIUM SYSTEM

B. Squires

This system is a high-temperature Rankine cycle using potassium as the working fluid. The system, originally started in January 1965, has operated approximately 40% of the time since that
date. Operational control of the system is manual; however, safety action is initiated by instruments, and more than 500 separate points of information are transmitted to the operators.

Two cathode-ray tubes are used; one monitors 91 internal temperatures of heaters, and the other monitors 91 ground currents from heater windings. While maintenance of the tubes and the associated mercury jet switch is not excessive, almost every startup has caused new problems due to noise. The interference problems have been decreased by the use of twisted, equal-resistance lead wires and capacitors and by careful attention to grounding. This problem appears to be alleviated further through the use of better heaters.

Low-temperature (400°F) pressure transmitters are used for some of the low-pressure readings. These were supplied as d/p cells with the low-pressure side evacuated and sealed. Calibration drifted until the low-pressure side was opened and connected to a vacuum pump. Difficulties with interpretation of the readings from these instruments still exist, since it is not known whether liquid, vapor, or a combination of both is in the tubes that connect the instruments to the process.

Turbine pump speed is detected by a magnetic pickup which is limited to 800°F and to no more than two or three cycles to this temperature. The frequency of pulses from the pickup are converted to revolutions per minute.

All data from pressure, level, flow, speed, power, and some of the temperature transmitters are recorded on at least two separate instruments. The recording instruments are conventional, miniature instruments, Sanborn oscillographs, and a Beckman Dextir data logger. While this has made for some additional calibration time, it has also resulted in better accuracy.

The use of "I" tube level elements in a liquid-metal manometer was first tried on this installation. This element consisted of a 48-in.-long element inserted into a 1-in.-diam tube. During the operating period, one element had to be removed and replaced.

Two small calculating instrument circuits are installed in this system. Both circuits have been successful in maintaining the accuracy guaranteed by the manufacturer, and no maintenance has been required on the equipment.

13.3 INSTRUMENTATION FOR SMALL POTASSIUM SYSTEM 3

C. M. Burton S. W. Fiveash\textsuperscript{1} E. H. Kelley\textsuperscript{1}
A. K. Stansberry\textsuperscript{1} T. P. Wicker\textsuperscript{1}

At one time the Reactor Division had a requirement for several small, out-of-pile, boiling-potassium Rankine cycle experiments. Small Potassium System 3 (SPS-3) would have been quite similar in nature to SPS-2 (Sect. 13.4). To accelerate the schedule for this project as much as possible, an instrument panelboard for SPS-3 was fabricated according to SPS-2 drawings and then minor, necessary changes were made during field installation. A five-panel instrument panelboard was fabricated.

\textsuperscript{1}Oak Ridge Gaseous Diffusion Plant.
A directive deferring this project indefinitely was issued. However, the five-panel instrument panelboard and a thermocouple patch panel were fabricated and were delivered to the job site.

13.4 INSTRUMENTATION FOR SMALL POTASSIUM SYSTEM 2

C. M. Burton  N. H. Briggs  G. W. Greene  B. Squires

This small boiling-potassium Rankine cycle loop is one of several out-of-pile tests for the development of the Medium Power Reactor Experiment (MPRE)\textsuperscript{1} or of other liquid-metal Rankine cycle systems. In this loop hot liquid potassium is supplied to a boiler, the potassium vapor is used to drive a turbine-pump, and the vapor is condensed in a condenser. Heat loss from the condenser is accomplished by means of radiation to a water-cooled heat sink. The Reactor Division of ORNL will use this loop to study problems associated with the boiling of potassium, potassium cleanliness, heat exchangers, rotating equipment, etc.

The loop has undergone considerable high-temperature shakedown operation without a turbine and is now being modified for installation of the first turbine. The original instrumentation has operated satisfactorily, and additional instrumentation is being installed to prepare for operation with a turbine. In addition to approximately 180 temperature measurements, 40 other parameters are monitored. Some are in auxiliary systems. If any of approximately 35 of these 220 parameters varies beyond preset limits, alarms, automatic loop shutdowns, or both are initiated.

Considerable experience has been gained in obtaining data from a boiling potassium system as well as with providing automatic shutdown actions for the avoidance of damage to the experiment. Of particular value has been the additional experience gained from the design, fabrication, installation, checkout, and operation of several resistance-type liquid-metal level elements of the I-tube configuration.\textsuperscript{2}


13.5 CONVERSION OF TEMPERATURE RECORDERS TO °C

T. L. McLean

Because of the extensive use of °C by nuclear engineers in the Irradiation Engineering Department of the Reactor Division, all temperature recorders on their experiments were converted from °F to °C. To make this conversion, all range resistors, scales, and charts for more than 70 recorders were installed in a coordinated schedule with the removal and insertion of experiments.

The timing of the change from °F to °C for a particular facility required that the changeover be made when all phases of the experimental operation could be changed at one time. Data sheets, set-point lists, computer programs, etc., were changed beforehand and then were used after a reactor shutdown during which new experiments were added to the facility.
Honeywell class 15 and L & N model H recorders using Chromel-Alumel thermocouples were changed to a range of 0 to 1200°C with factory-supplied parts, although it took several months to acquire a sufficient quantity.

For tungsten-rhenium alloy thermocouples, an instrument calibrated for 35 mV was used with a chart for a 35-mv output. A special scale was engraved for 0 to 2500°C and was used for both W–3% Re vs W–26% Re and W–5% Re vs W–25% Re thermocouples.

The Foxboro Company previously did not offer recorder charts calibrated in °C for their ECI line of instruments. Because of the large number of these instruments at the ORR Gas-Cooled Loop No. 1, the Foxboro Company made a set of plates from which charts for the ranges of 0 to 300, 0 to 500, 0 to 1200, and 300 to 1000°C can be supplied.

