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TITLE STABILIZED, HAND-HELD, GAMMA-RAY VERIFICATION INSTRUMENT FOR SPECIAL NUCLEAR MATERIALS

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STABILIZED, HAND-HELD, GAMMA-RAY VERIFICATION INSTRUMENT FOR SPECIAL NUCLEAR MATERIALS[*]

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Abstract

For many years, Los Alamos has developed intelligent, hand-held, search instruments for use by non-specialists to search for special nuclear materials (SNM). The instruments sense SNM by detecting its emitted radiation with scintillation detectors monitored by digital alarm circuitry. Now, we have developed a new hand-held instrument that can verify the presence or absence of particular radioisotopes by analyzing gamma-ray spectra. The new instrument is similar to recent, microprocessor-based, search instruments, but has LED detector stabilization, three adjustable regions-of-interest, and additional operating programs for spectrum analysis. We call the new instrument an SNM verification instrument. Its spectrum analysis capability can verify the presence or absence of specific plutonium isotopes in containers or verify the presence of uranium and its enrichment. The instrument retains the search capability, light weight, and low-power requirement of its predecessors. Its ready portability, detector stabilization, and simple operation allow individuals with little technical training to verify the contents of SNM containers.

Introduction

Verification is a term used in nuclear safeguards for a special nuclear material (SNM) measurement that is less accurate and less precise than assay measurements, which often have a 1%, or lower, goal for measurement errors. Verification measurements characterize an item being measured as one previously measured or as one of a particular type; in this case, 10% measurement error limits are usually acceptable. Verification measurements in nuclear safeguards include verifying the identity and contents of containers entering and leaving an SNM storage vault; confirming the mass and type of SNM in a container by shipper and receiver; and verifying that certain radioactive containers leaving a protected area do not contain SNM, which we call non-nuclear verification.

Our new hand-held, SNM verification instrument is designed for non-nuclear verification, and, thus far, its major application has been to verify that mechanical test assemblies (for example, missile warheads) do not contain plutonium. This application requires portable equipment because verification takes place at the location of the warhead, which may be on a production line, in a storage location, or aboard an aircraft or missile. Verification in a plant facility can be performed with portable equipment, such as small multichannel analyzers (MCAs) and NaI(Tl) scintillation detectors. These are easily backed up by making spare equipment available nearby. Verification on an aircraft flight line, however, requires equipment that is more portable. In this case, both primary and backup equipment must be transported, often over great distances, by commercial aircraft and rental cars. Under these circumstances, small, lightweight, hand held verification equipment is ideal.

As a starting point for a new hand held verification instrument, we began with the design for an intelligent, hand-held, SNM search instrument developed at Los Alamos.[1,2] These lightweight, battery powered instruments sense SNM by monitoring for its emitted radiation using a NaI(Tl) scintillation detector and microprocessor based alarm circuitry. To incorporate the peak stripping technique used to subtract Compton background in MCAs, we added a non-radioactive method of detector stabilization, three single channel analyzers (SCAs), and new operating programs. These additions and the resulting commercially available verification instruments (Fig. 1) were designed and produced by Jomar[**], who designated the instrument the model JHH II

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[*] This work was supported by the US Department of Energy, Assistant Secretary for Defense Programs, Office of Safeguards and Security.

[**] Jomar Systems, Inc., Los Alamos, NM 87544; (505) 662 9811.

