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**PACIFIC NORTHWEST LABORATORY
ANNUAL REPORT FOR 1965
IN THE PHYSICAL SCIENCES
to the
USAEC Division of Biology and Medicine
VOLUME 4: INSTRUMENTATION**

MAY, 1966

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IN THE PHYSICAL SCIENCES
to the
USAEC Division of Biology and Medicine
VOLUME 4: INSTRUMENTATION

By

Staff Members of
Applied Physics and Electronics Department
Instrumentation Section

Edited by
D. W. Pearce and J. K. Green

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VOLUME 4: INSTRUMENTATION

PHYSIOLOGICAL DATA TELEMETRY SYSTEM—N. C. Hoitink and N. S. Porter

Maintenance and modification work performed under adverse environmental conditions around reactors, in heat exchangers, and so forth created a need to measure continuously certain physiological parameters of the personnel involved. Telemetry instrumentation, capable of monitoring either temperature or heart function (ECG), was obtained and modified extensively to permit high temperature operation, simultaneous transmission of both parameters, and automatic time-shared recording of the information. Solid state circuits, needed to obtain desired performance, were developed and incorporated into the system. The completed system includes two miniature transmitters, ECG electrodes, thermistor temperature probes, two FM receivers, a developed demodulator unit, and a dual-channel recorder. Satisfactory performance is being achieved over 200-ft ranges in general field operation.

Discussion

The need for some method of monitoring the physical condition of men working under adverse environmental conditions became apparent during maintenance work in various high temperature areas at Hanford. Through observation of body temperature and cardiac activity, it is possible to detect the onset of heat exhaustion due to over-exposure in the hostile environment. Since it would be highly impractical to make parametric measurements in the usual manner, it was decided that the logical method for monitoring temperature and ECG was by biotelemetry. The block diagram of one channel is shown in Figure 1

There are commercial biotelemetry instruments available that meet some

of the system requirements of compactness, frequency, range, and function; however, no known commercial equipment meets all of the many system requirements. Therefore, it was decided to obtain some commercial equipment, modify it as necessary, and develop other required circuits to provide a complete, operational system.

The Biocom* Model 334-AS instrumentation was obtained as it could provide monitoring of either temperature or heart function (ECG). This included a miniature transmitter, operating in the 88 to 108 MHz FM band with a range of about 300 ft, an FM tuner with an included Biocom demodulator, and the

*Biocom Company equipment using a trade-name of "Biolink" for the miniature transmitter.

FIGURE 1. System Block Diagram of One Channel

necessary electrodes, sensors, and accessories. Two instrumentation packages were obtained since two technicians ordinarily work in a team during maintenance and modification effort.

As received, the equipment operated satisfactorily for the purposes for which it was intended on the commercial market; however, it was not suited for use in high temperature environments, nor was it equipped to transmit both ECG and temperature data simultaneously. The signal recovery stages (demodulators) were inadequate for our specific application in that slight detuning of the receiver, or variations in signal strength, caused an undesired deviation in the recorded signals. Also, the recovered signal intelligence "rode" on a large negative bias since the demodulators were of the count-rate type that provide an output voltage proportional to the input frequency. This was not acceptable for the Hanford application.

Extensive circuitry modifications were developed and incorporated to satisfy the requirements of the present system. The sub-carrier oscillator was temperature-stabilized by using stable capacitors and selected temperature-compensating resistors. Simultaneous transmission of temperature and ECG data was accomplished by changing the transmitters to allow the temperature signal to determine the center (quiescent) sub-carrier oscillator frequency and the ECG signal to frequency-modulate the center frequency. On the receiver, the demodulator was changed to include flip-flop circuits for pulse standardization, balanced ratio detector demodulators, and signal commutation.

The transmitters were tested in a temperature chamber to determine stability under the expected environmental conditions. The FM carrier was extremely stable up to 140 °F, the upper testing limit; however, the sub-

carrier oscillator demonstrated excessive drift which was reduced by substituting Mylar for ceramic capacitors and by selecting temperature compensation resistors. Subsequently, the resulting drift error, as referred to body temperature, was equal to a predictable 1 °F increase when the transmitter was operating at 140 °F. Although this amount of drift is not desired electronically, it is tolerable from a safety standpoint since it is above, rather than below, the real temperature. One other transmitter modification was the incorporation of a potentiometer in the ECG amplifier; this served to control the signal gain for calibration purposes.

The commercial demodulator circuit in each tuner was of the count-rate type which provides a dc output proportional to the input frequency. Thus,

the sub-carrier signal was detected and the ECG signal superimposed upon it as an ac signal at a large bias level. However, the temperature signals were dc level changes of the order of 10 mV/°F, and their detection required a "bucking" voltage with the magnitude of the bias level. Loss of the carrier would then impress the "bucking" voltage directly across the sensitive recorder. To improve this undesired situation, a ratio detector FM demodulator was developed to produce, when properly adjusted, an output voltage proportional to the frequency change but centered about zero at some quiescent frequency. The output is also zero for frequency excursions beyond the demodulator range; hence, the recording system is protected against loss of signal. The actual response curves are shown in Figure 2. Temperature sensitivity is approximately 20 mV. °F.

