ORNL-3378
UC-37 – Instruments

INSTRUMENTATION AND CONTROLS DIVISION ANNUAL PROGRESS REPORT

FOR PERIOD ENDING SEPTEMBER 1, 1962

OAK RIDGE NATIONAL LABORATORY
operated by
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for the
U. S. ATOMIC ENERGY COMMISSION

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For Period Ending September 1, 1962

C. J. Borkowski, Director
C. S. Harrill, Associate Director

DATE ISSUED

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1. Electronic Systems and Components

1.1 PRELIMINARY INSTRUMENTATION FOR THE APOLLO PROGRAM

N. W. Hill

R. K. Abele, M. M. Bowelle, H. R. Brashear, F. M. Glass, G. A. Holt, W. E. Lingar, J. L. Lovvorn, V. A. McKay, R. J. Scroggs, T. F. Sliski, R. D. Smiddie, H. J. Stripling, D. D. Walker, H. N. Wilson, J. W. Woody

For several years the Neutron Physics Division has conducted basic studies in the physics of high-energy protons incident upon thick shields to formulate design criteria for high-energy accelerator shielding. With the advent of space travel and the observation of proton and electron radiation in the Van Allen belts and solar flares, a similar problem of shielding space vehicles became a concern. The present ORNL program is to provide basic shield design data with experimental verification. The Instrumentation and Controls Division is assisting the Neutron Physics Division by developing nanosecond circuitry and conventional instrument systems for obtaining experimental data. Instrumentation supplied thus far has cost approximately $500,000. At present, experiments are being conducted at Harvard University, where the 150-Mev cyclotron is being used as a source of protons.

Primary radiation, which will contribute the major part of the total dose in space, will be studied, but emphasis will be on the contribution of secondary radiation, since this gives rise to the greatest uncertainty. The energies of the penetrating primary radiation can be calculated from range-energy considerations, but the energies of secondary radiation are less straightforward and, therefore, the calculations will be verified experimentally. In addition, reliability factors for survival from space radiation are likely to become more stringent for the Apollo vehicle and to increase the importance of secondary radiation effects.

The immediate experimental objective is to determine the intensity, energy spectra, and angular distribution of the secondary radiation emerging from various thicknesses of simple targets which are likely to be used as shielding (aluminum, carbon, water, and copper). These targets, from 0.3 to 1.2 proton ranges thick, will be irradiated with well-defined, monoenergetic, 160-Mev protons. The secondary radiation emissions of interest are neutrons, protons, and gamma rays; neutrons have the greatest intensity and therefore the greatest biological importance. In addition to these experiments, gross dosimeter measurements will also be made.

Methods of Measurement

Separate spectrometer systems based on known techniques are used for neutrons, protons, and gamma rays, with possibly as many as four different types being employed to adequately cover the large energy region of interest for neutrons. The proton spectrometers are similar to the neutron spectrometers except that the proton anticoincidence detectors and proton radiators are removed.

Bonner spheres are used to cover the neutron energy range from thermal to approximately 15 Mev. This system inherently has good discrimination for gamma rays and protons, but it is difficult to decipher the rather gross spectral shapes obtained. Data from a recent experiment at Harvard show reasonably accurate results for this energy range. By supplementing this information with that from bismuth and U^{238} fission chambers and a carbon activation chamber, neutron dosage information from thermal to 150 Mev will be obtained.[1]

Neutron energies in the 1- to 50-Mev range are measured by the time-of-flight method. From 40 Mev to the maximum energy (approximately 730 Mev), a high-energy-proton recoil telescope will be used.

A gamma-ray spectrometer with three well-shielded sodium iodide detectors will cover the gamma energy range from 0.1 to 2.0 Mev with an anticoincidence spectrometer and from $\sim$1.5 to 11 Mev by having the three crystals connected as a pair spectrometer. The neutron-induced gamma background is high in the pair spectrometer and is expected to be higher in the anticoincidence spectrometer.

The linear microsecond amplifiers used in the spectrometers were based on a design by Chase.[2] These amplifiers have sufficient bandwidth to permit the use of clipping lines as short as 0.5 μsec and as long as 4 μsec without degradation of overload performance. The gain of this amplifier is varied by feedback resistance change, which has the advantage of allowing the output voltage level of one loop to equal the input voltage of the following loop, thus avoiding pileup and overload problems. Gain changes accomplished in this manner, however, also result in bandwidth changes; these cause the rise time from minimum to maximum gain to change by a factor of 4 or 5. This change in rise time is unfortunate, since "zero crossing timing" is used. The change in rise time is compensated to some extent by reducing the high-frequency response of the minimum gain positions, but, owing to layout limitations, perfect compensation is not possible over the whole gain range. For these amplifiers the "walk" in the zero crossing time in any fixed gain position from a 0.5- to 10-v output appears to be 3 nanoseconds (nsec) or less, as observed with an externally triggered oscilloscope (with a Q-1212 mercury pulser). High-frequency peaking[3] in the output loop is used to shape the pulse for more effective performance of the discriminators, such as the "snip-snap" single-channel analyzer.[4]

The snip-snap single-channel analyzer, utilizing the power supply in the standard Chase amplifier, was modified by the addition of peaking chokes in the collector of transistors Q-19 and Q-25 (Fig. 1.1.1)

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[1]Personal communication from W. R. Burrus, Neutron Physics Division.

[2]R. L. Chase and V. Svelto, *IRE Trans. Nucl. Sci.* 8(3), 45 (1961).

[3]E. Fairstein, *Rev. Sci. Instr.* 27(7), 483 (1956).

[4]T. L. Emmer, *Nuclear Instrumentation for Scintillation and Semiconductor Spectroscopy*, ORNL TM-137, p 15 (May 3, 1962).

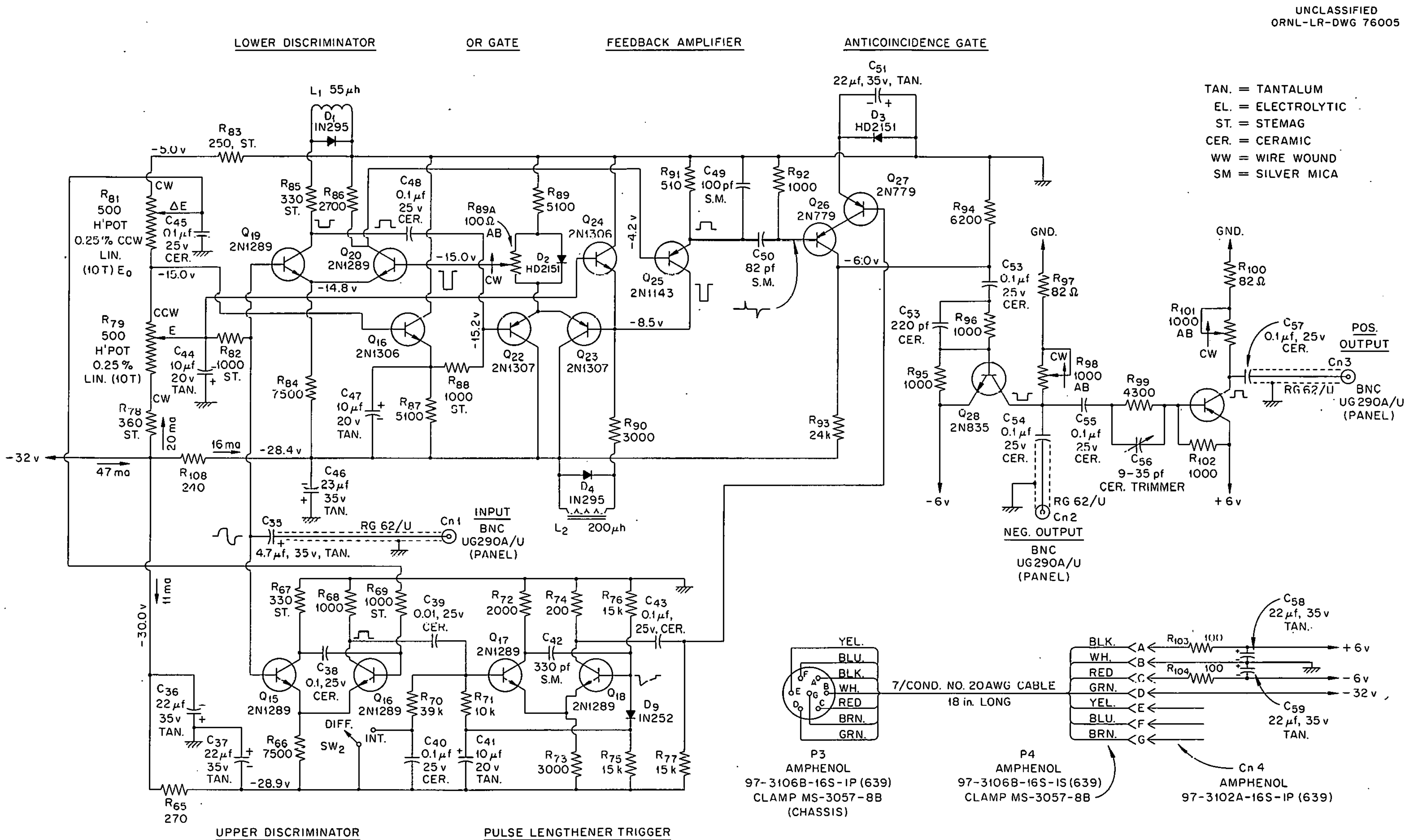

Fig. 1.1.1. Circuit Diagram of Snip-Snap Single-Channel Analyzer.

to give more reliable triggering. The number of half-fire pulses was further reduced by utilizing the forward drop of a germanium diode in the emitter of Q-27 to further bias off Q-26. The use of a potentiometer, shunted by a forward-biased diode in the common emitter of Q-22 and Q-23, permits zero adjustment of the *E* dial, thus giving readings directly in volts. The outputs of the snip-snap single-channel analyzers were changed to 6 v to drive equipment, such as scalers and the coincidence circuits. For driving the various cable impedances used with a 6-v 20-nsec rise-time pulse of both polarities, two transistors (Q-28 and Q-29) were added. With these modifications, typical "walks" with 0.1-μsec rise-time pulses were less than 8 nsec from 0.5 to 10 v (6 nsec was not unusual). Rapid time adjustments were made possible by incorporating 0.25-μsec 20-turn variable delay lines at the input of the coincidence circuits (Fig. 1.1.2). In order to make the basic instrument more versatile and flexible, coincident "in" and "out" front panel switches were added, which permitted rapid alignment of fourfold coincidences. This modification, along with a reduction of time constants in the output stage (R-30), permitted operation at rates up to 150,000 counts/sec.

The anticoincidence stage (Q-4) was changed to delay-line shaping also, thus permitting rapid change of anticoincidence widths. If the input pulse for some experiment was shorter than the length of the delay line used, the termination for that line was changed to account for the low *on* collector impedance of the shapers (Q-1, -2, -3, and -4). To prevent spurious pulses, it was necessary to effectively decouple throughout. The addition of a forward-biased diode in the emitter of Q-8 effectively prevented half-fire pulses from being counted.

An instrument system used in most experiments at Harvard University was the gating control system for data acquisition (Fig. 1.1.3), which works as follows. The charge generated in the ion chamber which intercepts the cyclotron beam is directly related to the number of 150-Mev protons passing through the chamber. The ion current is integrated, and a pulse is produced for a finite quantity of charge accumulated. The complete data-acquisition system, which includes two 400-channel analyzers, 12 scalers, Radsan dosimeters, clocks, etc., is then gated *on* and *off* by the length of time required to collect a preset number of these pulses. Since the duty cycle of a cyclotron is rather low, comparatively long periods of time would be spent accumulating background counts. To reduce background counts, the accumulation system may be gated *on* only during the times of beam extraction. Thus the data-acquisition system is gated *on* and *off* for periods of from 50 to 200 μsec at the 300-cycle/sec cyclotron macrostructure repetition rate.

Bonner Spectrometer System

The Bonner spectrometer system[5] (Fig. 1.1.4) for studying the neutron energy spectrum from thermal to 15 Mev consists of an $Li^6I(Eu)$ neutron detector located at the center of a polyethylene sphere, which moderates the incident neutrons from the target. There are five interchangeable spheres (2, 3, 5, 8, and 12 in.). Since thermal neutrons are absorbed in the surface of the $Li^6I(Eu)$ detector and since fast-neutron

[5] R. L. Bramblett, R. I. Ewing, and T. W. Bonner, *Nucl. Instr. Methods* 9(1), 1 (1960).

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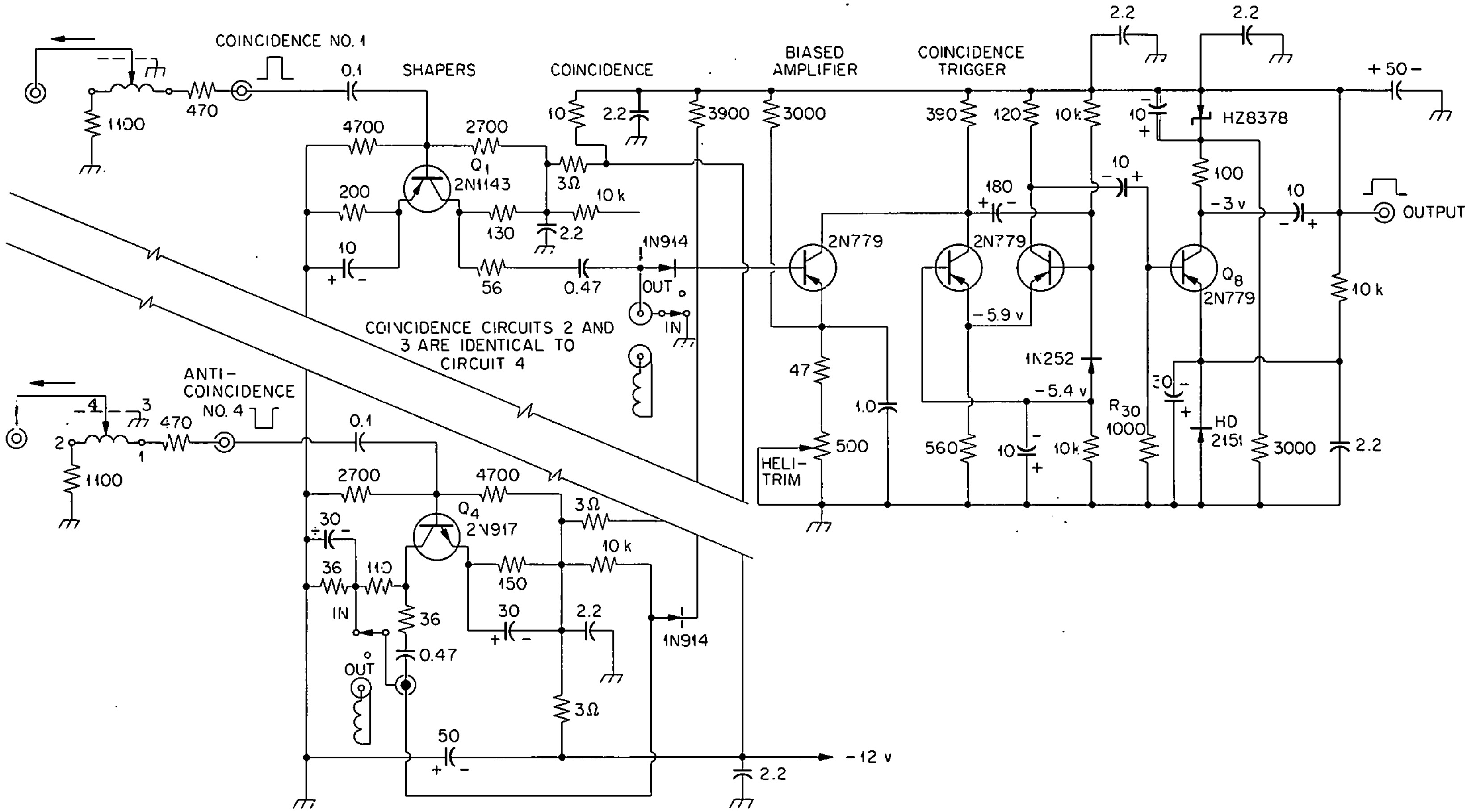

Fig. 1.1.2. Fast Coincidence Circuit.

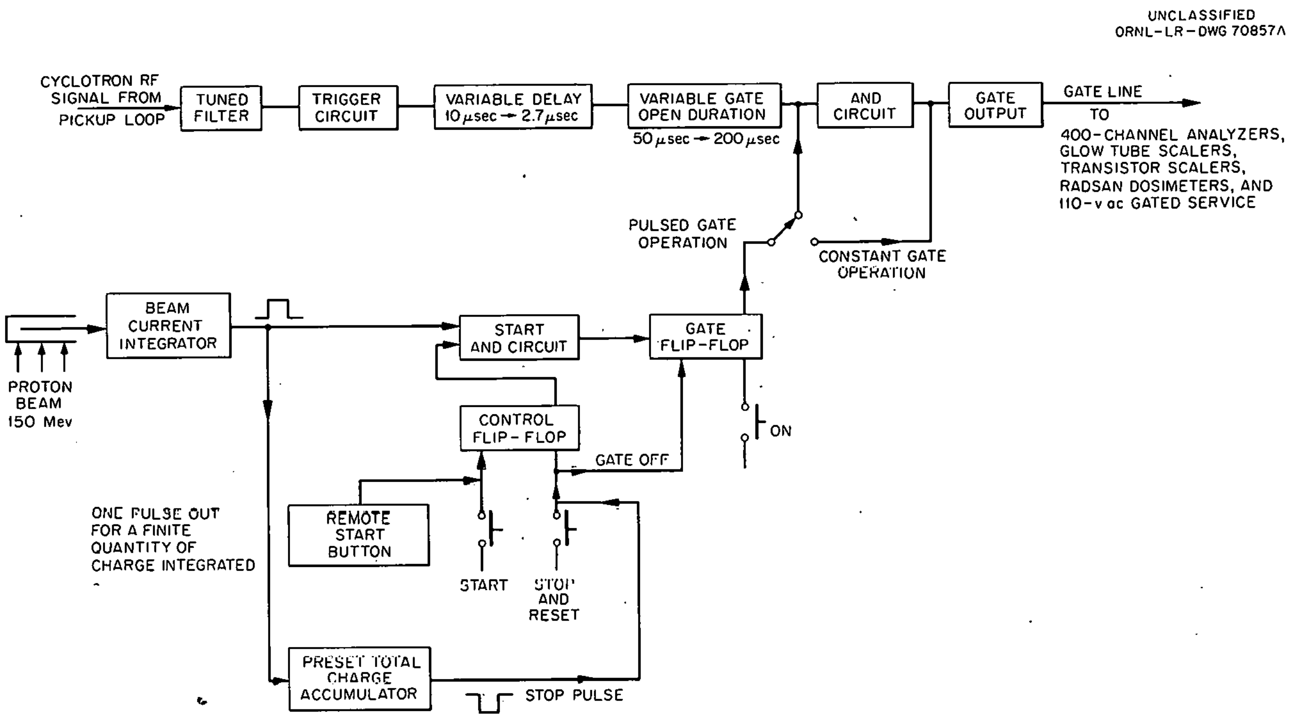

Fig. 1.1.3. Gating Control of Data-Aquisition Systems.

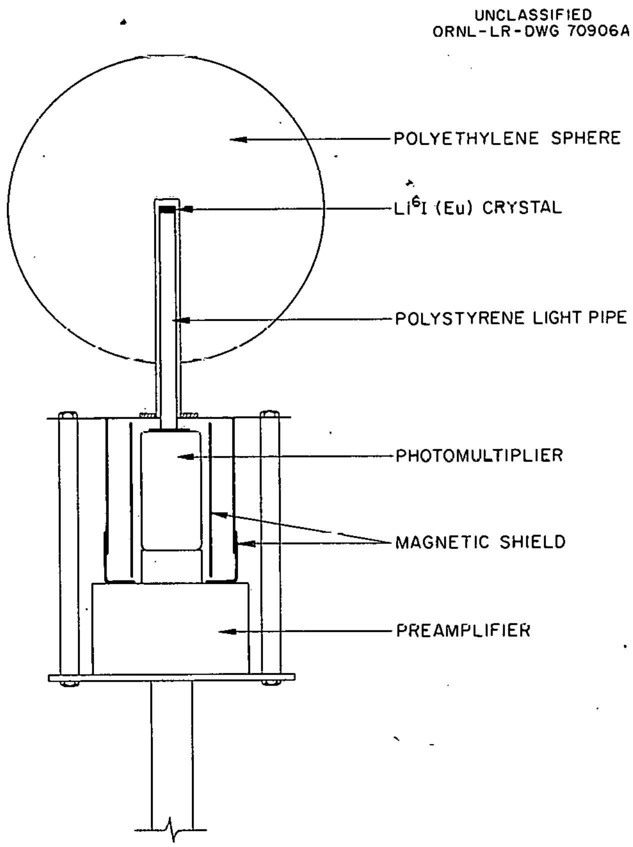

Fig. 1.1.4. Neutron Counter.

and gamma-ray efficiency is roughly proportional to volume, the small volume of the detector and the 4.8-Mev Q-value of the reaction give good discrimination against fast neutrons and gamma rays. Basically, each of the five spheres was calibrated as a function of neutron energy by exposing each to a given number of incident neutrons from monoenergetic point sources, that is, by plotting counts vs neutron energy for 10^6 (for example) incident neutrons for each sphere. The ratios of the count rates in the various spheres at a particular energy depend on the incident spectrum; some spectral information can be derived from experimental count-rate data by use of a suitable "unscrambling" method.[6]

High-Energy-Proton Recoil Telescope

The high-energy-proton recoil telescope (Fig. 1.1.5) operates as follows. Neutrons greater than 40 Mev born in the target interact with the hydrogen in a rather thick polyethylene radiator and produce recoil protons whose energies in the solid angle described by the telescope are proportional to the energy of the incident neutrons. Only those protons that occur in the proper time relation in two organic detectors and the NaI, dE/dX detector are analyzed. Protons emitted from the target or scattered from the beam are eliminated by an organic anticoincidence detector. Low-energy protons (i.e., high dE/dX) which will stop in the NaI, dE/dX detector are eliminated by using an upper-level discriminator on the dynode output from the organic crystal, which is also placed in anticoincidence. The height of the pulse from the NaI detector is a measure of the dE/dX of the proton, and since dE/dX is a unique function of the energy, the energy can be determined.

Sodium iodide was selected in preference to an organic scintillator because it produces a greater light output. Since dE/dX decreases with increasing proton energy, there is an inverse relation between the light out of the crystal and the energy of the proton. The slowness of the light pulse is not expected to be a limiting factor, since only the first 8 nsec of rise time is used.

[6] W. R. Burrus, *Neutron Phys. Div. Ann. Progr. Rept. Sept. 1, 1962*, ORNL-3360, p 19.

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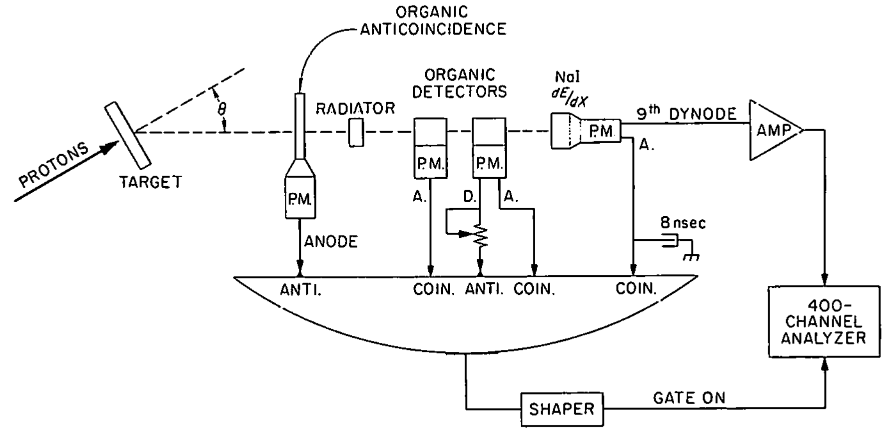

Fig. 1.1.5. High-Energy-Proton Recoil Telescope.

For the fast resolving times required by this experiment, a rather simple tunnel-diode coincidence circuit[7] was used (Fig. 1.1.6). The circuit is basically a simple diode "and" gate, which utilizes the fast switching speeds of tunnel diodes. Anticoincidence is obtained by permanently biasing the tunnel diode in its high-voltage state and switching it to its low-voltage state with the opposite polarity anticoincidence pulse. The output section consists of a conventional biased-off emitter-coupled amplifier which has good frequency response and an emitter follower. The large dynamic range of amplitudes from the photomultipliers in the high-energy telescope compromised the performance of this circuit, since widely varying amplitudes at the coincidence inputs made it impossible to set an effective upper-level discrimination point for the organic, dE/dX detector.

Gamma-Ray Spectrometer

The gamma-ray pair spectrometer (Fig. 1.1.7) uses three NaI crystals; two side crystals almost completely surround the cylindrical surface of a center crystal. The axis of the center crystal, along with the collimator, forms the angle θ with the trajectory of the incident beam. Gamma rays from the target strike the center crystal and form electron pairs with total kinetic energy just 1.02 Mev less than that of the

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[7]P. Franzini, *Rev. Sci. Instr.* **32**(11), 1222 (1961).

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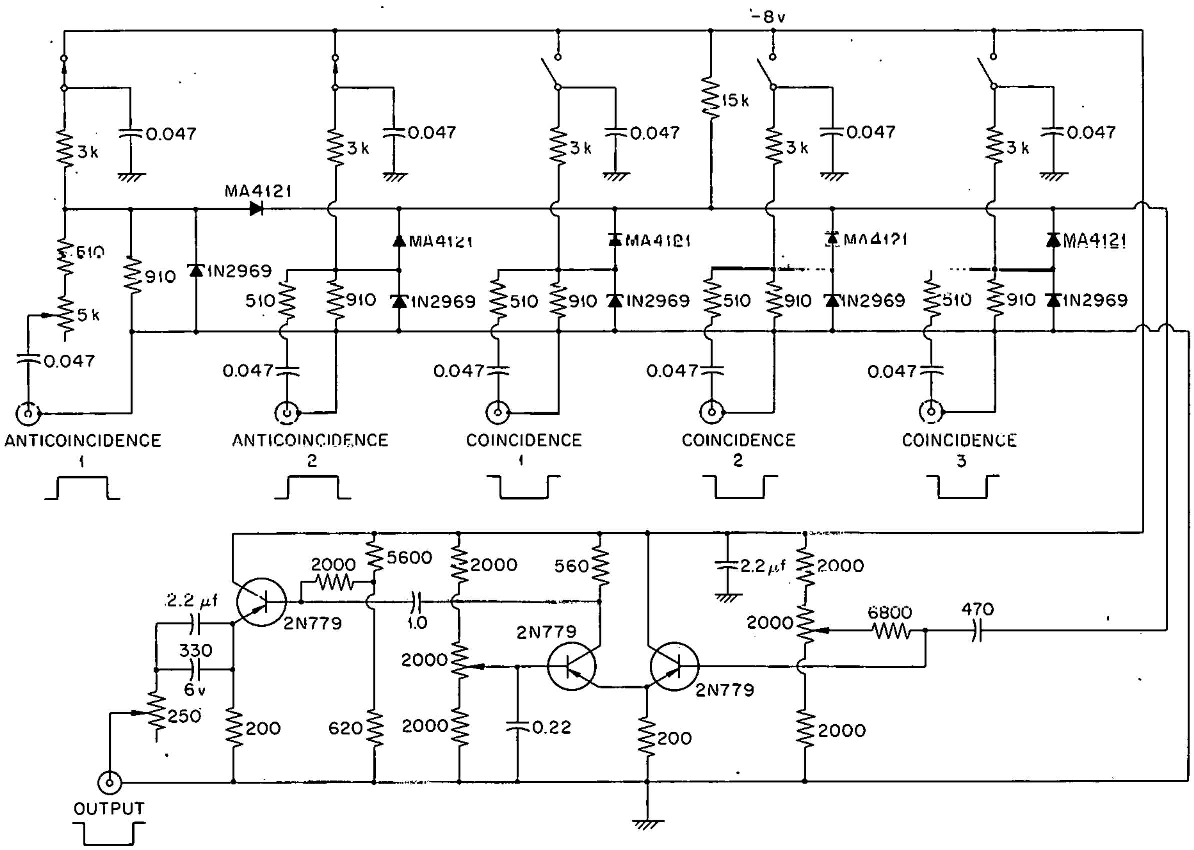

Fig. 1.1.6. Fast Coincidence–Anticoincidence Circuit.

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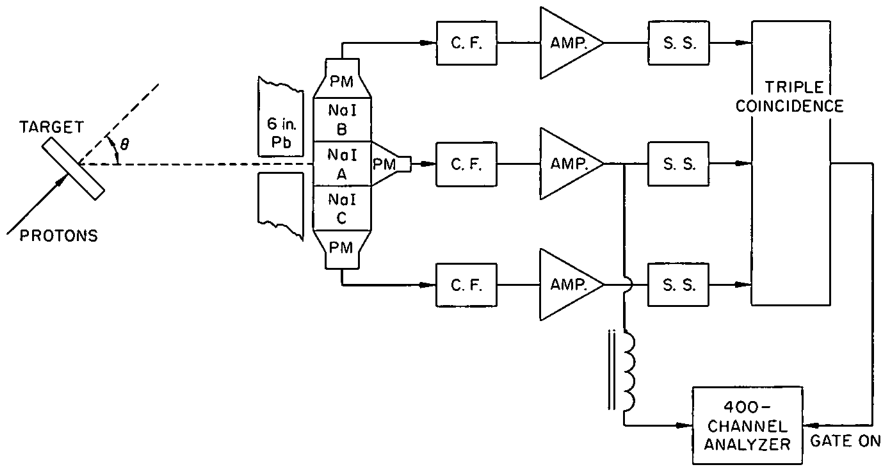

Fig. 1.1.7. Gamma-Ray Pair Spectrometer.

original gamma ray. This kinetic energy deposition in the center crystal, in coincidence with the detection of the positron annihilation radiation in the two side crystals, gates *on* the analyzer to look at the gamma energy deposited in the center crystal. The two side-channel snip-snaps are operated as differential zero crossing discriminators which look at the 0.511-Mev positron annihilation peaks. The center-channel snip-snap is operated as an integral zero crossing discriminator set to look at only those pulses above 0.5 Mev.

The total absorption spectrometer is obtained by operating the two side-channel snip-snaps as integral zero crossing discriminators with their biases set low and their outputs combining in anticoincidence with the output of the center-channel snip-snap operated in the same manner. Thus, only gamma rays whose energies are almost completely absorbed in the center crystal are stored in the analyzer.

Neutron Time-of-Flight Spectrometer

The neutron time-of-flight spectrometer (Fig. 1.1.8) has a thin polystyrene detector immediately in front of the target. The time between the detection of a proton in counter *A* and the detection of a neutron in counter *B* approximately 1 m behind the target is a measure of the time of flight (and therefore the energy) of the neutron traveling from target to detector. Counter *C* is used as a proton detector in anticoincidence with events occurring in detector *B* to eliminate background protons scattered from the primary beam, the target, etc. The counting rate in the primary beam must be low to prevent pulse pileup in detector *A* and to limit to one the number of protons detected during the time of flight of the lowest energy secondary of interest. Even so, the counting rates in counter *A* are still high (10^5 counts/sec, average), whereas, those in *B* are reasonably low. Thus, to prevent a large number of false starts in the time–to–pulse-height converter, the pulses from counter *A* are delayed by an amount equal to the time range subject to analysis and are used as stop pulses, whereas pulses from counter *B* are used as the start pulses.

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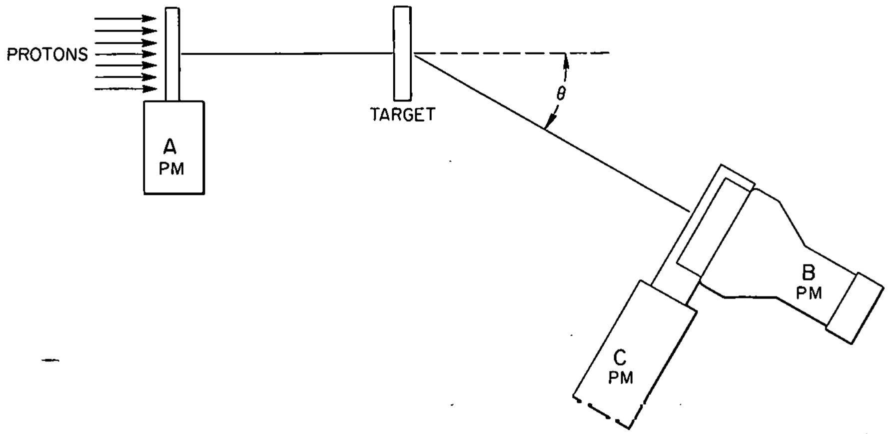

Fig. 1.1.8. Neutron Time-of-Flight Spectrometer.

The time–to–pulse-height converter (Fig. 1.1.9), the heart of the time-of-flight spectrometer, employs simple, germanium tunnel-diode discriminators in the photomultiplier outputs for both detectors *A* and *B*. These tunnel diodes act as amplitude limiters as well, but the large dynamic range of amplitudes encountered compromises their performance. Both the start and stop channels employ conventional biased-off amplifier stages to provide gain for the nominal 450-Mv signal from the photomultiplier tunnel diode. A pulse in the start channel switches tunnel diode TD-1 to its high-voltage state. This extremely fast rise signal is amplified by two biased-off amplifiers (Q-5 and Q-6) employing diode switching in the emitter to degenerate the gain of the transistor very quickly for the larger amplitude inputs. The output of Q-6 diverts the current normally flowing in emitter follower Q-7 to the emitter of a grounded-base transistor (Q-8), charging up the 100-picofarad capacitor in its collector at a linear rate until a stop pulse occurs; TD-1 is then restored to its initial condition, thus resetting the circuit. In the unlikely event that a stop pulse does not occur, the ramp output reaches the proper amplitude to fire a trigger pair (Q-16 and Q-17) which resets the circuit. This time–to–pulse-height converter, under ideal conditions, that is, with the *B* detector at 0° and detecting protons instead of neutrons, produced a spectrum peak whose full width at half-maximum was 1.1 nsec.