All active experiments operated by the Irradiation Engineering Department at the ORR were converted, and the necessary parts for conversion of Honeywell class 15, L & N model H, and Foxboro ECI instruments to the ranges listed are available for future conversion.
14. Maintenance Services

14.1 INSTRUMENT MAINTENANCE PROGRAM AT ORNL

C. S. Harrill

The total investment in instrumentation and control equipment at ORNL is about $30 million. Approximately 100 instrument technicians maintain this equipment at a total cost of about $2.5 million per year. Thus the average cost is about $25,000 per year for the salary, burden, overhead, and parts for one instrument technician to maintain $300,000 worth of equipment.

The Instrumentation and Controls Division maintains this equipment throughout the Laboratory. The four largest users of these services, adding up to about half of the total labor cost, are the Reactor Division, Physics Division, Operations Division, and Health Physics Division.

From the standpoint of administration and supervision, the maintenance groups are organized as functional units. All maintenance technicians are in the Instrumentation and Controls Division; this Division also provides development and engineering services for electronic, process control, and reactor control instruments and systems. Over the past several years the Division has constantly sought to improve the quality of the maintenance services and the productivity of the maintenance personnel to meet the needs of increasingly complex and sophisticated instrument systems and of the larger and larger amounts of installed instrumentation. Although the installation of radiation warning systems, multichannel analyzer systems, and radio communication systems has about tripled during the past five years, the total installed instrumentation and controls equipment at ORNL appears to have grown at an approximately linear rate. However, the rate of addition of maintenance technicians has not been proportional to the rate of installation of instrumentation and controls equipment. The following efforts to improve efficiency have contributed in making this slower growth rate of technicians possible.

Hiring Standards and Training. — Even though there was a shortage of available trained instrument technicians, hiring standards were gradually raised to upgrade, or at least to maintain, the average proficiency of the group. Openings were advertised in technical journals on the theory that technicians likely to be reading journals would be more apt to meet technical job requirements than technicians who read only newspaper advertisements. Of the applications received, about two-thirds were rejected immediately due to obvious inadequacy in training and experience. Many applicants selected for interview had received technical training during four or more years of military service and, in addition, had acquired four or more additional years of experience in private industry after leaving the military.
Each applicant who arrived for interview was tested and then interviewed by at least two members of the supervisory and technical staff of the Division. About 50% of the candidates were rejected as the result of interviews and failure to meet minimum standards on tests. Finally, if an offer was made and accepted, experience indicated that the technician was likely to become a very good employee.

Since qualified technician applicants were scarce, more employees in the helper category were recruited, making sure that they would be eligible to enter the next apprentice training class when it started. Here too, standards were raised significantly. Whereas a few years ago helpers were hired with no experience and only a high-school education, now even though they have had little experience, they must have training in electronics or technology equivalent to a military service school so that they are well grounded in the basics. Also, they must pass the same minimum standards on aptitude tests required of technician applicants. As a result of this recruiting technique, it was possible to upgrade the three-year apprentice training program so that a trainee could start at a more advanced level, be given more specialized and complex training during the program, and finish at a considerably more advanced level of technical knowledge than would have been possible a few years ago. One main advantage of this helper recruitment program is that applicants meeting the above requirements and eager to accept these jobs were available locally.

In addition to the apprentice program, training classes for technicians were conducted on a need-to-know basis. For example, a course on gas chromatography and the maintenance of gas chromatographs was taught to technicians responsible for the continuity of operation of these relatively new devices. Another course was the maintenance of the new second-generation reactor control instruments installed on the HFIR and the MSRE. A reactor controls simulator was used for training in maintenance techniques and typical systems problems. Recently, two instructors from the RCA Institutes came to the Laboratory to conduct a concentrated course in the elements, application, and maintenance of transistors, and transistor circuits (Sect. 14.3).

**Functional Specialization.** — The functional organization of the maintenance forces has resulted in improved efficiency of operations. Perhaps the most obvious reason is that a technician is not required to have knowledge of every instrument and system installed at the Laboratory. He is trained intensively to know all he needs to know about the maintenance of a more limited group of instruments or systems for which he is responsible. It has been easier to develop and maintain pride in workmanship and achievement when the technician knows that he personally is responsible for the continuing successful operation of some significant part of Laboratory equipment.

Another advantage of the functional organization is the close coupling and feedback between the maintenance group and the engineers and supervisors of the development and engineering groups working with the same specialized types of equipment. If maintenance problems indicate a deficiency in design, the designer is quickly informed so that appropriate corrective action can be taken.
Use of Engineers and Engineering Assistants. — First-line maintenance supervisors are encouraged to check actively on the progress of their maintenance jobs and to call for help when needed. Engineers have been utilized by all groups to aid in training technicians on new equipment and to serve as consultants in solving more complex field problems. Also, engineering assistants are available in some groups to aid in training new employees, to aid in the diagnosis of more complex maintenance problems, to keep drawings and instruction manuals up to date, and to assist in technical direction of the work when the foreman is not available.

Acceptance Testing of New Equipment. — Extra time is spent in acceptance testing of new equipment to ensure that the equipment meets the purchase specifications. For example, such tests showed that a significant number of pulse analyzers had failed to meet the purchase specifications or those published by the manufacturer. Some troubles are fixed promptly during checkout. Often the equipment is returned to the supplier, frequently more than once, before final acceptance. Once accepted and installed, the equipment does well in service.

Preventive Maintenance During Scheduled Shutdowns. — Thorough and complete tests of reactor controls systems and devices during programmed maintenance periods have resulted in near maximum reliability of these systems. For example, outages at the ORR due to instrument failures during the past three years have been practically nil, whereas most of the new power reactors in the United States do not appear to be doing this well.

Modular Design of Instruments. — Instrument designers have always influenced the efficiency of the maintenance program. An example is the modular design of the "second generation" of reactor control instruments installed on the HFIR and the MARE. If instrument failure should occur, a technician can analyze the problem and determine which module is defective, quickly replace the defective module with a good spare plug-in unit, and resume normal operation with minimal interruption to continuity of service. The defective module can be repaired at a later date in a central shop facility by a technician who needs to be an expert only on the module and not necessarily on the overall system in which it operates.