FIGURE 2. Demodulator Response Curves

One system requirement was the provision for time-sharing recordings of ECG and temperature for each man. The demodulated signal contains both of these signals, and since the temperature varies quite slowly, the ECG signals can be obtained by recording the total output of the demodulator. The base-line would change, of course, as body temperature changes. For temperature, it is only necessary to remove the ECG signal by filtering, thus removing it from the demodulated output and leaving the dc voltage determined by body temperature.

Three modes of operation, as well as nine ratios of ECG to temperature recording times, are available in the system. The signal commutator is an astable multivibrator which is off, locked in one mode, or running in correspondence to ECG only, temperature only, or to both alternately. Three time constants are available on both sides of the multivibrator to determine the recording ratio of one sig-

nal to the other. The multivibrator operates relay K1 to switch the filter across the signal output, and the three controls are located on the front panel of the demodulator section. Typical recordings are shown in Figure 3. Power for the unit is obtained from a regulated ± 15 V dc power supply.

Results

The system has been used successfully in laboratory tests and in general field operation. The data obtained from the recordings, Figure 3, provide surveillance to help protect the health of the workers. The completed system is shown in Figure 4. The transmitter will operate about 36 hr on one 8.4 V mercury battery; however, after about 8 hr of operation, drift occurs in the temperature channel because of supply voltage change. Hence, batteries should be changed every 8 hr of operating time. Field operation, with transmitter to receiving antenna separation of about 200 ft, has been satisfactory.

SOLID STATE GAMMA SPECTROMETRY DEVELOPMENTS - Gary J. Dau

To become acquainted with the characteristics of the lithium-drifted germanium detectors and to explore the potential applications to gamma ray spectrometry,^(1,2) a spectrometer system was assembled. The detector is housed in a vacuum chamber similar to that of Miner.⁽³⁾ It is believed that sputtering of titanium in the ion vacuum pump may have contributed to degradation of the system performance; therefore, the ion pump was removed and molecular sieve used as the pumping agent.

The electronic components for the system consisted of an Ortec Model 201 amplifier, and a high voltage power supply. Detector output pulses were analyzed by a solid state 512-channel pulse height analyzer. Two detectors have been used to date. One detector has an active area of 1.1 cm^2 and nominal depletion depth of 2 mm; the second has an active area of 1.1 cm^2 and a nominal depletion depth of 4 mm. Both detectors were purchased from Solid State Radiations, Inc.

FIGURE 3. *Typical Recordings*

FIGURE 4. Complete Physiological Telemetry System

With calibrated sources, data were taken from which the efficiency of the detector can be determined. Figure 5 is a plot of the experimentally determined efficiency versus gamma energy for the larger detector, where the efficiency is given as counts per photon emitted. The disk-shaped sources were placed 4 cm from the detector. System resolution for this detector is 2.85 keV (FWHM) for a pulse generator signal 2.0 keV (FWHM) for 662 keV photons.

Because much of the work is concerned with the detection and identification of plutonium, a highly resolved spectrum of ^{239}Pu was desired. The plutonium spectrum is shown in Figure 6, and a portion of the ^{241}Am

spectrum is in Figure 7. Purity of the plutonium was 99.79% ^{239}Pu with the following impurity ratios: ^{240}Pu :

$^{239}\text{Pu} = 0.00163$ and ^{241}Pu : $^{239}\text{Pu} < 6 \times 10^{-6}$. Counting time was 24 hr and a 24 hr background count was subtracted.

The data presented in Figures 6 and 7 reveal emissions which have not been observed previously. A comparison of the emission energies presented here with previously reported values (4) indicates that the Ge(Li) detector has, in many cases, resolved one emission into several separate entities that were previously combined due to the lower resolving capability of older detector systems.

FIGURE 5. *Detector Efficiency versus Gamma Energy*

FIGURE 6. Plutonium Spectrum

FIGURE 7. Portion of ^{241}Am Spectrum

The spectra presented indicate that much additional work needs to be done on decay scheme analysis of these isotopes and undoubtedly many others. Lithium-drifted germanium detectors are very useful in this type of work

where high resolution is needed. They also have potential for identifying isotopes in biological studies as well as identifying trace isotopes by the X-ray fluorescence technique.

FISH ENVIRONMENT DOSE RATE MEASUREMENTS—N. S. Porter

Measurement of the external dose rate of fish reared in reactor effluent waters is of importance to aquatic biologists studying the effects of radioactivity on these vertebrates. An existing logarithmic-response area monitor was adapted to measure from 0.1 to 10^3 mR/hr in 4 decades. The detector was a plastic scintillator, 2 in. diam by 4 in. long, and a 2 in. diam multiplier phototube was used. Relative accuracy, compared with radium calibration sources, varied from ± 10 to $\pm 30\%$ depending on the reading range. A strip-chart recorder was incorporated into the system to allow continuous monitoring of any given fish trough in the facility.

Certain studies of the effects of reactor effluent on marine life involve the hatching and growing of fish in various water temperatures and effluent concentrations. The exposure facility is located near the effluent discharge lines of a Hanford production reactor; hence, the fish not only receive exposure from the contaminants in the water (beta and gamma) but also receive the gamma-ray exposure from the rest of the environment to which the controls are subjected. It is important that a method be established for measuring the relative dose the fish are receiving during the course of experiments. Another requirement is that the dose information be continuously recorded for later analysis.