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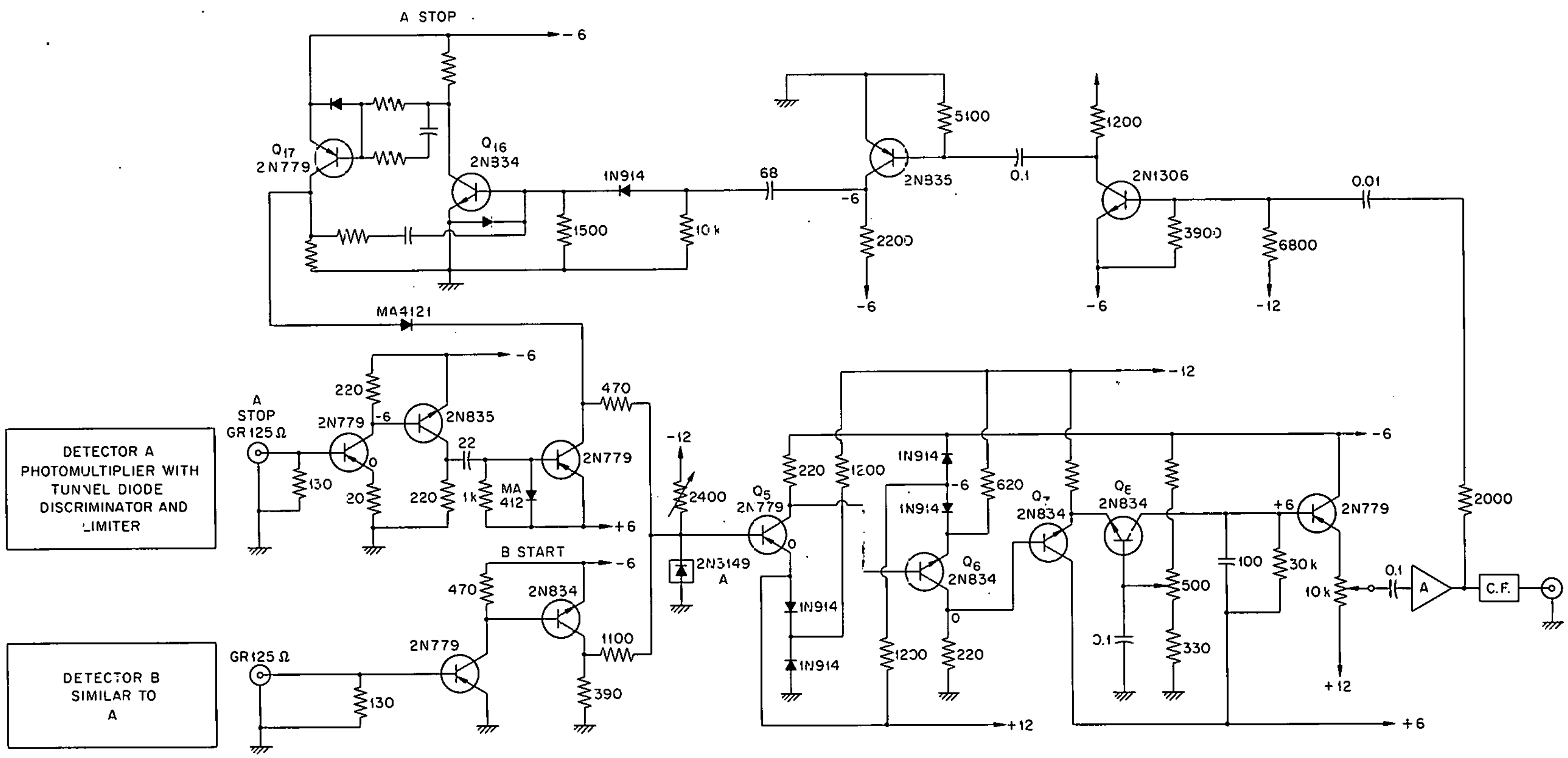

Fig. 1.1.9. Circuit of Time–to–Pulse-Height Converter.

1.2 CONTROL SYSTEM FOR THE OAK RIDGE ISOCHRONOUS CYCLOTRON

J. A. Russell, Jr. W. H. White, Jr.

A system for remote control of the cyclotron[1] and its experimental facilities was installed to reduce radiation exposure hazards and to make full use of the flexibility designed into the facility. Design of the control system was begun in January 1959. The control panel, console, and three relay cabinets were ordered in August 1960 and were delivered in March 1961. The system was first operated in March 1962.

Standard industrial control techniques and components were used in the system. Separate shielded areas were constructed for conducting experiments, and all controls were installed at a central location outside the shielded areas. This arrangement permitted operation in one area while experiments were being set up in others and allowed rapid shifting of the cyclotron beam from one target to another; it also reduced exposure of operating personnel to radiation, because many operations (such as operating vacuum and cooling-water valves and adjusting the position of the source and internal target) could be done with remotely operated manipulators rather than manually, as was formerly done.

Controls for the rf power amplifier and for power supplies for the magnets, source, and deflector were installed at the console so that this equipment could be operated from the central control system. Interlocks were installed in cooling-water and air lines so that, if water flow or air pressure failed, operators would be warned and the power would be shut off from all parts of the cyclotron that could be damaged by arcing or overheating.

Two systems for radiation protection of personnel were installed.[2] One system sounds audible alarms if hazardous radioactivity is present in office or laboratory areas, and the second system shuts down the cyclotron if the door is opened in a shielded area in which experiments are in operation.

To make maintenance of cyclotron sources easier and to reduce radiation exposure of personnel doing the work, a source retraction and insertion system was installed. With this system, which is operated from the control room, source equipment is removed or inserted automatically by remote control to permit manual replacement of filaments or carbon electrodes.

A flowmeter to measure the flow rate of source gas was purchased but not installed. This is a Foxboro, integral-orifice differential-pressure flowmeter with a special 0.003-in.-diam orifice drilled through a sapphire jewel. Full-scale calibration with hydrogen is 10 std cm^3/min. The flow-rate reading is transmitted pneumatically to the control room and indicated by a pressure gage mounted on the console.

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[1] R. J. Jones *et al.*, "Unique Features in the Oak Ridge Isochronous Cyclotron," paper presented at the International Conference on Sector-Focused Cyclotrons, Los Angeles, Calif., April 17–20, 1961; to be published in *Nuclear Instruments & Methods*.

[2] J. A. Russell and R. J. Jones, *System for Radiation Protection and Control*, ORNL TM-364 (to be published).

1.3 BEAM-PHASE MEASUREMENT STUDIES[1]

W. H. White, Jr. B. Duelli[2] R. J. Jones

A nonintercepting system was developed for measuring the phase of the internal beam of a cyclotron with respect to the rf voltage on the dee. The system was used during initial tests of the Oak Ridge Isochronous Cyclotron to improve the isochronous field shape. It will also be used in beam studies and during operation to provide data to improve the computed setting of the trimming coils. Beam pulses are detected on an electrostatic pickup probe. The differentiated wave form is presented on a sampling oscilloscope from which the width and shape of the beam pulse can be deduced. The system is sensitive to average beam currents to below 10 μa; average beam currents up to 1 ma have been observed. The precision of phase measurement can extend to 2° at 22.5 Mc/sec. The probe design criteria, circuitry, and some results are discussed.

[1]Abstract of paper presented at the Conference on Sector Focused Cyclotrons, UCLA, April 16–20, 1962; to be published in *Nuclear Instruments & Methods*.

[2]Exchange visitor from Nuclear Reactor Construction and Operation, Ltd., Karlsruhe, Germany.

1.4 MAGNET REGULATORS FOR THE OAK RIDGE ISOCHRONOUS CYCLOTRON[1]

W. H. White, Jr.

Twenty-one current-regulator systems were built, tested, and put in operation in the Oak Ridge Isochronous Cyclotron. Two motor-generator units rated at 800 and 1200 kw are regulated by transistor banks in the field circuits of the generators. Nineteen other magnet supplies are rectifier–magnetic amplifier systems with ratings ranging from 6 to 30 kw at 250 to 1200 amp; for regulation, these incorporate transistor banks in series with the load. All units are current-regulated to a few parts in 10^5; the transistor banks also reduce the ripple voltage of the rectifier units. By means of single controls, all units can be varied from 2 to 100% of rated output current. Design features and selection of components for these systems are discussed. The design of the large banks of paralleled transistors used and experience in their operation are also reported.

[1]Abstract of paper presented at the Conference on Sector Focused Cyclotrons, UCLA, April 16–20, 1962; to be published in *Nuclear Instruments & Methods*.

1.5 HIGH-CURRENT-REGULATED SUPPLY, COMBINING TRANSISTORS AND MAGNETIC AMPLIFIERS, FOR THE OAK RIDGE ISOCHRONOUS CYCLOTRON[1]

B. C. Behr[2] W. E. Lingar W. H. White, Jr.

Circuits are shown and design criteria are given for a current-regulated power supply which is typical of 19 supplies of four types built for the Oak Ridge Isochronous Cyclotron. These supplies range from 6.25 to 34 kw, with current ratings from 250 to 1200 amp. Current regulation and ripple of 1 part in 10^4 are obtained by separate ac and dc feedback circuits driving a bank of parallel power transistors in series with the load. The dissipation of the transistor bank is limited by a third feedback circuit, which drives a saturable reactor in the power supply to maintain a constant voltage across the transistor bank. The output can be varied from zero to maximum by setting a reference potentiometer which is supplied by a Zener reference with a low temperature coefficient. Plug-in circuits in the feedback networks allow versatility; any regulator can be used with a wide variety of magnets of varying time constants. A modular transistor bank simplifies construction and maintenance.

[1]Abstract of paper presented at the Joint Nuclear Instrumentation Symposium, Raleigh, North Carolina, September 1961; *IRE Trans. Nucl. Sci.* 8(4), 6 (1961).

[2]Present address: Parma Research Center, Parma, Ohio.

1.6 DESIGN CONSIDERATIONS FOR MAXIMUM BANDWIDTH IN TRANSISTOR PULSE AMPLIFIERS[1]

C. W. Williams J. H. Neiler[2]

Each of the transistor biasing configurations – common emitter, common base, and common collector – has disadvantages which greatly limit the use of cascaded, single-transistor stages for general wide-band amplification. A careful choice of a combination of biasing configurations in a single stage permits optimum use of the advantages of each configuration while minimizing the effects of the disadvantages. Considerations leading to the design of an acceptable wide-band pulse-amplifier stage are discussed. These principles have been applied to the design of a one-stage feedback amplifier, which has the following characteristics: gain, 25.8 db; rise time, 2.8 nsec; and linear amplification of either positive or negative pulses.

[1]Abstract of paper submitted to *IRE Transactions on Nuclear Science*.

[2]Formerly of the Physics Division, Present address: Oak Ridge Technical Enterprises Corp. (ORTEC), Oak Ridge, Tenn.

1.7 GATING OF PHOTOMULTIPLIER TUBES

J. H. Todd

An investigation was begun to determine a method of gating *off* a Du Mont 12-in. K1328 photomultiplier tube during a relatively intense radiation on the scintillator to prevent the amplifiers that follow the photomultiplier from becoming overloaded.

This work was requested by Block[1] and Russell,[2] who are conducting studies on neutron-capture cross section at Rensselaer Polytechnic Institute.

When electrons are accelerated and directed into target material by an electron linear accelerator, a (γ,n) reaction occurs. The primary gamma flash must be blanked off to permit observation of the subsequent neutron reaction. Conventional methods, such as pulsing the focusing electrode, cannot be used to blank off the gamma flash, because a large voltage swing is required. In the scheme developed, by pulsing both the first and second dynodes with pulses of the same shape but of opposite polarity, a field is produced which decelerates the electrons from the photocathode. The relative amplitudes of the two pulses can be adjusted to minimize capacitive feedthrough. In laboratory tests of this technique, the photomultiplier tube was gated *off*. This technique is now being tested by Block and Russell under actual conditions.

[1]Physics Division.
[2]Rensselaer Polytechnic Institute.

1.8 ROUTING CIRCUIT FOR A 400-CHANNEL ANALYZER

J. H. Todd

A circuit that accepts four input signals of either polarity and an input signal from an RIDL 400-channel analyzer was designed for use in several experiments, the first of which is to determine the ratio of the capture cross section to the fission cross section for various fissionable isotopes by using the beam from the 3-Mv Van de Graaff accelerator.[1]

The circuit detects coincidence between either of two signals and a third signal and combines the outputs of these two channels in both coincidence and anticoincidence to produce six outputs. Each of four of these outputs activates a 100-channel section of the analyzer. (Four of the outputs can be switched in pairs.) The analyzer is gated *off* for a time after an output occurs. The circuit will also accept the "dead time blanking" output from the analyzer and gate all signals *off*.

Fast-circuit techniques were used throughout to enhance switching times and prevent spurious signals. Pulse-shaping stages were made variable over a range of 1 to 5 for selecting coincidence and anticoincidence resolving times. Rise times throughout the circuit were minimized (all were on the order of 5 nsec) to produce pulses with a high degree of squareness so as to minimize time uncertainties.

[1]Experimental work by L. W. Weston and G. de Saussure, Neutron Physics Division.

1.9 SCINTILLATION PULSE SAMPLING AND ANALYSIS SYSTEM

J. B. Davidson

Experiments on the scintillation response of CsI(Tl) crystals to various particles require an analysis of the amplitude of the photomultiplier pulse at selected times after the crystal has been excited, because both "fast" and "slow" components exist in the luminescence decay. Measurements of the response of CsI(Tl) crystals were reported by Gwinn and Murray,[1] who used 1- and 7-μsec clipping times in two linear amplifiers. The amplifier outputs were fed to a multichannel pulse-height analyzer. The clipping times of the amplifiers were used to limit the amplitude to which the pulse from the photomultiplier rose before analysis.

At the request of Murray, a system was designed which allows measurement at 1, 4, 7, 10, and 15 μsec with a single linear amplifier. Preliminary measurements made with the system at 1 and 7 μsec, using gamma rays and alpha particles, agreed (within experimental error of less than 1%) with measurements made previously by Gwinn and Murray.[2]

The system (Fig. 1.9.1) consists of (1) a linear amplifier with a clipping time of 16 μsec for studying slower luminescence components; (2) a reference pulse generator whose output can be accurately fixed at 1, 4, 7, 10, and 15 μsec after the beginning of the scintillation pulse and used to gate *on* a multichannel pulse-height analyzer; and (3) a multichannel pulse-height analyzer.

The linear amplifier is a DD-2 amplifier which was modified by replacing the 1.2-μsec delay lines with 16-μsec lines. The coupling time constants of the amplifier were increased to extend the low-frequency response. Terminating and compensating adjustments required by the greatly lengthened lines, more shielding, and power supply filtering were added.

The timing pulse generator consists of a second DD-2 amplifier with a 1.2-μsec clipping. The input to the amplifier is the same pulse fed to the linear amplifier, and the output is a bipolar pulse whose crossover point is accurately fixed in time at approximately 2 μsec after the beginning of the pulse. The output pulse is delayed and used to trigger the lower trigger pair of the single-channel analyzer in the DD-2, which is adjusted for operation as a crossover pickoff.[3] The positive pulse-height-selector output from the single-channel analyzer operated in the integral mode is the reference pulse used to gate *on* the multichannel analyzer.

The multichannel analyzer is a Nuclear Data, Inc., ND-120. It has a coincidence input which allows the linear gate in the analog-to-digital converter to open for the duration of the coincidence pulse. The timing pulse applied to the coincidence input causes a 1-μsec sample of the 15-μsec pulse to enter the stretching and conversion circuits of the analyzer.

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[1]R. Gwinn and R. B. Murray, *Neutron Physics Div. Ann. Progr. Rept. Sept. 1, 1961*, ORNL-3193, p 63.

[2]Private communication from R. B. Murray.

[3]R. W. Peele and T. A. Love, *Neutron Physics Div. Ann. Progr. Rept. Sept. 1, 1957*, ORNL-2389, pp 249-59.

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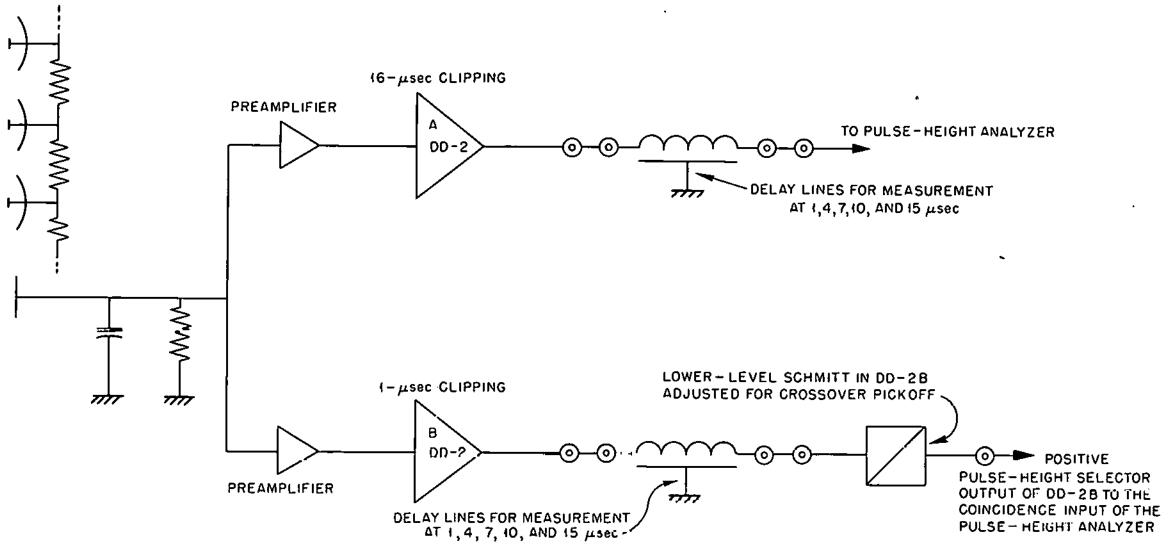

Fig. 1.9.1. Pulse Sampling System.

2. Semiconductor Research

2.1 GUARD-RING SILICON SURFACE-BARRIER DETECTORS WITH HIGH REVERSE BREAKDOWN VOLTAGES

R. J. Fox   C. J. Borkowski

The effectiveness of silicon surface-barrier detectors for energy measurements of heavy nuclear particles, such as alpha particles and fission fragments, is well known. The need for a detector capable of analyzing the faster and more penetrating beta particles has stimulated a search for methods of producing detectors with deeper sensitive volumes. This sensitive depth must exceed the maximum range of the incident particle if quantitative energy measurements are to be made.

One possible approach to the deeper barrier requirement is simply to operate a surface barrier at higher voltages, since the depth of penetration of the resulting electric field (and thus the sensitive depth) increases with the square root of the applied voltage. However, conventional detectors normally will not withstand the kilovolt potentials necessary to produce the required depths (1 to 1½ mm).

Studies at ORNL have shown that the breakdown of a surface barrier almost invariably occurs at the edge of the junction and that the breakdown voltage can be increased nearly one order of magnitude by appropriate control of the surface chemistry of the silicon.[1] In essence, a surface barrier is a metal-to-semiconductor junction formed by depositing (vacuum evaporation) a thin film of gold on one face of an *n*-type silicon crystal. The presence of certain chemical groups (notably O_2, I_2, CrO_4^{2-}, OH^-, and NH_3) on the silicon surface can alter the normal surface charge on the silicon. By the careful exclusion of ammonia compounds (as a derivative of ammonia, triethylenetetramine is a common constituent of the epoxy plastic often used to encapsulate the silicon) and water (operation in a liquid nitrogen–trapped vacuum) from the edge of the silicon-to-gold junction, the silicon surface charge distribution near this edge was modified (inverted) in a manner such as to permit continued operation in the kilovolt range.

Experimentally, such modified edges were found to be sources of electrical noise, but it has been possible to suppress this edge noise with the guard-ring structure[2] (Fig. 2.1.1). This arrangement separates the gold contact into two equipotential areas: a circular central spot (signal electrode) and a surrounding annular contact which serves to isolate the edge noise.

Guard-ring detectors have been operated over 1800 v, with resulting barrier depths up to 1½ mm. Figure 2.1.2 shows the Bi^{207} spectrum taken at 22°C. The superior room-temperature energy resolution

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[1] J. L. Blankenship, C. J. Borkowski, and R. J. Fox, pp 379–90 in *Nuclear Electronics* I, International Atomic Energy Agency, Vienna, 1962.

[2] R. J. Fox and C. J. Borkowski, *IRE Trans Nucl. Sci.* 9(3), 213 (1962).

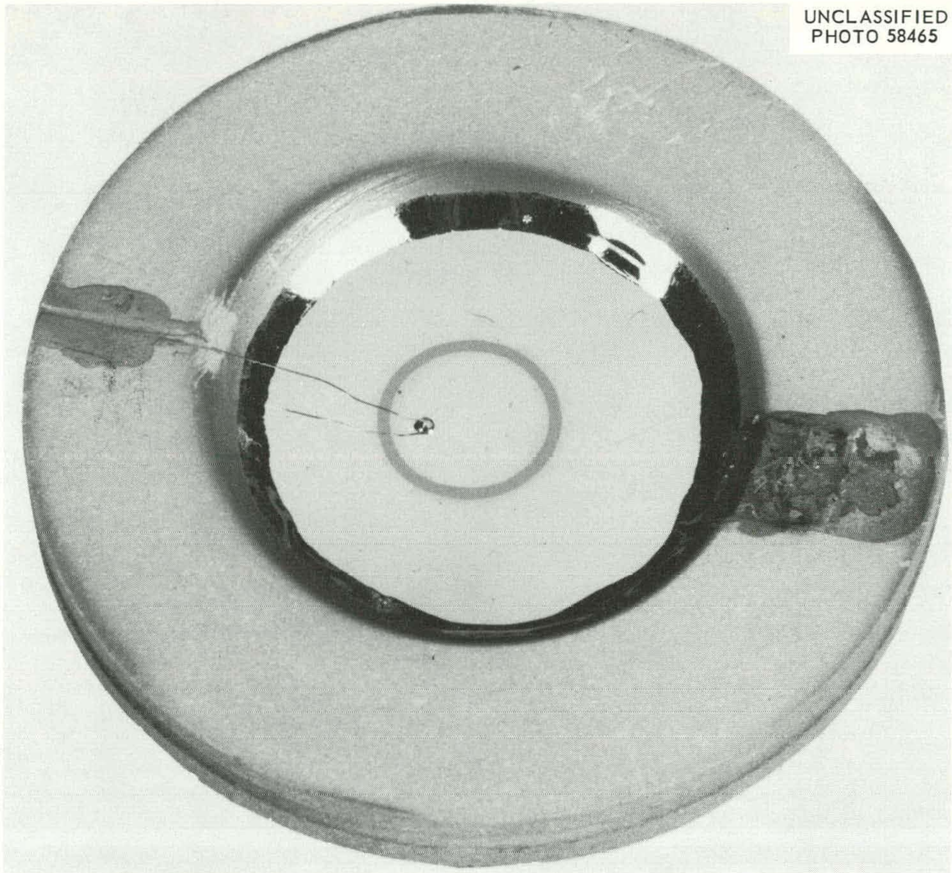

Fig. 2.1.1. Guard-Ring Structure for a Silicon Surface-Barrier Detector.

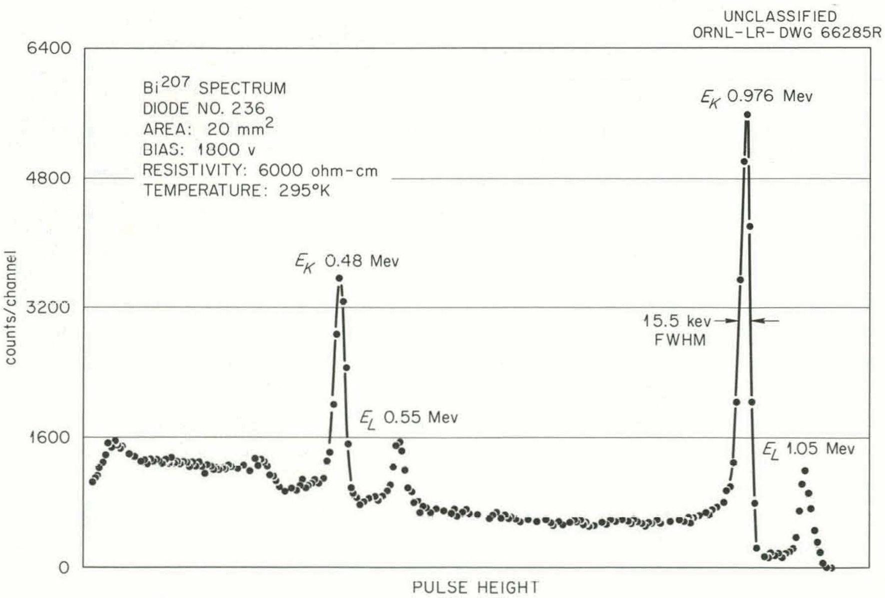

Fig. 2.1.2. Conversion Electron Spectrum of Bi^{207} Taken at 1800-v Bias with a Guard-Ring Surface-Barrier Detector.

exhibited by these devices is probably due in part to the absence of any thermal degradation of the silicon (carrier lifetime); production of a surface barrier requires no high temperatures.

Operation at somewhat reduced temperature and bias improved the resolution sufficiently to resolve (for the first time with a semiconductor detector) the *M* conversion electrons of Bi^{207} (Fig. 2.1.3).

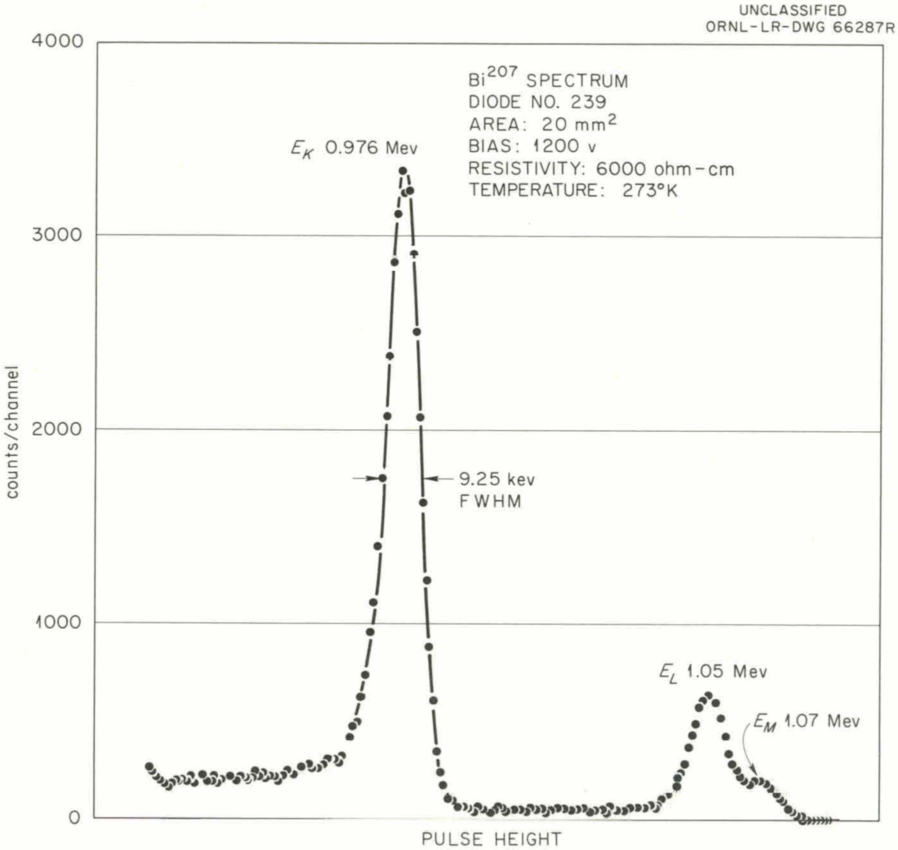

Fig. 2.1.3. Expanded Spectrum of the Conversion Electrons from the 1.06-Mev Transition of Bi^{207} Taken at 1200-v Bias and 273°K with a Guard-Ring Surface-Barrier Detector.

2.2 SILICON SURFACE-BARRIER DETECTORS WITH HIGH REVERSE BREAKDOWN VOLTAGES[1]

R. J. Fox C. J. Borkowski

Surface-barrier detectors with essentially no dead layer and with depleted depths up to 1.5 mm have been achieved by the combination of an inverted edge and a guard ring. The ability of these devices to withstand high reverse bias voltages ensures rapid collection of the charge carriers and, consequently, fast-rising pulses even for thick depletion regions. The energy resolution was 9.2 kev for 1-Mev electrons and was 7.5 kev full-width at half-maximum (fwhm) at 285°K for 0.6-Mev electrons.

[1]Abstract of paper presented at 8th Scintillation Counter Symposium, Washington, D.C., March 1–3, 1962; published in *IRE Trans. Nucl. Sci.* 9(3), 213 (1962).

2.3 IMPROVED TECHNIQUES FOR MAKING p^+-i-n^+ DIODE DETECTORS[1]

J. L. Blankenship C. J. Borkowski

Techniques for achieving a thin, dead layer exhibiting low sheet resistance on the N^+ side of a p^+-i-n^+ diode made by the lithium drift process have been developed. A controlled quantity of lithium was diffused through a 1- to 2-μ phosphorus-doped layer on the silicon diode. The phosphorus-doped layer provided low sheet resistance. Because most of the lithium-diffused layer was drifted into the bulk material, dead layers less than 7 μ thick were achieved.[2]

Detectors made by this technique have given 23-kev (fwhm) resolution for gamma rays and monoenergetic electrons at room temperature, limited by diode noise. Detectors cooled to 78–195°K gave 6.5-kev resolution for Cs^{137} conversion electrons (625 and 655 kev) and Pb^{207} x rays (74 and 90 kev). Detectors stored without bias voltage at room temperature did not change in performance over a four-month period.

An analysis of the drift parameters has shown that the lithium drift rate depended on the power dissipated in the diode during drift. An automatic control system which allows the lithium drift operation to proceed at power dissipations in excess of 50 w was developed.

[1]Abstract of paper presented at 8th Scintillation Counter Symposium, Washington, D.C., March 1–3, 1962; published in *IRE Trans. Nucl. Sci.* 9(3), 181 (1962).

[2]In later work a dead layer of 1.3 μ thickness was achieved.

3. Radiation Monitoring Systems

3.1 MODERNIZATION AND EXPANSION OF ORNL RADIATION MONITORING SYSTEMS

D. J. Knowles J. H. Holladay
J. A. Russell R. L. Shipp
J. E. Inman

Expansion and modernization of radiation monitoring systems at the Laboratory have been in progress since 1959. Three phases were previously reported.[1] Since then, several phases have been added, and the scope of participation by the Instrumentation and Controls Division has been expanded. The separate but interrelated programs are summarized according to the readout point of the systems involved (Fig. 3.1.1).

Work completed includes specifications for a new radio communications network, preliminary estimates for the Facility Radiation System and the Area Fallout Monitoring System, and a conceptual design of the Central Alarm Display.

Work in progress includes design and procurement for the Building Contamination System, additions to the Local Air Monitor System, and installation of the Central Alarm Display (Building 2500).

Future work includes design and installation of the Facility Contamination System, the Facility Radiation System, and the Area Fallout Monitoring System – all of which will indicate their alarms on the central display boards to be installed at Building 2500.

Operations Division Systems

The status of systems supervised by the Operations Division at the Waste Monitoring Control Center (Building 3105) is as follows:

Process Waste Water System. – This system routinely monitors flow and radiation levels and takes proportional samples at seven points and at the diversion box. The system is complete except for routine expansion.

Stack Monitoring Systems (Building 3039). – Devices for monitoring the radiation levels of particulates (alpha and beta-gamma) were installed in the stack and on the main ducts entering the stack. Flowmeters were also installed. Instruments are being developed to monitor I^{131}, rare gases, and gross activities at the top of the stack.

[1] D. J. Knowles *et al., Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, pp 34–35.

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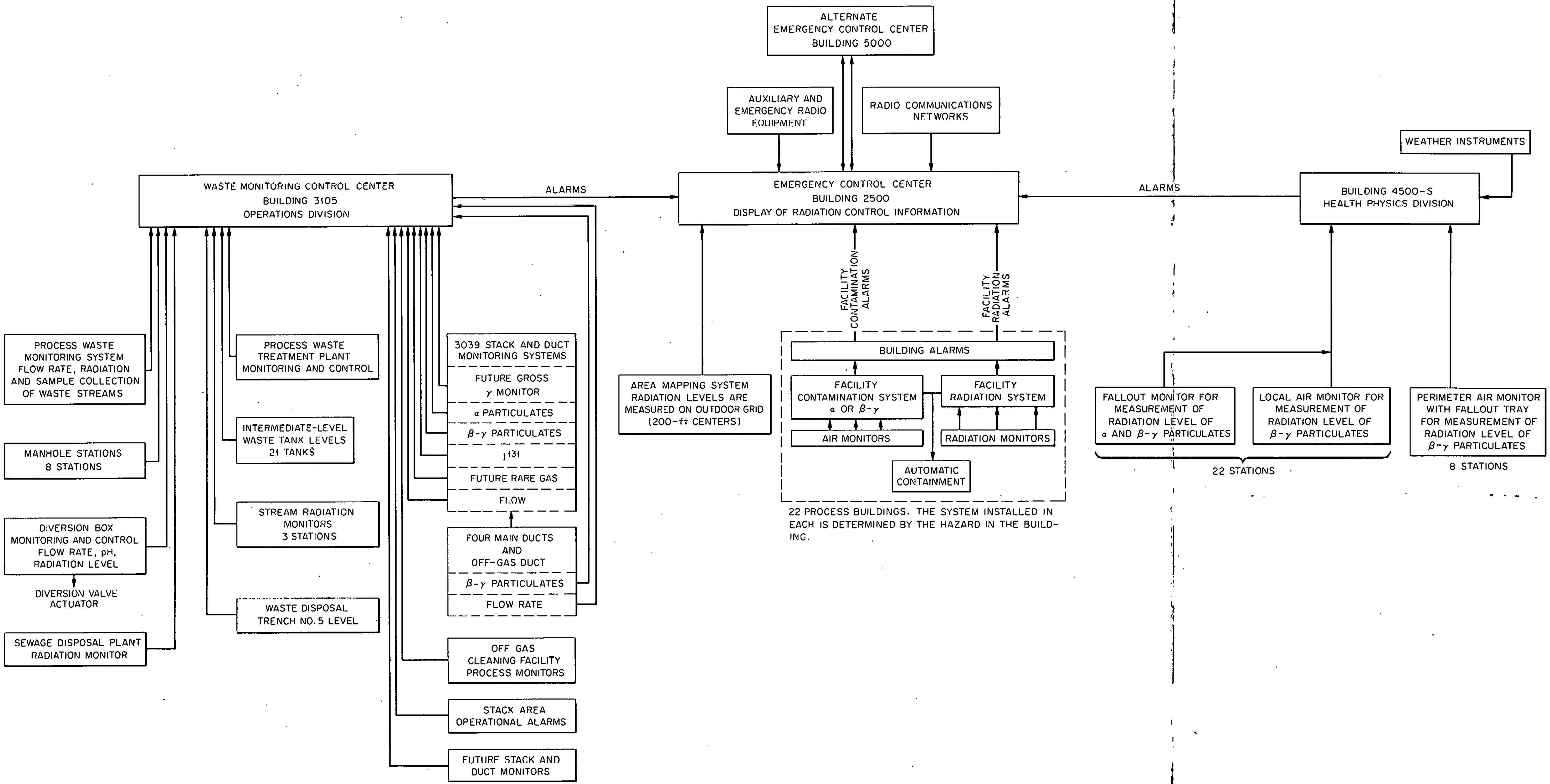

Fig. 3.1.1. Existing and Proposed Laboratory Radiation Monitoring and Control Systems.

