INSTRUMENTATION RESEARCH AND DEVELOPMENT IN U.S. DEPARTMENT OF ENERGY HEALTH PHYSICS PROGRAMS

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INTRODUCTION

The goal of applied research in instrumentation sponsored by U.S. Department of Energy's (DOE) Radiological Controls Division is to maintain the protection of radiation workers at the highest level commensurate with the current level of technology. Current research developments in the Division will be described in this paper.

Planning and controlling exposures to ionizing radiation require accurate, reliable instrumentation to establish and measure dose rates, to indicate high-exposure rate areas, and to control the spread of contamination. Control of the radiation environment, established with sophisticated portable and installed instruments, is verified by bioassay and dosimetry programs that also rely on sophisticated instrumentation.

The DOE Radiological Controls Division conducts several programs under the technical direction of the Pacific Northwest Laboratory (PNL), DOE's lead laboratory in health physics. These programs make use of DOE contractors, universities, and private companies to evaluate and upgrade measurement systems. Applied research is conducted in the areas of beta measurements, neutron measurements, internal dosimetry, air monitoring, and instrument evaluations.

INSTRUMENTATION PERFORMANCE

As a result of the observed poor performance of health physics instruments, a draft performance standard was written and evaluated experimentally at PNL. The evaluation [1] led to changes in the standard, so that all of the tests are practical; it is possible to design instruments that meet the various performance criteria. However, specific instrument types met certain selected criteria only with difficulty. An analysis of the errors for gamma survey instruments that passed the standard [2] showed that for Geiger-Müller (GM) detector-based instruments the expected accuracy would be ±30%, whereas for ionization detector-based instruments the expected accuracy would be ±26%. These are the quadrature sum of errors found during testing of the instruments and do not include errors in calibration, in reading the instrument (precision, recording errors, etc.), or in degradation of performance in the field. The dominant sources of error are angular dependence, energy dependence, and temperature dependence.

In order to meet recommended accuracies for field measurements [±30%, Ref. 3], instruments must be able to meet criteria similar to those found in draft American National Standards Institute (ANSI) Standard N42.17A. The DOE is planning a testing program for instruments used in their facilities.

NEUTRON INSTRUMENTATION

In the neutron program, a new type of radiation-detection instrument has been developed that uses the tissue equivalent proportional counter (TEPC) as the detector [4]. Based on developments in algorithms, counter stability, and electronics, a prototype instrument [5] was developed at PNL to measure the total dose equivalent in mixed radiation fields. This "Total Dose Meter" is designed as an alarming personnel monitor and complements existing dosimeters used for workers exposed to neutrons.

A block diagram of the electronic circuitry of the unit is shown in Figure 1. To measure the very small pulses from gamma rays, it was necessary to develop an ultra-low noise preamplifier, which has a root mean square (RMS) noise of only 130 electrons. To cover the wide range of pulse sizes, it was necessary to use two separate linear amplifiers, one for neutron events and one for gamma events. An analog to digital converter (ADC) was designed using a pulse-height-to-pulse-width circuit that is used to gate an oscillator. Pulses from the ADC are summed and stored in buffers until interrogated by a microprocessor.

BETA INSTRUMENTATION

Tests at PNL [6] have shown that many instruments have severe angular and energy dependence. Some instruments do have adequate characteristics; these instruments generally have a thin window (5 to 10 mg/cm^2) and a thin sensitive volume, both in terms of density thickness (1 to 5 mg/cm^2) and physical thickness (<2 cm). One instrument with suitable energy and angular response is based on a thin plastic scintillator (5 mg/cm^2) and uses pulse-shape discrimination to eliminate noise [7]. Because of this discrimination, complex power-consuming circuitry is necessary. This circuitry makes the instrument cumbersome and affects its long-term stability. Work is underway to improve the instrument and produce one that will operate reliably in the field.

Research has also resulted in the development of a coincidence system using a proportional counter and a thick scintillator to collect beta spectra in the field. This results in a scintillator that can collect either beta or gamma spectra with a rejection ratio of 1000:1. Spectra from a ^{207}Bi source are shown in Figure 2. Such a capability is important in studying beta fields present in a facility to implement effective protective measures.