Equipment failures are studied by maintenance personnel, and their recommendations are sent to the design groups. As a result the instrument designs are continually upgraded based on operating experience.

In-Place Testing. — Recent reactor control designs make extensive use of built-in devices for in-place testing of systems or segments of systems. A reactor operator can push buttons in the control room while the reactor is in operation and determine whether the safety system is operable and that it will initiate a shutdown for high temperature, low pressure, high heat power, high flux-to-flow ratio, high flux rate, or other preset out-of-tolerance variables. Various testing techniques are used — one is to squirt hot water on thermocouple junctions. Emphasis is placed on getting as much of the system as possible, from sensing element to control rod, into the test procedure. The gain in efficiency of maintenance has been significant in that
these several testing schemes do not have to be reinstalled for each reactor startup as has been done in the past.

**Analysis of Instrument Failures.** — An IBM card inventory system was prepared for all Brown recorders and other recording potentiometers, and an inventory of the new instruments installed in the TRU facility was completed. The cards have space for seven types of maintenance information as well as inventory information. Significant data can be printed in several different forms by the CDC 1604 computer. Of most interest is the early detection of basic weakness in newer types of instruments.

### 14.2 MAINTENANCE ACTIVITIES OF THE MONITORING SYSTEMS DEVELOPMENT GROUP

J. D. Blanton  S. B. DeHart  J. R. Sutton

The Monitoring Systems Development group, with 19 technicians and 3 foremen, maintains four types of equipment: fixed radiation monitoring instruments, portable health physics instruments, audio-visual equipment, and nondestructive testing instruments.

Facility radiation and contamination and building containment systems in 17 buildings were completed and checked (Buildings 2026, 3001, 3005, 3019, 3042, 3047, 3508, 3517, 3525, 3550, 4501, 4505, 4507, 4508, 7503, 7900, and 7920).

Routine maintenance of the expanded effluent systems at the Laboratory was increased. The systems being checked routinely are

1. process waste water system in Bethel Valley,
2. stack and duct monitors at the central radioactive gas disposal facilities (3039),
3. stack monitoring systems at the exhaust stack (3020) for the Radiochemical Processing Pilot Plant,
4. stack and process waste systems for the High-Radiation-Level Analytical Laboratory (2026),
5. stack and process water disposal monitoring systems for the HFIR,
6. stack monitoring systems for the MSRE,
7. stack and process water monitoring systems for the TRU.

The cell ventilation and process condensate monitors at the Fission Product Development Laboratory (3517) were checked weekly for the Isotopes Division.

The Radiation Instrument Maintenance group services approximately 1600 fixed health physics instruments in present use. During calendar year 1965, about 2276 units were serviced by this group. Four times during a calendar year each of approximately 1160 portable health physics instruments at the Laboratory is checked, repaired (if necessary), and recalibrated at the calibration facility. In the calendar year 1965, a total of 4942 units were serviced. A punch card system now in use for health physics instruments allows rapid printout of total inventory, maintenance performed on each unit, and other combinations of information such as a list of instruments over ten years old or a list of instruments with the highest maintenance index.
Approximately 200 pieces of radio communications gear are being operated on five frequencies. Expansion and installation was begun on a new narrow-band FM system (net 4) to replace the last wide-band FM system remaining at the Laboratory. A total of 1.5 man-years was required to service radio equipment during this period. New equipment was procured by the engineering group and installed by radio technicians. Technicians from the audio-visual group also serviced over 30 intercommunication systems and several large public-address systems. The transmitters and 212 portable receivers for the Laboratory radio paging system required about 0.35 man-year per year to service. An average of 1.2 services per unit per year was performed.

Approximately 270 personal radiation monitors were serviced, requiring about 0.5 man-year, or an average of approximately 3.2 hr per unit.

Laboratory-sponsored scientific meetings and symposia required procurement, maintenance, and operational assistance from the audio-visual technician group. This group maintained and operated audio-visual equipment used in auditoriums and conference rooms on site as well as at off-site meetings. For on-site meetings, a 279 man-days of technician time and a full-time supervisor were required; for off-site meetings, about 190 man-days of technician time and 45 man-days of supervisor time were required. Two men were assigned to this duty, and additional help was obtained from the other technician groups in the Division. Additional part-time supervision required for simultaneous meetings was obtained from the Monitoring Systems Development engineering group.

No new closed-circuit television systems were installed; more than 19 systems are now being operated.

14.3 ACTIVITIES OF THE SPECIAL ELECTRONIC SERVICES GROUP


A special electronic services group consisting of a field engineering group and two maintenance groups was formed.

The field engineering group consists of two engineers who provide consultation and field engineering for researchers in the Central Research and Administration Building (4500). The group contracted and administered a 40-hr intensive training class conducted by RCA Institutes for 57 instrument technicians on transistor theory and applications. A four-session laboratory course requiring about 16 hr supplemented the lectures and covered exercises in curve plotting of the characteristics of semiconductors, analog circuits, digital circuits, and nuclear instrument circuits.

One maintenance group consisting of a foreman and seven technicians provides maintenance services and assistance in construction of projects for the Oak Ridge Isochronous Cyclotron operations and researchers. Two 4000-amp transistorized regulators were constructed. Assistance was given in converting a surplus transmitter to a 50-megahertz 50-kw power source for use on the Separated-Orbit Cyclotron.
Another maintenance group consisting of a foreman and seven technicians provides maintenance and calibration for the more than 260 oscilloscopes, 17 Cary spectrophotometers, and a multiplicity of digital voltmeters, pulse amplifiers, nuclear scalers, signal generators, and other electronic instruments, most of which are commercial instruments. Although the overall reliability of the equipment is improving, the lack of adequate operating, service, and calibration information for many commercial instruments is a handicap. This group also maintains a central electronic maintenance shop in Building 3500 and a field repair shop in Building 4500 NM.