Auxiliary Systems. – Monitors of the operation of the Waste Treatment Plant, a radiation monitor for sanitary sewage, a liquid-level gage for the intermediate-level waste tanks, and radiation-level monitors for the ORR gaseous-waste ducts were installed.

External Alarms. – Alarms in the Waste Monitoring Control Center will be duplicated at the Emergency Control Center (Building 2500). A miniature illuminated panel showing the condition of the entire process waste water system is being developed as a first step toward a master radiation panel to be located at Building 2500.

Health Physics Division Systems

The status of systems supervised by the Health Physics Division at Building 4500-S is as follows:

Local Air Monitor System. – The original Local Air Monitoring System was replaced with modern versions of the field stations and central readout. This system is in operation.

Perimeter Air Monitoring System. – The Perimeter Air Monitor Stations were all updated previously, and readout was incorporated into the central panel at Building 4500-S.

Fallout Monitoring Net. – The pilot Fallout Monitor is being field-tested. These units will be installed at the Local Air Monitor stations.

External Alarms. – All systems for the Health Physics Division will indicate alarms both at Building 4500-S and at the Emergency Control Center (Building 2500).

Laboratory Radiation Alarm and Control Systems

The following systems were proposed for the detection and control of radioactivity in the Laboratory area. The criteria were developed by the staff of the Director of Radiation Safety and Control. Remote readout and display will be at the Emergency Control Center.

Facility Contamination System. – Individual process buildings supervised by various operating and research divisions will be equipped with at least three air monitors for either beta-gamma or alpha particulates. Outputs will be wired to a central supervisory panel in the building and will actuate an audible and visible alarm in the building on a two-out-of-three basis. In some cases this system will make use of existing containment installations and will actuate automatic containment.

Facility Radiation System. – Individual process buildings will be equipped with at least three monitors (ion chambers) and will parallel the Facility Contamination System in that a two-out-of-three alarm will actuate the local air horn and warning lights and transmit an indication of trouble to the Emergency Control Center.

Additions to Local Air Monitoring Systems. – The present system of 10 air monitors in outdoor cabinets will be increased by 12 additional units.

Fallout Detection System. – A fallout monitor which employs a rotating collector disk is proposed for each Local Air Monitor location. Both alpha and beta-gamma detectors will be used, with readout in the Health Physics Division Data Center.

Area Radiation Mapping System. – A new radiation probe for an outdoor grid (approximately 200 ft on centers) will undergo further development. It is proposed that radiation intensities at each point will be displayed at the Emergency Control Center. Radiation levels will be displayed on a panel to provide emergency control personnel with information needed to evacuate the Laboratory during an incident.

Radio Communications. – The present radio communications network will be replaced, and a new network will be installed for use during radiation emergencies and for routine communications.

3.2 CONTAINMENT INSTRUMENTATION

D. J. Knowles R. L. Shipp J. H. Holladay

Participation in the ORNL containment program has continued since the last report.[1] Since the beginning of the program, control devices which actuate air handling equipment to an emergency condition when airborne radioactivity reaches a preset level were designed and built (Table 3.2.1).

[1]D. J. Knowles, J. H. Holladay, and R. L. Shipp, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, p 33.

Table 3.2.1. Status of Installation of Containment Instrumentation

Location	Bldg.	Description	Completion (%)
Radioisotope Production Laboratory (A)	3028	New building. Alarm actuates containment.	80
Radioisotope Production Laboratory (B)	3029	New building. Alarm actuates containment.	40
Radioisotope Development Laboratory	3047	New building. Alarm actuates containment.	90
Fission Products Development Laboratory	3517	Revision and expansion of original containment system. Air monitors actuate containment.	80
High Radiation Level Examination Laboratory	3525	Alarms for air monitors actuate containment. Air monitors are backed by radiation-level alarms to actuate containment.	80
High Level Radiochemical Laboratory	4501	Supervision only; no automatic containment.	10
High Radiation Level Chemical Development Laboratory	4507	Alarms actuate containment.	100

It is now standard practice to connect the alarm outputs from all air and radiation monitors to a central panel where building supervisors can see at a glance the condition of all monitors in the building. This panel usually indicates normal operation, high radiation level, instrument failure, and, for air monitors, an intermediate radiation level. Matrix connections may be built into the modular central panel to actuate special alarms (such as evacuation horns) or special control operations (such as automatic containment) when a selected number or combination of monitors reach the alarm point. This basic scheme designed for containment is also suitable for the proposed facility contamination and facility radiation systems (Sec 3.1).

3.3 HIGH-VOLTAGE LABORATORY RADIATION MONITORING SYSTEM[1]

W. E. Lingar

A radiation monitoring system (Fig. 3.3.1) was designed to protect experimenters and other personnel in the vicinity of the tandem Van de Graaff accelerator from receiving more than a specified integrated dose rate based on an 8-hr period. The system was designed to allow maximum freedom of entry into the monitored areas while automatically protecting personnel. After the instrumentation was designed and fabricated, the system was interconnected and bench-tested. It operated as designed and is being installed at the High-Voltage Laboratory.

An "auction" circuit continuously compares the output of all remotely located electrometer amplifiers and selects the largest signal. This signal, which corresponds to the maximum amount of radiation that can be received anywhere in the area, is integrated and fed into an electromechanical register. The register can be preset to a number which corresponds to an integrated dose rate. If the register "counts down" within an 8-hr period (i.e., indicates that the specified dosage would be exceeded), the accelerator trip circuit is actuated; otherwise, a timer resets the system and the accumulation of counts is begun again. The system also has a rate trip circuit, which can be set to trip the accelerator at any dose rate within system limits. The rate trip will normally be set at the upper limit of operation. Thus, whenever an individual opens a door to enter an area of radiation higher than the rate trip set point, the accelerator trip circuit will be actuated automatically.

[1]Conceptual system design by C. D. Moak, Physics Division. Preliminary circuit concept by B. C. Behr, formerly Instrumentation and Controls Division; present address: Parma Research Center, Parma, Ohio.

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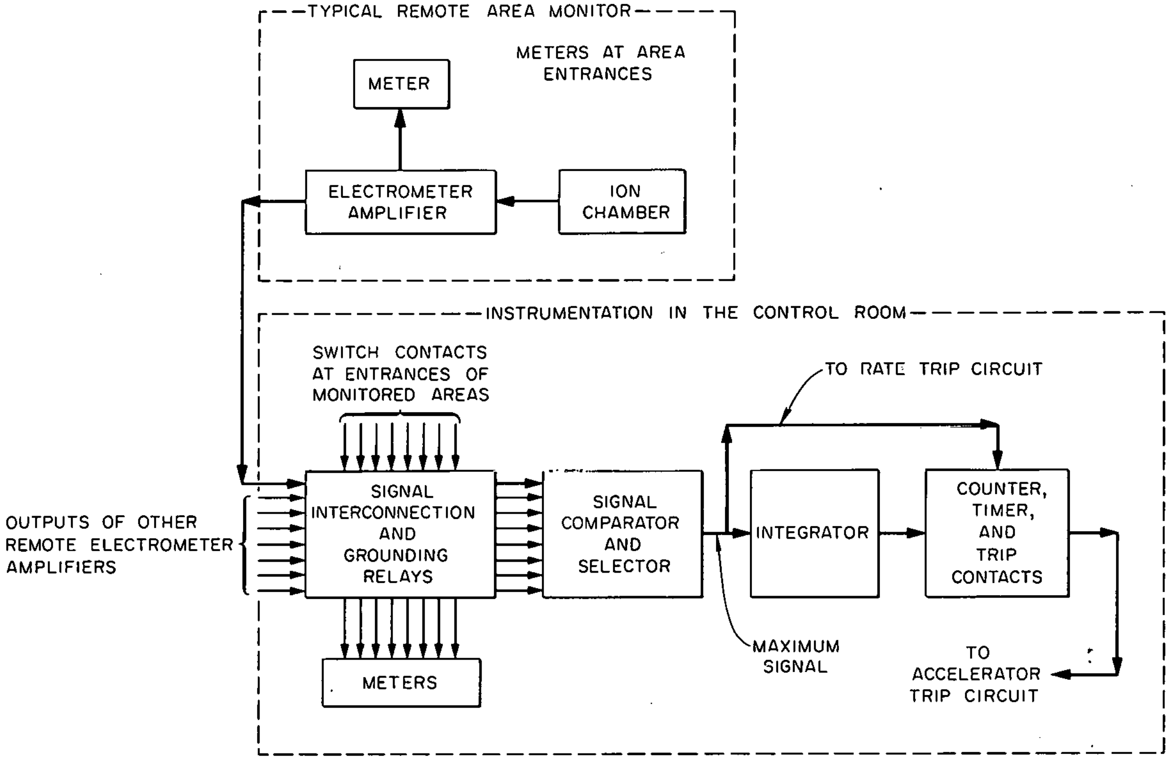

Fig. 3.3.1. Radiation Monitoring System for the High-Voltage Laboratory.

Extensive modification of the circuitry of the electrometer amplifiers was required to give the system a wide dynamic range. The amplifiers were modified to give an output voltage proportional to input current over a wide range of input without the necessity of range changing. The system will monitor radiation intensities from 2 mrem/hr to 1.25 rem/hr.

One of the key instruments in the system is the "auction" circuit, which compares the output voltage of all the electrometer amplifiers and selects the signal of maximum amplitude. Differential amplifiers were used as comparators. Each amplifier compares two signals and selects the largest one by means of complementary transistors and sensitive, mercury-wetted contact relays connected to its output. Since eight input signals are anticipated, three stages of selection are required. The differential amplifiers were selected as comparators because they could be made sensitive to low-level signals and, in addition, not be damaged or excessively load the electrometer amplifiers at high-level operation.

4. Radiation-Detection Instruments and Components

4.1 TRANSISTORIZED MONITOR FOR BETA-GAMMA OR ALPHA RADIATION

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

It has never been the practice of the Instrumentation and Controls Division to replace existing vacuum-tube equipment with transistorized versions of the same instrument unless better performance, more reliable operation, or better battery economy warranted the change. Two vacuum-tube general-purpose monitors (ORNL models Q-2091 and Q-2191) have been used widely in remote monitoring posts; in this type of service, the monitors were expected to operate without failure for a long time. However, some tube failures indicate that a transistorized instrument might be more economical even though the initial cost is considerably higher. A transistorized monitor (ORNL model Q-2277) was designed and is being field-tested to determine the validity of this assumption.

The new instrument, like its predecessors, is a linear count-rate meter with a pulse amplifier and a high-voltage supply for the detector. It has a charge-sensitive amplifier that allows as much as 200 ft of cable between the detector and the instrument. The instrument has demonstrated improved linearity and no drift in zero or calibration. It provides an alarm that is adjustable to any desired radiation level, a 10-mv recorder output, a 1-ma recorder output, and a 1-ma telemetering output. The resistance of the telephone pair does not affect the calibration of the instrument. Telephone lines having dc resistances as high as 6000 ohms may be used. This instrument may be used with alpha-scintillation probes, as well as with halogen-filled G-M tubes, and automatically compensates for counting losses in the G-M tube.

The monitor was tested for one month on 12 miles of telephone line and is currently being tested in the field. Preliminary results indicate that a transistorized instrument is superior in many respects to the vacuum-tube instrument. Serious consideration should be given to fulfilling future needs with the transistorized instrument.

4.2 DIFFERENCE MONITOR FOR CONSTANT AIR MONITORS

J. L. Lovvorn

Because daughter products of thoron and radon contribute to the background level and interfere with the detection of airborne alpha-contaminated particulates in laboratories where such materials are handled, a monitoring system which would detect lower levels of airborne alpha activity was required. This requirement was met by installing two identical constant air monitors in adjacent laboratories, both of which received air from the same nonrecirculating ventilation system, and measuring the difference in the count rates. The system has been installed in the Transuranic Laboratory (Building 3508) and is being evaluated.

For a single monitor the alarm level was set at 1250 counts/min to avoid alarms when the background was increased by temperature inversions in the outside atmosphere. The difference monitor, however, was set to alarm at a difference of 250 counts/min. An alarm level of a difference of 100 counts/min will be tested (a 50-count/min difference is noticeable).

The system consists of two Constant Air Monitors (ORNL model Q-2340),[1] which were modified to give a second output signal with a higher time constant for comparing the outputs from the two monitors. The difference monitor is a recording-type contact-making, 200-μa meter with a zero-center scale. The full-scale difference is ±250 counts/min, or 10% of full-scale indication of the air monitor. The contacts on the meter are adjustable and operate the alarm indicators in the air monitors.

[1]H. K. Wilson *et al.*, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, p 31.

4.3 CIVIL DEFENSE INSTRUMENTS

F. M. Glass E. E. Waugh C. C. Courtney

The development of an aerial monitor and a shelter monitor was completed for the Office of Civil Defense Mobilization, which has contracted with private industry to build both instruments in quantity. The experimental model of the aerial monitor previously reported[1] was modified to make it easier for the pilot to operate and observe the instrument while flying the airplane. The monitor is packaged in three pieces: an enclosed meter panel, a case containing the detectors and count-rate meter circuit, and a battery box (Fig. 4.3.1). The meter panel can be fastened to the top of the instrument panel in the airplane by airplane-type stud fasteners, which can be snapped into place in a few seconds. Captive cables connect the meter panel to the radio and to either the count-rate meter or a simulator; this makes it possible for a trainer to simulate a fallout pattern while training and testing a pilot. The battery box, which has a female plug that mates with male plugs at the ends of both the simulator and count-rate meter, can be plugged in and held in place by luggage fasteners.

The Civil Defense Aerial Monitor (V-781AX) is a new approach to the problem of rapidly scanning high-intensity radiation from fallout over wide areas. By use of halogen-filled G-M tubes having a wide spread in their respective sensitivities in a three-channel meter, fast response with good statistics is obtained. Ground-level intensities within the range of 30 mr/hr to 400 r/hr can be measured from an airplane flying up to 100 mph at altitudes between 300 and 900 ft. By flying at 1100 ft, the pilot can measure a ground-level intensity of 800 r/hr. Four decades are covered with the accuracy and stability of a good linear count-rate meter without switching ranges. Meter lights switch automatically and show at a glance which meter should be read. An audible tone, with a frequency of 100 cps in normal background, increases in frequency one

[1]F. M. Glass, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, p 15.

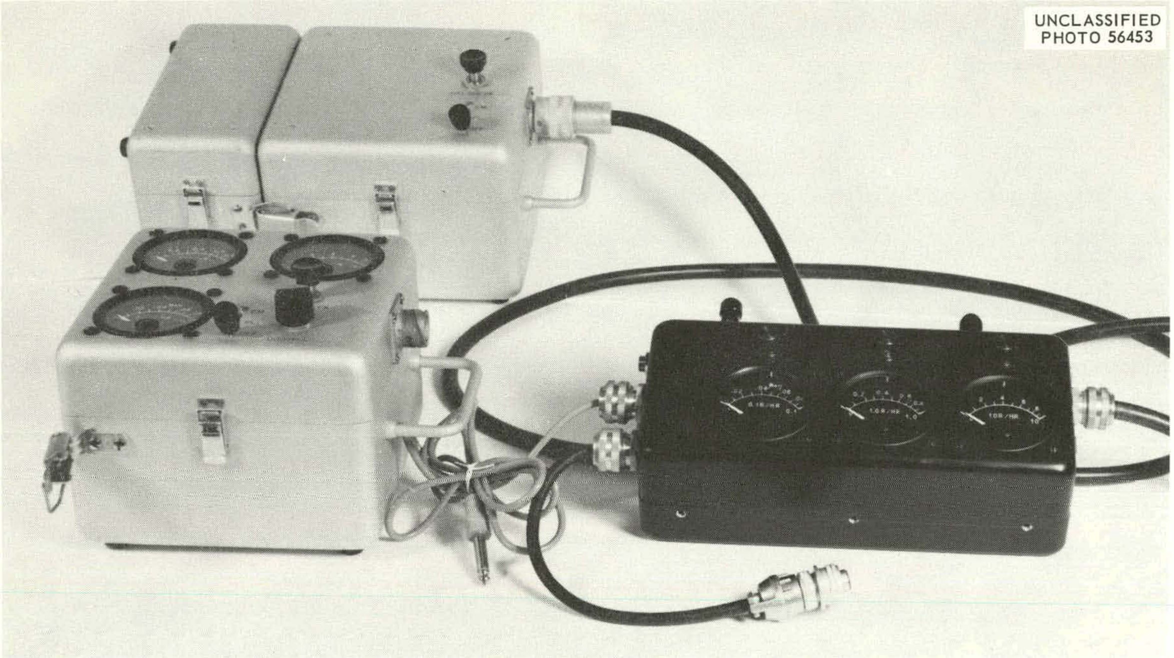

Fig. 4.3.1. Aerial Monitor and Simulator. The simulator is shown in the left foreground.

octave per decade. By taking meter readings only when the tone changes, the pilot can devote most of his attention to flying. The monitor is simple to operate, is lightweight, and has low battery drain. The monitor can operate on either the 12-v battery of the airplane or on two self-contained 6-v lantern batteries, which will give up to 80 hr of continuous service in normal background and 50 hr of service in a field of 5 r/hr.

The Shelter Monitor (ORNL model Q-2236-1) consists of an electrometer having full-scale ranges of 1, 10, 100, and 1000 r/hr when used with the explosion-proof chamber designed[2] for this use. The electrometer is powered by two 6-v lantern batteries, which are capable of supplying power for several months of intermittent use as required in a bomb shelter. A built-in calibration source not only checks the electrometer calibration on all ranges but checks the cable and ion chamber for leakage as well. A transistorized dc-to-dc converter supplies a well-regulated 500-v potential for the ion chamber.

[2]Chamber designed by M. M. Chiles, Instrumentation and Controls Division.

4.4 PORTABLE DECADE SCALER

F. M. Glass

Commercially available scalers were examined to determine whether a portable 12-v scaler suitable for use on a boat to survey nearby lakes and streams for low-level radioactivity could be obtained for the Health Physics Division. None of the scalers met the specifications without considerable changes in circuitry or packaging. Therefore, a scaler (ORNL model Q-2243) was designed to meet the specific needs of river survey teams. This compact scaler is of modular construction and is mounted in a watertight carrying case (Fig. 4.4.1). The weight complete with case is $4\frac{1}{2}$ lb.

Two commercial decades having a paired pulse resolution of 4 μsec are used. A charge-sensitive amplifier that precedes the two decades eliminates the necessity of having a preamplifier located at the detector, even though 125 ft of cable is normally used. The scalers are followed by a register driver and a 4-digit mechanical register. High voltage is supplied to the detector by a well-regulated dc-to-dc converter. The power requirement for the instrument is 12.6 $\pm$ 1 v at 0.2 amp.

Although this instrument was designed primarily for use in river survey work, it is finding popularity in other mobile uses, such as scanning streets and roads for contamination.

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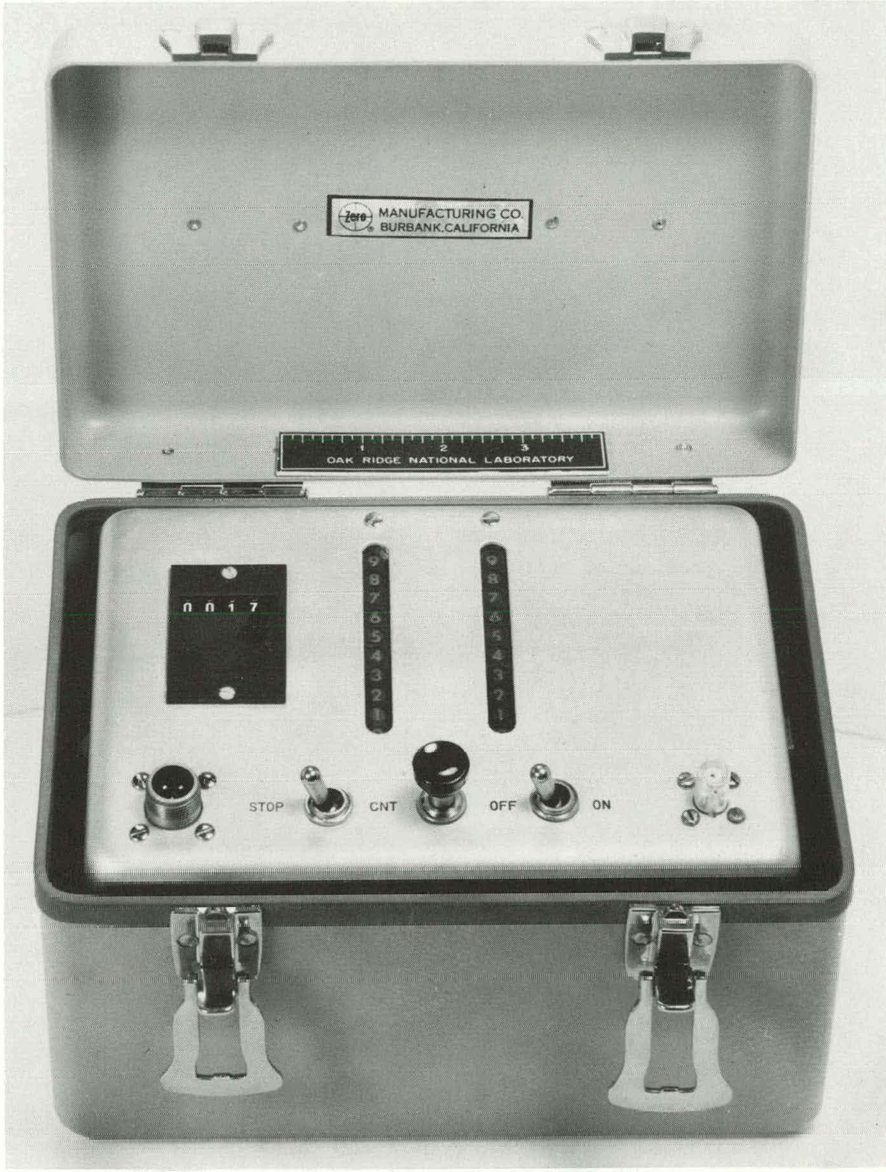

Fig. 4.4.1. Portable Decade Scaler.

4.5 NEUTRON MONITOR

F. M. Glass E. D. Gupton[1] E. E. Waugh

The need for an instrument that could monitor either fast or thermal neutrons in a low background led to the development of the Neutron Monitor (ORNL model Q-2296). This monitor is actually many instruments in one. It has a count-rate meter with a 10-mv recorder output and an alarm that can be set to actuate at any level between 5 and 50 mrem/hr. A single decade scaler and a mechanical counter provide a means of integrating extremely low flux levels over long periods. An additional count-down register can be set to close an alarm switch at any desired integrated dose. A fast-burst detector will actuate an alarm signal if a critical incident occurs within 200 or 300 ft of the detector.

The detector employed is a $B^{10}F_3$ counter mounted on the top of a cabinet (Fig. 4.5.1). A cylindrical, high-density polyethylene moderator and a cadmium shield are removable parts of the detector. With the

[1]Health Physics Division.

Fig. 4.5.1. Neutron Monitor.

moderator and shield in place, the monitor detects only the fast neutrons. With the cadmium shield removed, the monitor detects both fast and thermal neutrons. If both the shield and the moderator are removed, only the thermal neutrons and a few fast neutrons, which have been moderated by surrounding hydrogenous material, will be detected. The count-rate meter has a single-range full-scale calibration corresponding to 50 mrem/hr (Po-Be neutrons). It has been determined experimentally that, when the moderator is surrounded with 0.025 in. of cadmium, the RBE dose-rate response of the instrument is approximately the same for thermal neutrons as for Po-Be fast neutrons. Therefore, the instrument may be used as an approximate RBE dose and dose-rate meter for both thermal and fast neutrons and as a monitor for intermediate-energy neutrons.

The scaler has a paired pulse resolution of 4 μsec and a total storage of 10^5 counts. This corresponds to 4×10^5 mrem. The burst detector feature is optional and operates completely independently of the pulse amplifier and count-rate circuitry, which may be paralyzed by a fast excursion of the flux intensities encountered in a critical incident. The sensitivity of the burst detector is such that a 10^{15}-neutron 50-μsec excursion will be detected at a distance of 100 ft and through 9 ft of concrete. The burst detector responds only to short-time neutron flux excursions.

4.6 REACTOR-POWER MONITOR UTILIZING CERENKOV RADIATION

J. L. Lovvorn

Further studies were made to develop a monitor which measures at a remote point the power or gamma flux, or both, in the central region of a water-cooled reactor lattice. Work with a silicon solar cell was previously reported.[1]

An International Telephone and Telegraph Co. type FW114, high-current, biplanar phototube was used to detect the Cerenkov light at the porthole of the ORR tank, the same position used for the silicon solar cell previously reported. A current of 2.5×10^{-6} amp was obtained at a reactor power of 30 Mw. A plot of the output current from the phototube vs reactor power, as measured by an uncompensated neutron ion-chamber current, gave a replica of the curve obtained with the solar cell. The electrical current in the detector responded to an incremental increase in reactor power. The initial rise was proportional to the power, and it was followed by an additional increase in current of 4 to 5% with a time constant of approximately 4 min. The output signal of the gamma chamber was very similar in behavior.

The response of the phototube to gamma flux was linear. A plot of the phototube output current vs the gamma chamber current was a straight line within the limits of accuracy obtained from reading values from strip charts.

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[1]J. L. Lovvorn, *IRE Trans. Nucl. Sci.* 8(4), 3 (1961). An abstract of this paper was published in *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, p 77.

4.7 SCINTILLATION ALPHA COUNTER

R. K. Abele[1]

A scintillation-type alpha counter (ORNL model Q-2287) for counting smear samples was developed to produce an instrument that could be fabricated at a cost much lower than that of commercially designed units. The counter was designed to be used with a standard G-M tube scaler. Three units were fabricated and tested.

The test results from the three units show a high degree of unifomity. The detectors gave a count rate that was 44% of the disintegration rate of the Pu^{239} source ($\frac{1}{4}$ in. diam on a metal disk). The background counting rate, taken for a period of 4 to 5 hr, was 2.65 counts/hr (minimum) and 3.75 counts/hr (maximum). Phototube gains were such that the maximum operating voltage required was 800 v.

The whole counting system manufactured commercially costs less than $900 per unit; the previous unit cost to the Laboratory for commercially designed and fabricated units was more than $1500.

The smear sample is placed in a 2-in.-diam by $\frac{1}{8}$-in.-deep well in a movable slide. The slide is operated to position the sample under the detector.

The detector, a ZnS(Ag) phosphor coupled to the end of an RCA-6655A phototube with double adhesive-coated Scotch tape, is enclosed in a lighttight housing. There is no window or absorber between the sample and the phosphor. A double guard ring serves as a light seal between the sample slide and the detector and makes it possible to keep high voltage on the phototube at all times.

The output of the detector feeds into a standard scaler (ORNL model Q-2188), which is set at approximately 250 mv input sensitivity, and uses the positive high-voltage supply of the scaler.

[1] The author acknowledges the assistance of H. J. Stripling and R. L. Simpson in the design of this counter.

4.8 CRYSTAL-CONTROLLED PULSE GENERATOR

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

A crystal-controlled pulse generator (ORNL model Q-2167) was designed for checking the calibration of linear and logarithmic count-rate meters, since previous experience with commercially available instruments showed that they were unsatisfactory for this work. The commercial instruments usually consist of one or more variable-frequency sine-wave generators, a sine wave–to–pulse converter, and a digital counter for monitoring and accurately setting the frequency. Setting up the test equipment was laborious and time consuming; making critical frequency adjustments was also time consuming.

All Laboratory instrument groups engaged in testing and calibrating new equipment or servicing equipment in the field have been supplied with these new pulse generators.

The frequency-regulation circuit consists of a crystal-controlled oscillator followed by four decade dividers and dividers having scale factors of 2, 4, 6, and 8. Either a 30- or a 100-kc crystal may be selected by a switch. Two other selector switches in the divider circuit permit selection of scale factors of 1, 10, 100, 1,000, and 10,000 and pulse scale factors of 2, 4, 6, and 8. With this combination, any of 50 spot frequencies between 0.375 cps and 100 kc may be selected with the precision of the crystal oscillator. Pulse shapers, which follow the dividers, provide three different outputs: two (one negative, one positive) are 12-v square waves of 0.8-μsec duration with rise and fall times of 100 nanoseconds (nsec); the third (negative) has a 100-nsec rise time and a selection of six fall times ranging from 3 to 300 μsec. This output is from a 100-ohm attenuator with a maximum amplitude of 0.5 v when feeding a 100-ohm terminated line.

4.9 TRANSISTORIZED SUPPLIES FOR REGULATED HIGH-VOLTAGE POWER

F. M. Glass J. H. Todd G. A. Holt

Many of the portable survey instruments in use today require high-voltage supplies capable of delivering moderately high currents in terms of what is normally required for portable instruments, and some also require exceptionally good voltage regulation. The simple shunt-type regulator, which has a corona tube, is very inefficient and cannot provide the required regulation. A high-voltage supply (500- to 1400-v output) was designed that is capable of operating over a wide range of primary supply voltages and a wide range of loads with a regulation factor seldom achieved in precision laboratory supplies.

Several units are being built under contract and will be stocked in ORNL stores. The output voltages (500, 900, 1200, and 1400 v) of these units are the four most commonly used in ORNL-designed health physics survey instruments. All units (ORNL model Q-2291) are hermetically sealed in $1^{19}/_{32}$ by $1^{11}/_{32}$ by $2^{11}/_{32}$ in. cases and weigh 3.5 oz. They deliver 140 mw of power at an overall efficiency of 60 to 70%. The output voltages change less than 0.05% for a change from no load to full load. When loaded to half-capacity, the primary supply voltage can be decreased from 12 to 6 v without producing more than a 0.05% change in the output voltage; therefore, they may be powered from either 6- or 12-v primary supplies. A typical temperature coefficient is 0.001%/°C.

4.10 POWER SUPPLIES

J. H. Todd

A power-supply regulator circuit (ORNL model Q-2543) was designed which can be adapted to the requirements of a majority of the general-purpose instruments designed at ORNL. The components are assembled on a small, etched board, $1\frac{1}{2}$ by $4\frac{3}{4}$ in. Lists of components were prepared for constructing any one of 24 supplies having an output voltage in the range 24 to 6 v (either positive or negative) and current-limiting capacity of either 100 or 300 ma. By choice of a parts list, the instrument design engineer can use the same etched-board layout to produce any voltage and current capability within these limits.

Each supply is adjustable to ±2 v. Line and load regulation is within 0.5%, and ripple is 2 mv. The current limiter can be set at any convenient level, and the circuit will limit at this current level under a short-circuit condition for an unlimited time.

4.11 FAST-NEUTRON COUNTER

R. K. Abele

The standard fast-neutron counter with a built-in alpha source, a highly specialized and expensive instrument, was redesigned to reduce fabrication costs. The new design resulted in a reduction of $266 per unit, or 35% of the original cost, when comparing equal quantity purchases.

The design of this instrument, designated model IV, is covered by a series of drawings numbered Q-1696C and by Specification SF-229.

4.12 FLOW-PROPORTIONAL COUNTER

R. K. Abele H. J. Stripling

The windowless flow-proportional counter (ORNL model Q-2275) with a sliding sample holder was redesigned mechanically to reduce the cost of fabrication and to improve the operation of the slide. The new design is electrically and geometrically identical to the previous design, which had been in wide use at the Laboratory for many years.

The movable slide, which must move easily and also seal the chamber gas volume, can now be adjusted as to its loading on the chamber guard-ring seal. This adjustment was not possible on the previous model.

The first order for ten of these units built commercially was placed at a unit cost of $82. Previously, the unit cost was greater than $250.

5. Data Handling and Computation

5.1 DIGITAL COMPUTER ANALYSIS OF CLOSED-LOOP SYSTEMS USING THE NUMBER-SERIES APPROACH[1]

R. K. Adams

The theoretical foundation, the methodology, and examples of application show that the number-series approach to the analysis of closed-loop systems is a simple and accurate method. The ease with which the numerical calculations can be programmed for high-speed digital computer solution adds to the attractiveness of the procedure. The fact that some of the most common types of nonlinear systems may be solved using the number-series concepts, together with the simplicity of the operations, places the methodology within the reach of the practicing engineer for routine systems analysis. The advent of the very large, very high-speed digital computers allows this method to compete with and surpass, in accuracy and speed, any calculation method previously reported for the systems shown.