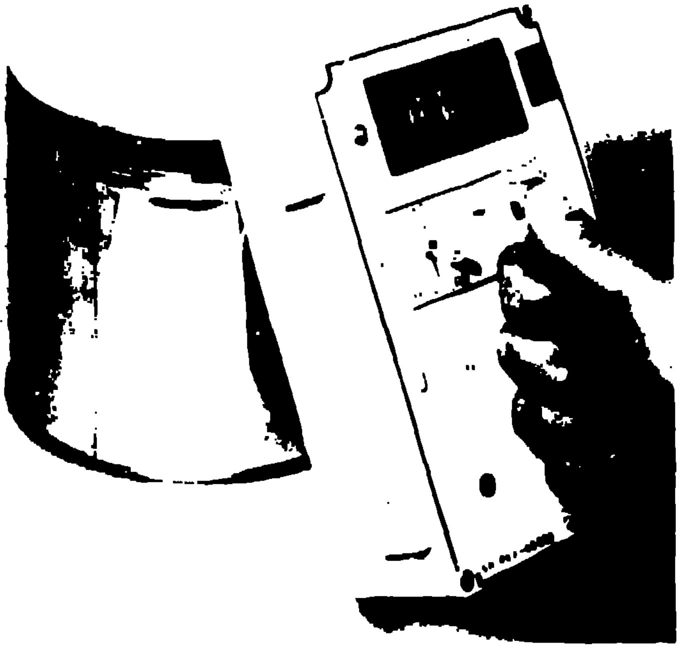

Fig. 1. The JHH-01 SNM verification instrument is an easily transportable, 1.8-kg package containing a well-protected measurement and analysis system operating from rechargeable batteries.

The New Verification Instrument

The JHH-01 verification instrument package (Fig. 1) contains all of the elements required for measurement and analysis: power supply, radiation detector, microprocessor, and information display. The package (9 cm high, 13 cm wide, and 20 cm deep) weighs 1.8 kg. It is powered by rechargeable batteries that are expected to provide about 16 h of operation; a complete recharge takes 8 h. Internal dc to dc converters supply operating voltages; high voltage for the photomultiplier tube (PMT) is provided as individual dynode voltages to eliminate power consumption in a voltage divider. The CMOS chips, including the Oki 80C85 microprocessor, also minimize power requirements.

The compact scintillator [a circular cylinder of NaI(Tl), 2.5 cm in diameter by 5 cm long] is coupled to the Hamamatsu 1924 PMT, which is almost the same size. The Bicron[a] detector assembly has a light pipe containing a green LED (1N6904) that flashes light into the scintillator. A thermally stabilized LED current produces 200 light pulses/s for amplifier gain stabilization. Stable operation keeps diode light pulses evenly divided between two adjacent SCA windows positioned well above useful gamma ray pulse heights. Measured gain stability by the manufacturer in our first prototype instrument was 1.5% over the -2 to +33°C temperature range giving the most variation in a dc stabilized instrument.[1]

Circuit Description

Figure 2 is a block diagram of the low power circuitry used in the JHH-01 for detector operation, data collection, and analysis. The LED is temperature stabilized by analog circuitry[a] and produces light pulses that are counted in the stabilization SCAs. These each have fixed outside pulse height limits and share a common central pulse height limit at an adjustable voltage (V8), which is used for fine amplifier gain adjustment. Any difference between the two stabilization SCA counts produces an error signal that the microprocessor uses to adjust the gain stabilization amplifier, by means of a digital-to analog converter, to move the diode pulse height toward V8.

Stabilized signals are also fed to a lower level discriminator (LLD) and analysis SCAs. The LLD enables six scalers to count data from the SCAs: one scaler for all pulses above the LLD, three for the adjustable analysis regions-of interest, and two for the stabilization regions. Scaler results are read periodically by the microprocessor for control, data analysis, and display.

The switches indicated in Fig. 2 control power; program reset; counting time or alarm level (thumb wheel switch); and operating modes. In addition to operating as a search instrument, there are three switch-selectable analysis modes and two setup modes in the operating program repertoire. The first setup mode uses the analog to digital (A/D) converter to read the voltage limits of regions of interest during calibration adjustments. The second displays each of the six scaler sums for troubleshooting purposes.

Operating Programs

Figure 3 is a flow chart for the operating programs. The basic search mode (left side) continuously measures counts above the LLD in 50 ms time steps and forms a 0.4 s moving average of the most recent ones. After each step, the moving average is compared with an alarm level derived from the background measured during the most recent program reset and an increment read from the thumb wheel switch. The LCD is updated each 1.2 s to show a 1 s average count rate converted to counts per second, and any alarms produce an audible chirp

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[a] Bicron Corp., Newbury, OH 44065; (216) 564 2251.

