AN ELECTRONICS SYSTEM FOR TRANSURANIC WASTE ASSAYS*

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MASTERSUMMARY

A slagging pyrolysis incinerator has been proposed to reduce the volume of stored transuranic (TRU) waste material. Reduced volume is achieved by burning combustibles and melting nuclear material along with soil to form a glass-type slag containing the (TRU) waste. Monitoring incoming waste and outgoing slag for TRU material is necessary to prevent the accumulation of a critical mass of fissionable material.

This report describes the electronics developed for a fast TRU waste assay system using photon interrogation.^{1,2} The system uses a pulsed electron beam from a linear accelerator to produce a high-energy photon burst, termed the "gamma flash", from a metallic converter. The photons induce fission in the TRU. A high-rate counting system is used to relate the production rate of photon induced neutrons to the amount of fissile material present in the waste.

The basic requirements for the system are a high count rate capability and rapid "gamma flash" recovery. We have achieved count rates of 4×10^5 counts per second with a 20% deadtime correction, and "gamma flash" recovery within 30 microseconds with the accelerator operating at 16 MeV, 500 mA, and a 2 μ s wide pulse at a 60 Hz rate. Future plans include the addition of hardware and software for automatic, on-line assay analysis.

PHOTON INTERROGATION

Figure 1 illustrates the generation of neutrons in TRU waste via photon interrogation. Electrons generated and accelerated to specified energies by a linear accelerator strike an electron target. The accelerator is pulsed at a periodic rate to generate electron bursts; for example, two microsecond wide pulses at a 60 Hz rate. The electron stream striking the target produces high energy photons. The photons induce fission within the TRU waste sample. Neutrons released from the waste are detected by ³He proportional chambers. The proton from the (n,p) reaction within the tube ionizes the ³He gas, producing electron-ion pairs. The electrons are accelerated towards the center wire, producing multiplication as more gas is ionized. The electronics used with the system convert the collected charge to pulses for data accumulation, processing, etc.

The proportional chambers detect not only the fission neutrons but also photons from the electron target. The photon sensitivity of the chamber is primarily wall effect. The ³He chambers are relatively insensitive to photons, but the large number of photons detected during the "gamma flash" tend to "pile-up" in the chambers and paralyze the electronics for an appreciable period of time.

Figure 1. Induced Fission Using Photon Interrogation

After each accelerator electron burst, the number of fission neutrons detected per unit time by the chambers will decrease with an apparent half-life determined by the die-away time of the detector assembly.

Die-away time is defined as either the time required for the neutron population within the assembly to decrease to $1/e$ of its initial value, or in some literature, to $1/2$ its initial value. Our assembly, consisting of ³He proportional chambers surrounded by a polyethylene moderator, has been designed for a die-away time of approximately 100 microseconds. "Prompt" fission neutrons decay to a background level within 20 die-away times. The background consists of "delayed" fission neutrons plus neutrons from other sources.

SYSTEM REQUIREMENTS

If the TRU isotope in the waste sample is known, or is assumed to be known, the amount of fissile material present can be related to the production rate of fission neutrons. With this assumption, no requirement exists for pulse shape or energy distribution analysis, and the initial requirement for the electronics is a high-rate pulse counting system.

The neutrons detected and counted per unit time to determine the production rate may be either the prompt, delayed or both neutron groups. This generates a requirement to separate prompt and delayed neutrons and to select the times after the accelerator electron burst when the neutron groups are counted.

A major problem exists that complicates the detection of prompt neutrons. This is the "gamma flash" caused by the photon burst from the electron target. A "gamma flash" that paralyzes the electronics for 1 to 2 milliseconds prevents the counting of prompt neutrons whose population decays within a few hundred microseconds. The electronics, primarily the preamplifier, must then be designed to recover from a "gamma flash" overload within a few tens of microseconds.

Additional requirements to complete the electronics are signal conditioning (base-line restoration and fast discrimination) and data acquisition.

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The requirements for the electronics system may be summarized as:

1. high-rate pulse counting capability
2. separation of prompt and delayed neutron pulses
3. rapid "gamma flash" recovery
4. signal conditioning
5. data acquisition

ELECTRONICS

Figure 2 is a simplified block diagram for one channel of the electronics system developed for the photon interrogation project.

The ^3He chamber is installed in an assembly using polyethylene as a neutron moderator. The signal is picked off the chamber and fed to a high-gain, current sensitive preamplifier followed by a voltage gain of 240. The amplifier drives a baseline restorer that eliminates low-frequency noise and establishes a stable dc baseline. The discriminator level is set above the electronic white noise amplitude and gamma ray pulses from external sources. The analog pulses from the restorer are converted to fixed amplitude output pulses to be counted by the data acquisition system. The logic module is used to separate prompt and delayed neutron pulses by generating selectable time gates after the photon burst when neutron pulses are to be counted. The logic module outputs are logic HI signals used as gate enables for counters in the data acquisition system. The module includes logic gates to measure prompt and delayed deadtimes. Amplifiers, restorers, discriminators, and logic modules are in-house items designed or modified for this project.³ Data are accumulated in a system using commercial counters, timers, and line printers.

