**PACIFIC NORTHWEST LABORATORY
ANNUAL REPORT FOR 1966
TO THE
USAEC DIVISION OF BIOLOGY
AND MEDICINE
VOLUME II: PHYSICAL SCIENCES
PART 4. INSTRUMENTATION**

AUGUST, 1967

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PACIFIC NORTHWEST LABORATORY
ANNUAL REPORT FOR 1966
to the
USAEC Division of Biology and Medicine
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Part 4. Instrumentation

By
Staff Members of
Instrumentation Section
Applied Physics and Electronics Department

Edited by
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These reports are drawn principally from personnel of the Instrumentation Section of the Applied Physics and Electronics Department. Contributions and coauthors from other organizations may also be included and occasional related activities not sponsored by the Division of Biology and Medicine may be included. Such facts are acknowledged by footnotes.

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AQUATIC ENVIRONMENT DOSE RATE MONITOR

N. S. Porter

Measurement of the external dose rate to fish living in reactor effluent waters is of importance to aquatic biologists studying the effects of radioactivity on these vertebrates. A waterproof scintillation detector, coupled to an operational amplifier, a dose rate meter, high and low voltage power supplies, and a strip-chart recorder comprise the completed system developed for this purpose. The detector comprises a 3 in. diam by 3 in. long plastic scintillator coupled to a 2 in. diam photomultiplier tube in a waterproof aluminum housing. At 0.1 mR/hr, the relative accuracy of the instrument, as compared with radium calibration sources, is +15%, but it is nominally better than $\pm 10\%$ over the upper ranges. With the exception of the photomultiplier and corona regulator tubes, all circuits and components are solid state. The completed instrument provides the required dose rate measurements from 0.1 to 10 mR/hr.

DISCUSSION

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 receive not only beta and gamma exposure from the contaminants in the water but also background gamma-ray exposure from the environment in which they are tanked. It is important that a method be established for measuring the relative dose

that the fish are receiving during the course of experiments. Another requirement is that the dose information be continuously recorded for later analysis.

The initial needs of the study were filled by using an available Logarithmic Area Monitor⁽¹⁾ modified for use in the fish troughs.⁽²⁾ Further development resulted in the more accurate, linear instrument using solid state components and techniques, shown in block diagram form in Figure 1. Detection of the various energies found in typical effluent water is accomplished using a 3 in. long by 3 in.

FIGURE 1. Block Diagram

diam N.E.-102* crystal mounted on a 2 in. EMI-9536B** photomultiplier tube with its voltage divider network connected as in Figure 2. Note that negative high voltage is applied directly to the cathode and that the anode current is measured as a function of the incident dose rate. Since the cathode prefers to operate at ground potential, considerable electrostatic stress is experienced between the cathode and the probe holder, which can, and often does, increase noise and lower the performance and life of the tube. Consequently, the magnetic shield surrounding the tube was insulated and floated at cathode potential. Ideally, the detector should "see" all the activity to which the marine inhabitants are exposed, including gamma rays from 0.32 to 2.75 MeV and beta particles ranging from 0.30 to 2.86 MeV. Such a detector would require a very thin window and would leave the housing structurally weak. As a compromise,

and considering that the most abundant isotopes are those with the highest beta and gamma energies, the detector was fabricated with a front window of 0.010 in. aluminum and a side window of 0.020 in. aluminum over the crystal area.

The scheme used to monitor the anode current is shown in Figure 3 (the circled letters are pin designations for the plug-in circuit board). Basically, the Nexus[†] SQ-1 operational amplifier is used to convert the input current to an analog voltage large enough to drive the output current through the meter impedances. Maximum detector current for full scale deflection is 1 μ A, and since the output voltage of the SQ-1 equals the input current times the feedback resistor, maximum output voltage is 5 V. Typical offset current associated with the SQ-1 is ± 10 nA; therefore, P1 is used to supply that current and zero the meter for no input. A one mA meter movement with two linear scales, 0-1 and 0-5,

* Nuclear Enterprises, Ltd., Winnipeg, Canada

** EMI Corporation, Ltd., Great Britain

[†] Nexus Research Laboratories, Inc., Canton, Massachusetts

EMI 9536B Photomultiplier Tube
With 3 in. x 3 in. NE 102
Crystal and Floating Magnetic
Shield Maintained at Cathode
Potential

FIGURE 2. Detector Details

is provided on the front panel for visual monitoring, while a 1 mA strip chart recorder is used for continuous recording. With the recorder connected and an input current of 1 μ A, P3 is adjusted to cause 1 mA to flow through the meter and recorder. With the recorder removed, P4 is then adjusted to maintain a 1 mA current through the meter, thus preserving identical cir-

cuit impedances either with or without the recorder. The capacitor bypassing the feedback resistor is used to increase the system time constant and average out statistical variations at the detector.

The operating voltages required for circuit operation are furnished by an Acopian* Model 15B40DL plug-in power supply powered from the 115 V ac mains. The two, 100 μ F capacitors across the outputs serve to eliminate possible oscillations from outside the supply. Figure 4 shows the wiring details.

A simple blocking oscillator, voltage doubler high voltage supply is used to power the photomultiplier tube. This power supply⁽³⁾ is unique in that it employs a feedback technique which avoids the inherent disadvantages of shunt voltage regulation, maintains constant corona-tube current, and uses the tube as a voltage reference rather than as a current shunt. Dropping resistors are used to adjust the voltages required for the full scale currents on the various ranges. The circuitry is shown in Figure 5. Maximum current through the dynode voltage divider network is 13.5 μ A on the 0.5 mR/hr range.

After being thoroughly tested and adjusted, the completed instrument, shown in Figure 6, was calibrated in a number of known radium gamma fields. The results, graphed in Figure 7, indicate the overall instrument accuracy to be $\pm 10\%$ over the desired ranges. Normal operation is expected to be between 1 and 10 mR/hr. When using

* Acopian Technical Company, Easton, Pennsylvania

positioned to obtain it. By selected placement of the probe, the maximum or minimum exposure may also be recorded. The instrument is presently being used in the field and no problems have been encountered.

D1, D2 = Unitrode US50
 K = Circuit Board Pins
 T = Microtran M-8050

FIGURE 5. High Voltage Power Supply

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FIGURE 6. Completed Dose Rate Meter

FIGURE 7. Fish Dose Rate Meter Calibration

REFERENCES

1. W. G. Spear. Unpublished Data, General Electric Company, Richland, Washington. 1962.
2. N. S. Porter. "Fish Environment Dose Rate Measurements", *Pacific Northwest Laboratory Annual Report for 1965 in the Physical Sciences, Volume 4: Instrumentation*, BNWL-235. Pacific Northwest Laboratory, Richland, Washington, May 1966.
3. E. M. Sheen. Unpublished Data. Pacific Northwest Laboratory, Richland, Washington, (Personal, Communication)

MINIATURE DOSE RATE MEASUREMENT INSTRUMENT

E. M. Sheen and C. A. Ratcliffe

An improved miniature pocket-size dose rate measuring instrument provides continuous meter and aural indication of the dose rate and has a high intensity selectable aural alarm. This instrument employs a G-M tube detector, 3 decade log count rate meter, and a 3 range linear count rate selectable alarm circuit. Circuits were designed to operate from either a 4 or 9 V Mercury battery to permit trade-off between aural output power and battery life. For low dose rates, the power consumption is only 10 or 25 mW when operated from the 4- or 9-V batteries, respectively.