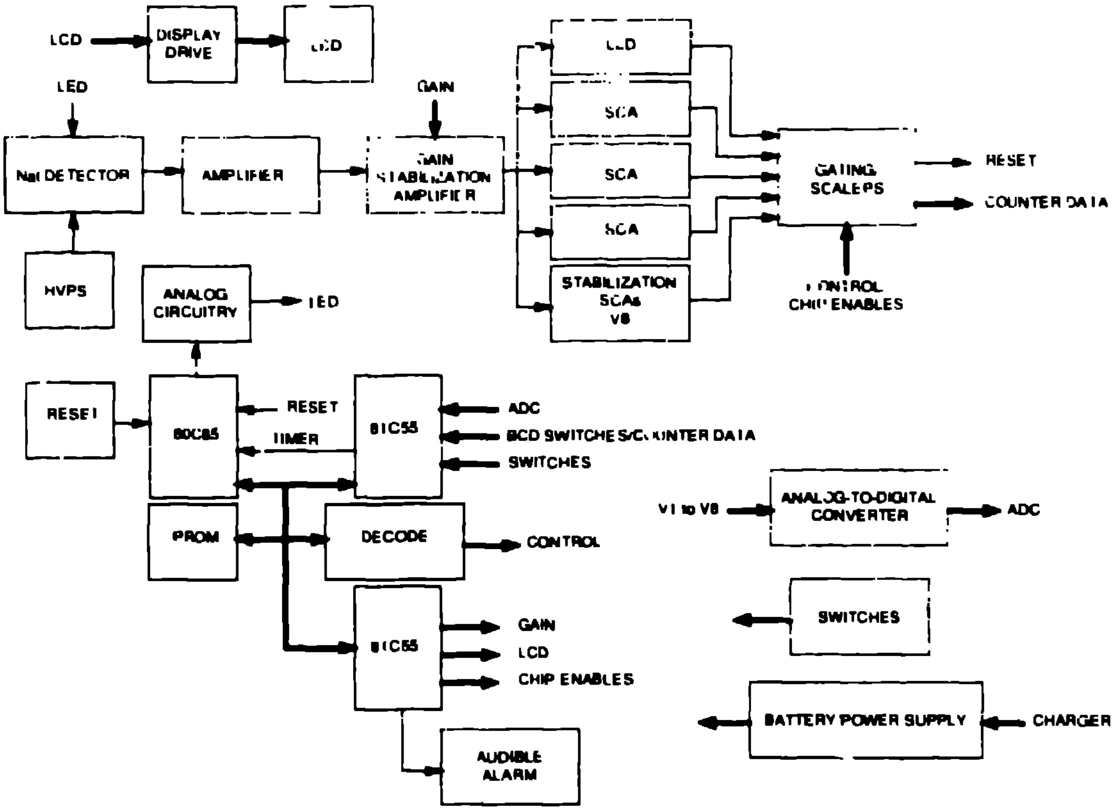

Fig. 2. The instrument's low-power circuitry operates and stabilizes the radiation detector, measures detector response, analyzes response data, and displays results.

