P
321
ANL-6292
MASTER

Argonne National Laboratory

A LOW DEAD-TIME NEUTRON-COUNTING SYSTEM

by

Robert J. Epstein

and

Donald C. Thompson

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or*
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.*

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

*Price 50 cents. Available from the Office of Technical Services,
Department of Commerce, Washington 25, D.C.*

ANL-6292
Instruments
(TID-4500, 16th Ed.)
AEC Research and
Development Report

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois

A LOW DEAD-TIME NEUTRON-COUNTING SYSTEM

by

Robert J. Epstein and Donald C. Thompson

Electronics Division

January 1961

Operated by The University of Chicago
under
Contract W-31-109-eng-38

TABLE OF CONTENTS

	<u>Page</u>
I. ABSTRACT	3
II. INTRODUCTION.	3
III. SYSTEM DESCRIPTION.	4
IV. DETECTOR.	5
V. PREAMPLIFIER	6
VI. MAIN AMPLIFIER AND INTEGRAL DISCRIMINATOR.	7
VII. DEAD-TIME MEASUREMENTS.	11
VIII. MEASUREMENT OF NEUTRON FLUX WITH HIGH GAMMA BACKGROUND	12
IX. MAINTENANCE	13
X. ACKNOWLEDGMENTS	16

A LOW DEAD-TIME NEUTRON-COUNTING SYSTEM

by

Robert J. Epstein and Donald C. Thompson

I. ABSTRACT

This report describes a counting system capable of processing input pulses at an average rate in excess of 3×10^5 counts per second with less than 10 percent counting loss due to instrumental dead time. The system is capable of detecting thermal neutrons in the presence of a high gamma background. It consists of a fission counter, a preamplifier, linear amplifier, and integral discriminator. Components of the system are described in detail, and circuit diagrams and layout information are given. Factors governing the design are discussed; testing procedures and the performance are outlined.

II. INTRODUCTION

A system capable of counting high rates of activity was developed by the Electronics Division at the request of the Reactor Engineering Division, for use in monitoring startup operations of the EBR-II reactor. The usual electronic method of monitoring the neutron flux level employs current-measurement techniques. An ionization chamber is placed at the location at which it is desired to measure the neutron flux. Current passes through the ionization chamber proportional to the magnitude of the flux. This current is amplified by an electrometer input tube operational current amplifier, the output of which operates recording devices, period-measuring devices, safety trip circuits, etc. The lowest measurable flux levels are fixed by the properties of the ionization chamber and electrometer amplifier in use.

The lowest current level which may be conveniently measured by this method is of the order of 10^{-13} amp. This magnitude of current is produced by a neutron flux level of approximately 2.5 neutrons/(cm²)(sec) for the type of ionization chambers to be used in EBR-II. In practice, this low neutron flux level cannot be measured because of the gamma sensitivity of the ionization chambers, which is about 3×10^{-13} amp/(R)(hr) when used as compensated chambers.

It was considered necessary to monitor lower magnitudes of neutron flux than the current-measurement technique would conveniently permit. It was decided to use a pulse-counting system employing a fission counter to

overlap the lowest decade measurable by the current technique and to extend the monitoring capability to almost four decades below the minimum afforded by the current-measurement technique. The current-measurement technique is considered to be no longer useful when the current contribution due to the gamma flux equals that due to the neutron flux. This is expected to occur at a neutron flux of 2.2×10^4 nv. The gamma flux at this neutron flux is expected to be 3×10^3 R/hr, i.e.,

$$\text{for neutrons} \quad (2.2 \times 10^4 \text{ nv}) \left(4 \times 10^{-14} \frac{\text{amp}}{\text{nv}} \right) \simeq 8.8 \times 10^{-10} \text{ amp} \quad ;$$

$$\text{for gammas} \quad \left(3 \times 10^3 \frac{\text{R}}{\text{hr}} \right) \left(3 \times 10^{-13} \frac{\text{amp}}{\text{R/hr}} \right) \simeq 9 \times 10^{-10} \text{ amp} \quad .$$

Therefore, for a one-decade overlap, the counting system must be able to operate at a neutron flux of 2.2×10^5 nv. Considering that the sensitivity of the fission counter is about 0.45 count/(sec)(nv), the counting system must be capable of processing

$$\left(0.45 \frac{\text{count}}{(\text{sec})(\text{nv})} \right) (2.2 \times 10^5 \text{ nv}) \simeq 10^5 \frac{\text{counts}}{\text{sec}} \quad .$$

At the lowest activity, the counting system must be able to recognize 2 nv in the presence of a 3×10^3 -R/hr gamma background.