14.4 MAINTENANCE AND SERVICE FOR THE HFIR

D. S. Asquith       W. Ragan
P. Rubel            K. W. West

Since the HFIR was in a phase between criticality runs and full-power operation, numerous instrument systems not needed for the criticality tests but required for power operation were field tested to ascertain their operational reliability. The operational tests were carried out by following detailed checkout procedures. When each system checkout was completed, the information obtained from the tests was transferred to an instrument card file. Additional information is included on the cards, such as manufacturer, model, dates of service, and set points, as furnished by the design group or as determined by actual operating experience. By maintaining this file on a daily basis, the instrument maintenance group will have an accurate case history on each instrument.

The HFIR is unique in that very little reactor downtime is available for maintenance and service, even though the instrumentation is much more complicated than that of other ORNL reactors. Hence built-in on-line testing of various instrument channels is a necessity. Systems are under continuous study for ways to simplify testing and to shorten the length of time for checkout. For example, test points were installed throughout the heat power systems, and calibration sheets were drawn up to reduce the channel out-of-service time to an absolute minimum.

Since much of the nuclear instrumentation is of the new generation and, consequently, very limited operational experience is available on which to base service schedules and maintenance procedures, the maintenance staff is somewhat hindered in the routine maintenance of the reactor. Maintenance manuals for the safety, servo, and wide-range counting channels are being prepared, based on this limited operational experience. The first drafts of the general description for each channel are completed. In addition, detailed checkout procedures for the wide-range counting channels and the safety channels were prepared. The procedures were tested during a reactor shutdown and found to be quite workable.
14.5 MAINTENANCE OF THE ORR AND THE LITR

H. G. O'Brien   J. B. Ruble   G. G. Stout
D. D. Walker   K. W. West

During 1966 two spurious scrams occurred at the ORR; both were charged to malfunction of
the reactor flux-level safety and period system. One scram occurred when three rods dropped as
the result of momentary trouble in a level sigma amplifier; the second scram was caused by mal-
function of the period amplifier. Prior to this time only one other spurious scram had occurred;
in 1965, five of six rods dropped, but no cause of this malfunction was established.

This record of three spurious scrams in 8 years of operation is significant since the ORR
employs the safety system developed nearly 20 years ago for the MTR. This system uses vacuum
tubes, has a very fast scram response time of 15 ± 5 msec, and is arranged so that any one of
three channels can produce a scram. It has not generally been believed that such a record could
be achieved with a system of this type. Modern power reactors use solid-state components, have
much slower scram response times of 500 msec to 3 sec, and in general require the agreement of
two channels to produce a scram. The ORR record compares favorably with that of the very best
of the power reactors. It is our conclusion that the serviceability, and perhaps the safety as well,
of reactor protective systems is strongly influenced by the quality of the on-line and preventive
maintenance.

Several minor improvements were made in both the ORR and the LITR. Provisions for built-in
testing of the fast period scram were added to the log N amplifiers in the period channels. This
is similar to the fast-scram test buttons in the sigma amplifiers in the flux-level safety channels.

In the ORR the chassis in the safety trouble monitor and the nitrogen gamma activity channels
were rebuilt to improve the circuits and reduce the panel space. The large annunciator system
was divided into ten subsystems to aid in troubleshooting. A small annunciator system was added
at the side of the reactor pool to aid the operators in transferring water from the pool to the stor-
age tanks by indicating when high and low water levels are reached.

In the LITR the main coolant pump control circuits were modified to give a better pump startup
sequence. The heat exchanger fan controls were modified to reduce the possibility of freezing the
heat exchanger by shutting down the fans on loss of coolant flow or low reactor inlet temperature.
Several ammeters used for readout in the process control systems had given erroneous readings
under the influence of an electrostatic charge which collected on the plastic front covers of the
instruments. This problem was eliminated by spraying the inside of the covers with an antistatic
material; however, before any life testing of the spray could be done, the meters were replaced
with recorders to provide a record of the variables in question during remote controlled operation
of the reactor.
The ORR safety systems were modified temporarily for a boiling experiment and for a neutron fluctuation analysis experiment in which the trip points for flux, coolant flow, reactor differential pressure, and reactor differential temperature were lowered. The extensive modifications were outlined in a step-by-step procedure in reactor controls change memos to ensure that they were done correctly and that the system was restored after the experiment.

14.6 MAINTENANCE OF THE BSR AND THE PCA

H. G. O'Brien  
D. D. Walker  
K. W. West

Responsibility for maintaining these reactors was assumed by the Operating Reactors Section of the Reactor Controls Department. A number of minor modifications were made to the systems in conformance with the practices of the Reactor Operations Division.

The wide-range servo system, which could hold the flux at a constant level or cause the reactor to follow increases in the flux set point, was modified so that it also caused the reactor to follow decreases in flux demand as large as two decades. This was accomplished by blocking out the "log N greater than flux demand" reverse whenever the flux was decreasing on a negative period, and by prohibiting the automatic insertion of the preferred rod whenever the flux was decreasing on a negative period less than 60 sec. This latter feature prevents the preferred rod from inserting more negative reactivity than the regulating rod is capable of removing when the servo levels the flux off at the new demand level.

The counting channels in both reactors were modified to eliminate spurious counts from electrical noise pickup. In the BSR the fission chamber and preamplifier were changed to types used in the PCA and the LITR. The new type of chamber has a better plateau that allows more discrimination against noise pulses. The preamplifier was moved from a location near the chamber to the reactor bridge. In the PCA the Sola-regulated power lines supplying the nuclear instruments were isolated from the unregulated power lines. The preamplifiers were moved from the poolside junction box to a separate shielded box. The filtering in the preamplifier power supplies was improved. Arc-suppressing capacitors were placed around the coils of several of the control relays.

Equipment for built-in testing of the fast period scram was added to the log N amplifiers in the period channels. This is similar to the fast-scram test buttons in the sigma amplifiers in the flux level safety channels.

The MTR-type compensated ion chambers used in the BSR log N and servo channels became defective and were replaced with newer PCP-II-106 chambers,¹ which give better gamma compensation and are interchangeable with chambers used in other ORNL reactors.