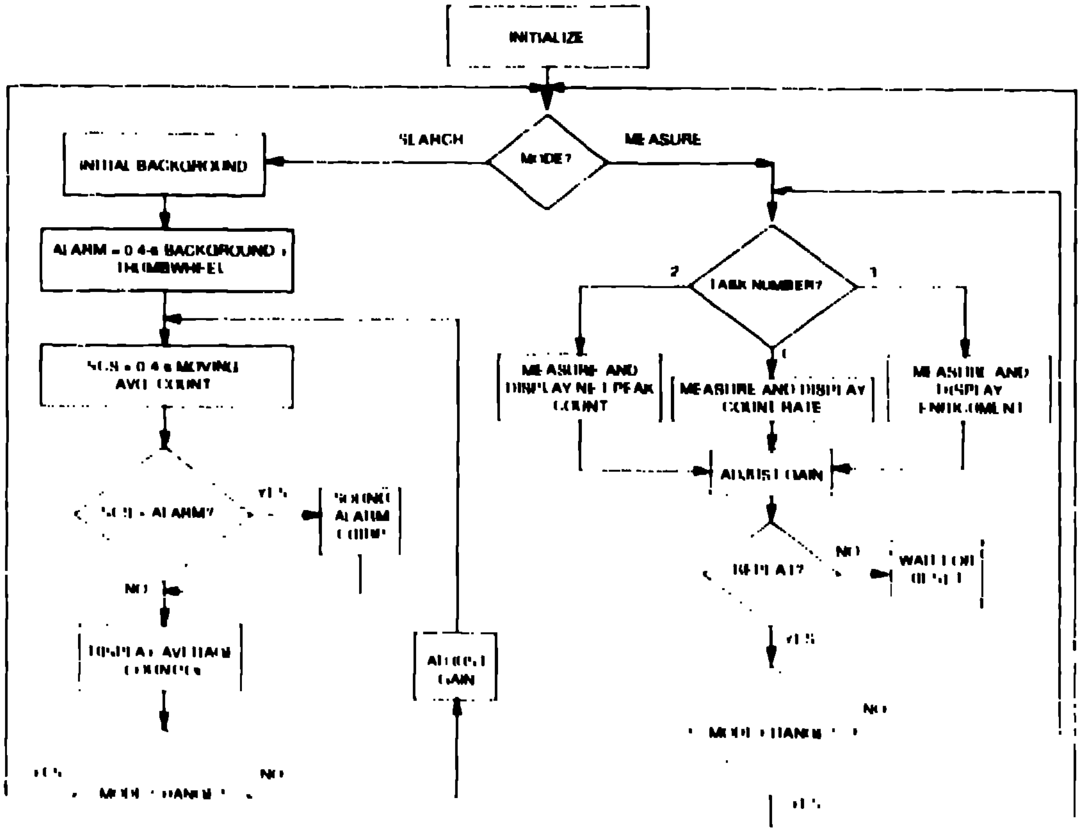

Fig. 3. The [illegible] operating program repertoire includes both search capability and measurement modes that provide precise averages, Compton stripped peak intensities, or uranium enrichment estimates.

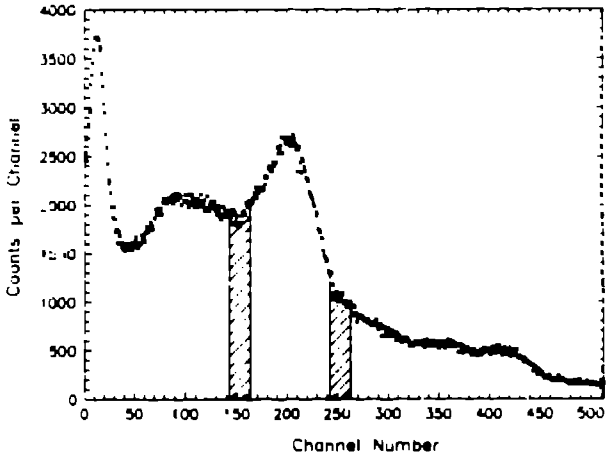

Fig. 4. The instrument's second task strips the Compton continuum from the penetrating plutonium peak region between 330 and 450 keV, using the two cross-hatched adjacent regions-of-interest to estimate the Compton contribution.