The approach presented in this paper lends itself equally as well to calculations on actual systems, in which weighting functions have been determined experimentally, as to calculations on the idealized systems.

[1]Abstract of paper presented at the AIEE-AIChE-IRE-ISA Joint Automatic Control Conference, Boulder, Colo., June 28–30, 1961. Published in *Appl. Ind.* 58, 370 (1962) and in *Joint Automatic Control Conference Digest of Technical Papers*, 1st ed., p 90, Lewis Winner, New York, 1961.

5.2 SIMULATION TECHNIQUES FOR "PLUG-FLOW" SYSTEMS[1]

S. J. Ball

The transient response characteristics of fluid-flow heat-transfer systems are of general interest in many process-control simulation problems. A large class of fluid-flow problems is often described by a "plug-flow" model, or one which assumes that there is complete mixing of the fluid in the direction normal to the flow but no longitudinal mixing.

Methods are presented for developing accurate simulations for heat transfer in the general class of "plug-flow" systems in which the fluid transport time is negligible. A simplified graphical method is also given for determining the approximate response of fluid temperatures in pipes that have significant heat capacity. Comparisons of the exact and approximate theoretical solutions are given in both step response and frequency response form.

[1]Abstract of paper presented at the Southeastern Simulation Council Meeting, Marshall Space Flight Center, Huntsville, Ala., July 20, 1962.

5.3 DIGITAL MAGNETIC-TAPE SYSTEM FOR EVALUATION OF THE VELOCITY AND ACCELERATION CHARACTERISTICS OF CONTROL RODS

J. W. Reynolds

A data-collection system was required for the determination of the velocity and acceleration of a control rod vs its position in order to perform acceptance tests on a prototype control-rod-drive mechanism for the EGCR.[1] The system was to be adaptable to future unspecified control-rod-drive studies. The system designed for this purpose consists of a magnetic-tape transport and control, a shaft-position digitizer and translator, and a test selector and control unit. The system is complete, except for installation and final testing at the Control Rod Test Facility.

This particular system was selected because of the requirement that the minimum detectable change in position of the control rod (or resolution) is to be 0.1 in. The maximum velocity of the rod is to be 24 fps. The magnetic-tape transport was selected in preference to a paper-tape transport, because it can record from 50 (minimum) to 7500 (maximum) four-digit numbers per second, whereas, the best paper-tape system can record a maximum of only 60 four-digit numbers per second.

The transport speed is 50 in./sec with a writing rate of 10,000 digits/sec. The sampling rate is 2500 positions/sec with four decimal digits per position. The minimum change in rod position that can be detected is 0.09 in. At a rod velocity of 24 fps and a writing rate of 10,000 digits/sec, the position of the rod is recorded every 0.115 in. of rod travel.

The block diagram of the system is shown in Fig. 5.3.1, where the data flow is indicated by a heavy line. The position information from the digitizer, which is electromechanically coupled to the control-rod

[1]Allis Chalmers Company, "EGCR Specifications RD-6, Revision 1, June 19, 1962, Control Rod Drive Mechanism Prototype and Acceptance Tests."

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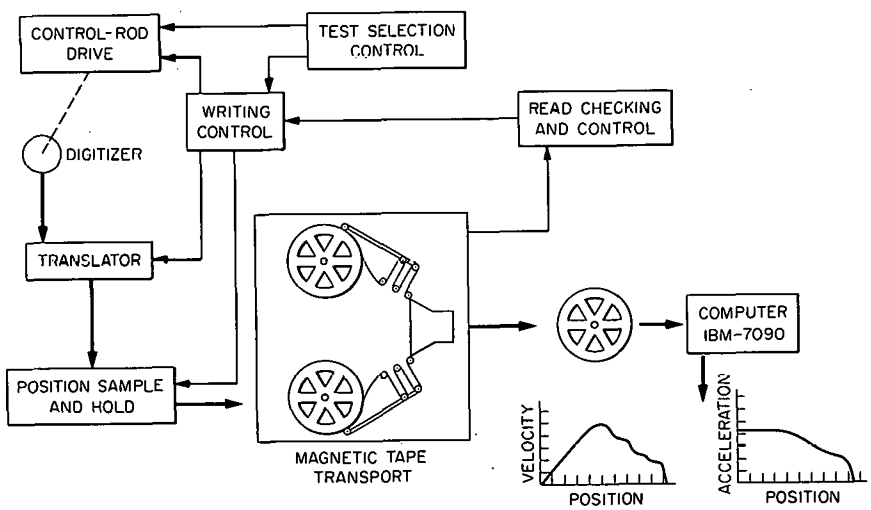

Fig. 5.3.1. Digital Magnetic-Tape System for Control-Rod-Drive Tests.

drive, is translated to binary-coded decimal before it is stored. The stored position is written serially on magnetic tape, which stores the rod position vs time for a particular test. The magnetic-tape data are processed in a computer to obtain velocity and acceleration curves vs position for normal, cycle, and scram tests.

It is possible to replace the shaft-position digitizer and translator with a unit of greater resolution and to change the speed of the magnetic-tape system, for achieving a higher sampling rate. This change would require revision of the internal wiring at the position sampling and hold circuitry.

5.4 DATA-HANDLING SYSTEM FOR THE MOLTEN-SALT REACTOR EXPERIMENT (MSRE)

G. H. Burger

Criteria were developed and specifications were prepared for a digital data-collecting and computing system to be purchased for the MSRE. A proposal was written to obtain approval for procurement in order to provide reactor operators and operations analysts with a modern, efficient, and rapid machine for collection, computation, and analysis of information from the experiment. This system will produce three types of information:

1. information required by the operators to keep the system in the designated operating range;
2. information which warns of impending troubles and identifies them when they occur;
3. information used to evaluate the reactor system and component design.

The system will contain input-signal conditioning equipment, input scanning equipment, an analog-to-digital converter, a magnetic-tape system, a digital-to-analog converter, a computer, an operator console, five electric typewriters (includes one spare logging typewriter), an *X-Y* point plotter, two paper-tape punches and readers, and equipment for producing analog and digital output signals (Fig. 5.4.1).

Previously, problems of handling data from a number of experiments and experimental facilities at the Laboratory, such as the HRT and EGCR test loops, had been studied to determine the data-handling requirements, to review methods of data handling, and to propose methods and equipment to meet the requirements for the MSRE. It was concluded that, with a conventional data-collection and display system (i.e., a system having standard indicators, strip-chart recorders, and manual logs), the long-term storage and retrieval of information needed for analysis of the experiment would be inefficient and time consuming, and it would be difficult to correlate this information with a common time base. For example, for the HRT, eight different manual logging operations were performed from one to two times per shift. Each operation required a separate log sheet. The total time required for these logs was 12 to 16 hr/shift. From these data and from data on chart records, a number of calculations were made to analyze the reactor operation. Among these were nuclear average temperature, core average temperature, blanket average temperature, effective U^{235} to book U^{235} inventory ratio, power spectrum and standard deviation of neutron level, system heat balance, and others. The estimated time required for the calculations was 43 hr/day. The complete analysis of an experimental run required even more time. Furthermore, important data were masked because large amounts of static data were recorded in order to have a record of transients and system operating changes.

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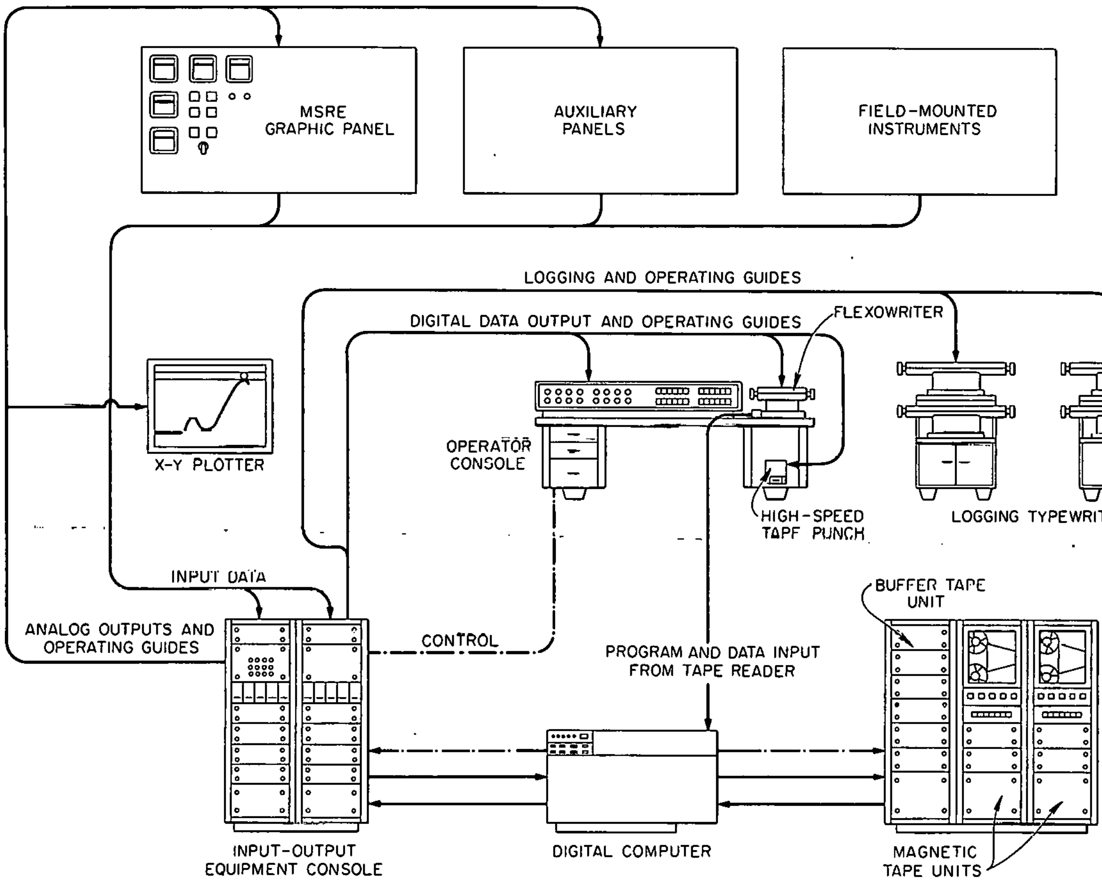

Fig. 5.4.1. Components and Flow of Information for the MSRE Data-Handling System.

With the new system, data will be made available for analysis virtually as fast as they are produced by the experiment and in a form readily assimilated by digital computer machinery. Results of any particular test will be available in time to influence plans for subsequent tests. Operational downtime and the associated nonproductive costs will be reduced. Test programs will be optimized, since the experimental results will be developed as the program progresses. The incidence of retesting to fill gaps in the data will be sharply reduced.

The system will perform three functions (Fig. 5.4.2):

1. Data Handling – scan and digitize data from the sensors, log the data, store data on magnetic tape for reactor operation and final operating analysis, compare data with preset alarm limits, and produce an alarm and alarm log when an alarm limit is reached or exceeded.

2. On-Line Computing – calculate information in real time for reactor operators and experiment analysts.

3. Off-Line Computing and Data Reduction – compile and store on magnetic tape the test data obtained during reactor operation and do general-purpose computing on accumulated data or scientific programs.

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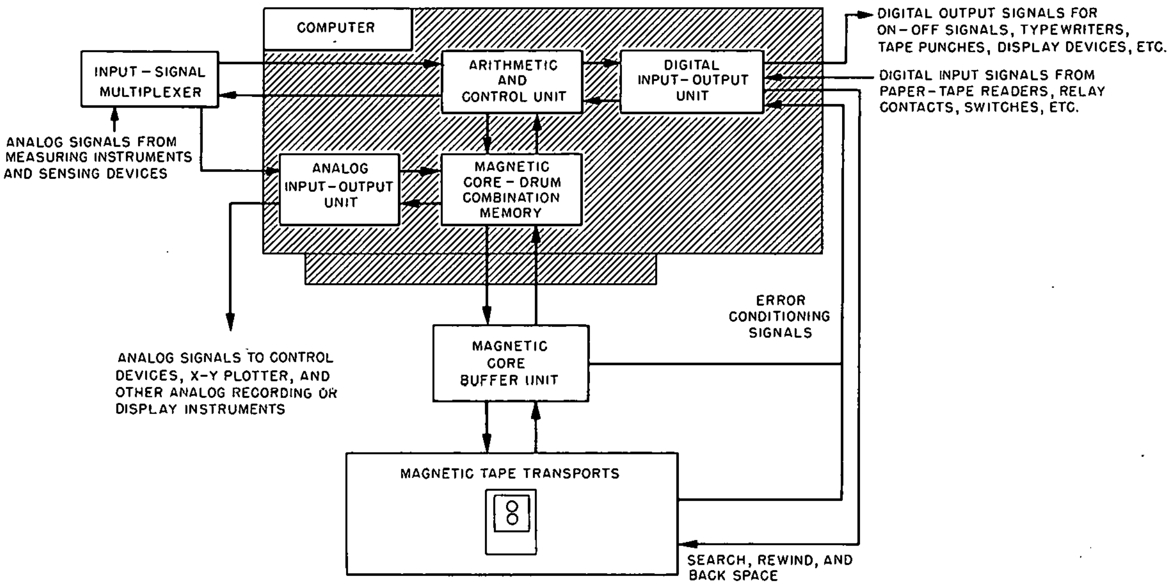

Fig. 5.4.2. Flow of Input and Output Signals for the MSRE Data-Handling System.

Input Signals

The system will be able to handle a minimum of 350 analog input signals and 112 one-bit digital input signals. Of the 350 analog input signals, 251 will be installed and 99 will be spares (Tables 5.4.1 and 5.4.2). The 112 digital input signals will consist of one-bit momentary or sustained, or both, contact closures from valves, switches, and other components and from one or more manual digital input banks of switches or push buttons.

Table 5.4.1. Analog Input Signals by Type of Signal

Signal	No. to be Installed	No. of Spares
0–10 v dc	6	5
10–50 ma (2–10 v) dc	25	13
0–10 mv dc	54	25
0–50 mv dc	160	40
90–140 v ac	6	6
180–280 v ac	0	10
Total	251	99

Table 5.4.2. Analog Input Signals by Type of Process Variable

Variable	No. of Units	Type	Signal
Flow	7	Foxboro, ECI	10–50 ma dc[a]
Flow	5	Statham strain gage	0–10 mv dc
Pressure	14	Foxboro, ECI	10–50 ma dc[a]
Level	4	Foxboro, ECI	10–50 ma dc[a]
Level	2	Statham strain gage	0–10 mv dc
Weight	5	Statham strain gage	0–10 mv dc
Speed	2	Count-rate meter	0–10 mv dc
Electrical	6	Power-supply voltage, 100 v	90–140 v ac
Position	6	Synchro with potentiometer	0–10 v dc
Radiation	38	Electrometers or rate meters	0–10 mv dc
Temperature	160	Shielded, grounded, Chromel-Alumel thermocouples	0–50 mv dc
Electrical power	2	Thermal converter	0–10 mv dc
Total	251		

[a]1–5 or 2–10 v.

Design Criteria

The system will operate with the reactor instrumentation and control equipment, but will not eliminate, decrease the reliability of, or impair the operation of the reactor instrumentation and control equipment nor will it cause the loss of critical data needed for reactor operation. The system will not be connected to the control circuits of the reactor.

System Operation. – The analog input signals will be scanned and digitized at a minimum rate of 100 signals/sec. During normal operation of the reactor, no data will be displayed except that programmed for periodic logs or manually requested. Data will be stored, either periodically or continuously, on magnetic tape during this period.

During periods of abnormal operation of the reactor, all data programmed as that required for operation of the reactor will be displayed. The values of abnormal variables or calculations will be displayed, and an alarm will be actuated when the value of any variable reaches a preset value, as programmed. Any variable or group of variables that the operator may select will be displayed at any time.

Changes in operation of the system, the program, alarm limits, or other operating parameters may be programmed without stopping the operation of the system.

Operating Priorities. – The system will operate in accordance with the following sequence of priorities:

1. scan and digitize input signals,
2. store data on magnetic tape,

3. scan values of input signals, compare these values with preset limits, actuate an alarm when a limit is reached, and log the values of the input signals,
4. make calculations and produce analog control signals,
5. print a demand log and make a visible display of data,
6. generate operating guides,
7. print a summary log of data,
8. print a periodic log,
9. reduce and analyze data.

System Control. – All functions of the system will be controllable either automatically or manually. Automatic control will be by instructions written into the memory unit of the computer or by instructions on magnetic tape under control of the computer program. The program will be changeable through paper- and magnetic-tape input or by the manual keyboard or switches at the console.

System Failures. – Failure of any major component in the system will be alarmed, and continued operation of the system will depend on programmed instructions. Manually controlled marginal tests will indicate probable impending failures and their location.

Momentary power failure of 5 cycles or less or power transients of ±10% will not cause the loss or alteration of any information in the memory of the computer, nor will it cause loss of operating continuity.

Feedback Control. – The system will contain equipment and circuitry to produce analog and digital signals such that feedback control may be put into operation whenever desired without requiring the installation of additional equipment. When analog or digital output signals for control are produced, the system will hold the controller set point at the last set position at system failure. Under this condition, an audible signal will be produced.

Modification or Expansion of the System. – It will be possible to modify or expand the number of input and output signals by adding equipment without modifying the internal system. The system will have the capacity to operate six typewriters, two 11-column line-printers, two paper-tape punches and readers, and four magnetic-tape units. Connectors will be supplied so that any or all of these devices will connect to the system by cables without requiring alterations.

6. Process Instrumentation and Control Systems

6.1 MODIFICATIONS AND ADDITIONS TO THE VOLATILITY PILOT PLANT

H. E. Cochran W. J. Greter B. Lieberman

In 1958, after the feasibility of the volatility process had been demonstrated by recovery of uranium from Al-clad fuel elements, the Volatility Pilot Plant was shut down for extensive modifications and the addition of head-end equipment for dissolution of Zr-U alloy fuel elements. Design of the additional instrumentation and improvement of existing instrument systems were started in April 1959. The design included instrumentation for the hydrofluorination equipment, a cell ventilation scrubber system, and containment of the processing cells and building. These large-scale plant changes necessitated extensive

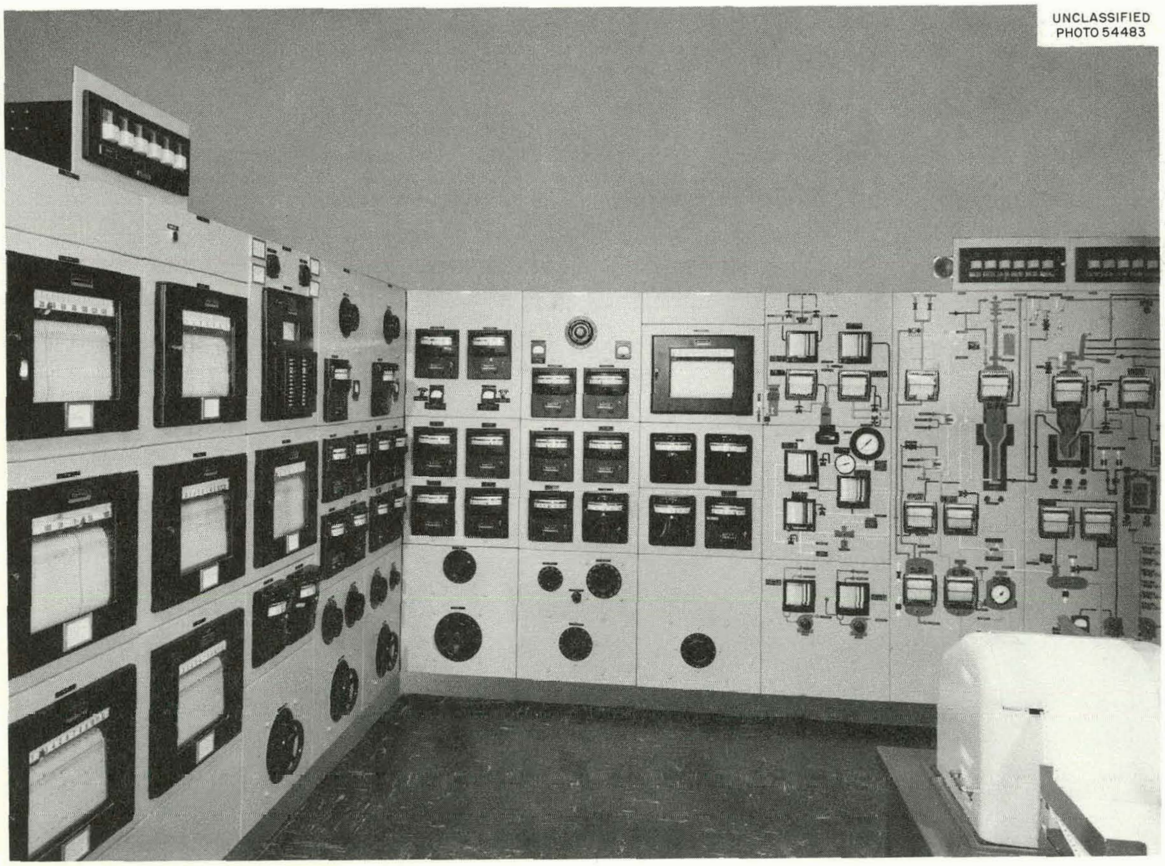

Fig. 6.1.1. Instrument Control Panel (Left Side) for the Volatility Pilot Plant.

revisions in much of the instrumentation, including the control panel (Figs. 6.1.1 and 6.1.2), transmitter rack, and blanket system. Instrumentation improvements included the replacement of approximately 400 standard thermocouples with ungrounded-junction metallic-sheathed thermocouple assemblies, which appreciably reduced 60-cycle ac pickup and provided greater durability. Another improvement was the installation of a data-collection system which permitted automatic computation and data reduction on the IBM 7090. The cost of these modifications and additions, which exceeded the cost of the instrumentation for the original plant, was $10,000 for design and $185,000 for materials and installation labor.

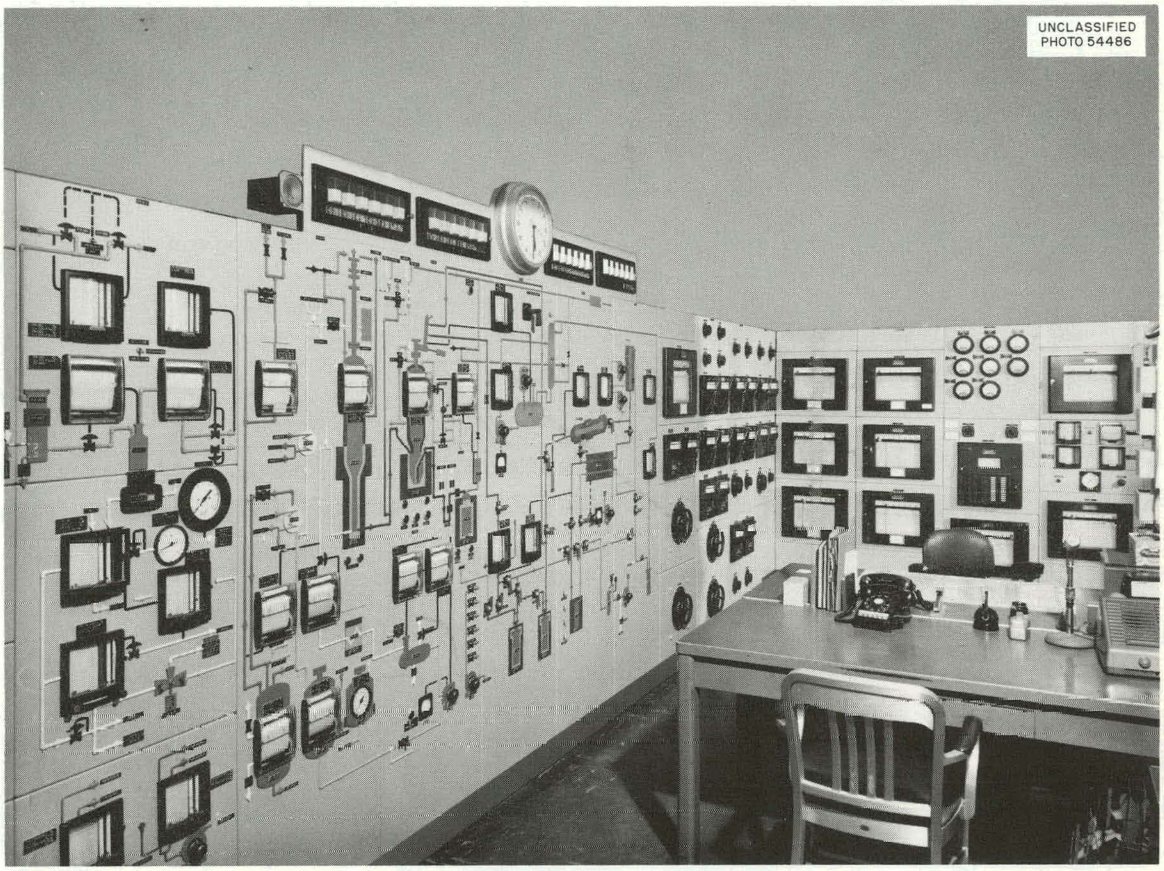

Fig. 6.1.2. Instrument Control Panel (Right Side).

6.2 TRANSURANIUM PROCESSING FACILITY

H. E. Cochran

The Instrumentation and Controls Division is participating in the transuranium (TRU) facility program by providing the detailed design of process instrumentation as well as the design criteria and drawing review for the architect-engineer's facility design. The cost of facility and process instrumentation will total about $600,000, or roughly 13% of the overall project cost.

The architect-engineer has completed approximately 80% of the instrument design for the facility (i.e., building, utilities, and auxiliary process instrumentation). The Instrumentation and Controls Division is scheduled to begin design of the process instrumentation Jan. 1, 1963. The target date for operation of the process is December 1965.

6.3 PROCESS INSTRUMENTATION FOR ORNL OPERATING REACTORS

C. Brashear B. C. Duggins A. H. Malone

The operating reactors at ORNL require a continuing program of instrumentation design support. During this report period, approximately $1\frac{1}{4}$ man-years of engineering time were devoted to this work, including redesign and renovation of existing instrument systems as well as new design for additional systems. Some of these projects are as follows.

1. The LITR process instrumentation was updated to meet the latest safety criteria and to permit remote indication and operation of the reactor. Many of the existing instruments were replaced with electric instruments utilizing a 10- to 50-ma dc transmission system. Dual measurement and dual track systems were provided for all safety signals.

2. The ORR scrubber system was redesigned to satisfy AEC and ORNL safety requirements. This included the elimination of control interlocks through simplification of the flow path, checking of critical components by continuous operation, and provision for continuing operation of critical instruments if either electric power or plant air supply fail.

3. Existing instrumentation from various locations was centralized in transmitter racks at the ORR North Facility, South Facility, and Pool Demineralizer.

4. Instrumentation for the new ORR pressurized off-gas system.

5. The addition of a number of temperature indicators and control systems at the ORR to protect against overheating of pump bearings and freezing of the cooling-water systems.

6. Other additions and improvements at the ORR include the pool cooling system, the normal off-gas system, the 30-Mw cooling tower fan, and pH and level controls on the cooling tower basin.

It is probable that further evolution of AEC safety requirements and accumulation of additional operating experience with the ORR, LITR, and ORNL Graphite Reactor will require more of this type of support.

7. Process Instrumentation Development

7.1 PNEUMATIC TEMPERATURE MEASUREMENT

E. W. Hagen

The pneumatic temperature measurement (PTM) system has been under investigation at ORNL for the past two years for (1) application in the EGCR and (2) determination of its general applicability to other high-temperature measuring problems. Previously reported[1] work was concerned with obtaining a fundamental understanding of critical flow through small (<0.070 in.) nozzles and the effect of variables, such as nozzle geometry, gas composition, etc., on accuracy.

Work this year was concentrated on selecting the best nozzle materials for long-term stability and accuracy in the EGCR and investigating the feasibility of using very small nozzles (<0.010 in.) for other temperature measuring problems.

Since a slight change in the physical characteristics of small nozzles can appreciably alter the flow calibration, the effects of simulated EGCR gas conditions, without the abrasive constituents, were investigated. Extended time tests on three nozzles fabricated from 304 and 321 stainless steels and from Inconel were conducted. Nozzle calibrations are shown in Fig. 7.1.1, where 100 hr of continuous testing is the equivalent of a minimum of 2.65 yr of cyclic operation in the EGCR. In each

[1] H. M. Hochreiter, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, pp 57–60.

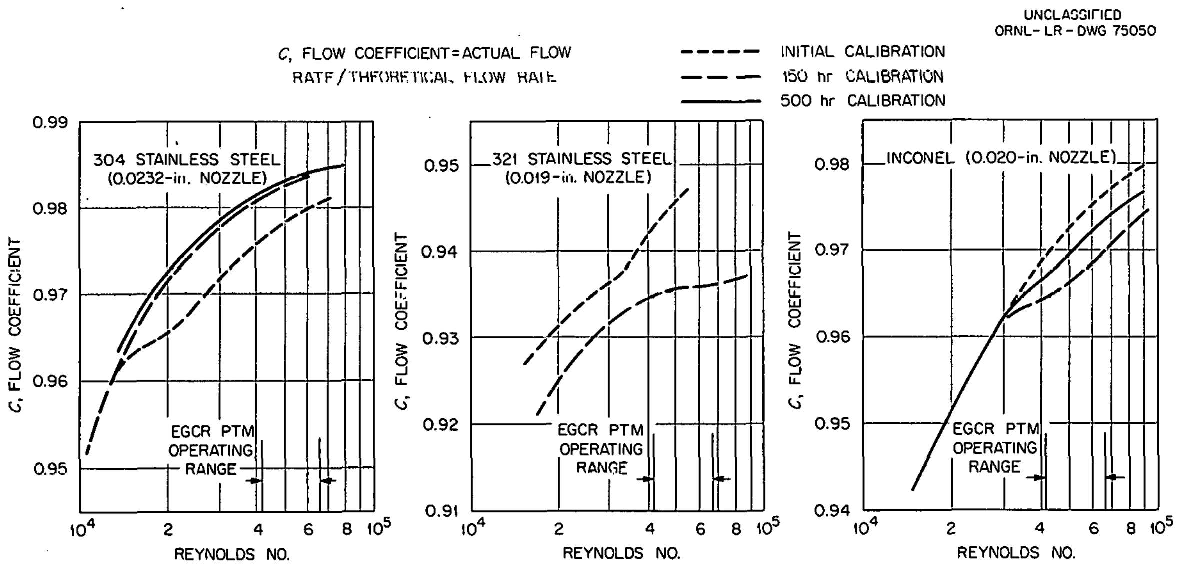

Fig. 7.1.1. PTM Nozzles – Flow Coefficient Stability.

case a shift in the value of the flow coefficient was noted at the second calibration, after 150 hr of high-temperature operation. This was apparently caused by changes in the material which altered the nozzle geometry and the dynamics of the gas-to-surface boundary conditions. Because of this phenomenon, it is advisable to pre-age or condition PTM nozzles for a maximum of 150 hr before final calibration and after they have been installed into probes.

An investigation was begun to explore the applicability of the relatively inexpensive cemented carbides to PTM. Small nozzles were made in samples of tungsten carbide with a cobalt binder and in chrome carbide with a nickel binder. Development of a satisfactory mounting technique is the current problem. Brazing with either copper or a nickel-palladium alloy into stainless steel holders has not produced an acceptable bond. Microscopic examinations revealed small cracks in the carbide nozzles, probably caused by differential expansion between the stainless steel holder and the carbide materials.

A temperature measuring system utilizing very small nozzles installed in $\frac{1}{8}$-in. tubing is being evaluated. Ambient temperature tests on 0.0025- and 0.005-in. throat diameter nozzles indicate that miniaturization of the PTM system is practical.

7.2 HIGH-TEMPERATURE ADIABATIC CALORIMETER FOR AQUEOUS SYSTEMS

T. M. Gayle L. H. Chase C. D. Martin, Jr.

The development of an adiabatic calorimeter, which will measure the heat evolved when a dry chemical is combined with a liquid, was continued. The calorimeter will determine heat quantities of about 0.006 j by measuring temperature differences as small as 20×10^{-6}(°C) at temperature levels as high as 250°C.

Since the last report,[1] work has been concentrated on two systems: (1) the calorimeter calibration system, and (2) the oil bath to house the entire calorimeter, adiabatic shield, and vacuum-jacket assembly.

The calibration system has been designed and fabricated and currently is being tested on another calorimeter. The system consists of a calibration heater, a control panel, and measuring instruments. Precise measurements of voltage, current, and time are made in order to determine the heat input of the calibration heater with an accuracy of better than 0.01%.

The oil bath is a right-circular cylinder, 40 in. in diam and 40 in. deep. When full, it will contain approximately 200 gal of oil. Various hydrocarbon oils were tested for extended periods at 250°C to determine their suitability for use in the oil bath; two acceptable oils were found. A control system for the oil bath, which is being designed, is expected to maintain the oil at a constant temperature, ±0.01°C.

[1]T. M. Gayle, G. W. Allin, and C. D. Martin, Jr., *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961,* ORNL-3191, pp 95–98.

7.3 DROP-TEST INSTRUMENTATION FOR RADIOACTIVE MATERIAL SHIPPING CONTAINERS

W. F. Johnson

Instrumented models of casks, weighing up to 13,000 lb each, for use in transporting radioactive materials were tested by dropping them from various heights at different angles of impact. Thirty tests were completed. Information from these tests (conducted by the Chemical Technology Division) will be used to establish minimum safety criteria for the design of future casks to be used in highway and railway transit.

Each cask, depending on the particular type of test performed, was instrumented with up to twelve strain gages, two accelerometers, four acceleration-sensitive switches, and nine compressometers to determine the condition of the cask during and after the test. The strain gages indicated maximum and permanent deformation at the point of gage application, and the accelerometers and acceleration-sensitive switches indicated the magnitude and rate of deceleration on impact. The compressometers, which were cold-rolled steel rods fitted with press-fit roll pins, were placed inside the cask so that, if the inside diameter of the cask decreased on impact, the roll pin was pushed into the rod an equal amount and indicated the maximum deformation of the inside diameter of the cask. A Minneapolis-Honeywell Visicorder recorded the information from the strain gages, the acceleration measuring devices, and a microphone connected to the armor plate on which the casks were dropped. Some casks were also coated with Stress-Coat, which cracked in proportion to the strain, to indicate the location and directions of the stresses. From this information, strain gages were placed in the proper places and in the correct orientation on the casks for later tests.