A survey of available instruments that could be used revealed that the Mark III Logarithmic Area Monitor (5) could be modified to fill the initial needs of this program. As designed, the instrument was capable of monitor-

ing fields of from 1 mR/hr to 500 R/hr over 6 decades on two logarithmic scales. Automatic scaling was provided, and the probe used a 2 by 4 in. NE-102* scintillator and an EMI-9536B** photomultiplier tube.

To increase the sensitivity by at least one decade, the detector crystal volume was doubled and the high voltage capability increased from a maximum of 1200 to 1400 V. The unit was then recalibrated using radium calibration sources from 0.1 to 1000 mR/hr. The calibration curves are shown in Figure 8, a plot of source dose-rate versus meter current. A strip-chart recorder with a logarithmic scale is used to

*Nuclear Enterprises, Ltd. Winnipeg, Canada

** EMI Corporation, Ltd., Great Britain

monitor the meter current on a continuous basis as desired. Since the probe was to be used in the water with the fish, it was placed inside a double plastic bag of a thickness which did not seriously attenuate the beta energies prior to their entering the detector windows.

The overall accuracy of the instrument is approximately $\pm 25\%$ over the ranges of interest. It is noted that

the instrument calibration is based upon the available radium sources and that the response at specific gamma energies has not been accomplished to date.

Further developments are continuing on a new instrument using linear scales for greater accuracy, a waterproof probe assembly, and a more advanced solid state circuit design including field effect transistors and operational amplifiers.

DIGITAL CONTROL FOR WHOLE BODY SCANNER—E. M. Sheen, H. E. Palmer, and J. L. Stringer

Many of the whole body radiation counters throughout the world are using a scanning method because this approach is less dependent on the distribution of radionuclides in the body than is the standard tilted-chair method. The body activity varies along the body long-axis and may be concentrated in specific organs. If the activity is high, the multichannel analyzer dead time counting losses can cause significant error in the measured activity if the scanner is moving at constant linear velocity. However, this error in measured activity can be avoided if the scanner velocity is based on the multichannel analyzer live time, rather than real time. A method of providing scanner velocity based on analyzer live time is described in this paper. A digital stepping motor is used to drive the scanner, and the motor is driven by solid state circuitry using the analyzer live timer frequency divider as a source of pulses. Each pulse causes the motor to advance 1.8° . The described circuitry additions are easily incorporated into the multichannel analyzer.

In the scanning method, either the scintillation crystal or the subject is moved such that radioactive material at any body location will pass through the same sequence of positions relative to the crystal and will be counted with the same efficiency. This method achieves less dependence on the isotopic distribution in the body than can be obtained using the standard tilted chair method.

The mechanical layout in Figure 9 shows a whole body counter ⁽⁷⁾ that utilizes the scanning method.

If the activity of gamma-emitting radionuclides in the body is very low,

the loss in total count caused by the multichannel pulse height analyzer dead time is negligible. Dead time is defined as the time required by the analyzer to process a single pulse and is approximately 30 μsec , plus 0.5 μsec per channel number, for the 512-channel analyzer used by the authors.

Dead time counting losses are significant for high counting rates and, if the majority of the radioactive material is concentrated in a particular organ, that organ will not receive an equal share of counting time during constant-velocity scanning.

FIGURE 8. Calibration of Logarithmic Response Mark 111 Scintillation Monitor Using ^{226}Ra Gamma Sources (510 & 1353)

This problem is easily avoided by controlling the scanner velocity with analyzer live time rather than real time, where live time is defined as real time minus the dead time. One currently used compensation method ⁽⁸⁾ utilizes the pulses from the live timer to drive an ac synchronous motor. This method is limited in amount of tolerable frequency deviation to the motor, and a mechanical adjustment is required to

effect a change in the basic scanning time.

The method developed by the authors provides operation of the scanning bed using a stepping motor with 200 steps per revolution. The motor is coupled by a gear belt to the scanner drive screw, and the motor-drive circuitry is electrically coupled to the pulse height analyzer live time circuit. This circuit provides a frequency decrease directly related to the analyzer

FIGURE 9. System Block Diagram

dead time and effects the desired speed control. Figure 9 shows the block diagram for the scanning system. The required analyzer modifications are quite simple, as it is necessary only to add a solid state, unity gain, buffer amplifier; a forward-reverse switch; and two connectors.

Figure 10 details the required modifications. Power for the emitter followers is obtained from the live timer binary supply. The binary circuit output signal is a square wave with a normal frequency of 200 Hz for 5 min scan

time and slower by factors of two for the other scanning times. A gear-tooth rubber belt and sprockets were used to drive the scanner screw, where the sprocket tooth ratio provides a total scanning live time of 5, 10, 20, or 40 min, depending on the position of the range switch. At the limit of travel in the forward or reverse direction, limit switches short the differentiated output signal to ground. This stops the stepping motor to eliminate possible damage in case of a live time setting error, which might cause the bed to over-travel.

The experimental system operated successfully and avoided the errors caused by dead time of the analyzer. This change in the whole body scanner is considered to be a simple but valuable addition, especially for use in medical applications where higher levels of radioactivity are often observed.