The measure mode has three switch-selectable tasks, all of which use the thumbwheel switch for setting a counting interval in seconds. The first task continuously displays total counts or count rate above the LLD as each counting interval is completed. The second task makes a net peak count or count-rate measurement in the central region-of-interest. Two smaller adjacent regions are used to estimate the Compton-scattered radiation contribution to the central region. Alternatively, a single region-of-interest at higher energy and a switch-set multiplier can be used to correct for Compton scattering. The third task estimates uranium enrichment from two regions-of-interest set to measure the 185-keV peak from ^{235}U and a higher energy region, which may include the peaks at 766 and 1001 keV from ^{238}U daughters.[5]

Operating Experience

To date, most of our operating experience is with prototype instruments used to verify the presence or absence of plutonium mixed with other radioactive materials in fairly standard containers. We use the second task with the central region-of-interest set for the 330- to 450 keV ^{239}Pu gamma rays, which easily penetrate container walls. Underlying Compton scattered radiation is subtracted by the instrument using an estimate made from the adjacent regions indicated in Fig. 4. Negative or small positive net results verify the absence of plutonium; large positive net results verify its presence.

Our verification procedure uses the search mode to sense that containers are radioactive, then uses the measuring mode to estimate whether the amount of plutonium, if any, exceeds a threshold amount. This procedure relies on knowing how the instrument responds to similar packages that do or do not contain plutonium. Benchmark measurements must be made on standard packages to provide a catalog of instrument measurement results for different amounts of plutonium. Thus, an operator can be given appropriate measurement limits corresponding to nuclear or non nuclear packages.

We began our application of prototype instruments to verify non nuclear test assemblies by making a catalog of verification measurement results for readily available weapon systems (containing plutonium) and test assemblies (either non-radioactive or containing depleted uranium). Subsequent field verifications with prototype instruments correctly identified all test assemblies as being non-nuclear. Field verifications also provided an excellent opportunity to discover needed additions and corrections to the instrument's design. However, they provided little experimental information on the precision and accuracy of the measurement results. To study the JHH-01 instrument's response variation with time and temperature, we devised a test fixture to reproduce either a non-nuclear or nuclear spectrum, and used it to evaluate prototype and production instruments.

Instrument Evaluation Procedures and Results

Our evaluation at Los Alamos used the test fixture (Fig. 5) to position the JHH-01 on a depleted uranium plate, which has a void below for positioning precisely a plutonium sample. With no plutonium in the void, the depleted uranium provides a non-nuclear gamma-ray spectrum. With plutonium in place, the spectrum is a nuclear one. Using the fixture, we studied the variation of measurement results in one production and two prototype JHH-01 instruments over a range of temperature and battery charge. In the process, we discovered and corrected a few shortcomings in the instrument's design that would not have been noticed otherwise. We also confirmed the adequacy of the instrument's operating programs and determined the precision of measurement results.

During our evaluation, instrument temperatures varied from a low of 8°C to a high of 40°C, but most measurements took place at an average room temperature of 24°C. The battery charge varied from a full charge to a discharge level where the pulser could no longer stabilize the instrument. The evaluation ended either at this point or at one of two other points: (1) when an instrument's measurement results decreased by 15% or more; or (2) after 24 h of operation. During evaluation, each instrument operated for about 8 h, then was turned off overnight. The total satisfactory operating time for the instruments varied greatly: the production instrument failed after 12 h; one prototype instrument failed after 8 h of operation; and the second was still operating satisfactorily after 24 h.