A photographic record of each test was made with a Fastex camera, and, in order to provide a time base on the film, a timer was placed on the pad near the impact zone. The timer consisted of a 2-ft-diam calibrated disk and pointer, which was rotated at 3600 rpm with a synchronous motor.

7.4 FUSED-SALT TORSIONAL VISCOMETER

P. B. Bien[1] T. M. Gayle J. G. Hemmann W. F. Johnson

In the precise measurement of viscosity of molten salts by the classical torsional pendulum method, a highly accurate direct readout system was desired for both period and decrement. A torsional viscometer was developed that eliminates the use of sensitive photographic film and the attendant lightproof housing, utilizes simple optics, and produces a direct readout record of sufficient size that magnification and projection is not required.

Figure 7.4.1 shows the system as developed and in current use. A high-pressure mercury light source provides a strong source of monochromatic, ultraviolet light. A condensing-lens system focuses the light on a mirror mounted on the torsional suspension wire, and the light is reflected to a rotating-drum receptor

[1]Reactor Chemistry Division.

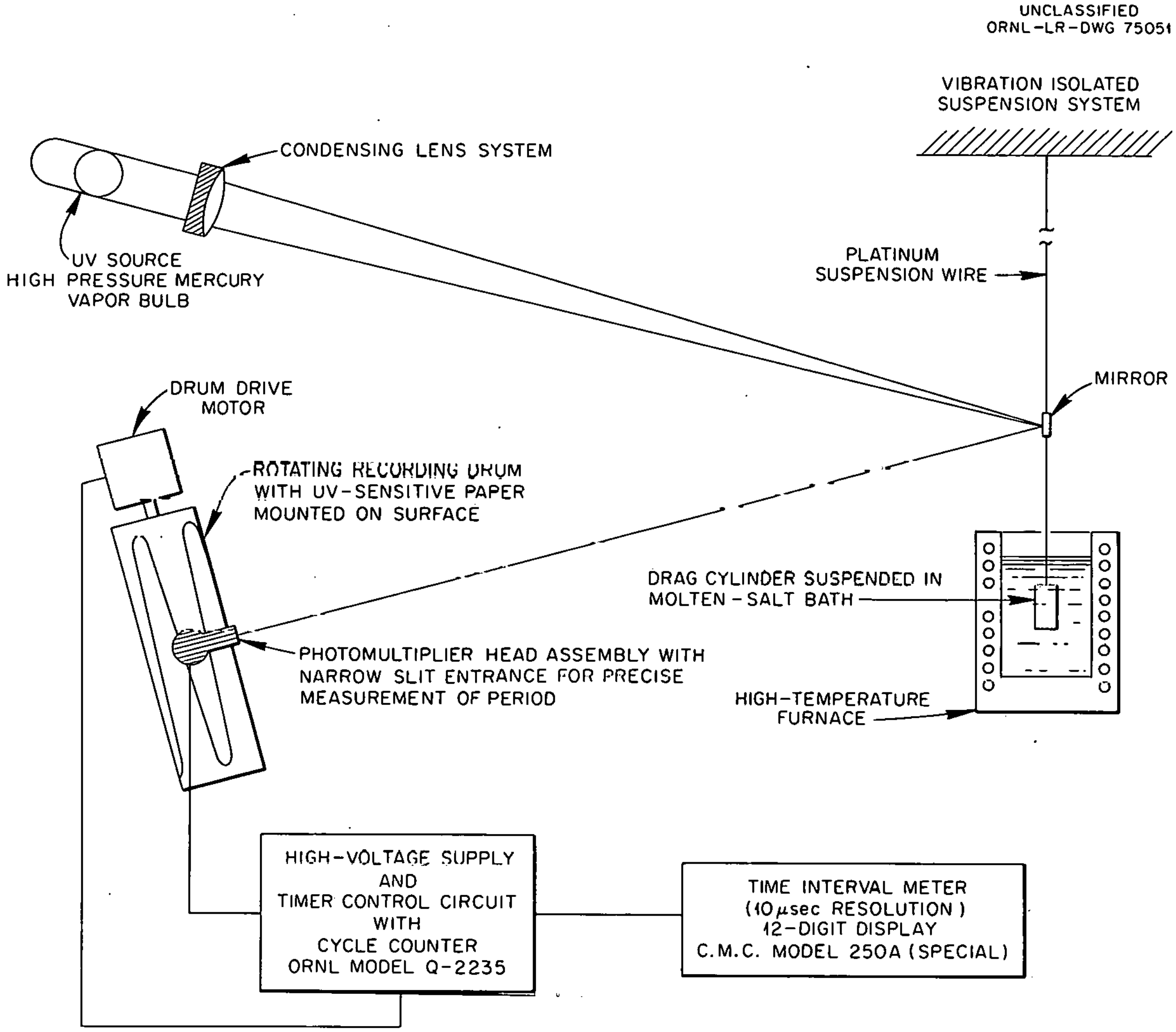

Fig. 7.4.1. Fused-Salt Torsional Viscometer.

assembly. The surface of the drum is fitted with a strip of ultraviolet-sensitive paper (currently used in many commercially available oscillographs), which is sensitive to very high levels of ultraviolet light but is relatively insensitive to light of longer wave lengths and to low-intensity ultraviolet light. As the drum is rotated, the traveling beam from the oscillating mirror is recorded on the paper. Subsequent exposure to low-intensity ultraviolet light from fluorescent light in the laboratory develops the trace in $\frac{1}{2}$ min. No chemical developing is required. The paper may be handled under normal room light at all times. Measurement of the pendulum decrement is taken directly from the chart by the experimenter.

The period of the pendulum is measured to within 10 μsec in typical periods of 10 to 30 sec with the same light source and mirror used for decrement recording. A photomultiplier tube with peak response in the ultraviolet region is used to detect the light-beam passage and to gate a twelve-digit time-interval meter. Appropriate controls are built into the system to enable the operator to measure directly any desired number of half-periods.

Advantages of the system include the ability to conduct all experiments and associated operations in room light, simplicity of the lens and light-beam focusing due to the use of monochromatic light, and direct readout of both period and pendulum decrement.

7.5 GRAPHITE-PARTICLE ELIMINATION FROM HELIUM SAMPLES FOR EGCR ANALYTICAL INSTRUMENTS

T. M. Gayle

Infrared moisture detectors and other analytical instruments associated with normal operation of the EGCR are dependent on samples of helium coolant free of solid contaminants. Economical removal of micron-size graphite particulate matter in the anticipated concentration of up to 100 ppm by volume could not be accomplished with conventional filtering and/or electrostatic precipitation techniques. Detailed studies of the performance of small-size cyclone-type separators and aerodynamically designed sampling probes indicate that centrifugal and inertial techniques may be used to provide a low-cost, efficient solution to the problem.

Both vortex-type inertial separators and conventional cyclone-separator designs were studied to determine efficiencies in the vicinity of a 2-μ particle size. Mathematical analysis together with projection of available operating data indicated efficiencies up to 93% for cyclone-type units. Analysis of the vortex units was somewhat limited in scope, but indications are that suitable removal of 2-μ graphite particles could be attained.

The original EGCR specifications state that particles up to 2 μ are to be considered, but there is no valid reason why the upper limit should cut off at 2 μ. Some type of statistical distribution will occur (Gaussian, Poissonian, or bimodal), which would mean that the bulk of the trouble-causing particles will be in the larger sizes. With this in mind, the sample probe inlet was designed to take advantage of the velocity of the gas in the main coolant loop to provide the centrifugal motion necessary to separate large particles from the sample being withdrawn.

Advantages of the systems described include: (1) no replacement of any element is required, as is the case in conventional filtering, (2) no moving parts are involved, and (3) no power supply or external energy is required, as is the case with electrostatic filtering assemblies.

7.6 GAS-SAMPLING DEVICE FOR PROJECT GNOME

C. D. Martin, Jr. J. W. Reynolds

ORNL participation in project Gnome consisted in the design, construction, and installation of a sampling device to collect gas samples from the vicinity of an underground nuclear explosion within 10 sec of the detonation. Instrumentation of the sampler provided for firing explosive-actuated valves on seven evacuated sample vessels, recording the firing impulses, and measuring and recording the pressures in the sample vessels. The firing sequence is given in Table 7.6.1.

Table 7.6.1. Firing Sequence of the Gas-Sampling Device

Sample No.	Valve Fires with Respect to Zero Time	
	Opening	Closing
1	Open at zero time	50 msec
2	40 msec	75 msec
3	60 msec	90 msec
4	75 msec	150 msec
5	150 msec	1 sec
6	1 sec	10 sec
7	Open at zero time	10 sec

The timing device (ORNL model Q-2264) consisted of a 1-kc oscillator, a four-decade scaler, and silicon-controlled rectifier firing circuits. Timing was accomplished by gating *on* the 1-kc oscillator at zero time, counting the output of the oscillator in the four-decade scaler, and gating the combinations of each decade to obtain the desired outputs. The firing circuits were identical for each valve. The valve firing currents (~4 amp) were passed through individual current transformers to produce pulses for the recorder (Fig. 7.6.1).

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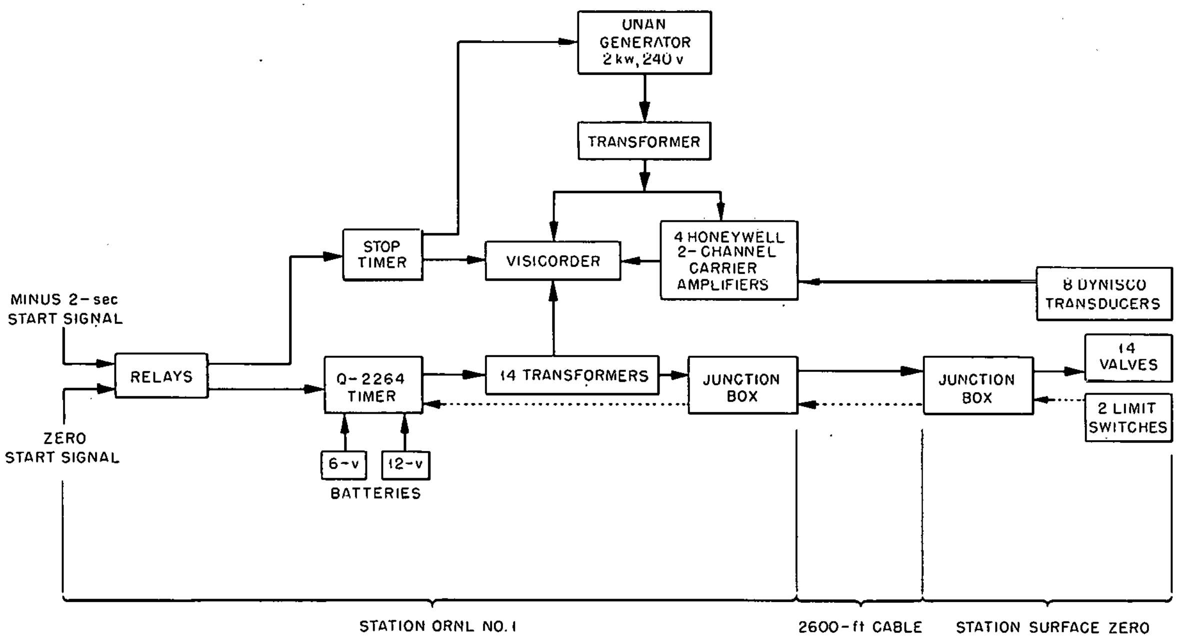

Fig. 7.6.1. Instrumentation for a Sequenced Sampler.

Pressures in the sampling tanks were sensed by Dynisco pressure transducers (0–30 psia), which were energized by the 5-kc voltage output of Minneapolis-Honeywell carrier amplifiers. Since the transducers were located about 2600 ft from the amplifiers, the 5-kc oscillators were synchronized to eliminate the effects of the beat frequencies produced by cross talk in the cables. A four-conductor, shielded microphone cable was used for each transducer; two wires carried the excitation voltage, and two carried the measurement signal. Tests of the cable at ORNL proved that it worked very well in such long runs and that coaxial cable was unnecessary.

Recording was performed on a 24-channel Minneapolis-Honeywell Visicorder at a chart speed of 80 in./sec with timing lines every 10 msec. The 8-in. chart width and high chart speed provided for recording 8 pressures and 15 firing and timing pulses with adequate resolution. Power was supplied to all 115-v ac instruments by a 2-kw gasoline-engine-driven portable generator, because local power at the site was shut down 1 sec after zero time, and this equipment had to operate for at least 10 sec. The all-solid-state timing device was powered by storage batteries.

As originally designed, the instruments were to be shock-mounted and located within a few hundred feet of surface zero (the ground surface area directly above the underground explosion), but later revisions by Lawrence Radiation Laboratory in the estimated acceleration and upheaval at surface zero required the location of the instruments $\frac{1}{2}$ mile from surface zero. This resulted in last-minute problems in obtaining the cable, and in some cases required the use of available materials instead of what was most desired.

The recording obtained during the explosion showed that all instrumentation functioned as designed. However, no actual samples were obtained due to a rupture of the sampling pipe in the area of the explosion. The valuable experience gained in this experiment will be applied in the test now scheduled for the spring of 1963.

7.7 STABLE MILLIVOLT REFERENCE SUPPLY

C. D. Martin, Jr.

In response to requests by ORNL experimenters, a millivolt reference voltage supply was designed to be used for "bucking out" or suppressing thermocouple emf's in order that they may be read on a low-range (0–1 mv) recorder.[1] The unit consisted of a commercially available zener diode regulated power supply and a simple voltage-divider network. The output of the original design (Q-2156-1) was continuously adjustable using a multiturn Helipot. Dial-setting accuracy was inadequate due to the number of convolutions and the nonlinearity of the wire-wound resistance element of the Helipot.

Increasing demand for these instruments prompted a search for a voltage-divider unit that would provide greater dial-setting accuracy. A suitable unit was found to be the Electro Scientific Industries' Dekapot. The Dekapot is a precision voltage-divider network using the Kelvin-Varley circuit. The unit consists of two 10-step resistance decades, plus a one-turn vernier, the smallest divisions

[1]C. D. Martin, Jr., *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, pp 98–99.

of which are 0.01% of full scale. The resistance wire used has an extremely low temperature coefficient and a negligible thermal emf to copper. Linearity of the unit is ±0.01%, and resolution is 0.003%. In combination with the other components in the reference supply, it improves the overall accuracy of the instrument to 0.01% (a factor of 10 better than most commercially available units) and drift to no more than 0.002%/°F.

The unit has been repackaged with the Dekapot on a $3\frac{1}{2}$- by 19-in. rack panel, as shown in Fig. 7.7.1, and is available in any one of three ranges (0–10, 0–50, and 0–100 mv).

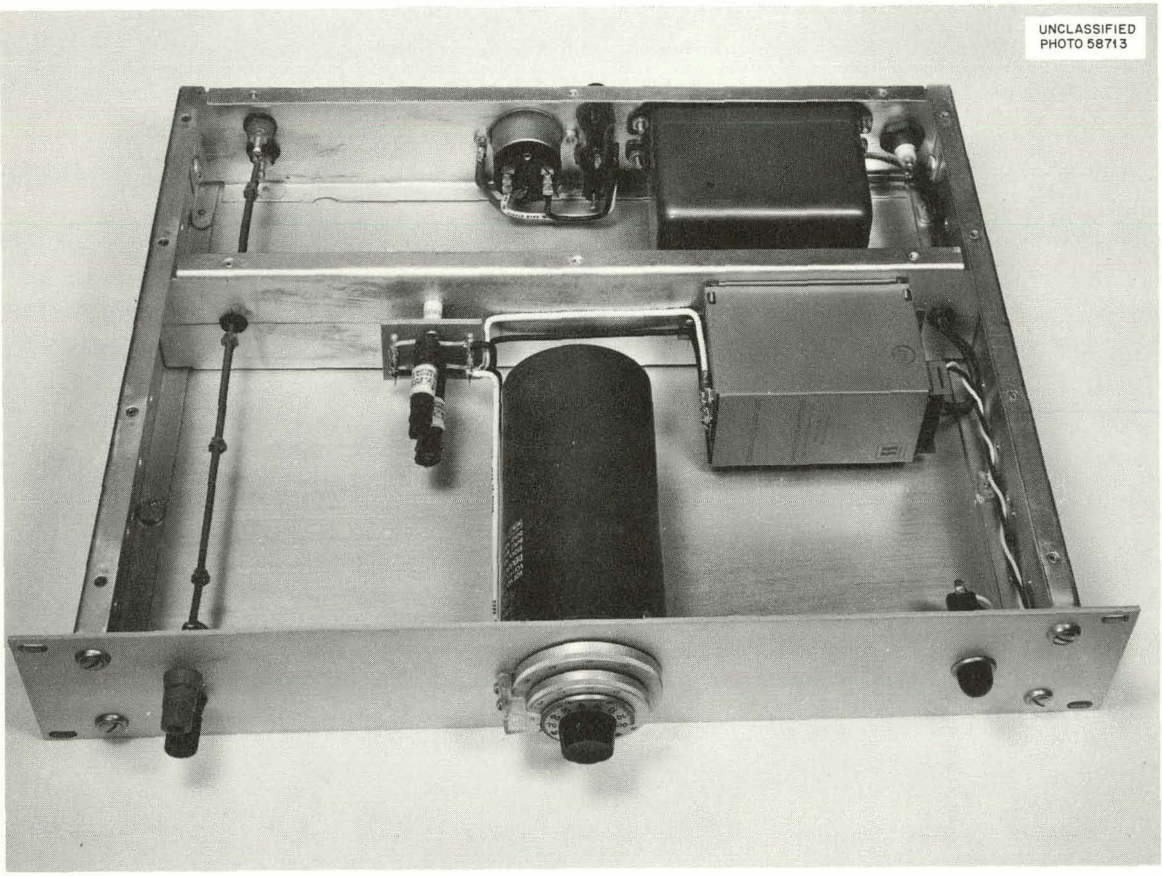

Fig. 7.7.1. Stable Millivolt Reference Supply.

7.8 SINGLE-POINT MOLTEN-SALT-LEVEL INDICATORS

J. W. Krewson R. L. Moore

A conductivity-type level probe is being developed for use in single-point indication of the molten-salt level in the MSRE drain and storage tanks. A device of this type is required in the MSRE for use in calibration of the drain-tank weigh systems.[1] Other devices previously used for this measurement, such as spark-plug probes and J-tube conductance elements, are unsuitable for operation in the MSRE owing to the relatively low conductivity of the salt (1 ohm-cm), containment requirements, and the effects of vapor deposition of salt. (Vapor depositions result in short-circuiting of spark-plug-type probes.) The selection or design of a probe for this service is also limited by the requirement that materials containing oxygen, including the ceramic oxides, cannot be used in areas where they will be in contact with the molten salt or in the vapor space above the salt.

The probe under development (Fig. 7.8.1) consists of an INOR-8 metal tube which is sealed by welding at the end and at the penetration of the vessel wall so as to present only metal surfaces to the salt or vapor. Current leads are attached to the top of the probe and to an excitation plate located between the vessel wall and the probe tip. Potential (signal) leads are attached to the excitation plate and to the probe tip. When the excitation signal is applied, a voltage is produced between the excitation plate and the vessel wall. If the salt level is below the probe tip, there is no flow or current to the probe tip, and the signal voltage is zero. When the salt touches the probe tip, a current

[1] *Molten-Salt Reactor Program Progr. Rept. for Period from August 1, 1960, to February 28, 1961*, ORNL-3122, p 67.

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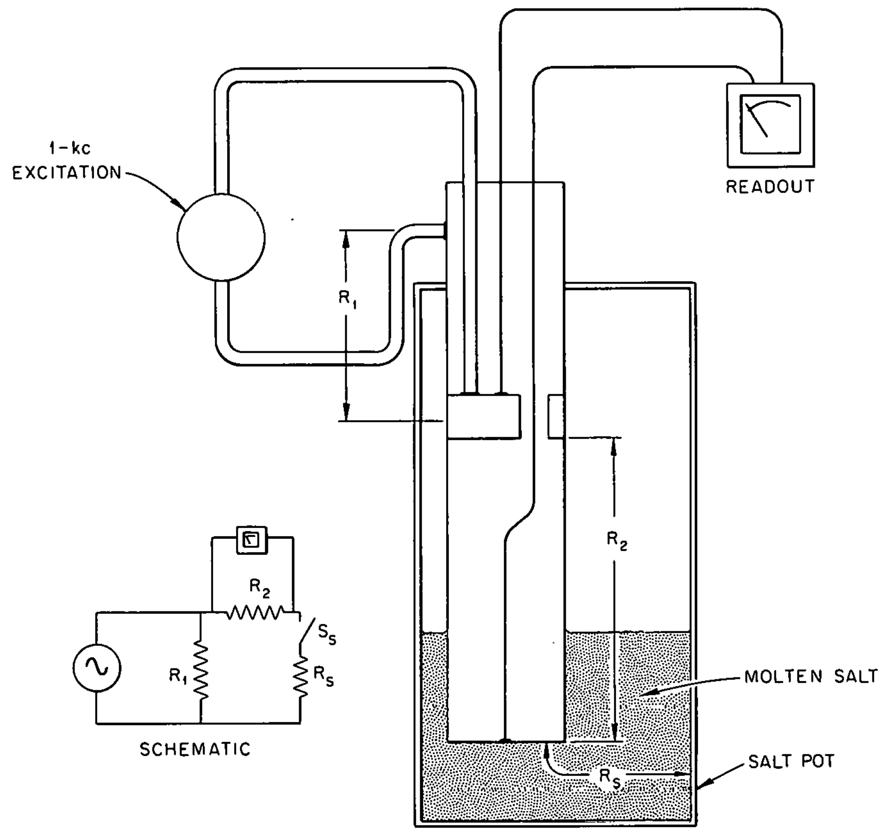

Fig. 7.8.1. Single-Point Level Indicator.

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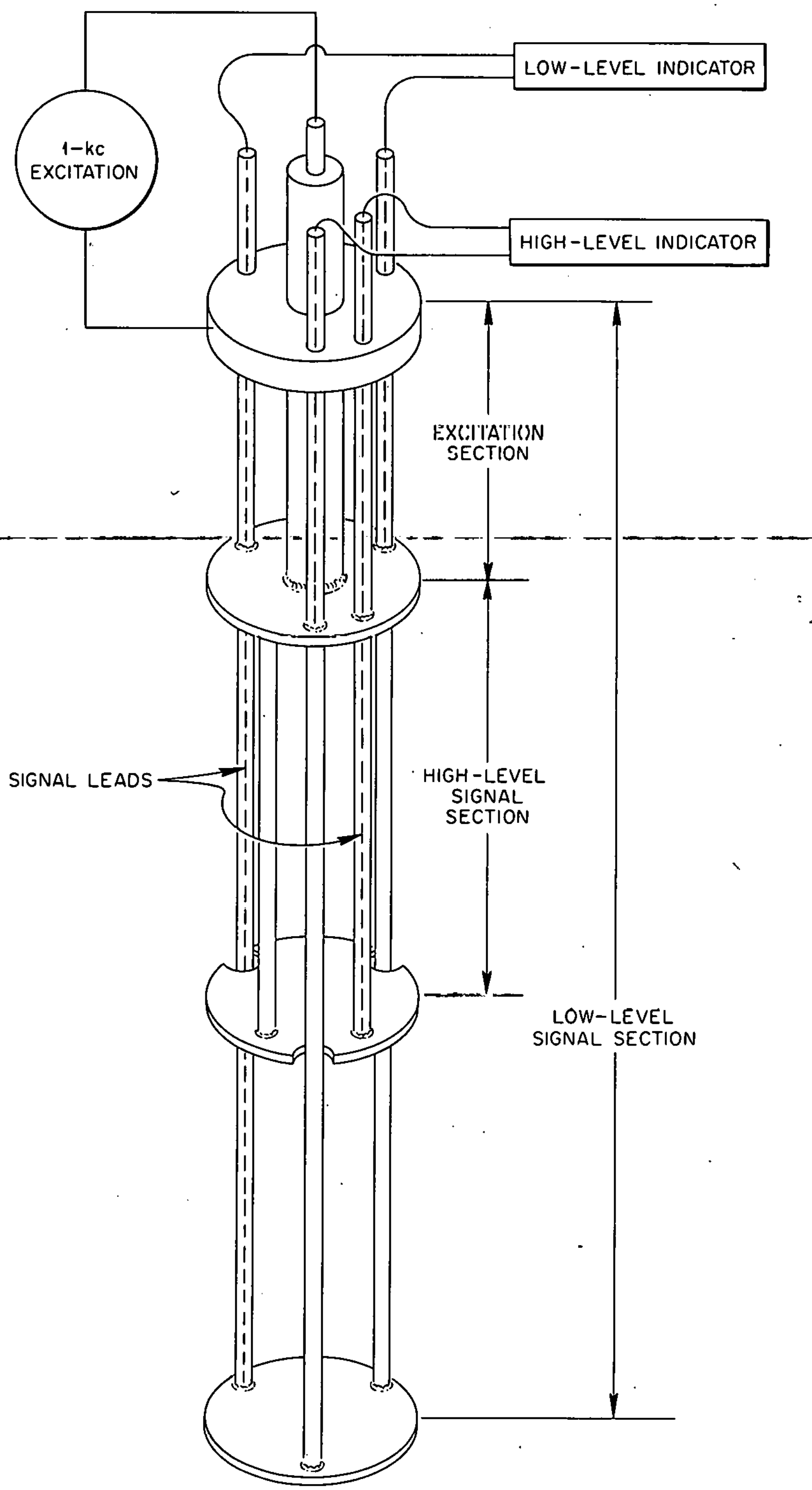

Fig. 7.8.2. Two-Point Level Indicator.

flows to the probe tip, and a signal voltage between the potential leads results. The signal is amplified and detected to produce an alarm. A probe of this type was operated for several hundred hours in molten salt without apparent damage.

In previous probe designs both the potential and excitation leads were connected at the probe tip, and the signal level, when the salt was below the probe tip, was a function of the excitation current. This produced a floating-zero effect and required the detection of a small change in a relatively large voltage. In the present design the floating-zero effect is eliminated and the signal is a small voltage deviation from zero. The magnitude of the signal is a function of the excitation current and the resistivity of the molten salt. The selection of the excitation frequency was based on the results of tests[2] which indicated that polarization effects decreased and signal amplitude increased as the excitation frequency increased. A 1000-cps excitation frequency was selected as a compromise between probe performance and losses in the signal cables. The use of this higher excitation frequency has the added advantage that stray 60-cycle pickup voltages can be rejected with appropriate filter circuitry.

A prototype model of a two-level conductance probe, which is based on the concept previously described and which is compatible with the physical geometry of the MSRE storage tanks, has been constructed and is being tested. This assembly (Fig. 7.8.2) is all welded, and INOR-8 is the only material in contact with the salt. All leads are brought out through $\frac{1}{4}$-in. INOR-8 tubes and are insulated from contact with the probe assembly except at the point of assembly.

[2] *Molten-Salt Reactor Program Progr. Rept. for Period from March 1 to August 31, 1961*, ORNL-3215, p 75.

7.9 THERMOCOUPLE SCANNER

G. H. Burger R. L. Moore E. Madden

A thermocouple scanning system was developed to monitor and display the signals produced by approximately 420 thermocouples[1] in the Molten-Salt Reactor Experiment. Thermocouple signals will be monitored and displayed to help prevent excessive thermal stresses of the associated pipes and components during reactor startup and shutdown. Radiator thermocouples will be monitored to detect a decrease in temperature of any of the 120 radiator tubes.

The system (Fig. 7.9.1) was constructed and is being tested under operating conditions on a molten-salt test loop. Operation of the system has been satisfactory. Testing will be continued to establish the long-term reliability of the system.

A difference signal is produced by bucking a reference thermocouple signal against each of the scanned thermocouple signals. The reference thermocouple is attached to a pipe or component having

[1] R. L. Moore *et al., Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, p 86.

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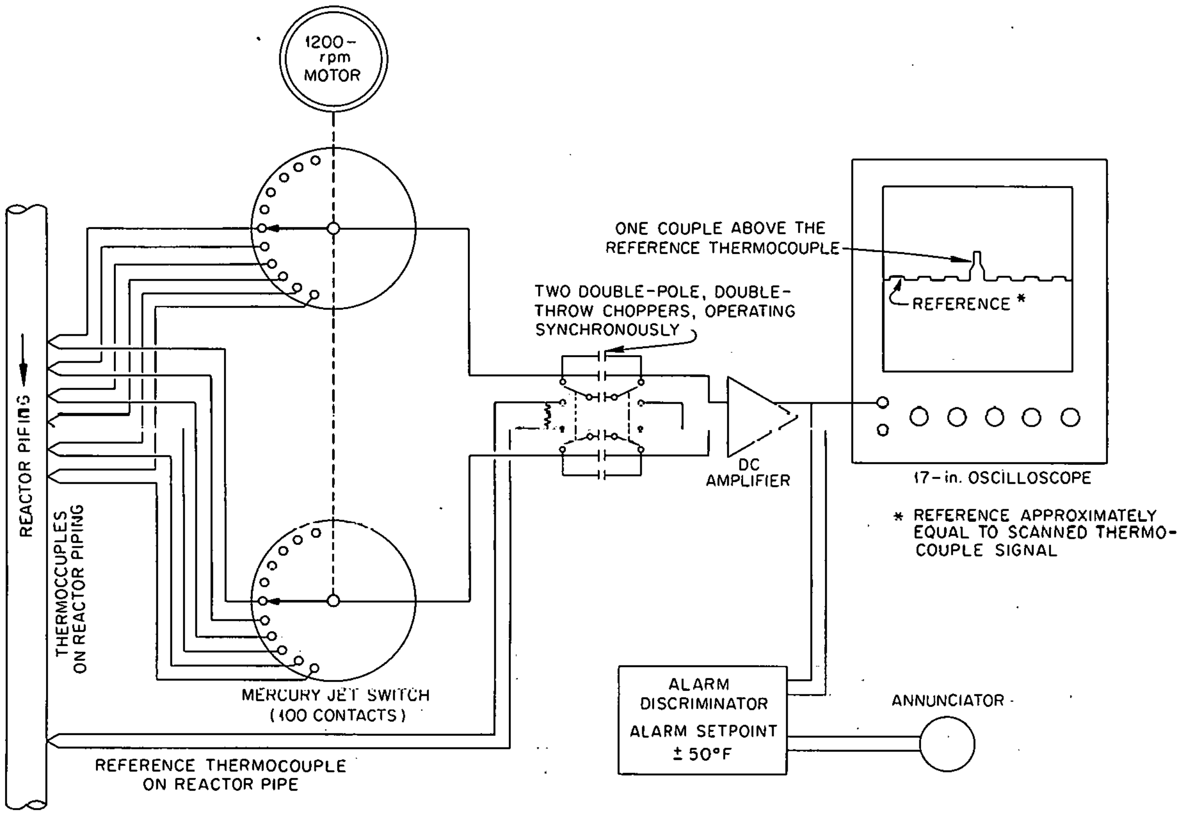

Fig. 7.9.1. Thermocouple Scanning System.

a slow thermal response. If no temperature difference exists between the reference signal and the output of the switch, a straight line is seen on the display oscilloscope. If, however, a temperature difference exists between all or any one of the scanned thermocouples and the reference thermocouple, pulses or a pulse of a magnitude proportional to this difference is seen on the oscilloscope. An alarm detector unit produces an alarm signal when this temperature difference exceeds a preset value. When the alarm sounds, the operator observes the scope and adjusts the appropriate heater to reduce the thermal gradient. The absolute temperature of the displayed signals is determined by precision indication of the signal produced by a second thermocouple located adjacent to the reference thermocouple.

A 100-point mercury jet switch is used as the commutator. The switch, driven by a 1200-rpm synchronous motor, gives a thermocouple scanning rate of 2000 points/sec. One hundred thermocouples from a portion of the reactor system are attached to the switch. The commutated output signals from the switch are fed to the signal bucking network. Here the integrated output of the switch is bucked against the reference thermocouple signal. In order to eliminate ground loops, caused by directly comparing signals from two grounded thermocouples, a capacitor switching system is used. Two double-pole double-throw choppers operating synchronously are used to sample the reference signal produced by each lead of the thermocouple. This is accomplished by storing the charge from each line in a capacitor, after which the chopper is switched to place this charge across an integrating capacitor in each lead from the commutator.

The difference signal thus produced is fed to a differential dc amplifier. The output of the amplifier is fed to an alarm discriminator for detecting signals which exceed a preset value. The discriminator employs an integrating circuit to eliminate false alarms caused by fast noise pulses. The alarm set point can be adjusted from ±50 to ±300°F by varying the amplifier gain and adjusting a potentiometer in the discriminator.

The output from the amplifier is fed also to a 17-in. oscilloscope for display. A grid overlay is used so that each pulse can be identified with a given thermocouple. The sync pulse for the scope is derived from a variable reluctance pickup mounted on the driving shaft of the switch.

7.10 MEASUREMENT OF MOLTEN-SALT LEVEL IN A PUMP BOWL

J. W. Krewson R. L. Moore

Development of a ball-float-type level indicator for measurement of molten-salt levels in the MSRE pump bowls was continued.[1] Two transmitters, each consisting of a graphite float, a core of Armco iron in a sheath of INOR-8, and a differential transformer, were fabricated and tested for six months of continuous operation at reactor temperatures (850 to 1200°F). One of these transmitters had the differential transformer mounted above the float chamber, while the other had the transformer mounted below the chamber. Design of a third transmitter was begun, in which the float will be a metal ball and the transformer will be mounted above the float chamber. This transmitter will be tested on an operating molten-salt engineering test facility under dynamic conditions which approximate those in the reactor system.

Future plans are to continue evaluation of the three transmitters and to develop a differential transformer with a cobalt core and Mica-Ramic sleeves for possible use at higher temperatures (1400 to 1800°F) in future reactor systems.