The pulse-counting system together with the current-measurement system provide the capability to monitor the neutron flux level over a ten-decade span.

III. SYSTEM DESCRIPTION

Each channel of EBR-II counting equipment consists of

1. a Westinghouse fission counter type WX4245,
2. a preamplifier, and
3. a main amplifier with integral discriminator.

The preamplifier mounts directly on the fission counter. The preamplifier and main amplifier are interconnected by two cables, a coaxial cable which carries signals from the preamplifier to the main amplifier, and a multiconductor cable which carries power from the main amplifier to the preamplifier and fission counter. Output signals from the integral discriminator are fed to pulse rate-measurement instruments. The schematic diagram and description of these pulse rate circuits is contained in the ANL Electronics Division File #2591. Four such pulse-counting systems have been constructed, three to be used in EBR-II and one as a spare.

IV. DETECTOR

There are several main considerations which influenced the choice of the type fission counter to be used.

1. Required Absolute Efficiency.

Considerations of counter efficiency, together with the least flux level it is desired to monitor, fix the lowest permissible quantity of fissionable material in the detector. It is desirable to use a counter with a minimum of fissionable material for the following reasons:

- a. A minimum of fissionable material means a minimum area for the counter electrode, and thus minimum electrical capacity and maximum output pulse amplitude.
- b. The fissionable material is a prodigious alpha emitter. This produces a low-energy background in the spectrum of output pulses. Pulse pileup due to these alpha particles is particularly troublesome inasmuch as it is the factor which determines the least usable fission fragment energy loss in the counter. This situation is made worse by the large background of gamma radiation, which also copiously produces small pulses in the detector.

2. Time Resolution.

Spacing of the electrodes, type of gas filling, and pressure of the filling gas influence the charge collection time of the counter. It is, of course, also strongly influenced by the field between the electrodes. In order to meet the dead-time requirement, the system must detect, amplify, discriminate, and recover in a time of one microsecond per input event. The system design calls for $\frac{1}{2}$ microsecond for detection amplification and discrimination, allowing $\frac{1}{2}$ microsecond for recovery. The charge collection time of the fission counter should be short compared with $\frac{1}{2}$ microsecond.

The detector used is a Westinghouse type WX 4245 fission counter filled with nitrogen and argon to a pressure of 1 atmosphere. A neutron-sensitive coating of U_3O_8 enriched to more than 90% U^{235} is deposited on the electrodes to a thickness of 1 milligram per cm^2 .

The total coated area of the counter is approximately 1020 cm^2 . Electrode separation is 0.15 inch. Electrical capacity between counter electrodes is 200 micromicrofarads.

Sensitivity measurements made with a plutonium-beryllium source showed a sensitivity of approximately 0.45 count/(sec)(nv).

Measurements of charge collection time vs. counter operating voltage were made with the same source by employing a long decay time constant in the detector output circuit, and observing the rise time of the output voltage pulse (i.e., the integral of the output current pulse) on a fast amplifier-oscilloscope combination. It was decided to operate the fission counter at 300 V, at which voltage the charge collection time was less than 7×10^{-8} sec. When greater pressures were employed, the charge collection time was too long to be useful at reasonable values of electrode voltage. Also, the gamma sensitivity increased with increasing gas pressure. The decay time constant of the detector output circuit was about 1.5×10^{-7} sec, long enough to insure that no substantial charge leaked off the capacity of the charge collection electrodes during the time of collection.

V. PREAMPLIFIER

Assuming

1. ~ 50 Mev is the energy of the most energetic fission fragments,
2. ~ 30 ev are required for the production of an ion pair,
3. only electrons are effective in contributing to the output pulse in the times of interest, and
4. the capacity of the collection system $\approx 250 \times 10^{-12}$ farad,

then

$$N = \frac{\text{number of electrons}}{\text{pulse}} \approx \frac{50 \times 10^6 \text{ ev/pulse}}{30 \text{ ev/electron}} \approx 1.6 \times 10^6 \frac{\text{electrons}}{\text{pulse}} ;$$

$$\left(\sim 1.6 \times 10^6 \frac{\text{electrons}}{\text{pulse}} \right) \left(1.6 \times 10^{-19} \frac{\text{coulomb}}{\text{electron}} \right) \approx 2.56 \times 10^{-13} \frac{\text{coulomb}}{\text{pulse}} ;$$

$$\frac{\sim 2.56 \times 10^{-13} \text{ coulomb/pulse}}{\sim 250 \times 10^{-12} \text{ farad}} \approx 0.012 \times 10^{-1} \frac{\text{volt}}{\text{pulse}} .$$

Thus, the largest pulses produced at the input of the preamplifier are on the order of one millivolt. Assuming it is desirable to operate over a dynamic range of 10 to 1, the preamplifier should be capable of handling 0.1-millivolt pulses without serious electronic noise problems.