The circuitry design permits the log-rate indication to be optionally omitted without modification of the linear alarm trip circuit. Continuous aural indication is also optional and, if used, it is electronically inhibited during the high intensity alarm output (wailing) to increase the apparent output sound intensity.

DISCUSSION

The miniature dose rate instrument previously described,⁽¹⁾ was completed and improved to increase the apparent

alarm output sound intensity. This 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 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 .

A block diagram of the system is shown in Figure 1. 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.⁽²⁾ For application in this instrument, the current feedback is obtained from the high frequency diode pump of the logarithmic count-rate circuit.

The logarithmic count-rate circuit follows Cooke-Yarborough⁽³⁾ but uses a novel, fully saturating binary to obtain a full voltage swing for driving the diode pumps. This binary also operates an audible alarm circuit which 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 energize the audible alarm circuit. A degree of

FIGURE 1. Dose Rate Meter Block Diagram

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⁽⁴⁾ with the modification that the pitch of the output is periodically modulated, by a 1 sweep/sec relaxation oscillator. Qualitative testing of this mode demonstrated that its ability to attract attention in the presence of high ambient noise is superior to that of a single tone. Experiments in the presence of background noise indicated that inhibiting the randomly occurring aural pulses due to the radiation greatly enhances the intensity of the alarm tone.

Figure 2 shows the details of the instrument circuitry. The high voltage supply comprises transformer T1, transistors Q1 and Q2, and associated components arranged in a blocking oscillator configuration with R1 supplying the base current used at low count rates. Output pulses from transformer T1 drive a voltage multiplying rectifier network to generate the dc high voltage for the G-M tube. Selection of diode D1, which avalanches in the reverse direction to provide a nearly constant output voltage, ensures G-M tube operation on its plateau. At high count rates, the output current of the high voltage supply is increased by means of a feedback path which increases the base current of Q1 by sensing the voltage from the high frequency portion of the logarithmic count rate circuit. Power consumed by the circuit is about 2.4 mW with a low incoming count rate.

Positive output pulses from the G-M tube (an Amperex 18509) are inverted

by transistor switch Q3 and operate the low power binary, Q9 through Q13 with associated components. Power consumption of this discrete component binary is only 0.3 mW as compared with 8 to 16 mW consumed by typical low power integrated circuit binaries. This binary operates down to a 30 μ sec pulse-pair resolution, which is amply fast for the application, and provides a full voltage swing bipolar output capability of 1 mA or more. Output voltage transitions are to within 50 mV of ground and the voltage supply.

The binary output pulses operate the Cooke-Yarborough logarithmic count rate circuit and the quasi-linear count rate circuit in the alarm trip. The double pump logarithmic circuit drives a 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, if correct full scale calibration is assumed, 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 quasi-linear rate circuit comprises the range selection capacitors C15-C18; the diode pump uses D11, D12, C19, and R25. The alarm trip circuit comprises Q14-Q17 and consists of a differential voltage comparator and saturating transistor switches. Resistor R31 provides a current path to change the comparison voltage on the base of Q15, preventing statistical counting fluctuations from improperly deactivating the alarm.

At the alarm trip point, the trip circuit output energizes the acoustic alarm. The basic alarm tone is generated by a blocking oscillator (Q5, T2 and associated components). The frequency is modulated by a very low frequency relaxation oscillator, Q8, and associated amplifier, Q6 and Q7. The resultant output is a "wailing" high frequency note which is easily discernible in the presence of high ambient noise. To permit larger acoustic output intensity, the design optionally provides 9.6 V or 4 V to the alarm blocking oscillator. Nominal working voltage for the other circuits is 4 V, and the entire instrument may be operated from a 4 V Hg battery. When using 9.6 V for the larger output, a voltage regulator (D13, Q18, Q19) provides 4 V

to all circuits except the audio oscillator.

Current drain below the alarm activation point is about 2.5 mA for either system. Satisfactory operation, including alarm, was demonstrated from +5 to 120 °F. A prototype instrument was packaged using 6 small, potted modules to contain the circuitry. Overall dimensions are approximately 2.3 by 1.1 by 4.5 in. for the prototype instrument.

REFERENCES

1. E. M. Sheen and C. A. Ratcliffe. "Miniature Dose Rate Instrument", Pacific Northwest Laboratory Annual Report for 1965 in the Physical Sciences, Volume 4: Instrumentation BNWL-235 4, pp. 14-16. Pacific Northwest Laboratory, May 1966.
2. R. H. Dillworth and C. J. Borkowski. Personal Radiation Monitor, ORNL-3058. Oak Ridge National Laboratory, Oak Ridge, Tennessee. October 18, 1961.
3. E. H. Cooke-Yarborough and E. W. Pulsford. "Accurate Logarithmic Counting Rate Meter Covering a Wide Range", Proceedings of the Institute of Electrical Engineers, vol. 98, pt. 2, p. 196. 1951.
4. A. R. Jones. "Miniature Warning Dosimeter", Health Physics, vol. 11, pp. 363-367. 1965.

LIVE-TIME AND HALF-LIFE CONTROL OF SCANNER
FOR WHOLE BODY RADIATION COUNTER

E. M. Sheen and H. E. Palmer*

INTRODUCTION

Many of the whole body counters throughout the world are now using a scanning method for counting to achieve less dependence on the isotopic distribution in the body than can be obtained using the standard tilted chair method.⁽¹⁾ 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. However, this approach can result in large errors due to analyzer dead time problems and to the decay during scanning of the radionuclides in the body. Methods to compensate for the dead time counting losses during experiments were described previously.⁽²⁾

This paper describes a system that permits the scanning of low-level distributed sources of short half-life radionuclides in a manner to provide a constant spectrometer count calibration versus scanner displacement. Thus, the developed system reduces errors caused either by multichannel analyzer dead time or by radionuclide decay during the scan. Life-time control is accomplished by operating the scanner with a stepping motor and reducing the input frequency directly with multichannel analyzer dead time. Reducing the frequency exponentially results in scanner

velocity decay that follows the radionuclide decay to give a constant calibration during the scan.

DISCUSSION

Live-Time Control

The mechanical configuration in Figure 1 shows a whole body counter⁽³⁾ which 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 dead time of the multichannel pulse height analyzer is negligible. Dead time, defined as the time required by the analyzer to process a single pulse, is approximately 30 μ sec (plus 0.5 μ sec 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 radioactivity is concentrated in a particular organ, that organ will not receive an equal share of counting time during constant-velocity scanning.

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 compensation method⁽⁴⁾ utilizes the frequency from the live timer as a signal source for an ac synchronous motor; however, this method is limited in amount of tolerable frequency deviation to the motor, and a mechanical

* Radiological Sciences Section

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FIGURE 1. System Block Diagram

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 live time circuit. This circuit provides a frequency decrease directly related to the analyzer dead time and effects the desired speed control. The required

analyzer modifications are quite simple, since it is necessary only to add a unity gain buffer amplifier, a forward-reverse switch, and two connectors.

Figure 2 details the required modifications for the analyzer. 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

FIGURE 2. Multichannel Analyzer Live Timer Circuit Modification

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 connect 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.