During a three-month test period, neither of the two transmitters shifted from zero or changed in sensitivity (Fig. 7.10.1). Temperature effects on the transmitted signal were less than 2% over a temperature range of 850 to 1400°F.

In either location of the differential transformer, above or below the float chamber, there are both advantages and disadvantages. When the transformer is installed above the float chamber, it is outside the pump-bowl furnace,[2] and maintenance or its replacement would be possible. When installed below the float chamber, the transformer must be within the pump-bowl furnace, and maintenance or replacement would be difficult, especially under reactor operating conditions.

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[1] J. W. Krewson and R. L. Moore, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961,* ORNL-3191, p 61.

[2] *Molten-Salt Reactor Program Semiann. Progr. Rept. for Period Ending February 28, 1962,* ORNL-3282, pp 61–66.

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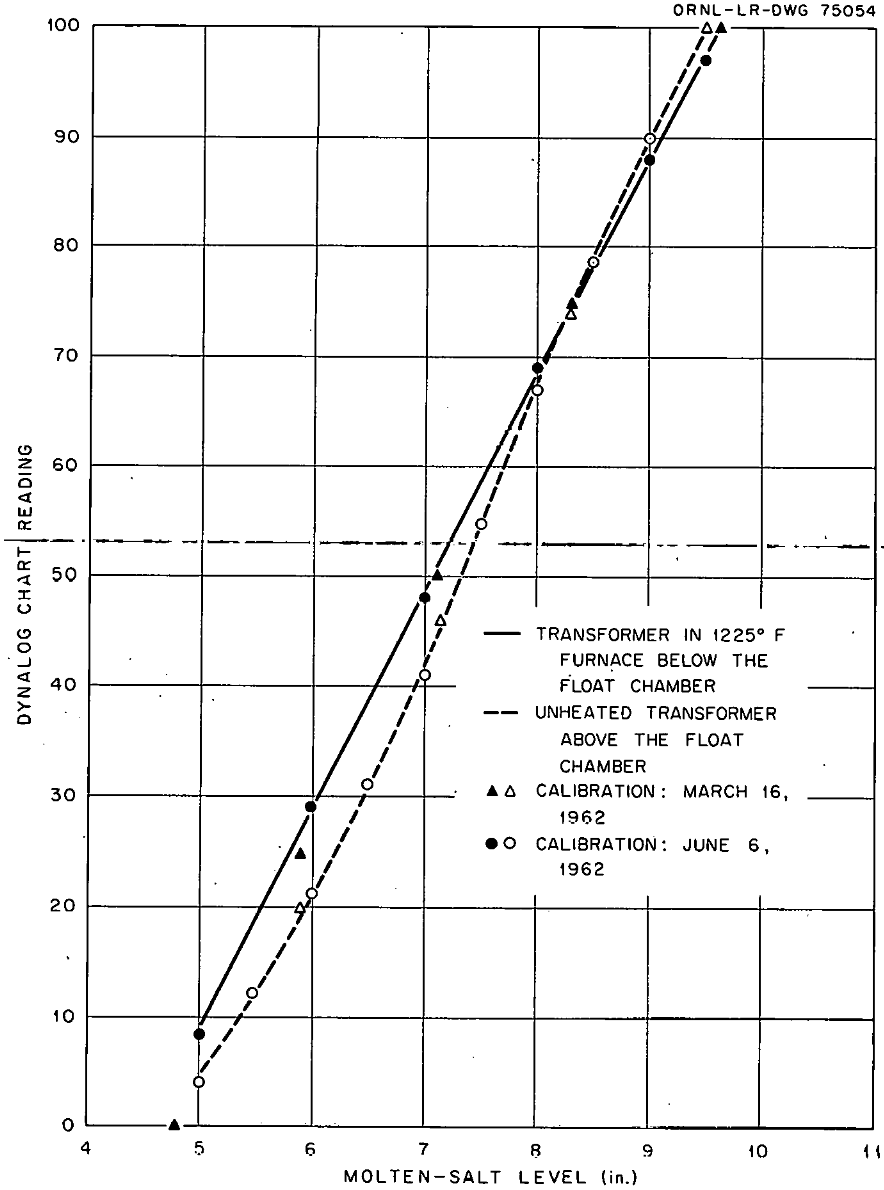

Fig. 7.10.1. Calibration Tests of Molten-Salt Level Transmitters.

The core tube would not contain molten salt and would be self-draining if installed above the float chamber; the present design of the MSRE will not permit drainage of molten salt from the core tube if installed below the float chamber. In the latter case the core tube could be ruptured if the salt solution were heated after being allowed to freeze.

Beta heating in the gas space above the float is not expected to be a problem with the MSRE, but if it does occur, as it may in future reactor installations, the transformer core assembly would be protected from damage from this effect if installed below the float chamber since the core would be cooled by molten salt. If the transformer were mounted above the chamber, there would not be this protection. Another disadvantage of mounting the transformer above the chamber is that solids from molten salt may build up on the walls of the core and core tube and lock the core or restrict its movement. (There has been no evidence of solids buildup, however, during the six-month test.)

The core is constructed of Armco iron, canned in an INOR-8 sheath to protect it from the corrosive molten salt, and is attached to the float. Although cobalt was first considered as material for the core because of its high Curie point (temperature at which the metal becomes nonmagnetic), Armco iron was selected as the material for use at 850–1400°F, since its magnetic properties would be satisfactory at these temperatures.[3] At higher temperatures (1400 to 1800°F) cobalt would be a better core material.

The differential transformer (Fig. 7.10.2) consists of three machined Lava "*A*" sleeves with the primary and secondary windings wound into machined grooves on the inner sleeves. The outer sleeve acts as a retainer and as protection for the windings. This assembly is canned by placing it in an Inconel can with well-fired Fiberfrax paper as packing for shock protection. Pure nickel-wire transformer leads are beaded and brought out of the transformer enclosure through tubing. Nickel was chosen after tests were made with Inconel, Hastelloy C, and nickel. Hastelloy C became very brittle when heated to 1500°F. Both Inconel and nickel windings stood up well under all physical tests, but at 900 to 1300°F the temperature-induced shifts on the zero and span of the transmitted signal were greater for the transformer wound with Inconel wire than for the transformer wound with nickel wire (Fig. 7.10.3). Below 700°F the Inconel-wound transformer was more stable with temperature, but since the MSRE salt freezes at 850°F, the instrument will not be operable in this temperature range.

Before the transformer with Lava sleeves was designed, several attempts were made to fabricate transformers with ceramic-insulated wire. In these transformers both windings were wound on a single sleeve with Fiberfrax paper as insulation between the windings and the metal sleeve. Every transformer of this design failed. In each case at 900°F or lower, the transformer would begin to operate intermittently and with a high noise level. No attempt was made to determine the exact cause of these failures; however, visual inspection of the windings revealed physical change to the ceramic insulation.

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[3] D. E. Meehan, *Electron. Design* **8**(10), 56 (1960).

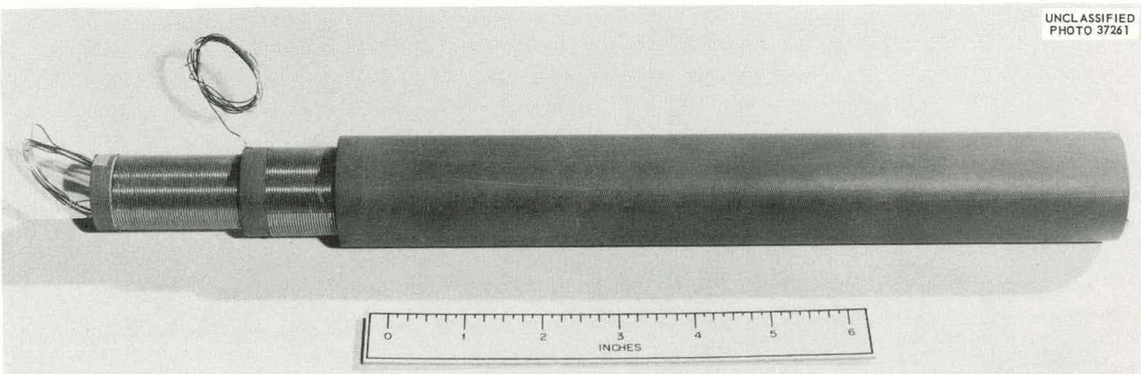

Fig. 7.10.2. Lava-Insulated Differential Transformer.

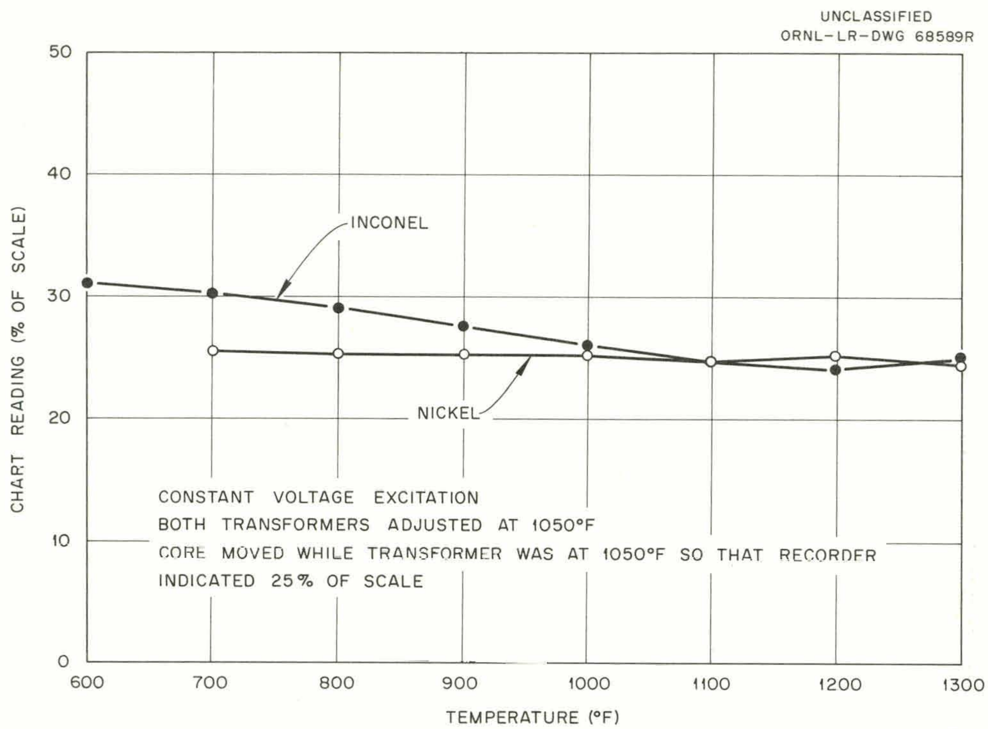

Fig. 7.10.3. Temperature Characteristics of High-Temperature Differential Transformers Wound with Nickel and Inconel Wires.

8. Reactor Instrumentation and Controls

8.1 REACTOR CONTROLS DEVELOPMENT

S. H. Hanauer — A. G. Klein[1]
G. C. Guerrant — D. P. Roux
L. C. Oakes — J. T. DeLorenzo
J. L. Anderson — W. Nelson[2]

Development was continued on the new group of second-generation ORNL reactor control instruments[3] which will meet the requirements of high-performance research and power reactors and which exploit the characteristics of modern electronic techniques. The new systems are arranged in parallel, independent channels of instrumentation and require a coincidence of two or more channels to initiate both control and safety action, which will be described separately.

Safety System

The new reactor safety system (Fig. 8.1.1) has as its coincidence element a special magnet with three electrically independent windings and a magnetic shunt.[3] The safety element will be held if any two coils are energized and will be released if any two coils are de-energized. One advantage of this approach is the ability to apply a static test, preferably by locally perturbing the process variable as detected by the sensor, confirming that as a result one coil in each magnet is de-energized. Thus the test encompasses the entire channel, excepting only the ability of the rod to drop. The test apparatus and procedure must not impair the ability of all sensors and instruments to detect a genuine danger condition at any time.

A system was developed to test the water-temperature sensors, and thus the temperature control and safety channels, in the HFIR and other water-cooled reactors. The in-process testing is accomplished by raising the actual water temperature at the sensors, one at a time. The apparatus consists of a storage reservoir for hot water, a pump, and a special nozzle at each temperature sensor. The nozzles, which have $\frac{1}{16}$- by $\frac{1}{2}$-in. throats, are located $\frac{1}{8}$ in. from the sensor bulbs, on the downstream side of the bulbs to avoid the possibility of generating cavitation zones at the sensors.

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[1]Research participant from the Australian Atomic Energy Commission Research Establishment.

[2]On loan from RCA.

[3]S. H. Hanauer *et al., Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, pp 66–72.

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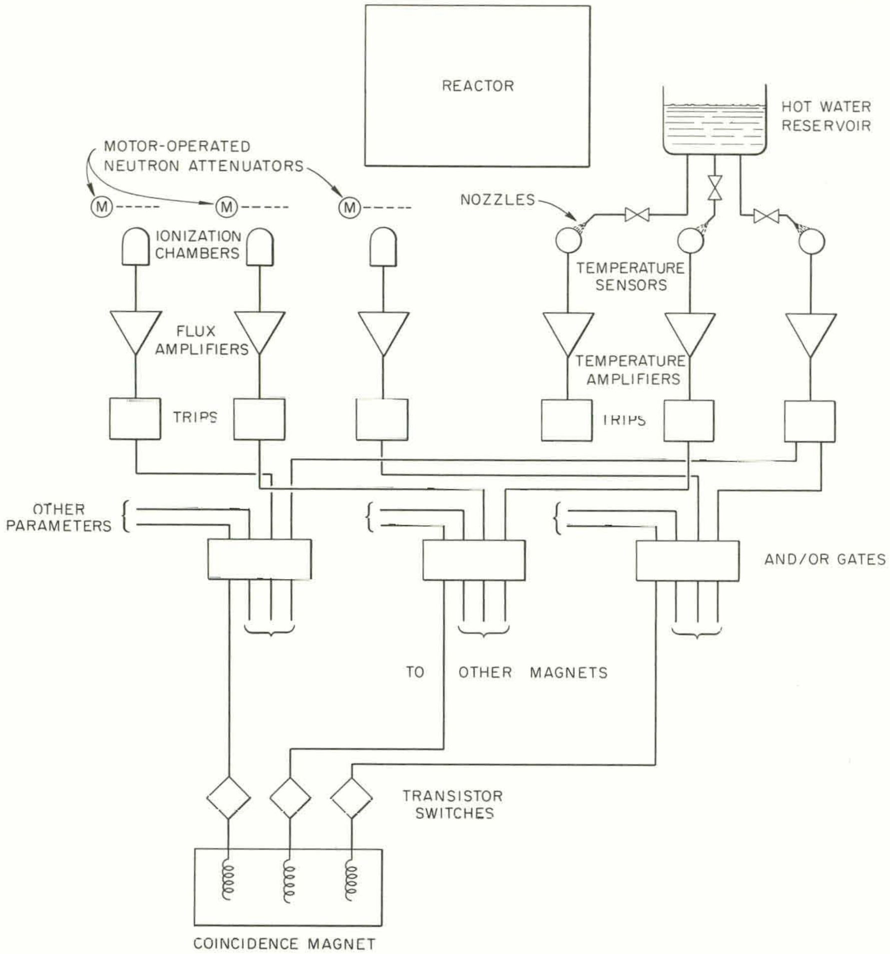

Fig. 8.1.1. Safety System with Coincidence Magnet and In-Process Testing.

A series of tests was performed in a test loop with a process-water velocity of 21.5 fps and a temperature of 120°F, as in the HFIR. The hot-water reservoir was at 180°F. The sensor was a commercial resistance thermometer with a published response time of 1.7 sec. Analysis of data with various hot-water injection velocities and orifice sizes indicated that the initial rate of rise of the sensor temperature is a function of the ratio of injection velocity to the process-water velocity; the best response will be obtained when this ratio is ~ 3. For the nozzle finally used, the injection velocity was 56 fps; the flow was 5.5 gpm at a nozzle Δp = 56 psi. Under these conditions, the asymptotic temperature rise of the sensor was 40°F. The indicated sensor temperature rise reached 63% of this maximum 2.4 sec after the hot-water injection was started; the sensor again read the process-water temperature of 120°F at 1.5 sec after the injection was stopped.

A figure of merit for such a system is the apparent reactor power increase seen by the sensor divided by the power input to the injection system; under the test conditions, the injector had a figure of merit of 1825.

Since the factors which influence the performance of the system are process-water velocity and nozzle Δp, the results of the tests at a system pressure of 27 psig can be extrapolated easily to the 600-psig operating pressure of the HFIR.

Analogous methods for in-process testing of instrumentation associated with process variables other than temperature, including neutron flux, are scheduled for development in the near future.

Development was continued on the new electronic circuits required for the safety system. A transistor amplifier much simpler than the one reported earlier[3] was devised for controlling the magnet current. Work was begun on a transistor operational amplifier suitable for use with low input currents, as provided by ionization chambers. Development was started on a stable reliable trip circuit.

Analog computer studies using a very preliminary model of the HFIR were helpful in analyzing the performance of the reset flux amplifier;[3] predictions were confirmed so far as possible with the crude reactor model used. In this amplifier the gain is varied slowly by a small instrument servo to recalibrate automatically the neutron-flux instrumentation to agree with an absolute measure of reactor power, such as heat power. This is done concurrently in three independent channels, using three instrument servos and three heat-power instruments.

Regulating System

Development and testing were continued on reactor controllers based on the multiple servo concept,[4,5] wherein a multiplicity of independent servo systems (at least three) have their output velocities added algebraically to actuate a single control element. Failure of any one servo channel will not shut down the reactor, since the others will be able to overpower its saturated output in either direction. Simple tests and observations easily reveal which channel is in trouble.

The concept of the multiple servo has been tested in a variety of configurations, using the analog computer to simulate some typical reactor systems. Both *on-off* and *continuous* velocity servos have been assembled using small motors and gears and transistor amplifiers. The calculations of Weaver[5] were confirmed. When one servo fails and stops, no perturbation of the regulated system is observed. When one servo fails by running away, however, some error in the controlled variable may be required to produce one-half the maximum velocity in the other two servos. For *on-off* servos, the error is never greater than the servo dead band and is therefore negligible. For *continuous* velocity servos, the error in the controlled variable depends on the servo gain; higher gain gives less error. On the other hand, the allowable gain is limited by stability considerations. For the examples studied, the maximum error in reactor power which could occur upon servo failure was <5%, which is acceptable for most plants.

The effect of a negative temperature coefficient of reactivity is to increase the allowable servo gain and, thus, to decrease the error in reactor power upon servo failure.

A model multiple servo system for the HFIR was built primarily to test mechanical components in this service, using $\frac{1}{4}$-HP dc motors and a triple-differential velocity adder. The motors were driven in the

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[4] E. R. Mann, private communication.

[5] C. H. Weaver, *Multiple Controllers for a Single Process*, ORNL CF-61-1-82 (Jan. 25, 1961).

velodyne mode by transistor amplifiers. The performance of the servo was adequate at the design load; however, further development of the HFIR rod drives has required that the servos be redesigned to suit.

Startup and Wide-Range Instrumentation

A great deal of effort was expended in perfecting the design of the miniaturized flexible fission-chamber and preamplifier assembly.[6,7] This is part of an apparatus comprising a fission chamber, a preamplifier, and a drive mechanism. The movable assembly, which has a maximum OD of 0.760 in., was made flexible so that a guide tube, curved as required, can be installed in the reactor shielding leading to the core. The assembly (Fig. 8.1.2) is waterproof and is designed to operate continuously in an ambient temperature of 100°C. Several developmental assemblies and one prototype have been tested in a new guide tube installed in the ORR. The integral counting rate (Fig. 8.1.3) shows a good plateau, and tests in a gamma-ray field of 1.8×10^6 r/hr demonstrated the negligible effect of gamma pileup.

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[6]D. P. Roux *et al.*, *Trans. Am. Nucl. Soc.* 5(1), 185 (1962).

[7]E. Fairstein *et al.*, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, pp 72–77.

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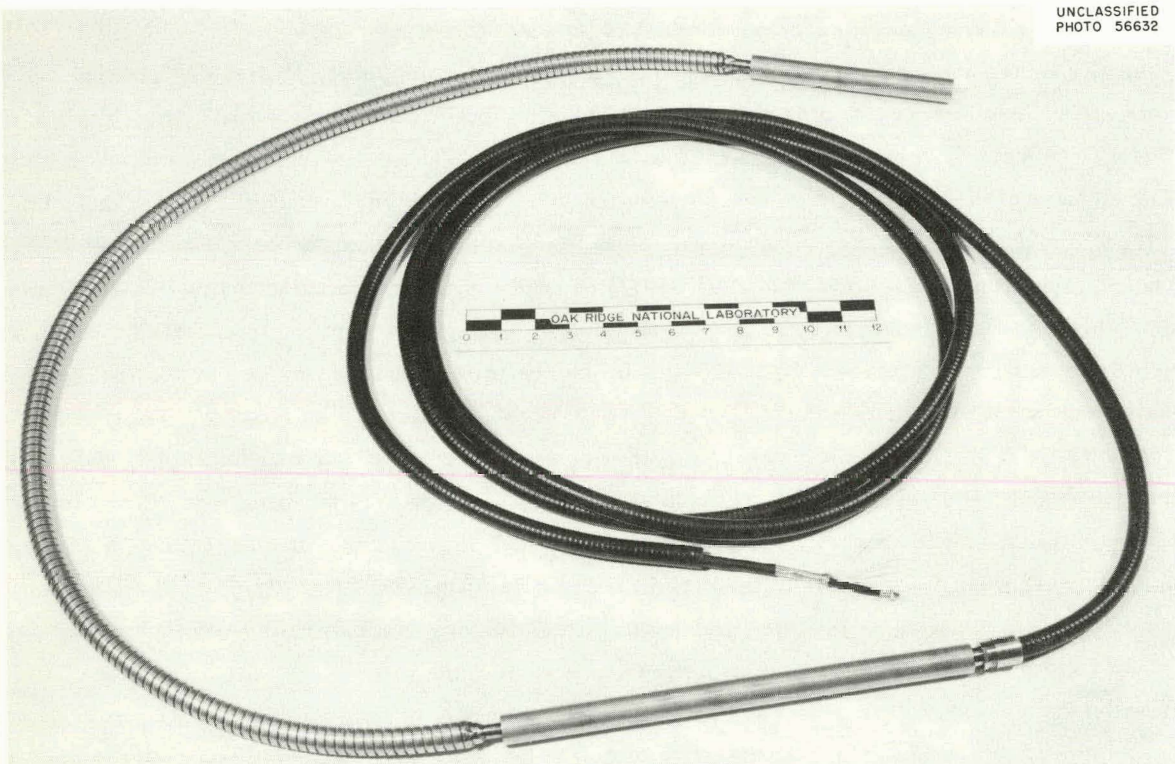

Fig. 8.1.2. Flexible, Radiation-Resistant Assembly of Fission Chamber, Preamplifier, and Interconnecting Cables.

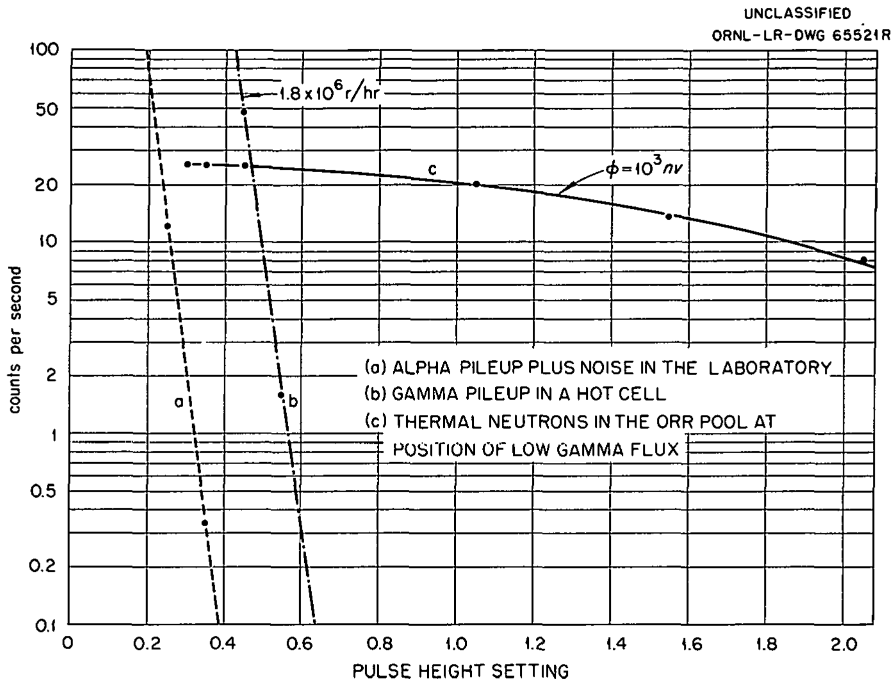

Fig. 8.1.3. Integral Counting-Rate Curves of the New Startup Channel.

Several minor circuit and layout changes have been made to decrease the susceptibility of the system to electrical noise pickup. This problem is potentially very serious in pulse-counting systems; in many reactor installations the counting-rate instrumentation is much too susceptible to spurious counting due to operation of welders, crane motors, or even rod-drive motors. It is important that the counters should count only neutrons to make evident the presence of a source and that counts of extraneous origin can make a reactor startup very disorderly.

In a study of pickup noise in the laboratory, some aspects of observations made in the field were duplicated. The study of relay systems as noise sources showed that shock excitation of the interconnecting power wiring is responsible for a substantial fraction of the pickup noise. Tests using different types of signal cables revealed, as expected, widely different susceptibilities to induced electrical noise. An experimental study of shielding and grounding demonstrated the value of complete double shielding. The grounding problem is complicated by capacitive coupling between grounds, leading to high-frequency ground loops; this work is continuing.

A complete transistor counting-rate instrument, comprising pulse amplifiers, a pulse-height discriminator, a logarithmic counting-rate meter, a fission-chamber position servo, and reactor power and period computers, has been developed to the breadboard stage and is being tested. Together with the fission-chamber–preamplifier-drive assembly described previously,[6] this instrument will complete the new wide-range counting-rate channel (servo fission chamber)[8] for the second generation of ORNL reactor control instruments.

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[8]R. E. Wintenberg and J. L. Anderson, *Trans. Am. Nucl. Soc.* 3(2), 454 (1960).

Ionization Chambers

Development and testing were continued on the new series of ionization chambers.[3] Each chamber enclosure can contain up to three independent active sections, with differing characteristics. The electrode configuration of all sections is parallel, circular plate, using aluminum or titanium coated with B^{10} or U^{235} for neutron-sensitive sections and Ni or stainless steel for gamma-sensitive sections.

Development of a good method for coating boron on plates continues; present methods, while adequate, are expensive (evaporation coating) or hard to control (spraying of dispersion), and many of the coatings have marginal electrical conductivity.

A fission chamber using the same configuration has been assembled successfully.

Preliminary tests in the BSR of a gamma-compensated structure were very encouraging: the effective gamma-ray sensitivity was reduced by a factor of 80 by the compensation, which was found to be independent of chamber orientation in a region of high field gradient.

Three developmental three-section chambers are now in service in the HPRR; their performance appears satisfactory.

A developmental gamma-sensitive chamber has been tested (Sec 8.2). A developmental two-section chamber was fabricated for the ORR and is being tested as a dual neutron- and gamma-sensitive safety chamber (Sec 8.2). The performance of both sections of the chamber has been satisfactory, with good sensitivity and saturation characteristics. Further development will be required to avoid a susceptibility to voltage breakdown which appeared in the developmental chamber.

8.2 USE OF GAMMA-SENSITIVE IONIZATION CHAMBERS FOR REACTOR CONTROL AND SAFETY

D. P. Roux   S. H. Hanauer
R. T. Santoro   C. B. Stokes

Gamma ionization chambers seem to be very promising for reactor control and safety, because the gamma flux is much less sensitive than the neutron flux to shielding modifications and experiment perturbations. In order to detect predominately the prompt gamma rays from fission and those capture gamma rays which are proportional to the reactor fission rate, a lead shield can be installed between the core and the chamber. The delayed fission-product gamma rays, with energy lower than the prompt gammas, are attenuated much more by such a shield, and the current produced by the ionization chamber is proportional to the instantaneous reactor power. Furthermore, it appears advantageous to combine in the same chamber, that is, at the same location, two electrically independent sensitive sections, one neutron sensitive and one gamma sensitive, which will not react in the same way to shielding perturbations and both of which can be used for reactor control and safety.

Two different kinds of chambers, which have a parallel, circular-plate configuration with plates 1.808 in. in diameter and overall sensitive length of about 4 in., were developed. The first is a single-section high-sensitivity gamma chamber, and the second is a two-section chamber with independent neutron- and gamma-sensitive sections sharing the same gas. The general configuration of these chambers has been described previously.[1]

Single-Section Gamma-Sensitive Chamber

The lead shielding between the core and the chamber required for correct operation makes the gamma flux low at the chamber location. Since it is desirable to obtain a large ionization current (e.g., in order to have a fast time response in the safety system), the chamber must be highly sensitive to gamma rays. The chamber is made with 92 nickel disks of 0.010 in. thickness and with an electrode spacing of 0.035 in. in order to have good saturation characteristics while at the same time incorporating the maximum of gamma-ray absorbing material. Nickel was chosen for its high density, its low activation by neutrons, and its mechanical rigidity. The chamber is filled with xenon at 2330 mm Hg (abs). Because of its high *Z*, xenon has the highest ionization density due to the secondary electrons emitted from the electrodes when they interact with a gamma flux. The chamber has a sensitivity of 1.7×10^{-10} amp-hr/r. The saturation curve is shown in Fig. 8.2.1.

[1]S. H. Hanauer *et al., Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, p 70.

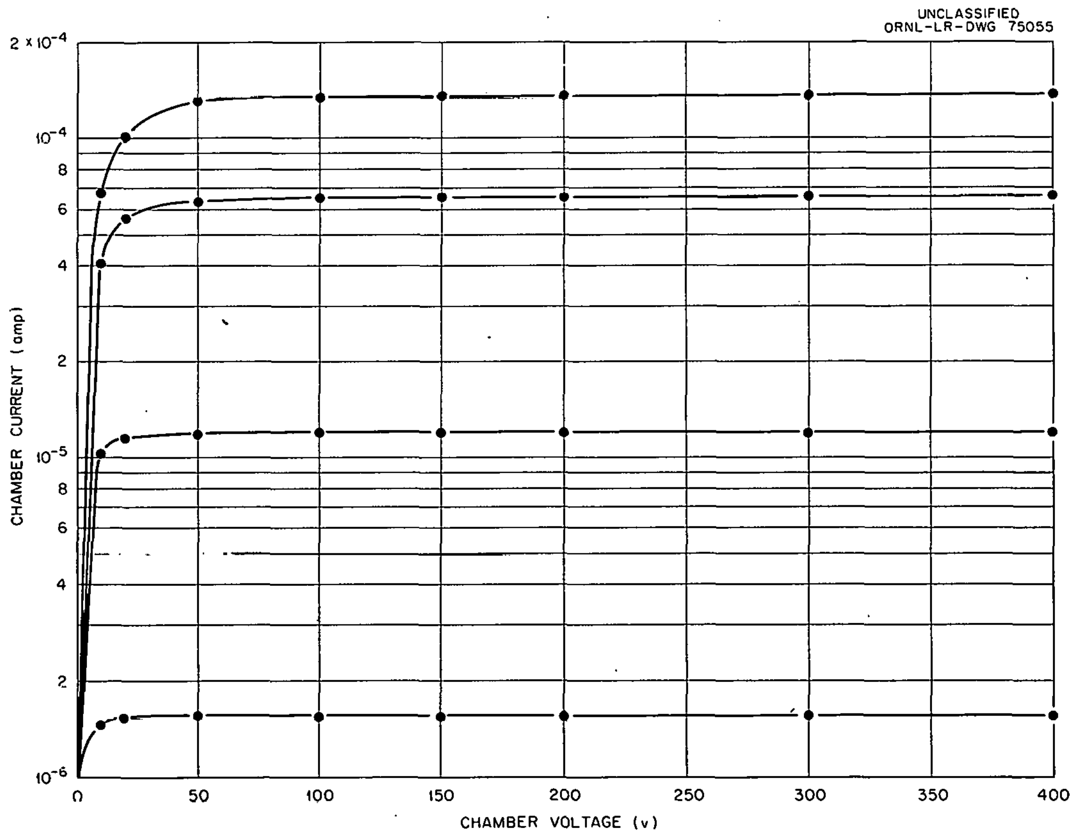

Fig. 8.2.1. Saturation Curve of the Gamma Ionization Chamber. The chamber is filled with xenon at 2330 mm Hg (abs), and the sensitivity is 1.7×10^{-10} amp-hr/r.

Neutron- and Gamma-Sensitive Chamber

When independent neutron- and gamma-sensitive sections have to share the same gas, a compromise must be made between high gamma sensitivity of the gamma section and low gamma sensitivity of the neutron section; the saturation of both sections must be satisfactory. The filling gas, its pressure, and the number of electrodes for each section, as well as the B^{10} deposit of the neutron-sensitive section, must be chosen as required. A two-section chamber was developed and built for the ORR. Figure 8.2.2 gives the neutron sensitivity of the neutron section as a function of the gamma sensitivity of the gamma section for different gases and gas pressure. The neutron section is made with seven titanium plates, each 0.005 in. thick and coated with 0.2 mg/cm^2 of B^{10}, and the electrode spacing is 0.037 in. The gamma section has 83 nickel electrodes of 0.009 in. thickness; the electrode spacing is 0.035 in. For the ORR application the chamber is filled with xenon at 800 mm Hg (abs). The gamma sensitivity of the neutron section is 6% of the gamma sensitivity of the gamma section.