The ambient temperature at the location of the preamplifier is 150°F. The preamplifier is also subjected to a high radiation field. The design of the preamplifier is a compromise considering low noise, gain stability (particularly with ambient temperature variation), radiation and temperature resistance, and few components. All capacitors in the preamplifier have ceramic dielectrics, and all resistors are a high-temperature-deposited carbon-film type where high stability is required. Bare or ceramic-insulated wire is used exclusively. The connector mounted on the preamplifier, which permits the latter to be connected to the fission counter, is an Amphenol type 82-38 with polystyrene inserts for increased radiation resistance. The preamplifier is housed in an all-aluminum tubular assembly. Figure 1 is the schematic diagram of the preamplifier. T_1 and T_2 form a stacked feedback amplifier of gain of about 30. The output of this stacked amplifier stage, taken from the plate of T_2 , is coupled to the grid of T_3 . Together T_3 and T_4 form a stacked cathode follower. The cathode follower has a gain near unity when driving a terminated 93-ohm output cable. The terminating resistance, which is located at the input of the main amplifier, is subdivided to provide a low-impedance attenuator for the main amplifier. RCA Tube type 7586 (Nuvistor) was chosen because of its low noise, small size, good high-temperature performance, and excellent uniformity of electrical characteristics. Measurements of the preamplifier gain stability as a function of temperature were made. The preamplifier gain change was less than 5% for temperature changes from 25°C to 90°C. Steady operation for two weeks at 90°C induced no observable change in performance.

VI. MAIN AMPLIFIER AND INTEGRAL DISCRIMINATOR

Figure 2 is the schematic diagram of the main amplifier and integral discriminator. The main amplifier consists of two rings of three, a cathode follower and a power supply. The first ring of three, T_1 , T_2 , and T_3 , provides a gain of about 75. Negative input pulses applied to this ring are amplified and inverted. The output of the first ring is taken from the plate of T_3 and fed to the second ring of three comprised of T_4 , T_5 , and T_6 , providing an additional gain of about 50. Positive output pulses from the second ring, at the cathode of T_6 , are applied through a short-time-constant, DC-restoring circuit to T_7 , a cathode follower. This short time constant is such as to deliver pulses of 0.4-microsecond duration, at the base line, to the integral discriminator. The variable biasing voltage applied to the grid of T_7 provides a variable DC level signal to the grid of T_8 , a moderately fast discriminator circuit. If an output pulse at the cathode of T_7 is larger than the threshold sensitivity of the discriminator T_8 , an output pulse is generated. The threshold sensitivity is controlled by a 10-turn Helipot on the front panel labelled "Discriminator Level." Tubes T_9 through T_{13} are in the power supply, which is a conventional electronically regulated supply.

Choice of the input tube T_1 is quite important. Tube type E180F, which has an excellent high-frequency figure of merit and is used throughout the amplifier, is not suitable here. It was found to have a mechanical resonance at 12 kc/sec which would have made the amplifier particularly subject to microphonic disturbances. Type 6922, which is used, has no resonances within the pass band of the amplifier.

Construction techniques and layout are important in achieving the desired performance. Figure 3 is a photograph of the underside of the chassis showing the layout. Note that the first ring is enclosed in an electrostatic shielding enclosure. Several relays are evident in this photograph and are shown on the schematic diagram. These are used in subsidiary control circuits and are not pertinent to the operation of the amplifier.

Figure 3. Chassis Layout

The overall maximum gain available from the preamplifier and amplifier is in excess of 5×10^4 , including the loss in the short-time-constant circuit between the amplifier output and the cathode follower. Rise time of the cascaded preamplifier and amplifier is less than 0.1 microsecond. Typical waveforms are shown in Sect. IX. R.M.S. noise voltage referred to the input is less than 30 microvolts. No more than average care has been taken to assure good overload performance. The amplifier is, therefore, not recommended for use in situations where severe overload is encountered. A typical pulse height distribution is shown in Figure 4.

Figure 4
Typical Pulse Height Distribution

VII. DEAD-TIME MEASUREMENTS

To ascertain whether or not the system met the counting-rate requirements, it was compared with another system, hereinafter referred to as the standard system. The standard system employed a very small fission counter, which, when subjected to approximately the same neutron flux as the detector for the system under test, produced counts at 1/100 the rate of the larger detector. The counting rate in the standard system was not sufficient to cause significant dead-time losses, for flux levels producing average counting rates of 10^5 counts/sec in the system under test. The flux level was varied from low values through those values at which the system under test suffered counting losses.