A simple test was conducted using a specific radionuclide source with an activity sufficient to cause a dead time of 25% when the source was directly under the large scintillation detector. In this test, the difference in total real scanning time of the two methods was only 4%. However, the new live-time method provided a 14% increase in total count and, in addition, fully compensated for the dead time losses of the constant velocity method.

FIGURE 10. Multichannel Analyzer Live Timer Circuit Modification

MINIATURE DOSE RATE MEASUREMENT INSTRUMENT— E. M. Sheen and C. A. Ratcliffe

Solid state circuit development was completed on a miniature dose-rate meter featuring selectable signal-alarm points and with both meter and aural indication for use in locations with high levels of acoustic noise. The instrument includes a miniature high voltage supply, G-M tube detector, log count-rate meter, linear count-rate selectable alarm points, and a continuous aural output. Circuits were designed to permit trade-off between acoustic output power and for both 9- and 4-V batteries, where the drain is approximately 2.5 mA (for either battery) for nonalarming conditions.

The dose-rate instrument was developed to provide an advanced method for personnel radiological measurements in acoustically noisy environments. The requirements dictated a small size for "shirt pocket" use, continuous meter and aural indication of dose rate, and an intense aural alarm. For this instrument, the dynamic range of dose rate indication is 1 to 10^3 mR/hr, or 3 decades. The initial work on this instrument was conducted by Horvath,⁽⁹⁾ and this led to the block diagram shown in Figure 11.

The detector is a miniature, halogen-quenched, G-M tube. A thin lead shield may be used to modify the gamma energy

response. However, if the lead shield is omitted, the low energy portion of the gamma energy spectrum will be enhanced, and the indicated dose rate will be higher than the actual dose rate if the calibration is based on a high energy source, such as ^{60}Co . Output pulses from the detector are amplified by a transistor switch that provides an input signal to the logarithmic count rate circuit and to the continuous audio output circuit. High voltage for the G-M tube is provided by a circuit described by Dilworth.⁽¹⁰⁾ For application in this instrument, the current feedback is obtained from the

FIGURE 11. Dose Rate Meter Block Diagram

high frequency diode pump of the logarithmic count-rate circuit.

The logarithmic count-rate circuit follows Cooke-Yarborough⁽¹¹⁾ but uses a novel, fully saturating binary to obtain a full voltage swing for driving the diode pumps. The binary consumes very little standby power between changes of state, yet can switch the output within 50 mV of ground or the supply voltage. The doublepump logarithmic circuit drives a 5/8 in. diameter meter with the scale marked in colored bands. Although the deviation of the double-pump output from an ideal curve approached $\pm 20\%$ of the reading with a temperature coefficient of $\pm 0.1\%$ of the reading per degree Celsius, these effects are small when meter accuracy, readability, and the use of the colored bands are considered.

If numerical indication is desired, the meter could be divided into units of dose rate over the 3 decade dynamic range. Then, the error, assuming correct full scale calibration, is that due to meter movement and scale nonconformity, reading inaccuracy, circuitry, and detector gamma energy response. For the very small meter scale, the reading error is probably the major source. For example, if the indication is incorrectly read by 4% of full scale linear, the corresponding logarithmic scale error is approximately 30% of the reading for the 3 decade scale.

The audible alarm circuit uses a diode pump and voltage comparator referenced to a fixed voltage. The switch-selected activation points are determined by the capacitors used to connect the binary output to the pump circuit. The comparator output, after

amplification, is used to enable the audible alarm circuits. A degree of hysteresis is incorporated to prevent statistical signal fluctuations from improperly activating the trip.

The audible output portion is of the blocking oscillator type shown by Jones (12) with the modification that the pitch of the output is periodically modulated, by a 1 sweep/sec relaxation oscillator. The frequency varies from approximately 1 kHz to 3 kHz during a period of the relaxation oscillator. Qualitative testing of this mode demonstrated that its ability to attract attention in the presence of high am-

bient noise is superior to that of a single tone.

Two experimental instruments were assembled, one operating from 4 V and the other from 9 V. Current drain below the alarm activation point is about 2.5 mA for either system. Satisfactory operation, including alarm, was demonstrated from +5 °F to +120 °F.

Further miniaturization and packaging remains to be completed and the use of small, potted modules (attached to a printed circuit base) is planned. Overall dimensions will be approximately 2.3 by 1.1 by 4.5 in. for the finished instrument.

MEASUREMENT OF RADIONUCLIDE UPTAKE BY ALGAE—Newell S. Porter, Neil C. Hoitink, and C. E. Cushing, Jr.*

Instrumentation was developed to enable investigators to make in situ measurements of radionuclide uptake by algae. The system comprises algae and background counting chambers, pulse amplifiers, count-rate circuits, an operational amplifier, a count-rate meter, high and low voltage power supplies, and a scaler. With the exception of the commercial scaler, all circuitry is solid state. Preliminary specifications of a detection limit at least 10^4 times the natural river background levels for ^{65}Zn and ^{32}P have been realized and bettered by a factor of three.