Laser heating of thermoluminescent dosimeters (TLDs) [8] provides a system that enhances the signal-to-noise ratio by rapid heating of the TLDs and also provides high throughput. Commercial CO_2 lasers are not designed to produce the ultra-stable light

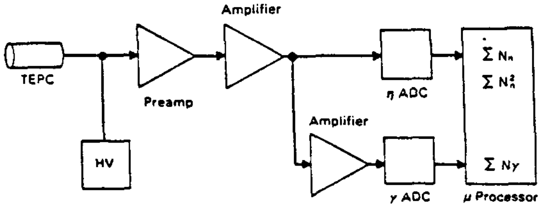

FIGURE 1. Block Diagram of Total Dose Meter Electronics. A neutron (n) and a gamma (γ) channel are used with the microprocessor summing the neutron (Nn) and gamma events (N_γ) and calculating dose.

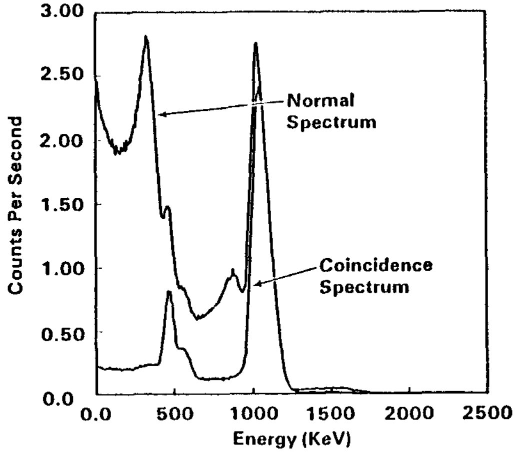

FIGURE 2. Spectra from ^{207}Bi Source in a Plastic Scintillator Operated Normally and in Coincidence with Proportional Counter in Front of the Scintillator

out-put needed to reproducibly read dosimeters. Applied research resulted in adding temperature stabilization and beam monitoring to the laser system to obtain reproducible heating of the TLDs. The beam profile from a laser system is gaussian (nonuniform) and research resulted in methods to produce uniform heating over a selected area (2 to 3 mm^2). The system can now reproducibly pre-anneal, read out, and post-anneal TLDs in 1 second.

INTERNAL DOSIMETRY

Accurate measurement of internal depositions of radionuclides is essential to determine radiation risk to workers who acquire an internal deposition of radioactive materials through inhalation, ingestion, or penetration of the skin. Bioassay techniques involve measuring trace amounts of nuclides in excreta, primarily urine. In 1982, PNL developed a new technique for precisely measuring uranium in aqueous solutions (urine). The technique, kinetic phosphorimetry [9], automatically compensates for quenching effects and therefore produces reliable measurements with less sample preparation than required previously. The instrument is extremely sensitive and can measure uranium concentrations down to a few parts per trillion. The DOE was awarded a patent for the unique capabilities of this technique, which has been commercialized.

The PNL is currently developing a new technique for measuring the concentrations of radionuclides [10]. This technique uses two pulsed dye lasers to resonantly excite only the target isotope to an electronic state just below the ionization threshold. Collisions with an inert gas ionize the excited atoms, and a thermionic diode detector measures the ion production. Recent results with calcium as an analog for the transuranic elements indicate that detection limits of less than one femtogram should be feasible. This unique technique offers the extreme sensitivity of laser measurements in a relatively simple and inexpensive apparatus that will be useful in measuring nuclides in excreta. The technique may also be useful for measuring nuclides in aerosols.

CONCLUSIONS

Efforts have also included development of a transuranic air monitor [11], specialized studies of instrument performance, and prototype evaluation of several detector systems including fiber optics, organic semiconductors, and others. Recent developments, together with the health physics instrumentation testing, have resulted in improved measurement capabilities. Health physics instrumentation of the future [12] should encompass the latest technological advances in detectors and electronics to improve basic measurement capabilities and to provide greater reliability of existing instrumentation. Applied research will continue to provide the means by which to improve accuracy, ease of operation, reliability, and versatility of health physics instrumentation.

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