A plot of the ratio of the counts/sec for system under test to the counts/sec for standard system as a function of counts/sec for the system under test is given in Figure 5. It is observed that the counting rate is

down to 90% of the true rate at a rate of 3.3×10^5 counts/sec. The tests were conducted in the thermal column of the Argonaut Reactor, where the detectors were placed side by side and the measurements made over a wide range of neutron flux levels. The gamma flux was not sufficient to influence these measurements.

Figure 5. Comparison of Counting Rates of Equipment with that of Standard System

VIII. MEASUREMENT OF NEUTRON FLUX WITH HIGH GAMMA BACKGROUND

Measurements of the sensitivity to neutrons in a high gamma background were performed at the Argonne National Laboratory Gamma Irradiation Facility. The effective sensitivity for neutrons is not influenced for gamma backgrounds up to about 10^4 R/hr. For backgrounds in excess of 10^4 R/hr, the sensitivity decreased, reaching 10% of the sensitivity for no gamma background at a gamma background of 10^6 R/hr. The sensitivity here is defined in a rather arbitrary way, and is for this apparatus a figure of merit indicating how well the apparatus counts neutrons in a high gamma flux. Consider the integral pulse-height distribution curve. In order to avoid counting alpha particles, the discriminator must be advanced to some arbitrary level above the largest alpha-particle height. When set at such a level, the output count rate corresponds to the neutron count rate above this energy level. In the presence of a high gamma flux, the upper limit of the pulse-height distribution for alphas plus gammas, including pileup, moves higher. If we now set the discriminator higher than the end of this distribution by the same amount as in the case of no gamma background, the fraction of the neutron distribution counted will be less. The sensitivity has been defined as the ratio of these two fractions of the neutron distribution counted. The loss in sensitivity as a function of the gamma flux is illustrated in Figure 6.

Figure 6. Loss of Sensitivity with Increasing Gamma Flux

IX. MAINTENANCE

Table I provides a list of voltage check points. The voltages should be read with a 10-megohm input impedance voltmeter. Plus or minus ten per cent of the indicated voltages indicates that there is likely nothing wrong with the portion of the circuit under test.

Table I

VOLTAGE CHECKS

Tube No.	Plate to Ground, volts	Screen Grid to Ground, volts	Cathode to Ground, volts	Cont. Grid to Ground, volts
Preamplifier				
1	105	-	75	-
2	48	-	10	-
3	85	-	49	-
4	49	-	11	-
Main Amplifier				
1	143	-	-	-
2	258	-	144	-
3	130	-	11	-
4	139	-	-	-
5	82	-	16	-
6	288	-	88	-
7	-	-	-	-
8	-	-	-	*
9	398	-	-	287
10	-	192	85.2	-

*This voltage should swing from negative 3.6 V to negative 21.6 V as the discriminator level Helipot swings from full counterclockwise to full clockwise.

Pulse Testing

The required equipment for the pulse testing of this counting system consists of

1. a Spencer Kennedy Lab. Model 503 fast rise pulse generator,
2. a Tektronix type 543 oscilloscope with type 53/54-L preamplifier, and
 - a. one 50 X probe
 - b. one 10 X probe, and
3. a special adapter to permit the pulse generator pulses to be fed to the connector which normally connects to the fission counter.

Test Procedure

1. Set the S.K.L. generator to deliver negative pulses, $\frac{1}{4}$ micro-second long.
2. Disconnect the 470- Ω resistor from the center pin on the special fission counter connector, and from this pin connect a 51- Ω resistor to ground.
3. Connect the output of the S.K.L. generator through a 50- Ω Z_0 cable to the fission counter connector on the preamplifier.
4. Set the amplitude on the S.K.L. generator, such that one volt output pulses are observed at the cathode of T_3 on the preamplifier, using the 543 scope and the 10 X probe. Observe the following waveforms.

5. Set the main amplifier gain to $\frac{1}{8}$. Connect oscilloscope 10 X probe to the output of the 1st ring in the main amplifier (the junction of the 22- Ω resistance and the 10-K resistor at the grid of T_4). Adjust the S.K.L. generator amplitude control to obtain a one-volt pulse at this point. Observe the following waveforms.

All indicated rise times are for 10 to 90% of the indicated signal excursions.

6. Connect the X50 probe to the output of the second ring (cathode of T_6). Set the S.K.L. gen. output to produce a 25-volt pulse at this point. Set the discriminator level Helipot to max. Observe the following waveforms.

X. ACKNOWLEDGMENTS

The authors are most happy to acknowledge the assistance of V. J. Elsbergas, R. M. Lill and M. W. Schultz for assistance on this project.