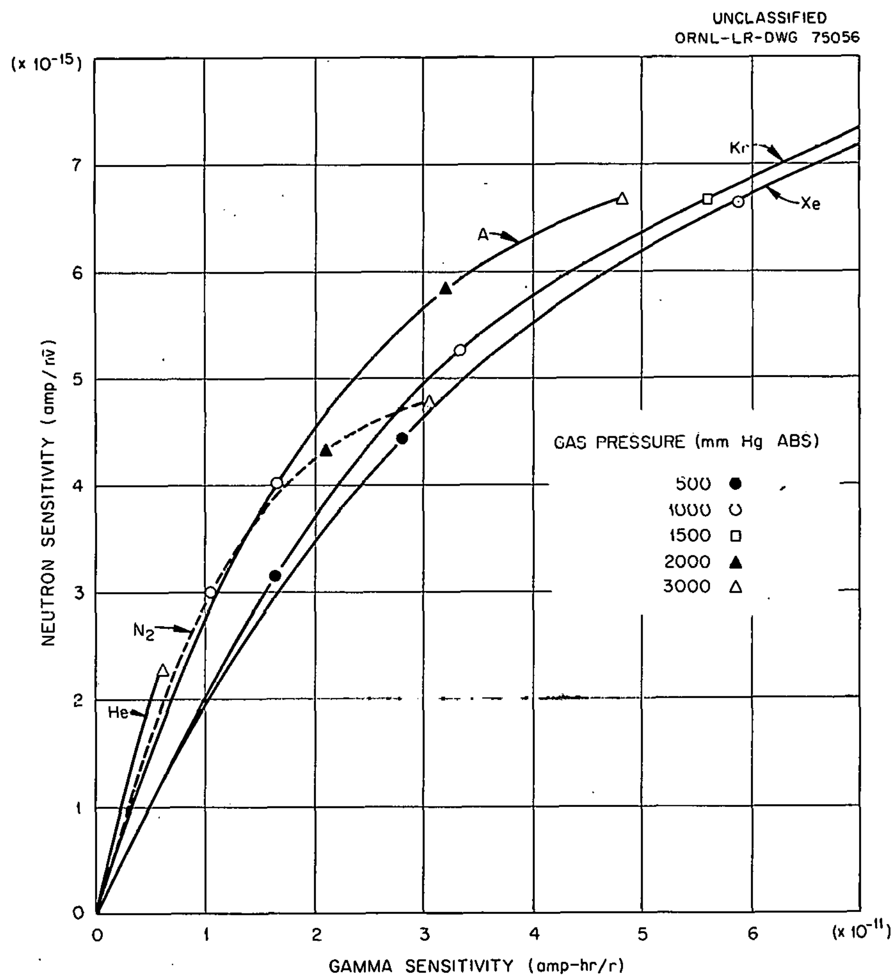

Fig. 8.2.2. Neutron and Gamma Ionization Chamber. The curves show the neutron sensitivity of the neutron-sensitive section as a function of the gamma sensitivity of the gamma-sensitive section for different gases and gas pressures.

8.3 ACTIVITIES OF THE OPERATING REACTORS SECTION

A. E. G. Bates

Organization and Functions

An Operating Reactors Section[1] was established which, as its main task, services and maintains instrumentation and control systems of reactors and installed experiments operated by the Operations Division. The Section was organized to bring together the designers of reactor instrumentation and controls and the field personnel who maintain it. All changes and improvements in systems or components which are suggested as necessary or desirable by the Operations Division or field personnel are studied and approved by a design engineer in this group before a detailed design is prepared; this is done so that all safety implications or possible side effects are thoroughly investigated before the change is made. Also, the design engineer can ensure that field personnel are obtaining the full capabilities which have been engineered into the equipment.

The Section is composed of instrument technicians, draftsmen, design engineers, and other technical personnel. Various other specialists are also available on call. Besides maintenance of reactors, the staff engineers are assigned related problems. For example, the Section is designing and installing new controls and instrumentation for the LITR, preparing to install and maintain instruments and controls for the MSRE, expanding, updating, and improving written procedures and drawings, and performing studies such as determining the reliability of off-gas cleaning and handling systems in the off-gas stack area (Building 3039).

Problems with Maintenance of Control Systems for Reactors and Experiments

The main problem of the Section, and one that is never solved, is making a large amount of complicated and interacting equipment operate continuously around the clock. Not only is a large amount of equipment being maintained, but it is also present in a wide variety of types and designs, some of which are further complicated by the nature of the environment in which they operate. Much of the instrumentation, such as that in the reactor nuclear channels, is peculiar to the business and, in fact, is almost peculiar to ORNL reactors. For example, the safety system is quite different from that which designers elsewhere say must be used where operating continuity is of prime importance. Typical response time for the ORR safety system is 10 msec or so compared to 200 msec or more for those found, for example, in all U.S. power reactors, including the EGCR. Only occasionally are industrial systems built which have responses as short as 50 msec. Furthermore, fast scrams can be initiated in the ORNL system by any one of three safety-level channels independently rather than on a two of three, or more, coincident arrangement. Fast scrams are also effected by the period channel, which is operated continuously rather than being turned off in the power range as is often felt necessary elsewhere.

A wholly different class of equipment is used for instrumenting and controlling processes such as the ORR pool and cooling systems and practically all experiments. Although most of the devices installed are

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[1]Reactor Controls Department of the Instrumentation and Controls Division.

standard manufactured items, many require special attention, since they perform protective functions and operate in deleterious environments.

The larger portion of the equipment now in service in the reactor buildings is part of various experiments. The GCR-1 loop, for example, has a complement comparable to that of the ORR itself, whereas the GCR-2 loop will have an even larger one. Both loops use a relatively new type of instrumentation system.

There are other and different types of systems, such as building containment and off-gas systems, to be maintained also. The very fact that there are several reactor and experimental systems, as well as others, to be serviced further complicates the problem, since the detailed approach to each is often unique.

In addition to having control and data-taking instrumentation, many experiments also require protective instrumentation, especially if they contain fissionable materials or operate at high temperatures or pressures. Left to their own devices, experimenters often tended to assume that the way to prevent the occurrence of incidents involving their installations was to scram the reactor every time one of the parameters of the experiment or auxiliary systems exceeded a boundary value. Early experiments did, in fact, have relatively large numbers of scram switches, and the number of reactor scrams became unacceptably high when many experiments had been installed. A study of the problem showed (1) that by properly designing and instrumenting the experiment and its control system, it could be made to correct its own troubles to a large extent; (2) where a reduction in reactor power was really needed for protection, it was seldom necessary to go beyond a setback. At present, experiments are arranged to give one or two of three signals to the reactor control room from each of a minimum number of carefully selected and critical parameters. In order of occurrence, in most cases of trouble, these signals are an annunciator alarm and a setback. If the reactor period does not go negative promptly following the initiation of the setback signal, the system automatically goes into reverse. In cases in which scrams are believed to be needed, these are effected directly without making an intervening setback request.

Duplicate sensor and readout channels are installed for each parameter. The setback and scram signals from all channels in a given experiment are independently summed by separate redundant switching systems, and then each is fed to the control room over its own double-track circuits. Assuming that quality components are used, this whole arrangement provides the experiment with a highly reliable protective system, since it employs the basic principles of duplication, independence, redundance, and depth.

Maintenance Results and Experiences

In four months of 1958 and all of 1959, there were four and eight failures, respectively, of reactor controls (Table 8.3.1). In 1960, three failures required 27 hr for correction. In that year, new instruments were being installed, and field personnel required more time to repair and adjust the instruments. In 1961 and the first eight months of 1962, there were no reactor shutdowns that could be attributed to failure of the control systems.

Controls for experiments failed more frequently. However, the decrease in the number of failures since 1960 indicates that improvement is being realized.

Table 8.3.1. Failures of Reactor and Experiment Controls

Year	No. of Failures	Downtime (hr) Total	Downtime (hr) Per Failure
	Reactor Controls		
1958[a]	4	116	29
1959	8	8.9	1.1
1960	3	26.8	8.9
1961	0	0.	0
1962[b]	1	0.45	0.45
	Experiment Controls		
1958[a]	0[c]	0	0
1959	3[c]	0.83	0.28
1960	21	4.3	0.2
1961	10	15.4	1.5
1962[b]	2	6.16	3.08

[a]Four months only.
[b]Eight months only.
[c]Experiments being installed.

Since maintenance of these systems seldom benefits from spectacular breakthroughs, improvement depends on training and experience of field personnel, refined techniques, better test facilities, and replacement of equipment with more reliable and less difficult to service, new equipment.

The Section observed that even though operating procedures, core loadings, installed experiments, and conditions at a reactor apparently remained about the same from year to year, the reactor's characteristics sometimes seemed to change. After the LITR complement of chambers had performed reasonably well for a number of years, a rash of failures occurred. Insulation inside the chamber noses melted, causing shorting. Subsequent measurements showed that the temperatures of the ends of different chambers ranged from 95 to 115°C during an operating cycle. Although a satisfactory explanation has not been found, it is believed that as the maintenance personnel found ways of increasing the on-the-line time of the reactors, the average temperature of the shielding rose in proportion, finally becoming excessive. The old chambers were replaced by others capable of operating in 300°C ambients. Study is continuing.

Another manifestation of change in the LITR was the unusual behavior of the counting channel. Although it could be made to operate satisfactorily during the lower decades of startup, the counting channel was very touchy above that and could not be made to track the other channels of instrumentation. According to this channel the power rose, in the upper decades, two or more times more rapidly than all other measurements seemed to agree was actually the case. This has not been explained, but the substitution of physically smaller fission chambers in the same location permitted tracking over more of the range. The measurement problem was solved by moving the fission chamber to a position above the reactor core, but it is still not clear what destroyed the usefulness of the original location.

8.4 INSTRUMENTATION FOR THE MOLTEN-SALT REACTOR EXPERIMENT (MSRE)

R. L. Moore

J. R. Brown B. Squires[1]
G. H. Burger S. J. Ball
P. G. Herndon J. L. Redford
J. R. Tallackson

General

The design of process instrumentation for the Molten-Salt Reactor Experiment has proceeded in accordance with the proposals discussed previously.[2] Basic instrumentation criteria and control philosophy are now well established. Detail design of the process instrumentation system is nearing completion, and design of the nuclear instrument system is under way. Specifications were prepared and procurement was initiated for approximately 80% of the components required in the process instrument system.

The layout of the instrumentation and controls system is well established. Instrumentation will be centralized in the main control area, where a graphic control panel and operating console will be located. Field panels will be used only where operating requirements demand. Auxiliary instrument and electrical panels, relay and thermocouple cabinets, and a data-logging system (Sec 5.4) will be installed adjacent to the main control room.

A second control area, the transmitter room, will be adjacent to the reactor. Instruments for the leak-detector system, drain-tank system, weigh system, and the gas-purge systems for the fuel and coolant salt circuits will be mounted on auxiliary panels in this area. Solenoid valves for controlling the air supply to valve operators on gas-control valves in the salt systems will also be located in this area, along with amplifiers and power supplies for the process variable transmitters. Eight other instrument panels with auxiliary systems will be installed at convenient operating points in the field. With the exception of control-rod drives, thermocouples, pump-speed pickups, microphones, high-level gamma-ionization chambers, weigh cells, and some control valves, all instrumentation components will be located in areas external to the reactor containment vessels. Instrument installations inside the containment vessels will be provided with remotely operable disconnects for removal of major components of the reactor system.

[1]On loan from Burns and Roe, Inc.

[2]R. L. Moore *et al., Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961,* ORNL-3191, pp 83–86.

Forty-two, 2-ft modular instrument panel sections will be required for the MSRE. Thirty panels have been designed, and design of the remaining panel sections is approximately 50% complete. The cost of these panels, including design and installation, is estimated to be $312,000.

Nuclear Control System

In the nuclear instrumentation and controls system (Fig. 8.4.1) the wide-range, servo-positioned fission chamber channels[3] are expected to provide continuous coverage of the full range of reactor operation from startup to full power (Fig. 8.4.2). The linear channels, with compensated chambers as the signal source, are the most accurate nuclear information channels and are used to monitor reactor power and to provide the flux signal for the servo controller. These channels have a span of four decades and, with combined range switching and chamber relocation, are useful over a wider range. The limit channels will be used to release the clutches to drop the rods. They will also provide a reverse mode which will call for all the rods to be inserted. During initial critical periods, two temporary counting channels with BF_3 counters located in the composite shield will be used.

Except for these BF_3 counters, all nuclear instruments will be located in the large 36-in.-diam water-filled penetration,[4] which is inclined approximately 45°.

Servo control of the MSRE is required because its very high value for the ratio of heat capacity to power density makes inherent self control by temperature coefficient sluggish and productive of power oscillations which, while not dangerous, are not acceptable from an operational standpoint. Functionally, the servo controller (Fig. 8.4.3) augments the temperature coefficient of the reactor.

Special Process Instrumentation

The majority of instrument components specified for the MSRE are commercially available; special instrumentation was required if a component was to be an integral part of the primary reactor containment, was to be located inside the reactor shield, or was to be either attached to or on an integral part of a high-temperature system. The following is a discussion of some examples.

Differential pressure and pressure transmitters will be Foxboro Instrument Co. (ECI) force-balance type with a stainless steel body modified to permit seal welding of all pressure-containing joints. The signal amplifiers, which will transmit a 10- to 50-ma signal, will be mounted remotely from the transmitter. A special feature of the electrical circuitry will provide a 5% adjustment of the span and zero at the amplifier location, which will be advantageous during reactor operation when many of the transmitters will be inaccessible. Process connections will be Autoclave fittings, $\frac{3}{8}$ in. in OD, 30,000 psi rating. For low-pressure service these fittings are considered to be as dependable as welds for leak-tightness. The pressure transmitter will have an all-welded measuring capsule mounted inside a standard high-pressure body with screwed fittings. When properly connected to the containment exhaust system through a block valve, the body will provide secondary containment for the measuring capsule, which contains primary

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[3] J. L. Anderson and R. E. Wintenberg, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1960*, ORNL-2787, pp 145–50.

[4] *Molten-Salt Reactor Program Progr. Rept. for Period from March 1 to August 31, 1961*, ORNL-3215, p 9.

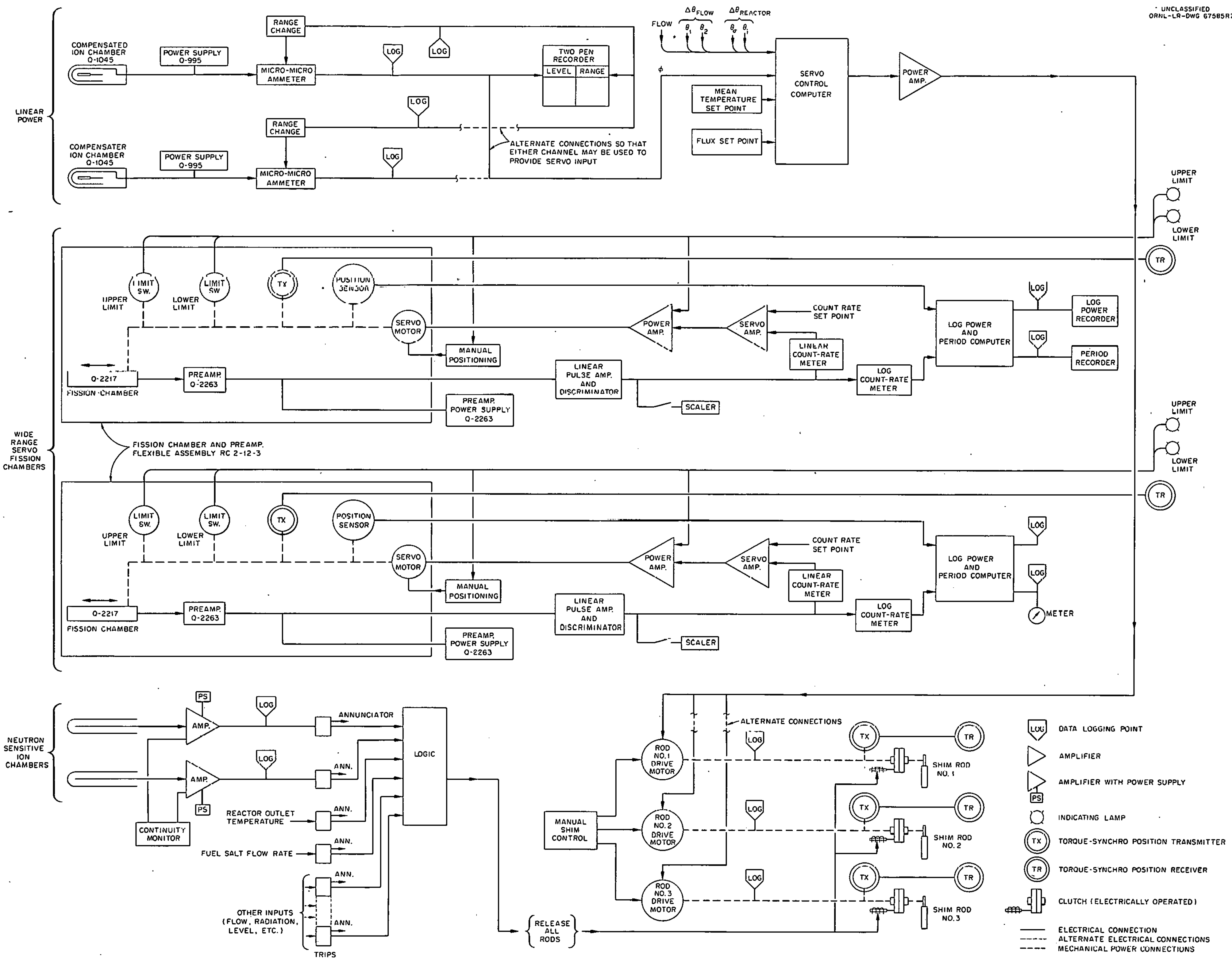

Fig. 8.4.1. MSRE Nuclear Instrumentation and Control System.

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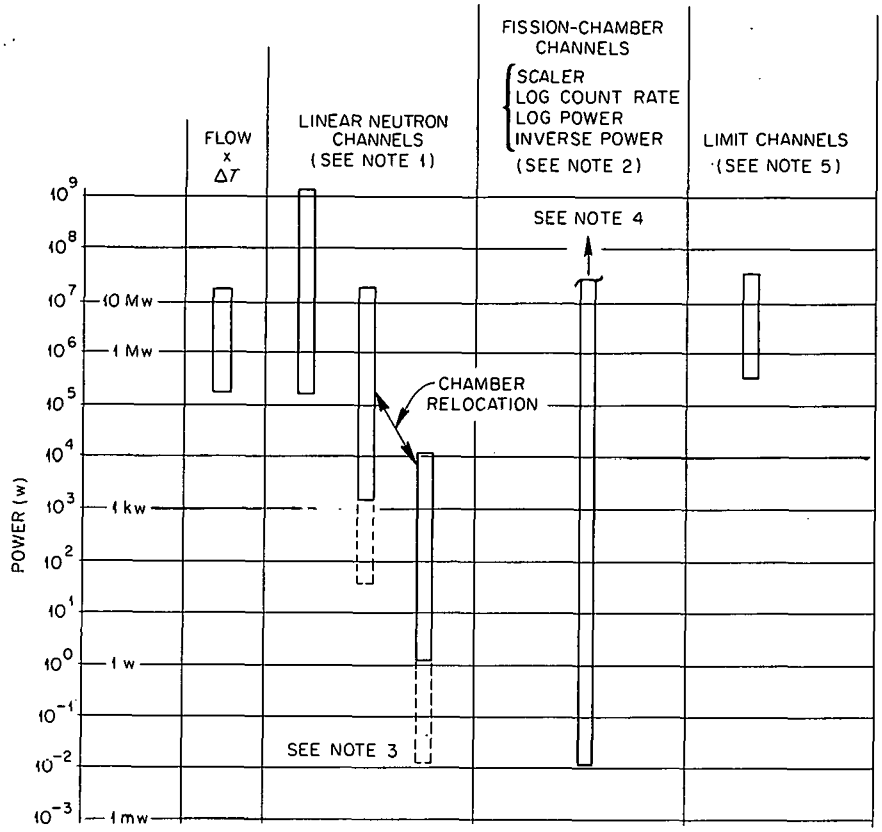

NOTES

1. Consists of compensated chamber to micromicroammeter. Used for servo flux input signal as well as recorder input. Lower threshold, possibly one decade below that shown, if all conditions optimized. Range switching not shown.
2. These are servo-operated fission channels and can be used to provide all readouts shown.
3. Under ideal conditions (low electrical noise and relatively clean fuel) the servo will control in the 10-Mw region.
4. Range of servo-operated fission channel dependent on movement in attenuating medium (H_2O), provided that no gross flux distortion exists in medium traversed by chamber.
5. The two-decade span may be located over a wide range.

Fig. 8.4.2. Ranges of MSRE Power and Nuclear Instruments.

process fluid. Sixty-four differential pressure and pressure transmitters will be required, most of which will transmit an electrical signal. Twenty-three of these will be weld-sealed differential pressure transmitters, and 15 will be weld-sealed pressure transmitters.

A Herschel short-form venturi machined from a solid 6-in.-diam bar of INOR-8 will measure the flow rate of molten salt in the coolant-salt system. The venturi will produce 500 in. of water differential pressure at a maximum flow rate of 950 gpm. The differential pressure will be sensed by a NaK-filled, slack diaphragm, high-temperature transmitter.

Twenty bellows-sealed control valves will be required for control of flow and pressure of helium cover gas in the reactor fuel, coolant, and drain-tank systems. These valves will be constructed similar to the

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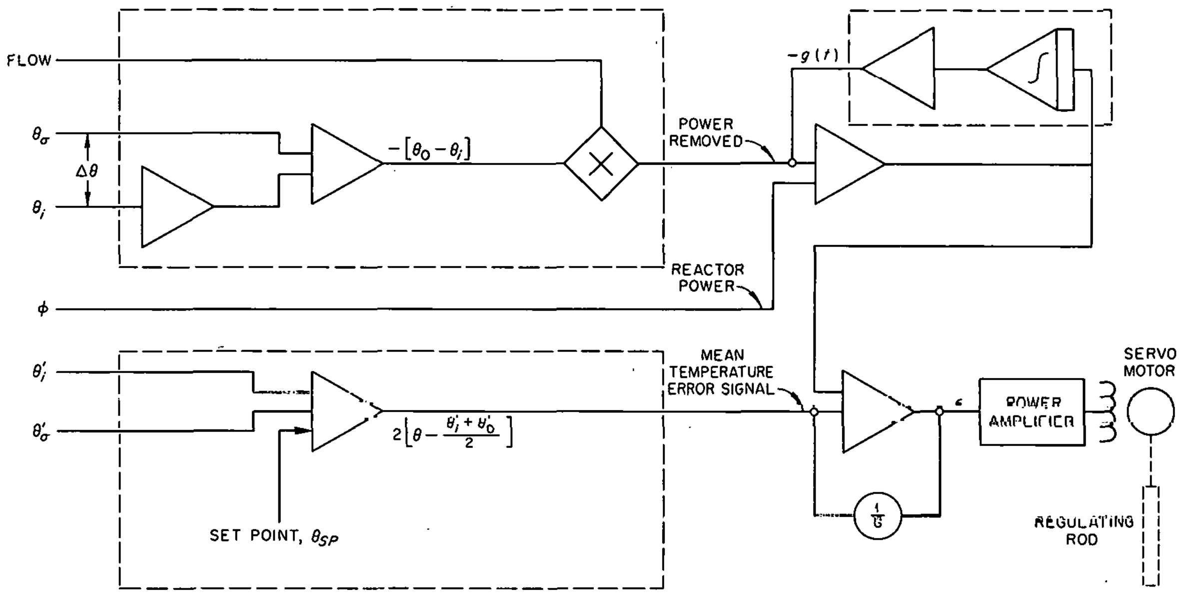

$$\epsilon = A\left[\phi - F(\theta_o' - \theta_i') - g(t)\right] - B\left[\theta_{SP} - \frac{\theta_o' + \theta_i'}{2}\right]$$

Fig. 8.4.3. MSRE Reactor Controller.

low-pressure valves used in the HRT.[5] The valve bodies will be forged stainless steel with integral O-ring flanges, which will facilitate remote maintenance. The stems will be bellows-sealed, and all joints between the valve bodies, stems, and bellows will be welded to prevent leakage of helium. The valves will be installed outside the reactor containment vessel and equipped with conventional pneumatic operators. Ten similar valves, which will have tight-shutoff and quick-opening characteristics, will be used to control venting of the drain tank to the off-gas system or to the pump bowls. Six of these valves will be located in high-radiation areas within the contained area and will be equipped with bellows-sealed all-metal pneumatic operators.

A large number of thermocouples will be required for the MSRE: 484 on the fuel-salt piping and components, 266 on the coolant-salt system (includes 149 on the radiator), and 62 on other auxiliary piping and equipment. The thermocouples will be terminated at a patch panel in the auxiliary control room. Any thermocouple may be connected to any readout device by plugging into the proper socket on the patch panel. A temperature scanning system (Sec 7.9) will monitor the output of approximately 400 of these thermocouples. Approximately 160 thermocouples will be connected to the data logger. Inconel-clad, $\frac{1}{8}$-in.-OD, mineral-insulated Chromel-Alumel thermocouples will be attached to fuel and coolant system piping and components and will operate at 850 to 1300°F. Thermocouples will be attached to heavy-walled INOR-8 pipes and vessels by means of an INOR-8 lug, which will be Heliarc-welded to the pipe

[5]A. M. Billings, *ISA J.* 5(6), 54 (1958).

and thermocouple. For thin-walled radiator tubes, the thermocouples will be attached with a specially developed band. Thermocouples located inside the contained areas will be terminated at a remotely operable, radiation-resistant, multiconductor disconnect. The disconnect will be connected to the exterior of the containment vessel with glass-insulated, copper-sheathed, multiconductor thermocouple cables.

The molten-salt level in the pump bowls will be measured using two helium-purged dip tubes. A ball-float-type continuous level indicator (Sec 7.10) is being developed as a possible replacement or backup for the dip-tube system. A conductivity-type single-point level indicator (Sec 7.8) is being developed to measure the molten-salt level of the drain tanks.

9. Support for the High-Voltage Accelerator Program

9.1 TANDEM VAN DE GRAAFF INSTALLATION AND OPERATION

G. F. Wells   J. W. Johnson
C. D. Moak[1]   H. E. Banta[2]

Installation of the 12-Mev tandem Van de Graaff began in July 1961, and final acceptance tests were completed in March 1962, with a 2-μa beam of 12-Mev protons produced on an experimental target. Since then, proton beams of various energies up to 12 Mev, nitrogen-ion beams of 30 Mev, and oxygen-ion beams as high as 42 Mev were produced for Physics Division experimentalists. Energy resolution of these beams was better than 0.1%.

These higher-energy beams were made possible in the tandem accelerator by the charge-exchange mechanism employed to achieve double acceleration. Singly charged negative ions were injected and accelerated to the positive terminal of the accelerator, where they encountered a higher-density oxygen gas region. The high-velocity negative ions lost electrons to neutral gas molecules and became positive ions, which were further accelerated from the terminal back to ground potential. When *e* electrons were thus removed from the negative ion, the particle gained *e* times the terminal voltage in energy. Thus, when O^- became O^{6+} at 6-Mv terminal voltage, the O^{6+} had $7\ e \times 6$ Mv = 42 Mev of energy on emerging from the accelerator.

The tandem accelerator was operated two shifts per day, five days per week since acceptance, with downtime only for maintenance and shifting of experimental areas. A shutdown is planned to install new product-90 analyzer magnets [maximum field capable of bending a mass × energy (Mev) product of 90 for singly charged ions through a 90° arc] to replace the present product-36 magnets. A further increase in maximum terminal potential is anticipated from the increase in dielectric strength obtained by adding SF_6 to the tank insulating gas.

[1]Physics Division.
[2]Oak Ridge Institute of Nuclear Studies.

9.2 CHARGE-CURRENT REGULATOR FOR THE 5-Mv VAN DE GRAAFF

W. T. Newton

The 5-Mv Van de Graaff employs a 50-kv supply, which furnishes current ranging from a few microamperes to about 300 μa, depending on the beam required, for charging the machine belt. The stability of the beam produced by the machine largely depends on keeping this charge current constant. The charge current may be caused to vary by changing conditions, such as inconsistency of the charge taken by the belt, or a changing distance between the moving belt and the charging points. These factors combine to produce a very unsteady charge current, and these unwanted variations appear in the beam current.

The charge current was stabilized by use of a circuit developed for a special vacuum tube, RCA-type 5890. This tube is essentially a cathode-ray tube which has a plate instead of a fluorescent screen. Because the plate is isolated from the cathode of the electron gun, plate current is independent of plate voltage and may be controlled by a negative bias applied to the grid of the tube. With this tube, charge current can be set at any desired value by means of a simple Helipot control, and there is no change in beam current due to the causes previously mentioned.

Since the charge current can be controlled precisely and conveniently, a further improvement was made. A dc signal is extracted from the current flowing in the energy control system of the machine, amplified, and placed in series with the manually controlled bias voltage on the 5890 tube, which determines the charge current. This system (Fig. 9.2.1) automatically adjusts the belt charge current for changes in operating conditions.

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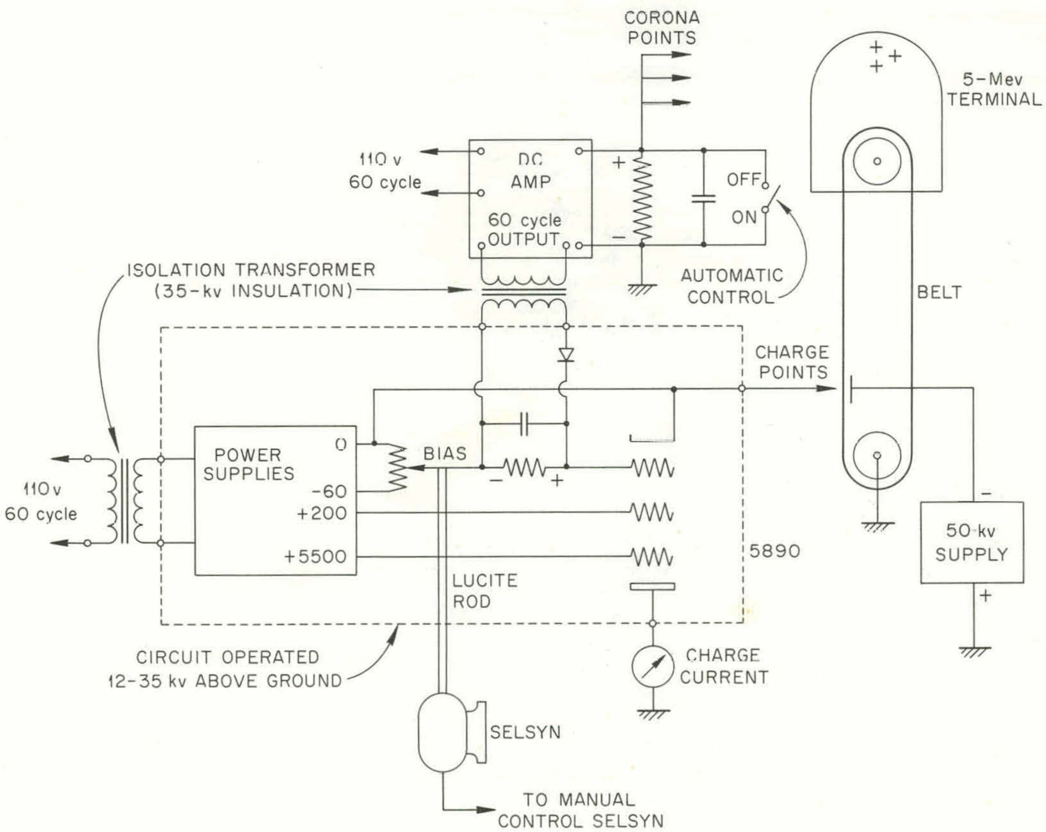

Fig. 9.2.1. System for Control of Belt-Charge Current for the 5-Mv Van de Graaff.

9.3 OPERATION OF DUOPLASMATRON PULSER TERMINAL IN THE 3-Mv VAN DE GRAAFF

J. P. Judish

The duoplasmatron ion source and beam pulser installed in the ORNL 3-Mv Van de Graaff[1] in 1961 (Fig. 9.3.1) has accumulated a useful operating time of over 1200 hr. Measurements at the output of the analyzing magnet disclose that, before bunching, a mass-1 hydrogen beam of about 4 nsec pulse duration, 700 μa peak current, and 1 Mc repetition rate has been consistently supplied to the target at energies up to 2 Mv. By remote operation, the rf deflection voltages in the Van de Graaff terminal can be decreased, permitting a larger-average beam current with a corresponding longer pulse duration. Pulses of 12 to 13 nsec duration were used in some experiments for which a large-average beam current was more important than short pulse duration.

[1]J. W. Johnson *et al.*, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, p 91.

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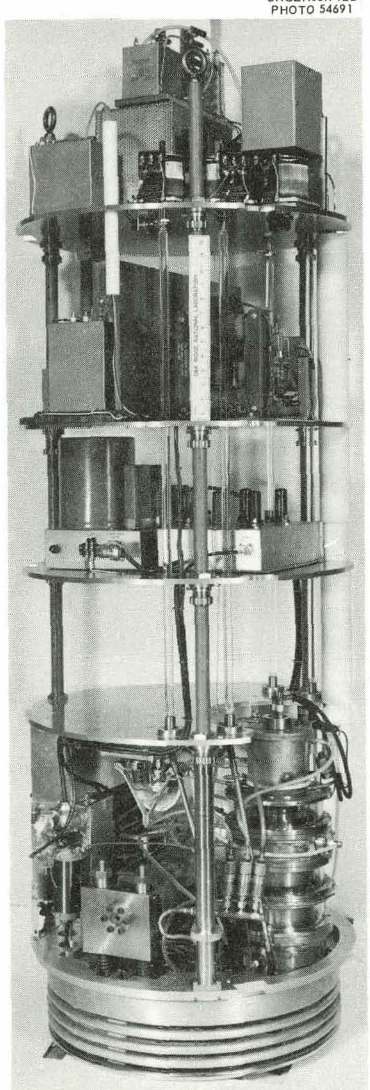

Fig. 9.3.1. Duoplasmatron Ion Source and Pulser Terminal for the 3-Mv Van de Graaff.