The control rod magnets in the PCA were damaged by water and were replaced with magnets of an improved design. The number of turns of wire in the new magnets was reduced by two-thirds to raise the magnet current into a more linear portion of the operating range magnet amplifiers. The scram release times were decreased to about 7 to 8 msec by reducing the vacuum holding effect between the magnet and armature faces by cutting radial grooves in the armature face with a straight knurling wheel.

14.7 CONVERSION OF THE BULK SHIELDING REACTOR TO OPERATE AT 2 Mw

J. L. Redford  A. M. Billings  P. Rubel
J. B. Ruble     J. A. Russell   D. D. Walker

To provide higher flux levels in the Bulk Shielding Reactor, the reactor and control system were redesigned for operation at a power level from 1 to 2 Mw.

A new reactor cooling system\(^1\) (Sect. 14.8) consisting of a decay tank, a heat exchanger, a demineralizer, a cooling tower, and circulating pumps was installed. The cooling tower was sized to handle both the BSR and the LITR loads, the latter to be added later.

The reactor control system was redesigned utilizing the Instrumentation and Controls Division standard vertical panels with an added built-in console. All the original features of the old reactor control system were retained and a "Run" mode for power range operation similar to that on other Operations Division reactors was added. Rod drives were upgraded, and the clutch holding and release current were made more uniform by improving the alignment of the magnet and its armature.

Provision was made for remote operation from the ORR control room. The vertical panels were arranged in an arc of a circle so that the control panels can be scanned with a closed-circuit television system. Instrument dials and indicating lights were modified for improved legibility. Both the control room and reactor pool areas are under the surveillance of the television and audio monitoring systems.

The BSR is the second reactor to be operated remotely from the ORR control room. For a number of years the LITR has been operated remotely, first from the Graphite Reactor and more recently from the ORR. In contrast to the BSR, which is under television surveillance, all the essential LITR instrumentation is duplicated at the remote console.

To eliminate spurious noise in the electronic systems, a single point ground was established. To achieve this, all panels were insulated from the concrete floor, and no conduit or piping was allowed to enter the panels without first being isolated from building ground.

Provision has been made for the automatic transfer of control circuits to the ORR emergency diesel generators in the event of ac power failure. This enables rod drives to be inserted, provides rod position information, and keeps the television monitoring and area radiation monitoring

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\(^1\)Designed by the Process Instrument Section.
systems in service. Since the reactor will not be operated on emergency power, the power to the nuclear instruments is not included in the transfer.

As many as six shim-safety rods can be installed in the core, although four is the normal complement. One of these will serve as a regulating rod in addition to its shim-safety role, an arrangement that is being used successfully in the HFIR, ORR, and MSRE. When a shim rod under servo control is used, it is necessary to limit the amount of reactivity thus controlled. The first such installation at the ORR consisted of motor-driven traveling-limit switches located on the rod drives. This unwieldy arrangement was later replaced by synchro-driven limit switches and a differential gear located on the console, and a similar package was developed for the MSRE. The HFIR employs a "piggy back" arrangement, wherein the entire rod drive is moved up and down under servo control to obtain a limited stroke. The BSR accomplishes this same result by employing the limit switches on a strip-chart recorder. This much more economical arrangement produces the same results and can be applied to almost any small reactor where it is desirable to convert a regulating rod to a shim-regulating rod.

A new set of control and instrumentation drawings was completed, and descriptive operation and maintenance manuals are being prepared.

Since the reactor is located on a traveling bridge and can be positioned in a variety of locations in the pool area, three special cables which contain all rod-drive control and instrument cabling were fabricated and installed. These cables, suspended overhead by a messenger cable/counterweight system, allow the reactor to be repositioned without any cable changes being required.

14.8 MEASUREMENT OF BSR DIFFERENTIAL PRESSURE AND TEMPERATURE

A. M. Billings    B. C. Duggins

A forced convection cooling system is being added to the BSR to permit operation at power levels to 2 Mw. As indicated in Fig. 14.8.1, water flow will be from the pool, through the core to the outlet plenum, through connecting piping to the suction of the circulating pumps, and then through heat exchangers and back to the pool. The measurement of core pressure difference and temperature difference presents unusual problems because (1) to achieve optimum response, the sensors must be located as near to the reactor as is consistent with their ability to withstand radiation damage; (2) the inlet temperature measurement should be the average temperature of water entering the core; and (3) the sensors must be suitable for remote installation under water.

Core pressure drop is measured by a differential pressure transmitter utilized as a water manometer. The low-pressure side of the transmitter is connected to the reactor outlet plenum, and the high-pressure side is open to the pool. With flow, the core pressure drop equals the
difference between the pool level and the height of the water column on the low-pressure side, and thus is sensed by the transmitter. The vent lines are extended above the pool level and are continuously vented to prevent the formation of air pockets.

Core differential temperature is measured by a pair of resistance thermometers. A perforated tube spanning the width of the core gathers a sample of the inlet water which is carried through an insulated tube to the inlet sensor located in the vicinity of the outlet sensor. Transport delay through both paths (i.e., through the sample tube and through the core) is designed to be equal so that the inlet and outlet measurements will be properly phased to yield a differential temperature free of transient errors. This is the first time such a concept has been used on an ORNL reactor.

Startup of the BSR following these modifications will be in late 1966.
14.9 INSTALLATION AND MAINTENANCE OF EXPERIMENTS AT THE ORR AND THE LITR
M. R. Beliew G. G. Stout K. W. West

All controls and instrumentation for experiments installed in the ORR and the LITR were maintained routinely, and were revised and reworked as required for changes in the experiment apparatus.

The General Electric Company tests experimental fuel elements under a variety of flux, temperature, and other environmental conditions in the ORR A-2 facilities. A hydraulic position control system was installed in the A-2 facility, and the facility was enlarged to accommodate more than flux-monitoring-type experiments. Instrumentation was installed in the LITR C-42 facility for testing fuel elements by the General Electric Company.