Scanner Control For Short Half-Life Radionuclides

If the scanner has constant velocity and the radionuclide half life is the same order of magnitude as the scanning time, the calibration of gamma spectrometer counts per unit activity

will vary during the scanning time. However, if the scanner velocity decreases exponentially with the same half life as the radionuclide, the calibration in terms of counts per unit activity will be constant with scanner position.⁽⁵⁾ A very simple and convenient means of obtaining the desired velocity profile is to operate the scanner with a digital stepping motor and to decrease exponentially the input frequency, which is obtained from the signal generator shown by Figure 3. In this circuit, an RC network is charged to a calibrated initial voltage and allowed to decay during the scanning time. This voltage is measured with an electrometer input operational

FIGURE 3. Exponential Decay Frequency Source

amplifier that has negligible input current compared with the current through the time constant determining resistor. The amplifier (a voltage follower) drives any convenient voltage-controlled oscillator, whose output frequency is divided by a binary chain to provide the nominally desired frequency, which must be less than maximum operating stepping motor frequency.

For the half-life compensation system, the dead time losses must be corrected mathematically or be negligible.

RESULTS

The experimental dead time compensation 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, compensated fully for the dead time losses of the constant velocity method.

The half-life correction system was readily adjusted to errors of less than 0.3% for 20 min (or less) half-life times and exhibited negligible drift over a several-month period. The system, which has contributed to the success of several experiments involving short lived internal radionuclides, should also be extremely helpful for studies involving short half-life isotopes induced by low level neutron activation, such as recently performed by several investigators.^(6,7)

ACKNOWLEDGEMENT

G. D. Crouch skillfully assembled the electronic circuitry for the described systems.

REFERENCES

1. H. E. Palmer and W. C. Roesch. "Scanning Counter," Research and Development Activities in the Radiological Sciences, HW-70050. General Electric Co., Richland, Washington. 1961.
2. E. M. Sheen, H. E. Palmer, and J. L. Stringer. "Digital Control For Whole Body Scanner," Pacific Northwest Laboratory Annual Report for 1965 in the Physical Sciences, Volume 4: Instrumentation, BNWL-235 4, pp. 11-14. Pacific Northwest Laboratory, Richland, Washington. May 1966.
3. H. E. Palmer and W. C. Roesch. "A Shadow Shield Whole Body Counter," Health Physics, vol. II, pp. 1213-1219. 1965.
4. R. A. Dudley. Unpublished Data, International Atomic Energy Agency. Vienna, Austria. (Personal Communication).
5. W. C. Roesch. Unpublished Data, Pacific Northwest Laboratory, Richland, Washington. (Personal Communication).
6. J. Anderson, S. B. Osborn, R. W. S. Tomlison, D. Newton, J. Rundo, L. Salmon and J. W. Smith. "Neutron-Activation Analysis in Man In-Vivo," The Lancet, pp. 1201-1205. December 5, 1964. Also presented at Annual Health Physics Society Meeting, Houston, Texas. June 21, 1966.

MEASUREMENT OF MIXED-FIELD NEUTRON AND GAMMA DOSE RATES

L. D. Philipp

The existence of mixed neutron and gamma sources at both the reactor locations and the fuel processing centers creates the potential for radiation exposures. Those who monitor personnel working in such areas require a continuous knowledge of the neutron and gamma dose rates to establish safe exposure limits. Thus, two instruments have been developed to separately measure the dose rates. The developed instruments feature solid state circuitry, portable rechargeable battery operation, rugged construction, and detectors isolated from the main instruments with appropriate cables. Thus, measurements may be made without unnecessary exposure to personnel.

The gamma dose rate information is 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 gamma instrument has been tested for temperature dependence, neutron response, and energy dependence with satisfactory results.

The neutron instrument features a calibrated polyethylene sphere with solid state, surface barrier detectors (covered by lithium fluoride foils) to measure the neutron dose rate. Signal pulses from the five solid state detectors are amplified and combined at the detection assembly and the resultant pulses are routed to a count rate meter in the main instrument. Calibration tests have been completed.

DISCUSSION

Gamma Instrument

A bakelite ion chamber was chosen for its air equivalence property and for the relatively high gamma to neutron rejection ratio. Features of the chamber include: a guarded center electrode, a container for desiccant pellets, and access holes for filling the chamber with dry air. Many of the construction details of the ion chamber have been discussed previously.⁽¹⁾ The experimental response of the ion chamber (Figure 1) is 4×10^{-13} A per mR/hr.

A block diagram of the completed gamma instrument is shown in Figure 2. The detector consists of an ion chamber, a solid state electrometer amplifier, and a remote linear range switch. The ion chamber current is converted to dc at the detector by the amplifier to avoid routing small currents through the cable to the readout instrumentation. The remote linear range switch is controlled at the readout instrumentation, which is separated from the detector to permit data acquisition without unnecessary exposure of personnel. The dc voltage from the detector is metered at the readout instrumentation by one of the eleven linear operating ranges. The lowest

range is 1 mR/hr and the highest range is 100 R/hr.

The gamma instrument, shown in complete form in Figure 3, was temperature tested by inserting the complete assembly in a controlled environment. A ^{60}Co source was used in a fixed geometry and the temperature was varied from -2 to +120 °F. The results indicated that the instrument response changed less than $\pm 2\%$ over that temperature range.

Several experiments were performed to establish the gamma to neutron rejection ratio for the ion chamber. The chamber response was compared with the response of both an aluminum wall ion chamber and a BF_3 neutron monitor to a PuBe source. The response was recorded both with and without lead shielding between the source and the detectors in order to place limits on the ion chamber neutron response. Without the shielding, the response of the gamma monitor was considered to be completely due to neutrons. This pessimistic assumption results in an absolute maximum response of 7.5 mR/hr per 100 mrem/hr. With 4 in. of lead between the source and the detectors, the response of the aluminum wall ion chamber was considered to be completely due to gamma rays. This assumption resulted in an absolute minimum response of 3 mR/hr per

100 mrem/hr. Thus, the gamma to neutron dose rate rejection ratio was established to be between 3% and 7.5%.

To determine the energy dependence of the gamma instrument, gamma irradi-

ation from a Van de Graaff generator was used. The energy range of gamma irradiation was from 0.6 to 2 MeV. Within the range tested, the instrument was accurate to within $\pm 5\%$ of the known dose rate.

FIGURE 1. Ion Chamber Current Versus Voltage with Gamma Dose Rate as the Variable Parameter

FIGURE 2. Block Diagram of Gamma Monitor

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FIGURE 3. Completed Gamma Monitor

Neutron Instrument

A method developed to measure the neutron dose rate independent of neutron energy is the neutron moderating sphere.^(2,3) The method employs a polyethylene sphere with a thermal neutron sensitive $^6\text{Li I(Eu)}$ scintillation crystal placed at the center.

Moderated neutrons are detected by photomultiplier as scintillations resulting from the $^6\text{Li(n,}\alpha\text{)}^3\text{H}$ reaction. The resultant pulses are amplified and read by a count rate meter. A 10 in. diam sphere has a reasonably similar response to incident neutrons from thermal to 7 MeV as does the human body. Thus, the relative counting

rate versus incident neutron energy curve for the sphere approximates the inverse of the radiation protection guide (RPG) information given in MBS Handbook 63.⁽⁴⁾ However, the scintillation system within the sphere is quite sensitive to gamma rays. Gamma discrimination is obtained by using offset amplifiers or discriminators. Typical discrimination levels result in a few counts per minute from a 1 R/hr ^{60}Co gamma flux.⁽³⁾

To reduce the gamma sensitivity, a detector employing a lithium fluoride foil placed over a silicon surface barrier diode was used to replace the scintillation system.⁽⁵⁾ In this case, the diode detects the reaction products from the $^6\text{Li}(n,\alpha)\text{T}$ reaction. This system has the disadvantage of having a low neutron detection sensitivity

compared to that of the scintillation method.