9.4 BEAM-PULSE PICKOFF SYSTEM

C. W. Williams

Before the duoplasmatron ion source was installed in the ORNL 3-Mv Van de Graaff, an electrostatic-inductive pickup was installed in the beam tube. The signal from the pickup was amplified by Hewlett-Packard wide-band amplifiers and used as a stop pulse to the time–to–pulse-height converter. This method had two distinct advantages over the capacity pickup from the target, which had been used previously: (1) the target capacity was no longer a consideration, and (2) the rf voltage pickup was greatly reduced. The theoretical disadvantage of this method is that there is a slight time variation introduced as a function of energy caused by the physical displacement of the pickup from the target; however, each experiment is at a fixed energy and this problem is secondary. The practical disadvantage is that the pickup pulse shape is not compatible with the time–to–pulse-height converter. To obtain a fast-rising positive pulse that is independent of beam-current amplitude, the slow-rising positive portion of the pulse was clipped and the negative portion was amplified, inverted, and limited. This system, which required six Hewlett-Packard amplifiers and a fast limiter, was unsatisfactory because the clipping was not complete, and, since it required careful adjustment, it was difficult to operate.

To improve the system, a two-stage fast-rise-time transistor amplifier,[1] a tunnel-diode limiter and clipper, and a limiting amplifier located at the beam pickup were used. A biased-off emitter-follower was included between the tunnel diode and the limiting amplifier to improve the clipping characteristic. The output of this system (Fig. 9.4.1) is a 1-v pulse of approximately 3 nsec rise time into a 200-ohm delay line, which is terminated at both ends. Two Hewlett-Packard amplifiers still remain in the system to control the amplitude and drive the long length (≤2 μsec) of RG-7U delay line.

[1] C. W. Williams and J. H. Neiler, "Design Considerations for Maximum Bandwidth in Transistor Pulse Amplifiers," submitted to *IRE Transactions on Nuclear Science*.

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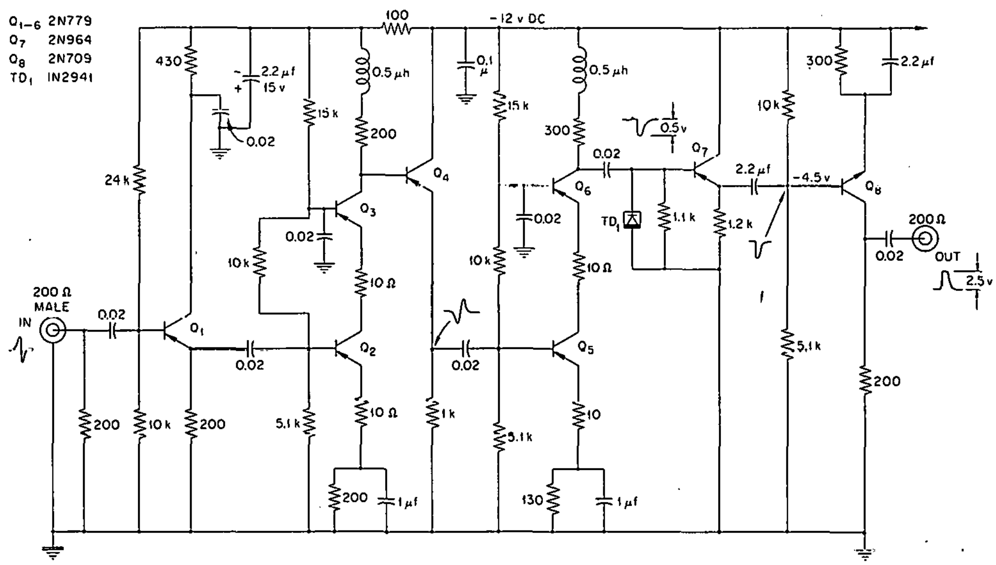

Fig. 9.4.1. Beam-Pulse Amplifier, Model 1 (Revised).

The most exhaustive tests performed to date are not conclusive enough to separate the time contribution of the different units of the timing system. A beam-pickup cup near the analyzing magnet indicates a minimum beam-pulse width of approximately 1.8 nsec, and the time converter measures 1.88 nsec for the complete system. The start side of the time system consists of a 56 AVP photomultiplier tube which receives pulses from a 1- by 1-in. Naton-136 scintillator. The output of the photomultiplier tube was amplified by one Hewlett-Packard amplifier and was used to start the time–to–pulse-height converter. The analyzer was gated with 10% of the 480-kev gamma-ray spectra from a thin lithium target. Since the noise (associated with the sampling scope which monitors the beam-pickup cup) prohibits a precise width measurement and the resolution of the converter is not precisely known, the time contribution of the stop-pulse system cannot be separated but is shown to contribute very little to the system resolution. It is expected to be no worse than 10^{-10} sec for an order of magnitude reduction in the peak current from that presently available (1.2 ma).

The tunnel-diode trigger point is 5 ma, which referred to the amplifier input is 30 μa, or 6 mv onto 200 ohms. With a load resistance of 300 ohms, the transistor amplifier has a voltage gain of 250, a rise time of 3.8 nsec, and a very low equivalent input noise. Each stage contains approximately 8 db of feedback, which contributes to gain stability. For very low beam currents, an order of magnitude more sensitivity could be obtained by substituting a current-mode trigger pair for the tunnel diode and limiting amplifier. The tunnel diode requires 5 ma to trigger, which corresponds to 1.5 v at a 300-ohm impedance level. A trigger pair can be designed to trigger at an input signal of less than 150 mv, with approximately the same percentage trigger variation as the tunnel diode and with a rise time equal to that of the limiting amplifier in the existing system.

9.5 PREACCELERATION KLYSTRON ION-BEAM BUNCHER FOR THE 3-Mv VAN DE GRAAFF

R. F. King W. M. Good[1]
J. P. Judish J. W. Johnson

Shorter pulse duration and higher peak current in the beam pulses from the 3-Mv Van de Graaff accelerator are dictated by the higher resolution requirements of the neutron time-of-flight experiments. The oscillographic beam pulsing[2,3] of the ion beam from a duoplasmatron ion source[4,5] is limited in this machine to about 3 nsec burst duration and 0.7 to 1.2 ma peak current. Shorter bursts have been obtained with postacceleration chopping[6] at the expense of beam intensity and increased beam-dependent background and accelerator tube loading. These limitations can be overcome by beam bunching.[7] Bunching

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[1]Physics Division.

[2]C. D. Moak *et al.*, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1959*, ORNL-2787, p 1.

[3]J. W. Johnson *et al.*, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, p 91.

[4]C. D. Moak *et al.*, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1958*, ORNL-2647, p 11.

[5]C. D. Moak *et al.*, *Rev. Sci. Instr.* 30(8), 694 (1959).

[6]R. F. King and W. M. Good, *Instrumentation and Controls Div. Ann. Progr. Rept. July 1, 1961*, ORNL-3191, p 90.

[7]J. H. Neiler and W. M. Good, *Fast Neutron Physics*, Part I (ed. by J. B. Marion and J. L. Fowler), p 509, Interscience, New York, 1960.

consists in changing, in a time-correlated fashion, the energy or momentum of a burst of ions in a manner such that the trailing ions overtake the leading ion at some specified time or distance. The Mobley-magnet method causes the leading ions to traverse a longer distance, thereby allowing the trailing ions to overtake them. The klystron-bunching method (used here) consists in altering the speed of the ions along their axial path. By use of preacceleration instead of postacceleration klystron bunching, the energy spread of the beam introduced by the buncher and the path length of after-acceleration flight were greatly reduced.

The buncher consists of an electrode located immediately below the duoplasmatron ion-source pulser in the terminal of the 3-Mv Van de Graaff accelerator. It is driven by a sine wave which is the 27th harmonic of the pulser repetition rate, or 27 Mc/sec. At the proper phase relation to the pulser, the beam burst will see a retarding voltage on the leading ions, zero voltage on the center ions, and an accelerating voltage on the trailing ions at each of two gaps. This equipment has been fabricated, installed, and checked out for beam energies up to 2 Mev.

With the present flight time at beam energies below 1 Mev and a buncher-induced energy spread of 400 to 500 v, beam pulses of 9 to 10 nsec duration can be compressed in time to less than 1 nsec, with a corresponding increase in peak current. Owing to shorter flight time at 2 Mev, the bunch factor reduces to about 3. Future modifications to the ion optic system in the accelerator terminal and optimizing buncher wave shape will be required to achieve the larger bunch factor at higher energies.

A postacceleration klystron buncher has also been developed and is in operation on the 200-kev Cockcroft-Walton accelerator. This system operates on the third harmonic of the pulse repetition rate, or 13.5 Mc/sec, and will accept a 30-nsec pulse with a bunch factor of 15.

9.6 COUNTDOWN SYSTEM FOR THE PULSED VAN DE GRAAFF ACCELERATOR[1]

R. F. King W. H. Du Preez[2]

The optimum repetition rate of pulsed Van de Graaff beams varies quite widely from one experiment to another. For example, whereas fast (Mev range) neutron experiments call for rates in the several-megacycle range, recent efforts in measuring fission parameters in the kiloelectron volt range call for a repetition rate of 100 kc/sec. Other neutron experiments are optimum for intermediate frequencies. All experiments, however, call for short burst duration ($\lesssim 5$ nsec). A system for reducing the pulse repetition rate from 1 Mc to 500, 250, or 125 kc is described. This system uses a pair of electrostatic deflector plates immediately above the analyzing magnet of a 3-Mv Van de Graaff accelerator to sweep the ion beam across a slit at the required frequency. The deflector plates are biased to allow the transmission of only one pulse in each cycle. A tuned ferrite-core antenna coil located in the bottom of the pressure tank picks up a signal from the pulsing equipment in the terminal. This signal is electronically converted to the required frequency and amplitude. Means for selecting the required frequency and for phase synchronization with the incoming pulse are provided.

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[1]Abstract of paper presented at Meeting of the *American Physical Society*, Southeast Section, at Tallahassee, Fla., April 5–7, 1962.

[2]Visitor from the South Africa Atomic Energy Board, Pretoria, South Africa.

10. Miscellaneous

10.1 WORK ORDER CONTROL AND SCHEDULING IN THE PROCESS CONTROL AND INSTRUMENTATION SECTION

R. K. Adams   C. D. Martin, Jr.   L. H. Chase

The Process Control and Instrumentation Section is an instrument-application service organization for the Laboratory and has an active list of about 100 projects at all times. Because of the wide variety of these jobs, the substantial dollar volume involved, and the large number of groups and crafts to be coordinated, it is desirable that work order control and scheduling methods be used to speed the progress and account for the costs of the work performed.

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WORK ORDER SUMMARY   SHEET NO 3
C. BRASHEAR   COST DATE 4- 1-62

COSTS BETWEEN 75 AND 90 PER CENT OF ESTIMATE

WORK ORDER NUMBER	ESTI-MATE	TOTAL COSTS	LABOR-COSTS	MATLS COSTS
A-22569.11	7500	6039	949	4531
A-23483.11	6230	5253	1273	3131

COSTS GREATER THAN 90 PER CENT OF ESTIMATE

WORK ORDER NUMBER	ESTI-MATE	TOTAL COSTS	LABOR COSTS	MATLS COSTS
A-20555.11	6030	8959	3426	3220
A-83272.02	7530	22473	11753	2336

WORK ORDER SUMMARY   SHEET NO 2
R.E.WHITT   DATE 5-14-62

WORK ORDER NUMBER	MAN-WEEKS REQD.	PREV.	T-CMP.	PCT. COMP.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16-29	30-UP
A 20435.11	• 0.	0.	0.	0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A 93321.02	• 0.	1.5	0.	0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A 93641.01	5.8	5.1	0.7	40.9	0.2	0.2	-0.	-0.	-0.	-0.	-0.	-0.	-0.	0.1	0.1	0.1	-0.	-0.	-0.	-0.	-0.
A 93795.30	12.0	9.6	2.4	55.5	0.4	0.4	0.4	0.4	0.4	0.2	0.2	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.
A 3075.65	-0.	4.3	2.5	103.6	0.1	0.1	0.1	0.1	0.1	-0.	-0.	0.1	0.1	0.1	0.1	0.1	-0.	0.1	0.1	1.3	-0.
A 3075.15	-0.	-0.	2.0	11.5	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	1.0	-0.	-0.	-0.	1.0
A 20621.11	• 0.6	0.7	0.	110.0	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.

WORK ORDER SUMMARY   SHEET NO 1
R.E.WHITT   DATE 5-14-62

WORK ORDER NUMBER	REQUESTOR AND DIVISION	DESCRIPTION	TYPE WORK	ASGND ENGR.	DATE WRITTEN	DATE REQ.COMP.	COST--DOLLARS EST.	COST--DOLLARS CUM. TO 5-13-62	PRIORITY WRIT.	PRIORITY COMP.
A 20435.11	•C.W.HANCHER CHEM.TECHNOLOGY	MODIFY 60 CHANNEL LOGGER	DPC	RKA	12-28-60	6-30-61	5000	16483	1	1
A 93321.02	•C.W.HANCHER CHEM.TECHNOLOGY	PURCHASE AUXILIARY COMPONENTS FOR 60CH	P	RKA	1- 3-61	6-30-61	4000	9017	2	2
A 93641.01	P.M.GRIFFIN ELECTRONUCLEAR	DIGITIZE MICROPHO-TOMETER	DPC	RKA	6-29-61	6-29-62	14200	1321	3	4
A 93795.30	G.P.SMITH METALLURGY	MODIFY DATA LOGGER FOR USE WITH 2CARYS	DPC	RKA	11-29-61	6-30-62	3500	4046	4	5
A 3075.65		SECTION MEETINGS SEMINARS,ETC.		REW	-0--0--0	-0--0--0	-0	-0	0	0
A 3075.15	R.E.WHITT	VACATION			-0--0--0	-0--0--0	-0	-0	0	0
A 20621.11	•G.C. WARLICK REACTOR CHEMISTRY	COLD JUNCTION FOR SYSTRON DATA SYSTEM	DPC	RKA	2- 1-62	4- 1-62	540	308	5	3

Fig. 10.1.1. Work Order Summaries.

In the Section each job is followed by one engineer, or one team, from initial design through procurement, installation, and checkout. Although there are many benefits from this method of operation, it requires each engineer to schedule his engineering time and receive schedule and cost reports on his jobs with as little delay as possible.

As a first-step solution to assist the engineer with scheduling and to supply cost reports rapidly, a *Work Order Summary Program* was written for the IBM 7090. The program, which has been in use since February 1962, gives five pieces of information to the engineers and the Section. It provides each engineer with up-to-date costs and a priority listing of the 15 to 20 jobs on his list (Sheet No. 1, Fig. 10.1.1). (Two priority lists are given: one is arranged by dates on which the work orders were written, and one is arranged by dates on which the work orders were requested to be completed.) It gives

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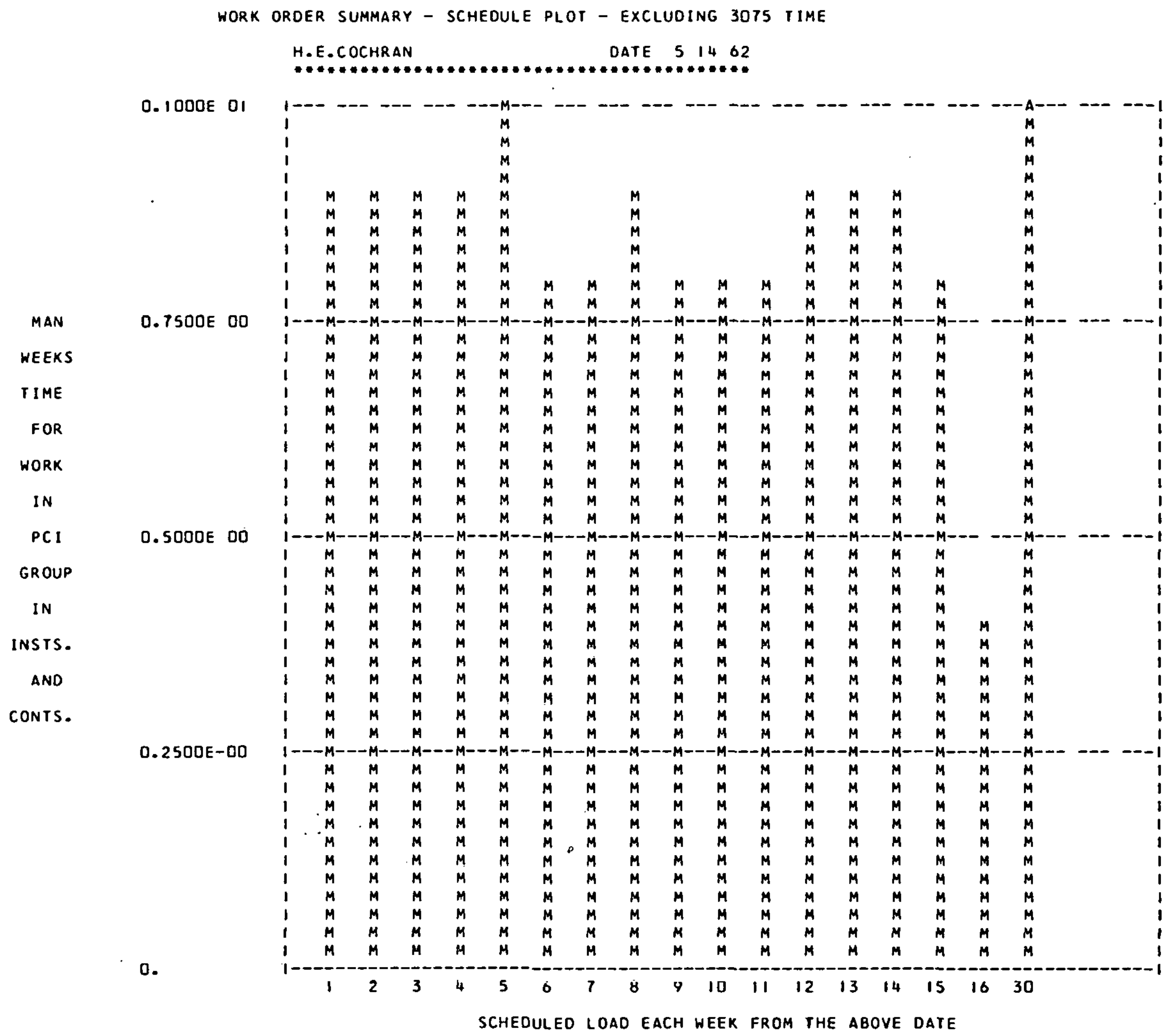

Fig. 10.1.2. Graph of Scheduled Work Load for an Engineer in the Process Control and Instrumentation Section.

the engineer a report of the time actually spent vs his initial estimate of the engineering time required (Sheet No. 2, Fig. 10.1.1). It shows the engineer which work orders have accumulated costs between 70 and 90% of his estimate and which have exceeded 90% of his estimate (Sheet No. 3, Fig. 10.1.1). It graphically depicts the scheduled work load of each engineer and of the entire Section (Figs. 10.1.2 and 10.1.3). It lists a summary of all current work orders in the Section and gives pertinent information on the status of each work order (Fig. 10.1.4).

The program has been successful. Cost information is obtained about three days after the monthly accounts are closed. However, other information is required, which this program was not intended to provide, and plans are being made to expand the program. The following information is being considered:

1. schedules for instrument technicians and the relation of these schedules to engineering design, installation, and checkout;

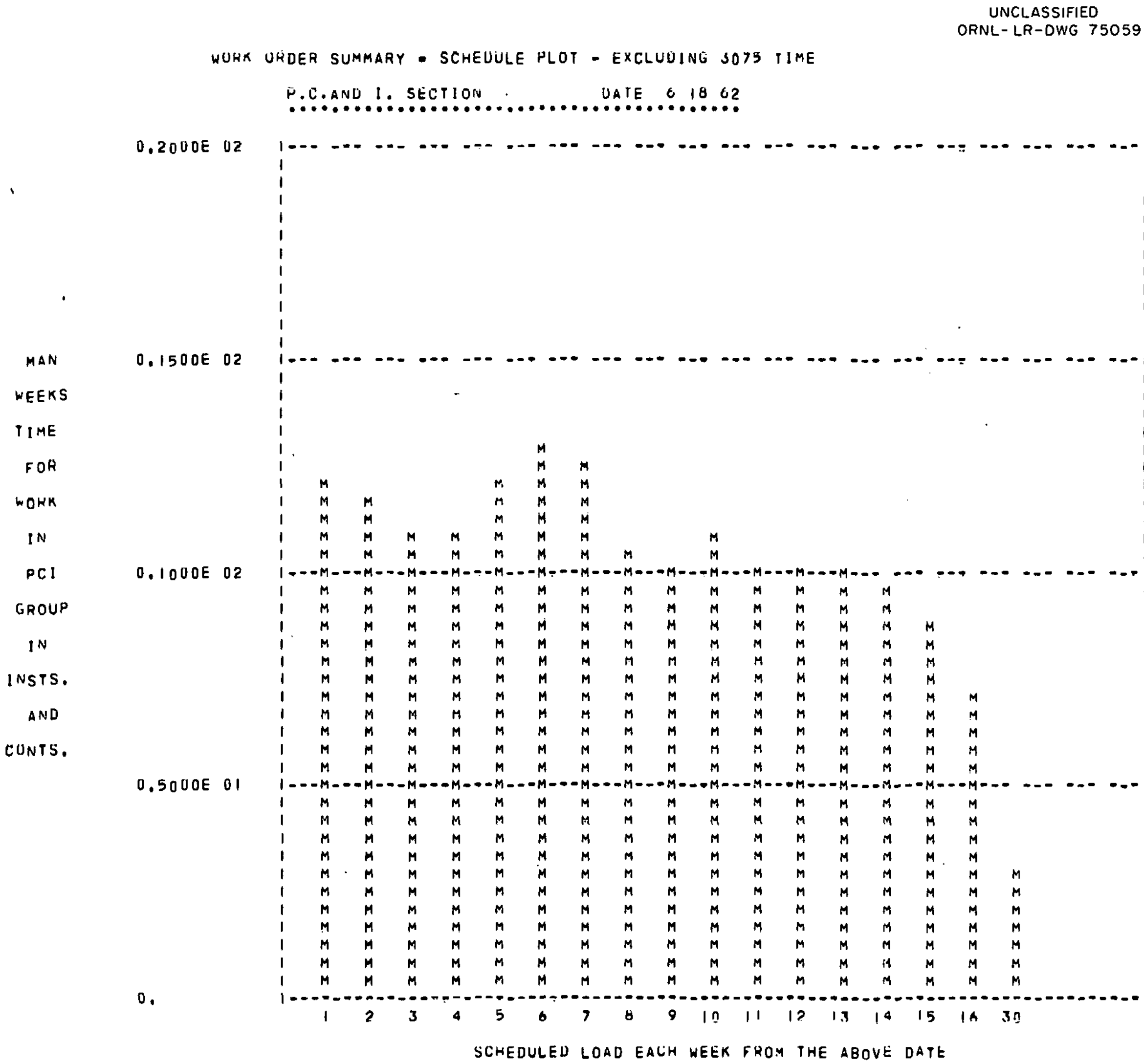

Fig. 10.1.3. Graph of Scheduled Work Load for the Process Control and Instrumentation Section.

2. schedules of other crafts for these projects. These schedules must dovetail Engineering and Mechanical Division schedules and job progress (probably through critical path methods);
3. reports of instrument procurement and delivery schedules.

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WORK ORDER SUMMARY

PROCESS CONTROL AND INSTRUMENTATION SECTION

SHEET NO 4
DATE
5-14-62

COST DATE 5-13-62

WORK ORDER NUMBER	DESCRIPTION	ASGND ENGNR	WEEKS TO START	WEEKS TO COMP	M/W TO COMP	PCT COMP	ESTI-MATE	TOTAL COSTS	LABOR COSTS	MATLS COSTS	OVER-HEAD
XA 31603.11	INST FOR DROP TEST	WFJ	0	15	3.0	65.9	4720	0	0	0	0
A 31609.11 •	KILOROD INSTRUMNTN	WJG	0	0	0.8	86.2	5000	25542	11280	6318	7944
A 31630.11	INST CALIBRATION KILORUD PROCESS	WJG	0	14	5.4	6.9	6835	7778	3839	1214	2725
A 03075.18	HOLIDAY	JLH	0	0	1.2	25.0	-0	0	0	0	0
A 03075.28	MILITARY LEAVE	HEC	0	0	0.	100.0	-0	0	0	0	0
XA 03543.11	HRLEL CARR. REPLIC.	CSL	0	30	0.3	93.5	2750	0	0	0	0
XA 33568.11	HRLEL CANNING EQT.	CSL	0	30	2.4	20.0	1020	0	0	0	0
XA 33597.11 •	HRLEL MISCELL.	CSL	0	0	-0.4	106.7	3000	0	0	0	0
XA 34649.11A•	ORR POOLSIDE EXP. FOR R.G.BERGGREN	AHM	0	0	0.0	100.0	2500	0	0	0	0
XA 35663.11 •	DESIGN EST.FOR NEW ILW LEVEL TELEMETER	TMG	0	0	1.0	-0.	1000	0	0	0	0
XA 06171.11 •	TITLE I MELTON VLY INST.DESIGN	TMG	0	0	0.	100.0	1360	0	0	0	0
XA 06427.[illegible]	[illegible] HISTORY	AHM	[illegible]	3	1.0	50.0	4000	[illegible]	0	0	0
[illegible]	[illegible] FOLLOW [illegible] ORGOP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
A 93649.01 •	MODIFY SPECTRONIC UNITS PER CF591298	TMG	0	0	1.0	-0.	1000	192	113	4	75
A 93695.01 •	INSTS.FOR TORSION PENDULUM	TMG	0	0	2.4	-0.	2985	0	0	0	0
A 93705.01	BED IRRADIATION EXP INST.ETR.	AHM	0	11	2.4	83.2	22300	22002	5750	14815	1437
A 93735.01	HRLFL RADIAT. MON.	CSL	0	16	2.8	6.7	13000	4620	3095	751	774
A 93795.30	MODIFY DATA LOGGER FOR USE WITH 2CARYS	RKA	0	7	8.9	55.5	3500	4046	2468	961	617
A 93815.30	CONTAINMENT 3517 MONITORING SYSTEM	DJK	12	16	-0.	0.	11700	2346	1072	1006	268
A 93840.30	HRLEL GAMMA SPECTR. FABRIC/INST.SPECTR.	CSL	0	30	1.9	5.0	30500	14321	8225	4010	2086
A 93849.30	DV BOX FLOW RATE REPEATER	TMG	0	0	0.0	100.0	671	0	0	0	-0
A 93003.30	CELL 10 BLDG 3517 GAMMA CHAMBER	RKA	11	11	0.2	-0.	2500	604	405	98	101
A 93913.30	LITR INST UPDATE	BCD	0	12	5.7	64.4	39870	3793	2677	447	669
A 93914.30	24 STATION TELETALK BLDG 3517	SBD	10	10	0.2	-0.	2500	445	101	318	26
A 93933.30	LIRA H2O IN AIR	TMG	0	11	0.3	25.0	1838	26	21	0	5
A 93944.31	ORR POOL SIDE EXP	AHM	0	16	7.4	7.5	50000	0	0	0	-0
			TOTAL		352.6		797245.	464971.			

Fig. 10.1.4. Work Order Summary for the Process Control and Instrumentation Section.

10.2 A LITERATURE SURVEY OF INSTRUMENT COSTS

R. F. Hyland

A study was made to determine whether widely quoted normal instrument investment percentages were documented in the literature and to reduce reported cost data to some common form so that a rapid comparison of costs could be made. The goal was to improve the accuracy of preliminary and final cost estimates at the Laboratory.

A literature search was made for instrument investment cost and instrument cost estimating data in both the nuclear and industrial fields. In the nuclear field, actual costs of completed installations were the only ones considered. Material of this type was scarce. Industry costs, in general, were either actual costs or cost ratios, percentages, factors, etc., based on completed installations.

Most of the information is of little value. Instrument investment percentages were sometimes based on the cost of the entire facility, including the real estate, office buildings, service buildings, power facilities, etc., in addition to the process facilities. At other times, this percentage was based only on the process and buildings and, in still others, on the process itself. In many cases this distinction was not clear.

Other factors, such as difference in labor costs in different areas, overtime, profits, degree of automatic control, use of expensive analyzers, safety requirements, and type of material used in the plant, resulted in major differences from plant to plant. In the nuclear industry, direct vs semidirect vs remote maintenance, safety and control philosophy, unusual conditions of temperature, pressure, radiation, corrosion, containment, etc., similarly affected the cost of instrumentation quite drastically. Even more fundamental were the variations in the definition of instrument cost, direct cost, indirect cost, process equipment cost, etc.

Normal investment percentages for instrumentation, which are so widely quoted, are meaningless. Only rarely was a reference found that gave the complete cost of an instrument installation.

The literature contains a considerable amount of unit cost data for various types of instrumentation, but the value of this information is questionable because it is difficult to update the costs, and the instrument installations vary widely. Ratio cost information, however, does not go out of date as does unit cost data. Bach,[1] Bernard,[2] and others make reasonably accurate preliminary cost estimates by using equipment ratio estimates. Hackney[3] has achieved accuracies of ±25% by using this method. Equipment ratio estimating is intended to be used only when a good set of instrument flow diagrams, elementary electrical diagrams, etc., are not available. When these drawings are available, a better estimate can be made.

In future work, these data will be correlated to determine if usable information can be obtained for cost-estimating purposes at ORNL.

[1] N. G. Bach, *Chem. Eng.* **65**(10), 155 (1958).

[2] J. W. Bernard, *Chem. Eng.* **67**(2), 120 (1960).

[3] J. W. Hackney, *Chem. Eng.* **67**(7), 119 (1960).

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Joint Nuclear Instrumentation Symposium, Raleigh, North Carolina, September 6–8, 1961

Behr, B. C., W. E. Lingar, and W. H. White, Jr., "High-Current Regulated Supply, Combining Transistors and Magnetic Amplifiers, for the Oak Ridge Isochronous Cyclotron."

Epler, E. P., "Dangers in Safety Systems."

Lovvorn, J. L., "Reactor-Power Monitor Utilizing Cerenkov Radiation."

National Topical Meeting on the Role of Computers in Nuclear Power Plants (Sponsored by the American Nuclear Society), Pittsburgh, Pennsylvania, February 24, 1962

Hanauer, S. H., "Automation for Reactor Startup and Operation."

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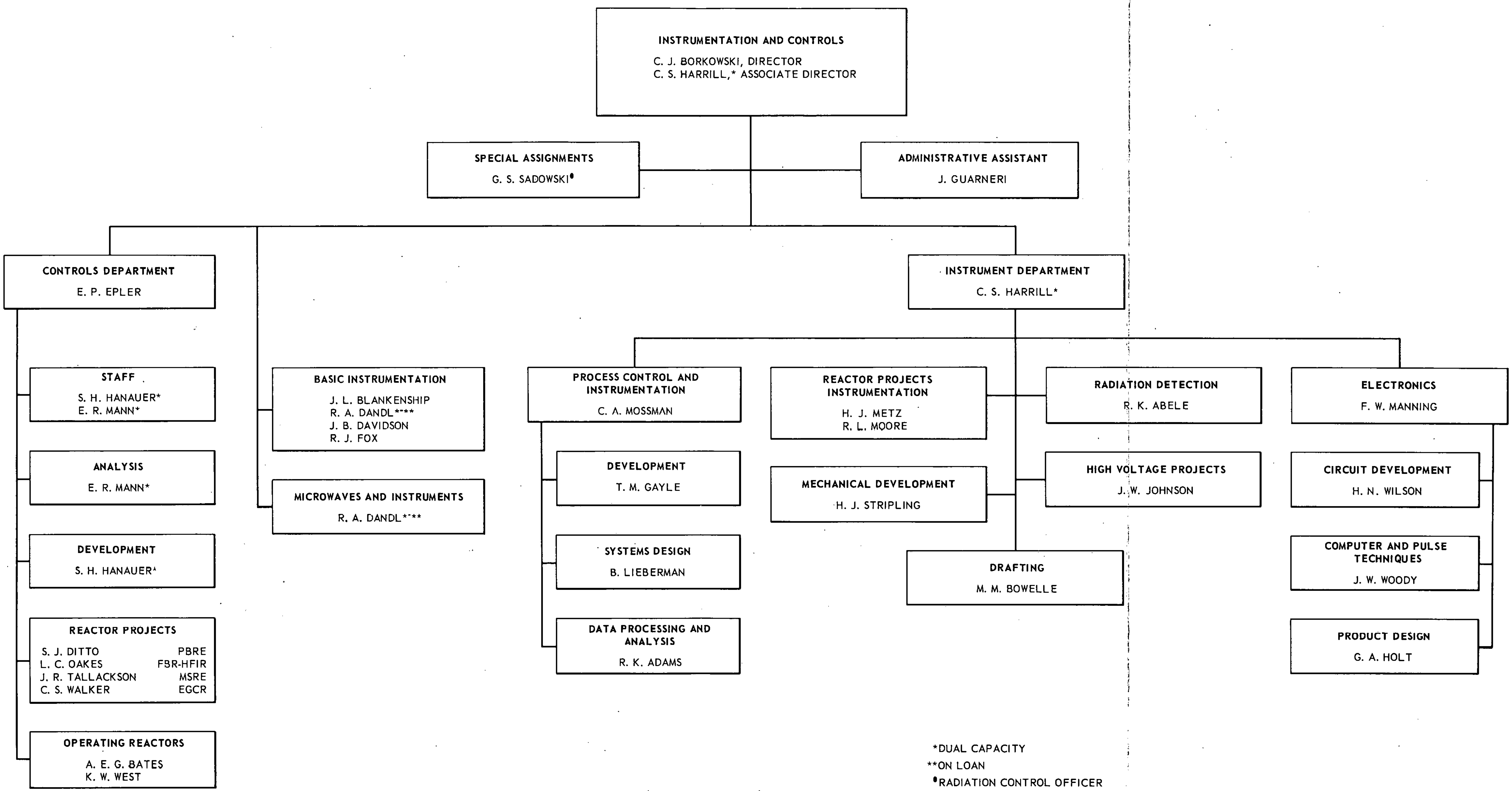
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