The Naval Research Laboratory uses the LITR facilities for experiments to determine the effects of radiation on the mechanical properties of metal test specimens. A new type of system was installed for making a series of steel specimen irradiation runs in which the temperature is controlled by varying the distance between the inner and the outer shell. This control was effected by adjusting the air pressure between the inner shell and the outer shell, thus changing the bow of the outer shell.

Instrumentation was installed in the LITR HB-2 facility for use by the Physics Division.

The ORR capsule test facility was expanded by the installation of a fast gas capsule facility. All temperature recorders in the test facility were converted from °F to °C. The pressure readout system was changed from gages to transducers and associated instruments.

A position programmer was added to the ORR C-1 facility. The programmer varies sinusoidally the position of the experiment within the lattice while holding the temperature constant. A Mosely recorder was installed as a parallel unit with the control unit to provide position readout. Caution must be used in paralleling a Mosely recorder with another system because, on the low ranges, the input impedance changes from high to low when the recorder power switch is in the "off" position.

The ORR F-9 facility was adapted to take burning-type experiments with variable ignition rates. A low-air-flow recorder was installed. Loop-1 temperature recorders were converted from °F to °C.

Two new facilities were installed at the ORR. Instruments were installed in HN-1 for operating a molten-salt loop by Reactor Chemistry. The installation of a pneumatic tube facility for neutron activation analysis by the Chemistry Division was completed. The control unit was checked out and placed in operation.
14.10 EARLY EXPERIENCE WITH ORNL SECOND-GENERATION INSTRUMENTATION AT THE MSRE

C. E. Mathews  E. N. Fray
J. L. Redford  J. R. Talackson

The MSRE was the first reactor to be fitted with the ORNL second-generation (all-solid-state) nuclear instrumentation.\(^1\) During the shakedown period following installation, several minor equipment design difficulties were corrected, and personnel learned through study and practice the differences between handling vacuum tube and transistorized hardware. Experience to date indicates that appreciably less routine service is required to maintain the newer equipment, partly because there are no vacuum tubes to be removed and tested or replaced (and only during reactor shutdowns) and partly because the newer systems are arranged to be checked during operation using built-in test systems. On-line replacement of assemblies in most cases is much simpler with the second-generation equipment.

Of the many differences between maintaining vacuum tube and transistorized equipment of all types, three stand out in the experience gained at the MSRE so far. First, transistor assemblies are more sensitive both to operating temperature and to temperature changes. Second, since most transistor circuits operate at low signal-voltage levels, more parts of a channel than of an input are subject to noise pickup and require special treatment. The various power supplies associated with the equipment introduce electrical noise from the ac power system. It was found helpful to connect arc suppressors across various relay coils, especially those controlled by contacts in the instrument modules themselves. Third, the larger transistors, which are mounted on but insulated from heat sinks, collect conductive dust and metal shavings too small to be easily noticed but which form low resistance paths across the insulation. Since the transistors might be located almost anywhere on a chassis or in a module, visual inspection may be most difficult and therefore omitted for extended periods of time.

An interesting problem developed with the safety and linear channel ion chambers which are mounted at the end of long aluminum tubing supports in a large thimble that contains water. It was observed that following a startup of a run at high power, the power according to the chambers continued to rise even though heat power measurements showed it to remain constant. The phenomenon was found to be related to the temperature of the water in the thimble, and corrections were made by holding the water temperature constant. Although elevated temperatures reduce the density (shielding) of water and increase the length of the support rods, both effects being in the direction of increasing the flux at the chambers, it is not clear that these two effects account for as much change as was observed.

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15. Support for the High-Voltage Accelerator Program

15.1 PULSING EQUIPMENT FOR THE TANDEM VAN DE GRAAFF ACCELERATOR

J. W. Johnson     R. F. King     C. D. Moak

The design and fabrication of equipment for producing a pulsed beam from the ORNL Tandem Van de Graaff accelerator, and previously described, were continued. The design was completed, and fabrication of the electrical and electronic equipment was 95% complete. This included building the klystron-buncher power amplifiers and power supplies and steering voltage supply, modification of a commercial 120-kv 60-ma injection voltage supply for remote operation, and a similar modification to a 120-kv lens voltage supply. Remote stations for varying the control functions were installed using a system of plug-in mounting for the selsyn transmitters. Since a total of 28 selsyn transmitters was required, considerable savings were effected by using plug-in modules.

Construction of the mechanical equipment was about 80% complete. This included the klystron-bunching section, a 100-kv einzel lens, a two-plate beam steering assembly, and a 120-kv accelerator tube. Still to be completed are the lens-pulser, the duoplasmatron ion source, and the gas feed system. The support structure for the terminal housing and the ground shield was installed.

Installation of the completed equipment is scheduled for September and October; initial operation and checkout will be made with an unpulsed beam. The test-bench ion source and lens-extraction will be used for checkout, with ion currents greater than 100 µamp of H− having been produced on the test bench.

1Physics Division.

15.2 TANDEM VAN DE GRAAFF ACCELERATOR OPERATIONS 1965–1966

G. F. Wells

Heavy-mass particles continue to dominate the research time on the Tandem accelerator, with fluorine added to the list of heavy ions (O, N, Br, and I) produced by the accelerator during the past year. Fluorine (19F−) ions are produced by ionization of SF6 gas in the negative ion source exchange canal using Ar+ ions from the duoplasmatron. Charge states to +7 and energies to 52 Mev are available.
The major maintenance item of the year was a return to the straight-field, high-energy accelerator tube in May 1966. The life of the inclined-field, low-energy tube used for the past two years was excessively short compared with the original straight-field tube installed in the accelerator. Surprisingly, the inclined-field tube installed in January 1963 is still in operation (12,000 hr). Protection from damage from stray beams by collimating slits placed at the entrance to the accelerator has played a major role in protecting the low-energy tube.

The accelerator was operated 3450 hr. During the last quarter of the year, the co-op student training program enabled full 24 hr/day operation, thereby increasing the operating time of the accelerator.