The neutron measurement approach described here is shown in block diagram form, in Figure 4. To increase the sensitivity, five surface barrier silicon diodes, covered with lithium foils, are placed within the 10 in. diam sphere. Pulses from the five diodes are amplified independently and summed in the detector housing before being cabled to the main instrument. At the main instrument, the pulses are amplified before driving a lower-level discriminator and count rate meter circuit. The output meter reading is directly proportional to incident neutron dose rate. Range of readout is from 3 mrem/hr to 1 rem/hr in six steps. The completed instrument is shown in Figure 5.

FIGURE 4. Block Diagram of Neutron Monitor

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FIGURE 5. Completed Neutron Monitor

The active area (50 mm^2) of the single diode used by A. J. Ahlquist⁽⁵⁾ produced an average of 2.25 counts/min per mrem/hr. The present instrument system uses five larger diodes (each 450 mm^2), placed in the sphere as shown in Figure 6, for a total surface area 45 times that used previously. The response of the system was approximately 90 counts/min per mrem/hr. The sensitivity of the detection system was isotropic except when the preamplifier chassis was placed directly between the incident neutrons and the sphere. In this case, the output count rate was reduced by about 23%.

Four data points were taken and normalized to compare with the previous work of A. J. Ahlquist.⁽⁵⁾ Three of the calibration points (Figure 7) were obtained using a positive ion Van de Graaff accelerator, and the points compared favorably with the previous work. The fourth data point was obtained at the PNL Thermal Test Reactor. The thermal neutron response was shown to be a factor of three higher than the inverse of the RPG. The high response to thermal neutrons indicates that, due to the geometry of the diodes, the detector tends to respond as an 8 in. sphere for lower energy incident neutrons.

Two methods to correct the low energy neutron response have been briefly considered. One method would be to place a thermal neutron shield foil around the present sphere. A second approach would be to use a larger sphere. Both methods will tend to correct the problem, but consideration must also be given to accepting the present conservative measurement.

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FIGURE 6. Construction of the Neutron Detector Assembly

FIGURE 7. Response of the 10 in. Sphere to Neutrons of Various Energies

Several tests are yet to be completed on the neutron instrument. The electronics will be temperature tested and the gamma sensitivity will be measured.

The basic system concepts were described in a technical paper presented in June 1966.⁽⁶⁾

REFERENCES

1. G. L. Erickson. New Ionization Chamber for HAPO Six-Decade Health Monitoring System, RL-REA-2560. General Electric Co., Richland, Washington, October 5, 1965.
2. R. L. Bramlett, R. I. Ewing, and T. W. Bonner. "A New Type of Neutron Spectrometer," Nuclear Instruments and Methods, vol. 9, pp. 1-12. October 1960.
3. D. E. Hankins. A Neutron Monitoring Instrument Having a Response Approximately Proportional to the Dose Rate from Thermal to 7.0 MeV, LA-2717. Los Alamos Scientific Laboratory, 1962.
4. H. H. Rossi, Chairman, National Committee on Radiation Protection and Measurements Subcommittee 4. Protection Against Neutron Radiation Up to 30 Million Electron Volts, National Bureau of Standards Handbook 63. 1957.
5. A. J. Ahlquist. Calibration of a Silicon Surface-Barrier Detector to Read Neutron Dose Independent of Incident Energy. Master of Science Thesis, University of Washington, 1965.
6. L. D. Philipp. Mixed-Field Neutron and Gamma Dose Rate Measuring Instrument, presented at Health Physics Society Annual Meeting, Houston, Texas. June 1966.

WOUND COUNTING WITH SOLID STATE DETECTORS

K. L. Swinth

A developed solid state detector system, now being fabricated, will allow accurate measurement of the depth at which a plutonium particle is located in tissue. The system will determine the transmitted intensities of the three, L X-rays of plutonium and their distinct tissue absorption coefficients to permit measurement of the thickness of the interposed tissue.

DISCUSSION

A recurring problem in health physics is the location of plutonium particles embedded in surface tissue. Since one body burden of ^{239}Pu is $0.65 \mu\text{g}$ (a sphere about 90 microns in diameter), it is virtually impossible to visually locate a particle. This has led to removal of more tissue than is necessary in certain cases.

Collimators have inherently poor depth resolution, but a technique using the distinct absorption in tissue of the 13.6 keV, 17.2 keV, and 20.1 keV X-rays of ^{239}Pu is presently being developed. By knowing the original intensities of the three X-rays and their absorption coefficients for tissue, the ratios of the transmitted intensities can be used to calculate the depth at which the particle is located.

Figure 1 shows how the calculated ratios of the three X-rays vary with the amount of interposed tissue. The unattenuated ratio of the 13.6:17.2:20.1 keV X-rays has been taken as 4:4.67:1.⁽¹⁾ One can see that large differences in the transmitted intensity occur for small thicknesses of tissue. The ratio of the 13.6 keV X-ray to the 20.1 keV X-ray shows the steepest slope and should be the most accurate measure of depth; however, for very low levels of activity, the ratio of the 13.6 keV X-ray to the 17.2 keV X-ray may be more accurate due to the low intensity of the 20.1 keV X-ray.

Application of this interesting technique requires a high efficiency, high resolution detector that can be

placed near the wound. The recently developed lithium-ion-drift silicon detectors with a cooled input preamplifier adequately meet the necessary requirements. Using the above technique and an 80 mm^2 silicon detector, it was estimated that a 1 nCi source under 2.5 mm of tissue could be located to $2.5 \pm 0.1 \text{ mm}$ in a 1 min counting period. The location of a plutonium particle by this technique should be better than indicated for

FIGURE 1. Ratios of Plutonium X-ray Intensities Transmitted Through Various Thicknesses of Tissue

high levels of activity, but errors will be caused by 1) distributed or multiple sources, 2) self-absorption in the source (half thickness of plutonium for 13.6 keV X-rays is 2.96×10^{-4} cm), 3) errors in the knowledge of absorption coefficients or in the experimental calibration, and 4) a small geometrical error caused by the solid angle intercepted.

To explore the application of this technique, a detector with better than 0.9 keV resolution (FWHM) at 17 keV was obtained. A special housing was fabricated for the detector and a cooled preamplifier stage. The added housing attaches to a vacuum chamber similar to that of Miner.⁽²⁾ The housing has an aluminum window that absorbs about 40% of the 13.6 keV X-rays but will eventually be replaced with a thin window of beryllium.

Various types of cooled preamplifiers are to be tested with our detector before proceeding with the final system. Preliminary measurements with the first test preamplifiers have allowed us to resolve the three plutonium X-rays, but better resolution is anticipated.

Figure 2 shows the cryostat and preamplifier system for a silicon diode with a source being positioned for counting.

REFERENCES

1. H. J. Israel. "Soft Radiations from Pu^{239} ", *Phys. Rev.*, vol. 88, pp. 682. 1952.
2. C. E. Miner. *Mountings and Housing for Lithium Drifted Silicon and Germanium Detectors*, UCRL - 11946. University of California, February 1965.

COUNTING OF PLUTONIUM IN THE LUNG

H. V. Larson* and P. E. Bramson*

Several detectors have been purchased or fabricated to evaluate the quantity of plutonium deposition in the human lung. The study includes an intercomparison of proportional counters, scintillation counters, and solid state detectors. The purpose of this intercomparison is to

determine which of the counters is most suitable for routine use at Hanford. A lead enclosure was fabricated to shield and house the lung counters and subjects being examined. The first counters to be intercompared will be an array of sodium iodide crystals designed by Radiological Physics and a proportional counter designed by Dr. R. Maushart, Karlsruhe, Germany.