Figure 2. Simplified Block Diagram for One Channel of the Photon Interrogation Electronics System

AMPLIFIERS

A simplified schematic for the amplifier is shown in Figure 3. Negative high voltage is applied to the case of the detector tube through the high voltage filter, R_1C_1 . This allows direct coupling from the anode to the amplifier input and eliminates the long time constant overloads associated with capacitive coupling. The operational amplifier uses a fast differential amplifier stage developed in-house.

Figure 3. Simplified Schematic of Detector with Direct-Coupled Preamplifier

The proton from the (n,p) reaction from neutrons striking the tube ionizes the ^3He gas producing electrons and positive ions. These charges are collected respectively at the anode and case. The time for charge collection is determined by tube geometry, gas pressure, applied voltage, and charge mobility, and is independent of any external circuits. The total charge collection time for the tube is determined primarily by the ion collection time because of the low ion mobility. Typical collection times are 500 to 1000 microseconds.

In the circuit of Figure 3, the charge collection generates a signal current, i_s , through the amplifier feedback network and the filter capacitor, C_1 . After the charge is swept out of the tube, C_1 discharges through R_1 . The signal current, i_s , is proportional to the derivative of the charging voltage for capacitor C_1 .

In a charge-sensitive preamplifier using R_2 and C_2 in the feedback network, the amplifier output is proportional to the voltage drop across C_2 . A voltage is developed across C_2 during the tube charge collection time. After the charge is swept out of the tube, C_2 discharges through R_2 . The amplifier output is proportional to the capacitor voltage curve shown in Figure 3.

In a current-sensitive preamplifier using only R_1 in the feedback network, the amplifier output is proportional to the voltage drop across R_1 , and is therefore proportional to the signal current, i_s .

Comparison of the v_C and i_s curves in Figure 3 shows that the current-sensitive amplifier has a

shorter output pulse, and therefore a higher count rate capability than a charge-sensitive version.

A direct-coupled, current sensitive preamplifier was selected for this project to meet the high count rate requirement. The current-to-voltage converter stage of Figure 3 was coupled with a high-gain, inverting voltage amplifier. A simplified schematic of the amplifier with a baseline restorer is shown in Figure 4.

Figure 4. Preamplifier, Voltage Amplifier, and Restorer with Appropriate Voltage Waveforms

The voltage curves of Figure 4 illustrate the amplifier and restorer outputs for neutron pulses and a "gamma flash" overload. The restorer can be adjusted for base line restoration within 30 microseconds. However, the overload holds the amplifier in saturation for approximately 400 microseconds. The long saturation is caused by the long decay tail

of the first-stage output, generated by the signal current requirement from the detector tube charge collection.

The network consisting of R_3 , R_4 , and C_3 was added to the amplifier first stage. The initial signal current through R_1 drives the output positive. The capacitor, C_3 , is charged through R_4 , and discharged through R_3 . The discharge through R_3 furnishes the signal current required by the detector tube charge collection. The resistor, R_4 , is adjusted for optimum C_3 charge and discharge, such that after C_3 charge, the discharge furnishes all of the signal current requirement. With no current requirement through R_1 , the first stage output goes to zero volts and eliminates the long decay tail. "Gamma flash" overload recovery within 30 μ s has been achieved with the accelerator operating at 16 MeV, 500 mA, and a 2 μ s wide pulse.

The direct-coupled, current sensitive amplifier with the compensating network meets the requirements for high count rate capability and rapid "gamma flash" overload recovery.

LOGIC MODULE

The requirement for separation of prompt and delayed neutron pulses was met by the development of a Variable Time Gate Generator (VTGG). A simplified block diagram is shown in Figure 5. Two positive-going pulses (T1 and T2) are generated as gates to enable the prompt and delayed scalars respectively in the data acquisition system.

Figure 5. Simplified Block Diagram of Variable Time Gate Generator

Four sets of 3-digit thumbwheel switches are used to pre-select the start and stop times for T1 and T2. The T1 times are in μ s. The T2 times are in tens of μ s. The switch outputs are compared with a timer output driven by a 10 MHz oscillator. The oscillator generates a 1 MHz clock. The 1 MHz clock increments the comparator timer. The timer is enabled by a trigger pulse from the accelerator. The trigger pulse occurs at the start of the accelerator electron burst. The content of the timer, at any time, t , is the elapsed time in μ s from the trigger input to time t . Two comparator networks control

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CONCLUSIONS

The electronics system described above meets the basic requirements for the photon interrogation project. Count rates of 4×10^5 counts per second with a 20% deadtime correction, and "gamma flash" overload recovery within 30 μ s with the accelerator operating at 16 MeV, 500 mA, and a 2 μ s wide pulse at a 60 Hz rate have been achieved.

Future plans include a modified logic module with more flexible delays and pulse widths, the addition of internal trigger capability, and I/O interface for hard-copy output. The development of multi-scaler modules is being considered with interface capability for output to a processor for automatic data processing.

REFERENCES

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Figure 6. Block Diagram of Five-Channel Electronics System for Photon Interrogation