A knowledge of the uptake rates of radionuclides by algae in the Columbia River is of fundamental importance to mineral cycling studies of this ecosystem. Studies of this phenomenon have been hampered by the necessity of destroying a part of the community for each sequential analysis and by the absence of a suitable flowing water system to simulate river conditions. The present system was developed to over-

come these problems using in situ radiation detectors coupled to an external counting system and providing for a flow of water over the sessile algae. Other environmental parameters such as light, temperature, water velocity, and ambient radionuclide concentration can be investigated with the complete system, which comprises three general components: the water flow loop, electronic equipment for detection, and the environmental incubator.

* *Biology Department*

A complete block diagram of the developed system is shown in Figure 12. Riverflow simulation is obtained using a circulating pump to move the water, Tygon tubing, and provision for injecting radionuclides into the Stream. Two GM detectors are included in the system, both with the same geometry; one reads background activity, and the other one measures that of the algae. Filtered water is added to and the other one measures that of the algae. Filtered water is added to the system through an injection "tee" and the pump is started. Through injec-

tion of radionuclides into the system uptake studies can then be performed. As water circulates in the system, the sessile algae absorb the radionuclides from the loop; consequently, the activity seen by the algae detector increases while that seen by the background detector decreases until equilibrium is reached. A lead shield is placed between the two chambers to prevent accumulated activity in the algae from influencing the counting rate of the background detector.

Pulses from the detectors are coupled to the preamplifiers and raised to

FIGURE 12. Block Diagram Algae Radionuclide Uptake Monitor

9 V. The amplified pulses drive binary flip-flop circuits, which create pulses of uniform height and shape. These pulses are amplified and used to drive count-rate circuits through one of the range coupling capacitors, as switch selected. The pulses, which occur at one-half the input frequency to the flip-flop circuits, drive linear diode-transistor charge pump circuits to provide a 0 to 5 V peak output voltage integrally linear with counting rate to within $\pm 2\%$. Output signals from the count-rate circuits are directly coupled to an operational amplifier, which is connected in an adder-subtractor mode. In this manner, the output from the background channel is algebraically subtracted from the total count rate, the difference being that due to the algae only. Thus, the current to the count-rate meter is proportional to the radionuclide uptake of the algae. As shown in the block diagram, accurate count rates from either the

background or the algae channels can be obtained using the scaler and the selector switch. Power for the circuitry is supplied by a regulated, solid state, low voltage supply. Detector voltage is provided by a blocking oscillator type, single transistor, high voltage supply, which uses corona tube regulation.

Preliminary instrument specifications called for a detection limit at least 10^4 times the natural river background levels for ^{65}Zn and ^{32}P . In the tests to date, this sensitivity has been three times better. Counting efficiency is excellent, and the flow system has been satisfactory in the closed loop in that no sloughing of the algae has been observed. The system lends itself well to a variety of experimental techniques and gives promise of becoming a valuable tool for fundamental studies of this ecosystem. The completed instrument is shown in Figure 13.

FIGURE 13. Completed Algae Radionuclide Uptake Monitor

INSTRUMENTATION TECHNIQUES FOR TOXICITY STUDIES OF INHALED RADIONUCLIDES—N. S. Porter

The specialized instrumentation required to obtain physiological data during toxicity studies of radionuclides inhaled by animals is constantly being improved and expanded. A respiration register has been developed to count automatically total respirations during the course of any given biological experiment. In addition, improvements have been made to the valve controller to facilitate the use of direct current devices.

During the course of inhalation experiments with animals, and in the subsequent study of experimental results, pathology, etc., it is often necessary to determine the total respirations of the subject. The general practice has been to use a hand-operated counter and visually detect each inspiration; however, this procedure requires much technician time. An instrument to count inspirations automatically would greatly facilitate data taking for subsequent calculations for tidal volume, total deposition, etc.

A respiration register was developed to count the respirations of test animals automatically under a variety of conditions--in the exposure laboratory during experiments, in the physiology laboratory, or during training exercises or studies with canines. The register includes a power supply, a 4-digit register, voltage comparator and relay-driver circuits, and a thermistor transducer. In operation, the thermistor transducer is placed in the inhaled air stream to sense the respirations

which cool it, thereby changing its resistance and hence, the bias on a voltage comparator. The resulting change of state across the comparator saturates a relay driver stage, thus advancing the register with each inspiration. A schematic of the device is shown in Figure 14.

The respiration register has been in continuous use during the past year and demonstrated satisfactory operation. The register response is limited by the thermal time constant of the thermistor which is 0.5 sec; therefore, the maximum respiration rate which it will follow is approximately 120/min. Figure 15 shows the completed instrument.

The inhalation-exhalation control valve previously reported (13) has been expanded into a family of different valves which include dc drivers. To accommodate both ac and dc controllers, the electronic switch power supply was modified to provide up to 30 V dc or 115 V ac power. Development has also continued to improve the transducer by making it more sensitive and rugged.

FIGURE 14. *Respiration Register
Schematic*

FIGURE 15. *Respiration Register*

RAINDROP CHARGE AND VELOCITY MEASUREMENT TECHNIQUES—C. A. Ratcliffe and N. C. Hoitink

A solid state instrument was developed which is capable of measuring charges on raindrops as low as 0.7×10^{-14} C and raindrop speeds from 30 to 1000 cm/sec. The transducer consists of a pair of shielded inductor rings, connected to low noise charge sensitive amplifiers; the raindrops pass through the inductor rings. The electrical output of one of the amplifiers is recorded (after filtering) and is proportional to raindrop charge. Both amplifier outputs are reshaped and are used to control a gated ramp voltage. The height of the recorded ramp is proportional to the time of flight of the drop between inductor rings, and thus inversely proportional to drop speed. The battery operated transducer may be operated in excess of 500 ft from the line operated recording equipment.