* Dosimetry Technology Section

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*FIGURE 2. Cryostat and Preamplifier
for Silicon Diode Showing a Source
Being Positioned for Counting*

The detection limit for ^{241}Am in the human lung was established at 1 nCi using a 4 in. x 9 in. NaI(Tl) detector, the iron-room whole-body counter, and measuring the 60 keV gamma rays. This limit was demonstrated using a "Remab" Phantom whose lung cavities were filled with a mixture of lung-tissue equiv-

alent material and 1 nCi of ^{241}Am . Estimation of a lung burden of plutonium may be approached in this manner using the 4 in. x 9 in. detector when the previous history of the plutonium is known and the relationship of the rate of the removal of plutonium to that of americium is established.

ANIMAL ACTIVITY MONITOR DEVELOPMENT

R. L. Wilbur

INTRODUCTION

The physical activity and expended energy exhibited by irradiated rodents greatly affects the biological half-life of the isotope in the test animal. Increased physical activity results in less isotope retention in the body than that retained by sedentary rodents. At present, it is quite difficult to acquire quantitative information on the amount of expended energy or the activity patterns of rodents. This report, a continuation of previous effort,⁽¹⁾ describes a system that is far more sophisticated than previously reported and provides both expended energy and rodent positional data in digital form. Two sensor systems associated with the rodent positional monitor are discussed. The sensor system for the energy monitor utilizes accelerometers which circumvent the un-

desirable requirement of computing the expended energy with arbitrary physical constants. The system is to utilize a computer for data evaluation. Connections will be incorporated into the system to allow the use of a small on-line computer in place of the magnetic tape recording unit.

DISCUSSION

The envisioned composite system (Figure 1) is a six cage system, each cage providing acceleration, position, and time information to the signal conditioning circuitry.

The dynamic expended energy is measured by an accelerometer. From basic mechanics, $E = 1/2 mv^2$, where E = energy, m = mass of cage floor, and v = velocity. This can be changed to $E = 1/2 m(at)^2$ where a = acceleration and t = time. Since we are interested

only in the general expression and $a = f(t)$, the energy $E = f(at)^2$. This can be generally expressed in integral form: $E = \int (adt)^2$.

Figure 2 shows the cage configuration and the position of the acceler-

ometer. The floor is light weight hardware cloth and is four point suspended with sponge rubber as shown. Displacement of the floor by activity of the rodent imparts a force to the accelerometer. The accelerometer in

FIGURE 1. Animal Activity Monitor System--Block Diagram

FIGURE 2. Animal Activity Monitor System--Prototype Cage Configuration

turn then produces an output voltage proportional to acceleration.

This voltage is amplified and integrated with respect to time. The integrated signal is sent directly to the energy register or is further conditioned to make the information acceptable for magnetic tape recording.

Rodent position is determined by a three dimensional matrix of infrared detectors as shown in Figure 2. Whenever a light beam is interrupted, the level detectors note the change and the print circuits are energized printing out the new position of the rodent in the particular cage. Each cage has the same configuration of sensors and circuitry and it is the responsibility of the logic circuits to maintain the time sequence when two or more rodents are moving about at the same time.

A test cage was fabricated with only the infrared position sensors installed.

A two week testing period was initiated to determine any noticeable behavioral changes in the rodent's activity due to the infrared. As far as visual observations and printer readout can be trusted, there were no discernible activity pattern changes. These results were also compared with the system results from the pressure transducer configuration reported last year⁽¹⁾ and no apparent changes were noted in activity pattern. No attempt is being made to imply that infrared does not affect the rodent or that the rodent is unaware of the infrared beams, only that a two week test indicated no discernible activity and behavior pattern changes.

The logic circuitry conditions and routes the energy, position, and time information for the particular readout device used. It also provides the time base information for the integration of acceleration data. These circuits are

quite versatile because of the many readout devices which are utilized by the biologists.

There is space in the system to allow for food, water and waste sensors and the associated necessary circuitry. These sensors allow for a measurement of potential energy available into the system.

The infrared position sensors at this time create enough heat to produce a 1 °F temperature gradient diagonally across the cage. Attempts to reduce this effect have been unsuccessful to date. An alternative sensor system, ultrasonics, not yet tested, will be tried to see if the rodents' position can be determined to the required distance of 1.5 in. resolution.

Energy calibration difficulties arising from the square cage configura-

tion may call for a cage configuration change. Present calculations seem to favor a circular cage. Concomitant with this change will be one to a three point suspension system instead of the four presently utilized. This change will not alter the basic methods used to determine energy in any way. Neither will it affect the method being used to determine position.

REFERENCES

1. R. L. Wilbur. "Animal Activity Monitor Development", Pacific Northwest Laboratory Annual Report for 1965 in the Physical Sciences, Volume 4: Instrumentation, BNWL-235 4, pp. 22-25. Pacific Northwest Laboratory, Richland, Washington, May 1966.

TIDAL VOLUME AIR MEASUREMENT

R. L. Wilbur

Studies of deposition of inhaled radionuclides in canines require an accounting of the amount of air respired. The tidal volume information and the known concentration of the radionuclide aerosol yield approximate levels of deposition. Also desirable is continuous monitoring of the respiration parameters during exposure to determine changes in respiration pattern. This report describes a monitor for measuring the total number of respirations, the tidal volume per inhalation, and the tidal volume per exposure. The information is displayed on a digital printer. Volume flow is measured with a stainless steel venturi tube and a sensitive differential pressure transducer mounted in the inhalation path. The output signal of the pressure transducer is recorded on a strip chart for subsequent comparison with digital information. Signal conditioning circuitry accepts signals from the pressure transducer and, with the aid of a voltage to frequency converter, converts the slowly varying dc voltage to Binary Code Decimal (BCD) information, which is routed to the digital printer. Print and reset commands are generated by the trailing edge of the flow signal to make the system fully automatic during exposure. Manual controls include 1) a "total" switch, activated at the end of an exposure, to record the total number of breaths and total tidal volume;

2) a manual reset, which insures that all counter circuits are in the correct mode prior to recording; and 3) the calibration controls, which, with an inserted known volume of air, adjust the signal conditioning equipment to produce a corresponding output on the printer. Each readout entry includes respiration number and tidal volume in cubic centimeters. This system can be used on a variety of test subjects simply by altering the venturi tube dimensions.

DISCUSSION

Present methods of determining the number of breaths, tidal volume per breath, and the total tidal volume per experiment or exposure are prohibitively time-consuming and quite inaccurate. One such method is to visually integrate the squares under a respiration tracing from a Sanborn 150 direct writing recorder. Therefore, it is desirable to have an accurate, automatic monitoring system which has the capability of counting breaths,

computing volume per breath, volume per experiment, and resetting itself automatically. The system to be described satisfies these requirements and exposes only the sensory transducer assembly to radiation contamination.

The flow sensor is a small stainless steel venturi flowmeter with 1/8 in. throat diameter. This is inserted in the aerosol inhalation tube which has a 1 in. diam (Figure 1). The position of the venturi tube can be varied from midstream to the edge of the inhalation

FIGURE 1. Inhalation Tube and Venturi Flowmeter

tube to accomodate various flow rates and provide adequate sensitivity for the signal-conditioning circuits. The venturi tube is grounded by an external lead to prevent the aerosol particles from being attracted to the venturi. A Sanborn Model 270 differential pressure transducer is used to detect the change in velocity in the inhalation line. This is mounted in the inhalation glove box outside the dog and aerosol chambers at a level equal to that of the dog's mouth. This removes any possible residual readings created by differences in elevation.