15.3 NUCLEAR MAGNETIC RESONANCE PROBE FOR MAGNETIC FIELD MEASUREMENT

G. F. Wells        R. F. King

Nuclear magnetic resonance (NMR) measurement of the Tandem accelerator analyzing magnet field is the primary method for determining beam energy, according to the equation \( mE/q^2 = k H^2 \), where \( m \) is mass, \( E \) is energy, \( q \) is charge state, \( k \) is magnet constant, and \( H \) is field density. The proton resonance presently used is limited to approximately 10,000 gauss by the existing oscillator and frequency measurement equipment. Measurement of higher field strengths of which the magnet is capable requires a change of probe to accommodate a deuteron resonance which occurs in an entirely different frequency range from the proton resonance.

The possibility that a single probe might cover the entire useful range of the magnet field strength, utilizing the \(^1\text{H}\) resonance for low field strength and the \(^7\text{Li}\) resonance for higher field strengths, was suggested;\(^1\) following a prescription by Lemer,\(^2\) such a probe was made. The mass-energy product, magnetic field, and frequency ranges are shown in Table 15.3.1. The useful mass-energy product range of the magnet is covered with a frequency range of 2.65:1, which can be easily accomplished with a single tuning capacitor and coil in the rf oscillator. Appropriate overlapping occurs to ensure full range coverage.

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\(^1\)Suggested by Ralph Livingston, Chemistry Division.


Table 15.3.1. Characteristics of NMR Probe

<table>
<thead>
<tr>
<th>Mass-Energy Product (^a)</th>
<th>Magnetic Field (gauss)</th>
<th>Frequency (megahertz)</th>
<th>(^1\text{H})</th>
<th>(^7\text{Li})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>2,368</td>
<td>10.085</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.17</td>
<td>6,094</td>
<td>25.950</td>
<td>10.085</td>
<td></td>
</tr>
<tr>
<td>14.00</td>
<td>6,285</td>
<td>26.762</td>
<td></td>
<td>10.400</td>
</tr>
<tr>
<td>92.70</td>
<td>16,174</td>
<td>26.762</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Mass in amu; energy in Mev.
The amplitude of the probe signal suffers at high field strengths due to inhomogeneous fields in the only allowable probe location, that is, near the edge of the magnet pole. Efforts are being made to reduce the size of the probe and thus gain deeper magnetic field insertion.

15.4 TERMINAL GENERATOR VOLTAGE REGULATOR FOR VAN DE GRAAFF ACCELERATORS

R. F. King

Heteropolar, self-excited alternators are being used as top-pulley power generators in Van de Graaff accelerators probably because their power output per unit volume is larger than previously used alternators having fields produced by permanent magnets. However, their voltage regulation is usually poorer, being typically 20 to 30%. This poor regulation can be a serious problem in the operation of a modern pulsed accelerator.

A requirement of the generator is that it must not reduce reliability, and a Van de Graaff terminal is a notably hostile environment.

Heteropolar, self-excited alternators use a bridge rectifier to supply direct current to the field winding from the ac output of the alternator. Excitation is controlled by adjusting a resistor in series with the ac side of the bridge (R1, Fig. 15.4.1).

The addition of one current transformer and one resistor (CT and R2, Fig. 15.4.1) improves the alternator voltage regulation from 1 to 5% (Fig. 15.4.2). The current transformer should have a volt-ampere rating that is at least equal to the difference between full load and no load excitation volt-amperes, and a turns ratio approximately equal to the generator full-load current divided by the full-load excitation current. The ratio of R1 to R2 can best be found empirically.

Such regulators were designed and installed on the ORNL 5.5- and 3-Mv Van de Graaff accelerators.

Fig. 15.4.1 Heteropolar Alternator Circuit.
15.5 PULSE MONITORING PICKUP

R. F. King

It is desirable to be able to continuously monitor the nanosecond and subnanosecond beam pulses delivered by pulsed Van de Graaff accelerators. Although satisfactory Faraday cups can be made, they require that the beam be switched from the target to the cup for observation.

A nonintercepting pickup was designed and built which gives good time and amplitude information and makes it possible to monitor continuously, and to make adjustments if necessary, while the beam is on the target.

The pickup (Fig. 15.5.1) is a 1.25-cm-ID hollow cylinder through which the beam pulse passes. Plates with 1-cm apertures prevent beam particles from striking the cylinder and reduce the electric field penetration of the approaching beam charge. The cylinder is supported at the center by a conductor which, with its surrounding enclosure, has a 50-ohm impedance geometry.

The amplitude of the induced signal has best accuracy (within a few percent when compared with the signal from a fast Faraday cup) when the cylinder length is just equal to the physical
length of the group of charged particles comprising the pulse. This latter depends upon the time
duration of the pulse and the particle velocity.

Three models of the pickup were made, differing in the length of the cylinder. One can be
chosen for a given experiment to make \( \tau = vt \).

15.6 AN ADJUSTABLE REPETITION RATE GATE FOR THE 5-MV
VAN DE GRAAFF ACCELERATOR

W. T. Newton

The beam pulse rate of the 5-Mv Van de Graaff accelerator was formerly 4.5 Mc. A variable
pulse-rate gate similar to the one used on the 3-Mv Van de Graaff\(^1\) was constructed to furnish a
lower and variable pulse rate. The unit, its power supplies, and associated equipment (which
had to be converted from 4.5 to 2 Mc) was completed and bench tested.

The drive signal for the unit is obtained from a crystal oscillator which supplies a 2-Mc sine
wave to the upper pair of deflector plates. This signal is given the correct phase by a variable
delay line and is divided to the desired beam pulse frequency by switching to the appropriate output
of one of seven cascaded flip-flop circuits. Following this the signal is amplified and shaped
to feed the grid of the power output tube. The output is a rectangular wave with a 1200-v peak

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which drops to about 100 v for 70 nsec. These gating pulses are applied to the bottom set of
deflector plates which in conjunction with the upper deflector plates (positioned at 90° to the
lower plates and sweeping the beam at a 2-Mc rate) causes the beam to be swept across an ap-
erture and turned on for 10 nsec at a rate determined by the gating frequency selected at the con-
sole. Beam current is furnished by a duoplasmatron ion source.