Previous work by others(14, 15) measured raindrop charges and masses by various techniques, including optical methods and vacuum tube type equipment. In an effort to read small charges, measure speed, and make the field equipment lighter and independent of mains power, the solid state system of Figure 16 was developed.

The system comprises a shielded inductor ring transducer, charge sensitive amplifiers, cabling, circuits for providing a "time of flight" signal, and a two channel recorder. The transducer has two inductor rings, through which the raindrops pass, with an amplifier connected to each ring. The charge-sensitive amplifiers (16) produce output voltages propor-

tional to the charges on the drops. At the recording station, these voltages are smoothed and recorded for later analysis. The voltages are also reshaped and used to gate a ramp generator on, then off. The height of the recorded ramp voltage is proportional to the time of flight of the drop between the inductor rings and thus inversely proportional to the drop speed.

The charge-sensitive amplifiers are battery operated and capable of driving at least 500 ft of coaxial cable and so may be placed in the field remote from the rest of the apparatus. Live power operates the recorder and the auxiliary circuits for shaping and filtering.

FIGURE 16. Schematic Diagram of Rain-drop System

ANIMAL ACTIVITY MONITOR DEVELOPMENT—R. L. Wilbur

In many physiological experiments, it is desirable to know the physiological response to various stimuli and control conditions. Visual observation of the test animal introduces unwanted factors and is prohibitively time consuming. A method is being developed to monitor the physical activity of an animal by providing X-Y position data and time. This paper describes a system of two animal cages with special transducers in the floor of the cages to monitor the animal's position. One cage is to be used as the control while the second will monitor the animal under test. The signals will be conditioned to provide either a digital readout or magnetic tape readout for later use on a computer. The system is being developed with enough versatility to achieve ultimately a work function system.

The system under development will consist of two cages with miniature pressure sensitive transducers situated in a matrix array on the floor of each cage. Each transducer is one leg of a bridge circuit which is activated when stepped upon by the animal (Figure 17). The small dc signals are amplified by level-detection circuits and routed to the logic and print circuitry, where the logic circuitry conditions the signals for digital or analog output, and

the print circuitry triggers the recording device whenever the animal changes position. Clock circuits provide time information, and this is sent to the output for recording. The output signals can be read out on a digital printer or placed on magnetic tape, as desired by the investigator. Resolution of the system is such that the animal's position is known within at least 1-1/2 in.; this is substantially less than the body width or one-half of the body

FIGURE 17. Animal Physiological Monitor

length of any of the typical test animals.

The cage floor (12 by 18 in.) utilizes hardware cloth as floor material to facilitate waste collection; and, with only slight modifications, this method provides the foundation for the pressure-sensitive transducers.

The hardware-cloth floor is modified by removing specific wires (Figure 18) and then coating the wires with "Uni-chrome" or some other appropriate sealant. The transducer wires and transducers are then woven into the hardware cloth to restore the floor to the original configuration. The transducer lead-in wires are insulated with tubing to isolate the sensing system from the remainder of the cage.

Transducers utilizing pressure-sensitive resistive paint are being fabricated for further detailed testing. Presently, the results indicate four times more sensitivity than for the best commercial transducers; however, more development is needed to increase the sensitivity. Table 1 shows transducer data.

The most sensitive transducer fabricated to date is shown in Figure 19.

Uniformity in cage floor structure and color is extremely important when

dealing with test animals, particularly rodents. Any discontinuity in structure or color creates an abnormal interest by the test animal, and this interest can cause the introduction of erroneous activity information into the experiment. Miniature transducers are used for the same reason.

Signal level detectors (with saturator circuits) are used to amplify the signal from 2 V dc to ± 12 V dc. Signal levels of this amplitude make it possible to use commercially available logic circuits (on cards).

The print circuit receives a signal from the signal level detectors, conditions it, and sends it to the print-command inputs on the recording equipment. This circuit operates only on a change of signal which (referred back to the cage) indicates movement on the part of the animal.

The clock circuit is a standard 24 hr electronic clock consisting of frequency division circuits acting upon the 60 Hz line voltage; an included reset returns the circuitry to the original position after the 24 hr period has elapsed.

The system is to be made in such a way as to allow for additional receptors or transducers which will increase

TABLE 1. Transducer Comparison Table

Transducer	Size, in.		Resistance, Ω	Force Applied, g
	Diameter	Thickness		
Desired	0.25	0.25	∞ to 30	10 to 20
Experimental	0.25	0.25	∞ to 30	20 to 30
Commercial	0.25	0.25	∞ to 30	100 to 150

FIGURE 28. Cage Floor With Transducers

the system capabilities. Some of the proposed additions are transducers on the walls of the cage to monitor vertical movement, weighing devices to determine food and water intake, and waste-weight devices.