The data retrieval system utilizes a Sanborn Model 150 Series, 8-channel direct writing recorder for transducer excitation and analog readout of the respiration data. The digital portion of the data system receives its input from the output of the Sanborn 150 and includes Schmitt triggers, decade counters, zero crossing detectors, reset, print, and logic circuits which provide BCD volume information.

Readout is achieved by a Hewlett Packard 562 A Digital Printer.

Operation of the system can best be visualized by referring to Figures 2 and 3.

FIGURE 2. Tidal Volume Air Monitor--
Block Diagram

FIGURE 3. Tidal Volume Air Monitor--Waveshapes

Excitation of the differential pressure transducer is accomplished with a Sanborn Carrier Preamplifier and the output of the associated galvanometer amplifier provides a dc signal of 0 to +8 V over a volume range of 0 to 150 cm³ (A, Figure 3). This signal is routed to the pen galvanometer of the Sanborn 150, the breath-counting Schmitt trigger, and the voltage-to-frequency converter (A, Figure 2). The breath-counting Schmitt trigger produces a square wave having a duration equal to the inhalation cycle (B, Figure 3). The breath counter provides a 1-2-4-8 BCD output corresponding to the particular inhalation cycle. The particular breath is printed out on each inhalation. The print circuit is triggered by the trailing edge of the squared inhalation waveshape (B and C, Figure 3). This insures that the entire inhalation cycle is integrated prior to print out. At the completion of the inhalation cycle and subsequent print out, the volume per breath counter must be reset.

The trailing edge of the print command energizes the reset circuits yielding the waveshape (D, Figure 3), which returns the volume per breath counter to the initial mode.

The slow varying dc output voltage from the Sanborn 150, representing the inhalation cycle, is sent to a voltage-to-frequency converter (A, Figure 2). Here the dc voltage is converted to a sinusoidal waveshape whose frequency is dependent upon the input dc voltage level (E, Figure 3). Now that the total number of cycles is indicative of the area under the waveshape (A, Figure 3), it is necessary only to count the number of cycles present per inhalation. This is accomplished with the zero crossing detector and produces square waves (F, Figure 3), compatible with both the volume per breath and the total volume per experiment counters. The volume counters, identical with the breath counter, provide 1-2-4-8 BCD information to the digital printer.

The logic circuits merely enable greater utilization of available channels in the digital printer.

A "total" switch (not shown in Figure 2) causes the logic circuits to switch in the total volume counter and switch out the volume per breath counter. The logic circuits also provide a manual print command to record the total number of breaths and the total volume of aerosol inhaled.

To insure proper operation, a manual reset switch is included (not shown) to return all counter circuits to the initial mode prior to starting the next exposure.

Calibration of the system is accomplished by injecting a known volume of

air and varying the input voltage range of the voltage-to-frequency converter to read out the corresponding volume on the digital printer. If sensitivity problems arise, the venturi flow may be positioned so that calibration may be achieved.

The system now operates well for specific volumes and small volume ranges; however, linearity problems of the venturi flowmeter prevent the

use of the system over the full scale volume requirements of 150 cm³ of air. Methods to produce full scale linearity to $\pm 5\%$ are now in progress.

The system lends itself quite well to several different respiration measuring devices. Additional interface circuitry is all that is required to make the unit compatible with any transducer configuration.

ACCELERATOR ION BEAM CURRENT REGULATOR

E. M. Sheen, W. A. Glass*
and C. A. Ratcliffe

Development of a beam current regulator for the PNL positive ion accelerator enabled dosimetry studies using adiabatic calorimeters to be made. This current regulator operates by causing a high voltage deflection system to sweep the beam across a pair of slits and measuring the average current passing through the slits with an electrometer connected to the target. The electrometer output voltage is compared to a reference voltage and the error voltage is then amplified and converted to a triangular high voltage wave that drives the beam deflection plates. If the beam current stays within the controllable limits, the average current is constant to within the electrometer drift, approximately 0.1% per half hour.

DISCUSSION

Dosimetry studies conducted with the positive ion, 2 MeV Van de Graaff accelerator required the average beam current stability to be better than 1% per half hour at 1 nA. It is difficult in normal operation to maintain the beam current within $\pm 10\%$ at 1 nA. For these dosimetry studies, the target was two small calorimeters that were to be

exposed to the same dose rate with uniform exposure. This exposure requirement led to the linear deflection controller shown in block diagram form in Figure 1. Current control was obtained from the 1 kHz vertical system shown, and a constant width low frequency horizontal linear sweep gave the required uniform exposure. Current control by the vertical deflection system was obtained by passing only a portion of the total current through the

* Radiological Sciences Section

FIGURE 1. System Block Diagram

slips to the target, measuring the target current with an electrometer, comparing the electrometer output voltage to a reference, amplifying the difference voltage and converting it to a high voltage linear triangular wave which drove the deflection plates.

High voltage for the plates is obtained from a high output voltage op-

erational amplifier designed by the authors. This amplifier is shown in Figure 2 and consists of a high voltage beam pentode combined with a solid state operational amplifier and associated coupling and feedback components. Vacuum tubes are used only for output high voltage circuit elements. The ac voltage at the positive (+) input of

FIGURE 2. High Voltage Operational Amplifier

the solid state operational amplifier is 4 V peak-to-peak with a 4 kVpp at the tube plate. The voltage gain is set by the 10 MΩ and 10 kΩ feedback resistors connected to the positive input terminal of the solid state amplifier.

Figure 3 shows the reference amplifier and triangular wave converter. The output voltage from the electrometer operational amplifier ($10^9 \Omega$ feedback resistor) is converted to current and compared with the reference current at the negative input terminal of operational amplifier A1. The difference current passes through resistor

R3 giving a voltage e at the output of A1 on the emitter of Q1. This voltage is inverted to give $-e$ at the output of the inverter A2. These two voltages are alternately disconnected from the input of an integrator by transistor switches Q3 and Q4 which are operated at a 1 kHz rate from the output of the binary.

Assuming $-e$ and $+e$ are constant during the 1 msec cycle, the output voltage of the integrator increases and decreases linearly, giving the desired triangular wave to the linear high voltage amplifier input. As shown in Figure 1, an inverter is used in

FIGURE 3. Reference Amplifier and Triangular Wave Converter

conjunction with another identical high voltage amplifier to provide push-pull deflection voltages.

This system is being successfully used with the accelerator and has given promising results. Figure 4 is a chart

record showing the electrometer output voltage with and without the regulator in operation. Short term stability, as inferred from the voltage measurement, is approximately 0.1% drift in 0.5 hour.

CHART SPEED: 1 INCH PER MINUTE
ELECTROMETER
VOLTAGE OFFSET: 3 VOLTS DC
CHART RECORDER
CALIBRATION: 100 MILLIVOLTS FULL SCALE

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FIGURE 4. Regulator Performance

PROGRESS ON THE DEVELOPMENT OF ELECTRONICS
FOR SOLID STATE DIODE DETECTORS

L. D. Philipp

INTRODUCTION

Late in 1965 and early in 1966 a gamma ray spectrometry system was developed using lithium-drifted germanium or silicon diodes and commercially available electronics. The resolution of the developed system proved to be 3.2 keV (FWHM) for 662 keV photons using the germanium detector. A typical spectrum is shown in Figure 1. The spectrometer has been useful for the detection and identification of plutonium, the examination of photon energies of irradiated samples, and as a general instrument for specific laboratory analyses.