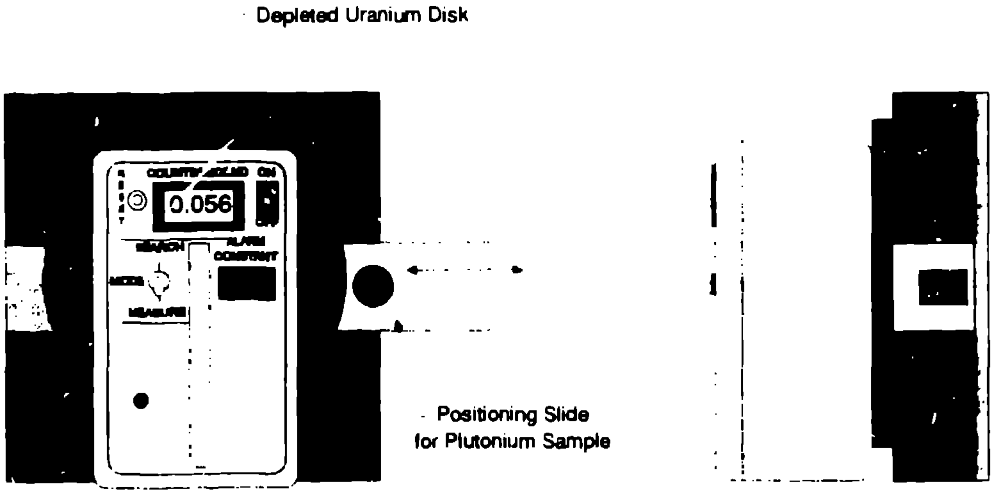

Fig. 5. The test fixture, shown here in top and side views, provides a reproducible arrangement of depleted uranium and plutonium for evaluating the accuracy and precision of the JHH-01 instrument's measurements.

During the evaluation, we monitored the pulse heights of both the LED pulser and ^{137}Cs 662-keV gamma rays to test the stabilization method. We found that the pulser stayed within ±2% of its mean pulse height in all the instruments. On the other hand, the cesium gamma-ray pulse height varied ±3% to ±4% from the mean in the prototype instruments, but only ±2% from the mean in the production unit.

We judged each instrument's precision from sets of six, repeated, 20-s nuclear measurements. The sets of measurements were initially made 1 h apart and, thereafter, approximately 2 h apart. The measurements in each set fell within 2 std dev of the mean, a good indication that the variation was from normal counting statistics.

We judged the accuracy of each instrument from differences between its measurement set means and the overall average of its measurements. In this case, the set means fell 8.5 to 19 std dev from the overall average, which corresponds to a 6% to 14% variation. This amount of variation is usually insignificant for non-nuclear verifications. If it were significant, much of the variation could be avoided by operating near room temperature for not more than 8 h before recharging the batteries.

Strong and Weak Points of the Instrument

The instrument's strong point is its ability to provide measurement results normally obtained only with much less portable and more fragile equipment. Other strong points include the following characteristics.

- Its small size, light weight, and self contained design make it easy to transport and use.
- A non specialist operator does not need to cope with fragile external detectors and the problems of worn out cables and connectors.
- The instrument's operating time is usually long enough to allow verification, even if battery charging were overlooked during preparations for a trip.
- Its high sensitivity allows simple functional checks after travel using gasoline lantern mantles.
- Its stabilized detector eliminates the need for recalibration with a reference spectrum before each verification.

The instrument's weak points are few. A basic weakness stems from pulse pileup at very high count rates, which arises when intense uranium x rays pile up with plutonium peaks to shift them out of the analysis window. We cope with this shortcoming by reducing the count rate, first by shielding the detector with lead (0.15 cm thick), and then with a spacer that provides additional distance between the detector and source of radiation. We use the instrument's count rate in its search mode to tell whether or not the spacer is needed (>10 000 counts/s) for a particular type of verification measurement.

Another weakness arises when verifying isotopes that emit only low-energy characteristic radiation, such as the 153 keV gamma ray of ^{238}Pu. Such low energy gamma rays are subject to interference from other radioactive materials. Many gamma rays with nearly equal energy or backscatter peaks from higher energy gamma rays may fall in the same energy range. As a result, some innocent items may be rejected, which seldom happens when higher energy characteristic radiation is used for verification.

Summary

We have developed a very useful and convenient instrument for performing non nuclear verifications under field conditions that require commercial travel. The instruments can provide precise and accurate verification results that are equivalent to those obtained with MCAs, particularly when an instrument has been fully charged before use. The instruments have proven to be rugged and easily operated by non-specialists and have been well accepted by users. Two spin-off variations of the instrument already exist, or are being developed: One of these uses external neutron and gamma-ray detectors for uranium holdup measurements; the other operates a Fidler detector for contamination surveys.

Acknowledgments

We are indebted to our colleagues, past and present, who have participated in developing new instruments for nuclear safeguard applications over the years. Their accumulated experience in instrument development, both at Los Alamos and Jomar, has made developing the new verification instrument a much easier task.

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