This system will enable biologists to conduct tests on the work functions of various animals under a multitude of

test conditions. System capabilities will provide information directly compatible with an analog computer so that many experiments can be conducted giving position and time information. Many stochastic processes will now be possible where before inadequate and inaccurate data prevented biologists from reaching any sound conclusions on work and activity.

Transducer Material: Brass

FIGURE 19. Pressure Transducer

ANIMAL PHYSIOLOGICAL FUNCTION TELEMETRY DEVELOPMENTS—N. C. Hoitink, N. S. Porter and C. A. Ratcliffe

A measurement and telemetry system was developed to provide continuous monitoring of several physiological functions of free-ranging animals. The system comprises appropriate sensors, three channels of FM/FM telemetry, and appropriate receiving and readout instruments. Body temperature, respiration rate, and heart rate are monitored. Successful operation can be achieved over a 200 ft range with the equipment, which utilizes the standard FM broadcast band as authorized by the Federal Communications Commission for telemetry, and it employs subcarrier channels operating low-power at standard frequencies. The transmitter, packaged in a 11 in. by 3 by 6 in. case, employs all solid state circuitry and a 1.35 V mercury battery, which provides adequate energy for several days of continuous operation. The three sensors include a thermistor for body temperature measurement, another thermistor (inserted in nasal passage) for respiration rate determination, and a stainless steel cuff (containing two strain gauges) for artery encirclement and measurement of the pulse rate. The arterial cuff also provides information regarding the blood pressure of the animal; however, for the present experimental work, such information is not required. The receiving station utilizes a standard FM tuner and developed signal recovery, conditioning, and demodulator circuits. The solid state signal recovery and conditioning circuits include the necessary filters and amplifiers to separate the three circuits including the necessary filters and amplifiers to separate the three sub-carrier channels, and the demodulator employs ratio-detection FM discriminators to provide recovery of pertinent physiological data. These data are then recorded for later analysis.

Development during the past year has included completion of the blood pressure measurement channel, improvement in the existing channels, packaging, and design and construction of the signal recovery and demodulation circuits for the receiver.

The blood pressure measurement, as reported last year,⁽¹⁷⁾ is made with a commercial transducer which is essentially a strain-gauge bridge mounted on a cuff which is placed over the artery where the pressure is to be monitored. The output of the bridge is amplified and demodulated with a synchronous demodulator which is quite linear over the range of interest and more importantly has only a few millivolts of offset. The filtered output of the demodulator is used to vary the frequency of the voltage-controlled sub-carrier oscillator. Laboratory tests of electronic components were quite successful; however, the results expected from the actual measurement of the pressure in the artery are expected to fall short of expectations. This is because the transducer output appears to drift over a significant portion of the pressure range. The problem seems to be mechanical and no solutions have been found. The blood pressure channel is expected to provide pressure differential between systolic and diastolic and may give true blood pressure over short periods of time following calibration. The actual usefulness of the information and the limitations will be determined during field tests on animals. Some consideration is also being given to purchasing a different transducer which

must be implanted inside the vessel. It appears that the transducer would be compatible with the existing blood pressure channel circuitry.

No modifications of significance have been made to the temperature measurement channel as reported previously⁽¹⁸⁾ with the exception of some component size changes to optimize the performance of the circuits. The circuits include an RC relaxation type sub-carrier oscillator in which the frequency is modified by change in the resistance value of a thermistor which is the temperature transducer.

The respiration channel has been modified to convert it to an FM channel similar to the blood pressure and temperature channels. The respiration transducer is a hot thermistor in a voltage divider arrangement which produces a changing voltage as the thermistor is cooled by air passing it in the nostril. This voltage change is amplified and used to frequency-modulate another voltage controlled oscillator. The respiration rate channel, as reported previously⁽¹⁸⁾ was an amplitude-modulated channel, but it introduced some undesirable interference and also proved more difficult to recover and demodulate at the receiver. The new FM channel performs satisfactorily.

All three channels are coupled to the mixer and transmitter stages through individual bandpass filters to reduce inter-channel interference and to produce sinusoidal sub-carrier signals. The transmitter stage has been modified to include a common-base, tuned, RF amplifier following the tunnel diode oscillator. This

eliminated the carrier frequency shift which existed previously due to oscillator detuning caused by touching or moving the transmitter antenna. A slight increase in signal strength was also obtained.

The thyroid radionuclide uptake monitoring channel had been bench tested satisfactorily; however, the high voltage supply, used for the GM tube, was too large and too heavy to include in this prototype. Additional work is presently being done on a miniature high voltage supply.

The signal recovery and demodulator circuits have not been reported previously. Since all three channels are similar, only one demodulator will be described. The block diagram and specific circuits for a typical channel are shown in Figures 20 and 21, respectively. All three channels are connected to the output of a commercial FM receiver (or FM tuner). The tuner requires a preamplifier between the tuner and the signal recovery circuits. The first thing which must be done to the signals as received is to separate the sub-carrier frequencies into their respective demodulator channels. This is accomplished with commercial bandpass filters. For impedance transformation purposes, the bandpass filter is driven with a common-base amplifier and the output is coupled to the demodulator circuits

with an emitter-follower stage. The signal is then amplified in a common-emitter stage, which is fed into a level discriminator used to eliminate any small amplitude noise that might be present. The output of the level discriminator is coupled to a saturator, which presents (at its output) a square wave with the same frequency as the output of the filter. This square wave is used to drive the ratio detector demodulator to provide the analog output of the original physiological signal. The demodulator includes two tuned circuits, one tuned about 10% above and the other about 10% below the center frequency. The output of the tank circuits is then rectified and filtered by an emitter-follower output stage to drive the recorder. This type of demodulator produces a dc output proportional to the change in frequency and centered about zero volts at the channel center frequency,

The completed prototype transmitter is shown in Figure 22. It will be field tested soon and any necessary improvements made. One improvement in particular is anticipated, that being the purchase of an intravascular blood pressure transducer. The radionuclide uptake channel may also be included; however, some consideration is being given to using it separately as a single channel device.