FIGURE 1. Low Energy ^{133}Ba Spectrum

DISCUSSION

Recent interest has focused on low energy photons and X-rays and the usefulness of this spectrometry system is severely limited. To achieve the desired results a system with substantially increased resolution is being developed. The design goal is 0.5 keV (FWHM) resolution or better for 17 keV photons.

Due to the relatively low photon detection efficiency of lithium-drifted diodes, long counting times are required for many samples. Counting times as long as 36 hr have been used with success in this system with reduction of long term drift through the use of a spectrum stabilizer.

Several alternate paths are being studied in an attempt to obtain the highest quality low noise amplifier system possible. The preamplifier is being modified and cooled to approximately 150 °K. This should substantially improve the present system noise level. The charge sensitive preamplifier, similar to ones recently described,^(1,2) will have a low noise cooled FET cascade input stage to aid in providing approximately 0.8 keV (FWHM) (Ge) resolution with 9pF input capacitance.

The final spectrometry system will be used for low energy X-ray and gamma studies, alpha-gamma coincidence work, and other current laboratory investigations.

Methods for stabilizing spectra for long counting times are being examined. A resulting spectrum stabilizer will be included to optimize the completed spectrometer.

2. E. Elad and M. Nakamura. "High Resolution Beta- and Gamma-Ray Spectrometer," IEEE Transactions on Nuclear Science, vol. NS-14, no. 1, p. 523. February 1967.

REFERENCES

1. K. F. Smith and J. E. Cline. "A Low Noise Charge Sensitive Preamplifier for Semiconductor Detectors Using Paralleled Field-Effect," IEEE Transactions on Nuclear Science, vol. NS-13, no. 3. June 1966

SURFACE CONTOURED DIODE INVESTIGATIONS

K. L. Swinth

A small detector unit utilizing a contoured diode and obtained through the AEC Division of Biology and Medicine was investigated for its radiation measuring characteristics. The highest intrinsic efficiency ($4.8 \pm 0.5\%$) was obtained for plutonium L X rays. Lower efficiencies resulted at both higher and lower energies.

DISCUSSION

Detector units utilizing a gallium-diffused silicon detector* are being tested to establish their usefulness as radiation detectors. The detector is an avalanche device which yields a large signal and relies on geometrical shaping of the junction surface to achieve stability.⁽¹⁾ Multiplication of 10^2 to 10^3 is achieved when these units are operated at about 1,700 V. The detector is coupled to

a tunnel diode circuit which acts as a charge-sensing circuit. This does not allow one to obtain energy information, but it does enhance the signal-to-noise ratio,⁽²⁾ resulting in low background count rates.

Figure 1 shows a typical detector unit. The central hole on the front surface (3/32 in. diam) opens on the front surface of the detector. The detector itself is not visible; however, the tunnel diode logic and tunnel diode line driver circuitry housed in the same case is visible.

The unit as pictured will drive a scaler directly with the proper biases supplied to the detector, the

* Developed under Contract AT-(30-1)-3246 between the General Electric Company, Space Sciences Laboratory, and the U. S. Atomic Energy Commission.

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FIGURE 1. Surface Contoured Diode and Tunnel Diode Counter Assembly

tunnel diode, and the line driver. In our tests the detector was operated 10 V below avalanche (1,770 V) and the tunnel diode 0.1 V below oscillation (5.93 V).

The intrinsic efficiency of the surface contoured diode was measured for a few isotopes with low energy photons. For the ^{239}Pu X rays (17 keV average energy) the intrinsic

efficiency is $4.8 \pm 0.5\%$; however, the efficiency drops to $2.2 \pm 0.15\%$ at 5.9 keV (^{55}Fe) and to 0.53% at 4.8 keV (^{51}Cr). This drop at lower energies is due to a thick dead layer that absorbs many of the incident photons. The detector also has a thin sensitive layer causing the efficiency to drop to $0.54 \pm 0.04\%$ at 60 keV (^{241}Am).

The detectors have very low background count rates. The measured background is 0.37 ± 0.21 count/min and in the geometry used for measuring the plutonium counting efficiency, two standard deviations of the background correspond to $0.1 \mu\text{Ci}$. The high detection limit is due to the small area (0.05 cm^2) of the detector which resulted in a poor geometrical efficiency.

With a 25 mil diam collimator on the detector, ^{238}Pu particles, 1 mm apart, could be differentiated. These particles ranged from 10 to 49 microns and from about $0.1 \mu\text{Ci}$ to $10 \mu\text{Ci}$. The detector could be placed within 2 mm of the sources resulting in a high geometrical efficiency and allowing 1 min counts. Attempts to localize a plutonium particle in a slice of lung tissue were unsuccessful due to the low efficiency of the detector. A collimated NaI crystal was finally used to localize the

particle because of its high geometrical and intrinsic efficiency.

The contoured diodes may be useful for measuring dose rates in the field. A count rate of 12.5 counts/min was obtained in a 1 mR/hr radium field.

Tests using conversion foils to increase the efficiency of detection have led to nondefinitive results. These tests will continue.

Figure 1 shows a typical unit employing both a surface contoured diode and a tunnel diode.

REFERENCES

1. G. C. Huth, J. B. Trice, and R. A. McKinney. "Internal Pulse Amplification in Silicon p-n Junction Radiation Detection Junctions", *Rev. Sci. Instr.*, vol. 35, p. 1220. 1964.
2. R. J. Locker and G. C. Huth. "A New Ionizing Radiation Detection Concept Which Employs Semiconductor Avalanche Amplification and the Tunnel Diode Element", *Applied Physics Letters*, vol. 9, p. 227. 1966.

PROGRESS IN X-RAY/ALPHA STUDIES WITH SOLID STATE DETECTORS

K. L. Swinth

INTRODUCTION

Correct interpretation of X-ray counting data for internally deposited plutonium depends upon a knowledge of the number of X rays per unit dose or per maximum permissible body burden (MPBB), for the material

in question. The number of X rays per MPBB can vary by greater than a factor of two depending upon the isotopic composition of the plutonium. Progress is described on a counting system to determine the X rays per unit dose and the isotopic composition of plutonium samples.

DISCUSSION

The only intense photons from plutonium isotopes that can be used for counting internal depositions of plutonium are the L X rays. Counting these easily absorbed X rays is difficult in itself, but interpretation of counting results is further complicated by the fact that the intensity of the X rays depends upon the isotopic composition of the material. Table I⁽¹⁾ shows how the isotopic composition of plutonium varies and how it depends upon the irradiation history of the ^{235}U .

One can see that the composition depends on both the flux level and the irradiation time.