15.7 AN E-H CROSS-FIELD ANALYZER FOR THE TERMINAL OF THE 5-MV
VAN DE GRAAFF ACCELERATOR

W. T. Newton

Due to the need for larger He\(^{2+}\) beams, an electric-magnetic cross-field analyzer was con-
structed and installed in the terminal of the ORNL 5-Mv Van de Graaff accelerator. This device
separates the doubly charged beam from the much larger singly charged beam before acceleration,
allowing the source to be operated at a higher current and also greatly reducing the load on the
machine. The output of He\(^{2+}\) ions was increased to 0.5 \(\mu\text{A}\) from 0.1 \(\mu\text{A}\).

The analyzer consists of two deflector plates at right angles to the permanent magnet poles.
These are mounted in place of the bottom deflector plates of the duoplasmatron pulser assembly.
The \(E\)-field plates require about 1400 v for He\(^{2+}\) particles with the \(H\) field from the permanent
magnet being \(\approx 1400\) gauss. The beam was furnished by an rf ion source.

A larger beam is expected to be obtained by using a duoplasmatron as a source of particles
for the analyzer. This setup has been completed and is being bench tested.

15.8 DUOPLASMATRON ION SOURCE DEVELOPMENT

J. P. Judish

The upper limit of peak unbunched target currents obtained in the 3-Mv Van de Graaff is about
800 \(\mu\text{A}\). Experimenters could presently use beam currents two or three times as large if they were
available. Because the amount of beam current loss caused by possibly excessive ambient pres-
sure was not known, some measurements of beam loss were made on a test bench at ambient hy-
drogen pressures ranging from \(2 \times 10^{-5}\) to \(100 \times 10^{-5}\) torr. Only a direct-current beam through a
25-cm flight path was studied. The pressure in the 3-Mv Van de Graaff pulser was also measured
under full operating conditions and then compared with the test data. Results show that ambient
pressure in the Van de Graaff beam flight path is not responsible for a major loss of beam current.

Further test bench investigations are to be made with both pulsed and direct-current beams at
different ambient pressures, flight paths, and duoplasmatron arc currents in an effort to achieve
the desired increase in Van de Graaff beam current without sacrificing quality.
15.9 INEXPENSIVE MOLECULAR SIEVE TRAP

J. W. Johnson

Mechanical vacuum pumps are well known for their high rate of backstreaming of pump-oil vapor. The resulting contamination of the pumped system, be it the oil in an oil diffusion pump or the surface of a solid-state radiation detector, has motivated the introduction of various types of traps in the vacuum line to the mechanical pumps. The molecular sieve trap has been accepted as an effective and service-free technique for stopping backstreaming. The trap consists of a body, or can, which has the central volume separated from the annular outer volume by a cylindrically shaped wire mesh. The central space is filled with molecular sieve material, Linde 13X. In the very center is a cartridge heater for reconditioning the sieve material. The inlet and outlet connections are arranged to be optically blocked by the molecular sieve material. In some traps, baffles are added to the open annular space to increase the number of bounces an oil particle must make to pass from the outlet to the inlet of the trap. This baffling increases the chance of an oil particle being absorbed by the sieve material.

An inexpensive trap of this type was made using a 1200-ml stainless steel beaker for the body and welding a coverplate over the open end with a screen to contain the sieve material and a blind-end tube in the center for the heater cartridge (Fig. 15.9.1). Copper fins are attached to the tube for the heater to conduct heat faster to the sieve material. Simple stainless steel baffles made from sheet stock are attached in the upper part of the annular area. Tubes for vacuum hose connections are welded into the side of the beaker.

These traps are routinely used in the High-Voltage Accelerator Laboratory to stop the backstreaming of pump oil from mechanical vacuum pumps. On a typical vacuum system there is no noticeable contamination of the diffusion pump oil after many months of continuous operation. Also, sensitive items such as solid-state radiation detectors may be pumped with mechanical pumps safely for long periods of time if a molecular sieve trap is used in the vacuum line. This general type trap is available commercially from many vacuum equipment suppliers for those who do not wish to build their own.

15.10 LIQUEFIED-NITROGEN AUTOMATIC CONTROL STATION

J. P. Judish

Several cold traps in the vacuum system for the 3-Mv Van de Graaff accelerator must be filled with liquid nitrogen. During operation of the accelerator, the traps sometimes are not accessible because radiation is present. Previously, the accelerator was shut down while the cold traps were filled. A device consisting of a probe nozzle and an electronic circuit was designed and installed; this device, when used in conjunction with a 100-liter liquid-nitrogen storage vessel, keeps the cold traps filled automatically without stopping the accelerator. The circuit also monitors, locally and remotely, the level of liquid nitrogen in the storage vessel so that there is
ample warning of a need for refilling. Transfer of liquid nitrogen from the storage vessel can take place with manual or automatic switching. In the automatic switching mode, either an external switching circuit or an internal electronic switching circuit can be used. The internal switching circuit uses transistor diode logic to control a solenoid valve. The circuit responds to a signal derived from two 0.5-w carbon resistors in such a way that the level of liquid nitrogen is allowed to fluctuate between the positions at which the resistors are set.

In typical use, a 1-liter cold trap can be kept filled automatically for about 100 hr for each filling of the 100-liter storage vessel.
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*Conference on Nuclear Electronics, Bombay, India, Nov. 22–26, 1965*

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*Institute of Electrical and Electronics Engineers, Regional Meeting, Dayton, Ohio, Feb. 2, 1966*

Oakes, L. C., "Instrumentation for High-Performance Reactors."


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Saxe, R. F. (Consultant, North Carolina State University), "The Acoustic Characteristics of ORR."

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Fox, R. J., "Lithium Drift Rates and Oxygen Contamination in Germanium."

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