*FIGURE 20. Typical Signal Recovery
And Demodulator Block Diagram*

Filter and Amplifier Stages

Demodulator

FIGURE 21. Typical Signal Recovery And Demodulator Circuit Details

FIGURE 22. *Completed Prototype Transmitter*

MEASUREMENT OF MIXED- FIELD NEUTRON AND GAMMA DOSE RATES—L. D. Philipp

Mixed neutron and gamma fields at reactor locations and fuel processing centers create radiation hazards. Personnel working in such areas require a knowledge of the neutron and gamma dose rates to establish safe exposure limits; thus, two instruments are being developed to measure the dose rates separately. Both instruments feature solid state circuitry, portable rechargeable battery operation, rugged construction, and detectors isolated from the main instruments with appropriate cables. With the detectors separated from the readout instrumentation, data may be taken without unnecessary exposure to operating personnel. The gamma dose rate information will be obtained using an air-equivalent ion chamber where the ion chamber current is transformed to a suitable dc voltage at the detector to avoid routing small currents through the cable. The neutron instrument utilizes a calibrated polyethylene sphere with solid state, surface barrier detectors (covered by lithium fluoride foils) to measure the neutron dose rate. The pulses from the five solid state detectors within the sphere are amplified and combined at the detector assembly, and the resultant pulses are routed to a count-rate meter in the main instrument.

Personnel requiring fast and accurate measurement of mixed neutron-gamma environmental fields need reliable, rugged, and portable instruments to establish safe exposure limits. Two instruments are being developed to satisfy these needs by providing separate neutron and gamma dose rate information.

An ion chamber, shown in Figure 23, was chosen to measure the gamma dose rate, because accurate measurements can be made independent of the neutron flux and because an ion chamber can be quite ruggedly constructed. The center electrode is constructed on a Teflon plate to obtain a high input impedance to the insulated-gate, field-effect transistor, electrometer amplifier. The amplifier transforms the ion chamber current to a dc voltage at the detector to avoid routing small currents through the cable to the readout instrumentation, which is separated from the detector so data may be obtained without unnecessary exposure to operating personnel. The final construction

and calibration of the instrument is not completed; however, a block diagram of the device is shown in Figure 24.

A method has been developed (19,20) to measure neutron dose rate independent, to a degree, of neutron energy. The method employs a polyethylene neutron-moderating sphere with a lithium iodide scintillation crystal placed at the center. The crystal is coupled to a photomultiplier tube by a light pipe and the resultant pulses are amplified and read out by a count rate meter. The relative counting rate vs. neutron energy curves for the sphere approximate the inverse of the radiation protection guide for exposure to neutrons given in NBS Handbook 63. (21) In another approach to the problem, a lithium fluoride foil placed over a silicon surface barrier diode and centered in a 10 in. diam polyethylene sphere has also been calibrated for neutron response. (22) The calibration results are shown in Figures 25 and 26.

FIGURE 23. Internal Construction of Ion Chamber

FIGURE 24. Block Diagram of Gamma Monitor

FIGURE 25. Calibration Curve for
Single Collision Dose Theory
(10 in. sphere)

FIGURE 26. Estimation of the Response
of the 10 in. Sphere to Intermediate
Energy Neutrons

The active area (50 mm^2) of the detector used to calibrate the sphere produced an average of 2.25 to 2.5 counts/min per mrem/hr. The calibration results indicate that such a detector could read an apparent dose rate five times greater than the correct value. This is the worst estimate for neutrons in the intermediate energy region. In the actual situation, the total neutron dose rate will depend upon neutrons of many energies, so the total dose rate will not be over-estimated by such a large factor. The dose rate readings will provide a much closer approximation to the actual dose rate in the region from 0.9 to 5.0 MeV. The neutron detector assembly is shown in Figure 27.

For the developmental instrument, a total of five silicon surface barrier detectors each with a surface area of 450 cm^2 should provide a response of approximately 112 counts/min per mrem/hr. The effect of placement of the detectors on the overall response is not yet known, as the instrument is not yet completed. A block diagram of the final design is shown in Figure 28. Pulses from the five diodes are amplified and summed at the detector head before being cabled to the main instrument. At the main instrument, the pulses are amplified and sent to a lower-level discriminator, a multivibrator, and a saturator circuit before going to the count rate meter.

Both instruments are powered by rechargeable nickel-cadmium batteries to allow portability and will have individual battery charging units.

Detailed calibration testing will commence as soon as the instruments are completed.

FIGURE 27. Construction of Neutron Detector

FIGURE 28. *Block Diagram of Neutron Monitor*

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