Table II shows how the calculated X ray to alpha ratio and the calculated relative MPBB per unit weight of plutonium material varies with the isotopic composition listed in Table I. It is clear that ^{241}Pu is a major contributor to the MPBB of a given mass of plutonium, especially if the material is of high exposure. This is due to its high specific activity and to the fact that its

TABLE I. Typical Plutonium Isotopic Compositions from Irradiated ^{235}U ⁽¹⁾

Sample	Flux Level, $\text{n/cm}^2\text{-sec}$	Integrated Flux	Isotopic Composition				
			^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
1	5×10^{13}	5×10^{19}	0.17×10^{-6}	0.9939	6.08×10^{-3}	5.39×10^{-5}	0
2	5×10^{13}	2×10^{20}	3.2×10^{-6}	0.9665	0.0323	1.15×10^{-3}	2.18×10^{-5}
3	5×10^{13}	2×10^{21}	136×10^{-6}	0.6917	0.234	0.058	0.016
4	5×10^{13}	1×10^{22}	4340×10^{-6}	0.406	0.262	0.098	0.230
5	2×10^{14}	2×10^{22}	11.8×10^{-6}	0.336	0.209	0.080	0.374

TABLE II. Effect of Isotopic Composition on Maximum Permissible Body Burden

Sample	MPBB per Unit Mass of Sample, Relative	X Rays/MPBB, Relative	X Rays/alpha	% of MPBB Due to ^{241}Pu
1	1.56	6.09	0.041	0.4
2	1.80	6.34	0.046	7.8
3	9.50	2.76	0.074	74.0
4	16.5	3.28	0.093	73.0
5	11.47	1.80	0.082	85.5

most abundant daughter, ^{241}Am , is an alpha emitter of high specific activity.

Figure 1 shows the number of X rays per MPBB and the variation of this quantity with time. The increase with time is due to the growth of ^{241}Am from the decay of ^{241}Pu . The ratio of X rays to alpha particles shows a similar behavior with time; however, the initial values show an inverse relation with isotopic composition as in Table II.

Some measurements of the X ray to alpha ratio were made with a NaI

FIGURE 1. Variation of X rays/MPBB of Plutonium with Time for Five Isotopic Compositions (See Table I)

detector gated in coincidence with a proportional counter. For a source of known isotopic composition, an experimental ratio of 0.066 was obtained compared with a calculated value of 0.063. Although the X ray per alpha measurements give a rough indication of the biological hazard of a plutonium sample, it is desirable to know the isotopic composition to determine more accurately the hazard (X rays/MPBB).

A system is planned that will use solid state detectors to count the photons and alpha particles from a plutonium source. By coincidence technique, it will be possible to determine the amounts of ^{238}Pu , ^{239}Pu , ^{240}Pu , and ^{241}Am . It will be necessary to measure radiations from the daughters of ^{241}Pu to infer its content in a sample. Mass spectrometry techniques do not have high sensitivity for measuring ^{238}Pu and ^{241}Am when present in small amounts, but counting techniques do have. This is due to the normally low abundance of these isotopes and their high specific activities.

The planned system will use a surface barrier diode to detect the alpha particles and lithium-drifted silicon and germanium to detect the photons. The lithium-drifted detectors will utilize a cooled preamplifier to improve the resolution. This system is planned and partially completed, and all the necessary detectors are on hand.

Figure 2 shows the electronics system and cryostat for low energy X-ray detection. The cryostat houses a silicon detector.

Neg 0670678-4

FIGURE 2. Electronics System and Cryostat for Low Energy X-Ray Detection. The cryostat houses a silicon detector.

REFERENCE

1. R. P. Schuman and R. L. Tromp.
Calculation of the Composition

of Reactor Irradiated Heavy Nuclides, IDO-16571. Idaho Operations Office, Idaho Falls, Idaho, 1959.

NEUTRON SENSITIVE CRITICALITY ALARM SYSTEM

F. L. Rising*

A neutron sensitive, but gamma insensitive, criticality alarm was developed to meet the requirements of 10CFR70.24 under all conceivable conditions. It can be set to alarm to 20 mrem/hr or less of neutrons, but will not alarm at a gamma dose rate of 1000 R/hr.

It will alarm in from 1 to 5 sec when the dose rate is between the set point and 60 mrem/hr and in less than 1 sec at dose rates greater than 60 mrem/hr. It has been tested at the Oak Ridge Health Physics Reactor and at the Sandia Pulsed Reactor Facility. At Sandia, it alarmed at a distance of 1,150 ft from a burst of 1.27×10^{15} fissions with the reactor shielded by 1 in. of polyethylene, 1 in. of boron, and 54 in. of ordinary concrete.

The detector is an undermoderated BF_3 tube which is sensitive to a wide spectrum of neutron energies. The pulses from the detector are amplified and then fed into a multivibrator and driver circuit. The pulses from the driver are then fed into two high level trip circuits; the primary circuit has an adjustable trip point, the backup has a fixed trip point at a dose rate of about 30 mrem/hr. The outputs of both of these are fed into the alarm relay. There is also an audit circuit which receives the output of the driver circuit. If there is not a pulse from cosmic ray caused background neutrons within a specified time period, a failure signal is given. This checks the entire detection circuit. There is also an analog recorder output to make it possible to estimate the magnitude of any excursion that might occur.

* Dosimetry Technology Section

IMPROVEMENTS IN RAINDROP CHARGE MEASURING SYSTEMS

C. A. Ratcliffe

Improvements made in the earlier equipment are in transducer design, better charge sensitive amplifier stability, and easier field adjustment and operation. The transducer was modified to be more tolerant of breezes during the rain or snow shower being sampled. The charge sensitive amplifier was improved to provide higher gain, more stability, and an easier adjustment procedure than previously. Different cabling, connectors, and power supply arrangements have made field operation and maintenance simpler, especially when the ambient temperature is low.

DISCUSSION

Earlier work on this system was reported⁽¹⁾ a year ago. Work this year has been directed toward improved operation of the system, both electrically and mechanically.

Perhaps the most important change was the redesign of the transducers. The old transducer was a large cannister (barrel) containing the inductor rings used for the measurement. It operated well but was intolerant of any breeze which caused the raindrop fall to be very different from vertical. The new transducer has the inductor rings mounted close to the top of the shielding enclosure box and closely spaced together. A cylindrical vertical shield is seen in Figure 1. This physically shields against drops arriving with too much horizontal component of velocity and also shields against existing electric fields. A shorter cylindrical shield is also sometimes used.

The charge sensitive amplifiers were changed to incorporate a commercial

operational amplifier. This provided more gain, smaller current consumption and easier adjustment. Greater stability with time and temperature was also achieved.

A new power supply, also shown in Figure 1, provides voltage regulated power and has batteries with longer life and with a greater temperature range of usefulness. Better connectors and fittings are incorporated, simplifying field use and repair, particularly at low temperatures and during snow showers.

Laboratory calibration shows that the inductor ring-charge amplifier combination produces one volt of output for about 3.2×10^{-12} coulomb. Using a post amplifier with a gain of 28 gives one volt of output for 1.1×10^{-13} coulomb. On the chart recorder we can discern (at 0.5 V/cm) 0.1 V with ease, for a sensitivity of about 10^{-14} coulomb. The recorder cannot be used at arbitrarily high gain, however, as during rain showers there are many charged particles suspended in the air,

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FIGURE 1. Raindrop Charge Spectrometer Transducer and Power Supply

giving a background having considerable variation or drift. The chart must be able to handle the drift plus the anticipated signals, each with either polarity referred to zero.

Field measurements during snow showers at White Pass, Washington, indicated that almost all of the flakes bore negative charges ranging from 2×10^{-14} to 2×10^{-13} coulomb. Rain showers near Richland, Washington, produced drops with both polarities and many uncharged drops. Charge magnitudes observed were from 10^{-14} to 10^{-12} coulomb.

Further field work is planned to obtain more spectra and to improve the speed measuring capabilities of the apparatus.

REFERENCES

1. C. A. Ratcliffe and N. C. Hoitink. "Raindrop Charge and Velocity Measurement Techniques," Pacific Northwest Laboratory Annual Report for 1965 in the Physical Sciences, Volume 4: Instrumentation, BNWL-235 4, p. 21. Pacific Northwest Laboratory, Richland, Washington, 1966.

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