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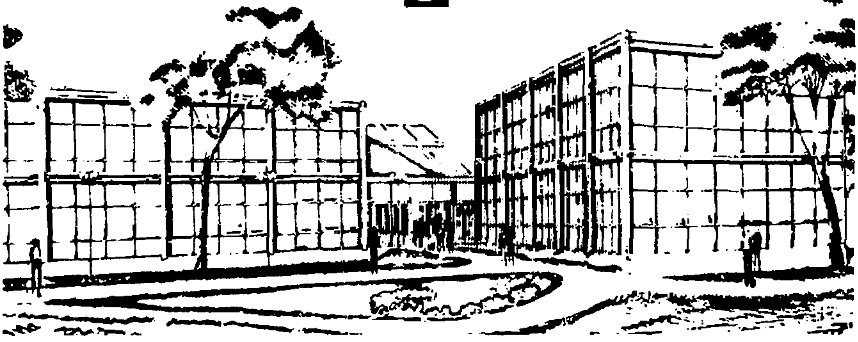

A 1024–CHANNEL PORTABLE GAMMA–RAY SPECTROMETER

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Abstract

An instrument is described which is designed to determine radioactive isotope spectra in the field under adverse environmental conditions. The instrument is battery-powered, sto''es and compares multiple spectra, and performs computations upon the resulting displayed graph.

Introduction

In the fields of environmental monitoring, health physics and emergency response, it is sometimes necessary to measure radioactive isotopes in the field or in areas such as hospital emergency rooms in which bulky permanent equipment is not available or cannot be used easily. In all cases, the user needs a completely self-contained, easy-to-use instrument that will determine type and quantity of nuclear isotopes present in his sample. The instrument should be very adaptable to measure the source in whatever form it may be found and in whatever location or severe climate. The instrument should not be dependent on electrical power or other equipment to do its job. The instrument should be easy to carry and lightweight. Until recently, with the design of our first-generation instrument, this type of analyzer was not available.

Measurement of Isotopes

Presently used gamma-ray analyzers work in a similar manner to identify isotopes present in an unknown sample. Most radioactive isotopes in nature emit a number of different x-ray or gamma-ray energies of varying rate or strength, depending on their stability. Certain isotopes also emit alpha and beta particles and neutrons, but these are not of primary concern with this type of analyzer, although knowledge of these other particles, energies and rates would help determine the isotope type.

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The emitted rays may range from 10-keV x-rays to 3-MeV or higher gamma rays. The low-energy rays have low penetration power and may easily be stopped by metal, concrete, air, etc. and thus are difficult to detect at a distance. The higher energies are easier to detect as the case material of the instrument is transparent to them and the detector may be left inside the case. The range of gamma-ray energies usually encountered is from about 100 keV to 3 MeV. Lower energies are more difficult to measure and usually require a more specialized detector.

There are several types of detectors that convert the passing of a gamma ray through the device into an electrical pulse of a height proportional to the energy in keV or MeV lost by the gamma ray. The detectors may be made using a sodium iodide crystal viewed by a photomultiplier tube (NaI PM detector) in which the crystal emits a light pulse of intensity proportional to energy which is then converted to an electrical pulse by the tube.

Another type that has better resolution for use with samples that have many gamma rays is made using a relatively pure germanium crystal. It has the disadvantage of needing very low-temperature cooling for operation, and may cost $10,000.

The sodium iodide detector is more widely used for general applications because of its low cost and ease of use. It is the main detector for our portable instruments, although the germanium type may be used externally. By using an analyzer coupled with one of these detectors, a preliminary survey of the type of isotope present may be made. After that, searching for location and quantity of isotopes may be done using less complex hand-held scintillation counters or Geiger counters.

Measuring the Energies

The voltage pulse output from the detector is measured as to height, and a location in a memory which represents that height is incremented one count each time a pulse is emitted from the detector. After some time has elapsed and a random number of pulses representing gamma rays hitting the detector have been measured, the resulting counts versus memory location may be plotted on a cathode-ray tube.

This plot of counts versus memory location is proportional to counts versus voltage pulse height which in turn is proportional to counts versus energy of the gamma-ray spectrum. By knowing the elapsed time, the curve becomes pulse rate versus energy of the pulses (see Fig. 1 for a generated curve made by the first-generation analyzer). A health physicist can then determine from the peaks on the curve what isotope or isotopes are present in his sample. Books of isotope charts are available for help in identifying isotopes. The Gaussian shape of the peaks is due to the statistical nature of the light emission and current multiplication in the NaI PM detector. With a germanium detector, the peaks would be one-tenth as wide.

Features Needed on the Instrument

Obviously, the instrument to measure the gamma rays and plot the energy spectrum should be capable of reading out the spectrum in units of keV or MeV and elapsed time in seconds. A method of determining energies of the peaks should be available. Sometimes integration of a peak is desired, and it must be easy to set limits and read out results. It should be possible to record several spectra in succession, to compare them against each other, and to add to or subtract from them. Record keeping data such as time of day and sample number should be read out and displayed in a format along with all of the other parameters and spectra, such that a recording camera may photograph all information simultaneously and thus not require the user to write more information on the photo. Digital information storage such as magnetic tape would be also useful for recording all the information.

First-Generation Spectrometer

In 1973, LLL designed and constructed its first-generation gamma-ray spectrometer, a 256-channel machine (see Figs. 2 and 3). Channel refers to the number of memory locations used for the energy axis of the generated curve. In other words, the viewed spectrum, whether it is 0 to 100 keV or 0 to 3 MeV, is divided into 256 equal increments of energy. The resulting curve is made of 256 dots, as seen in Fig. 1.

The first-generation machine had memory for only one spectrum, and could integrate and do a background subtraction approximation based on a straight line drawn between the two points to be integrated. It had two movable markers on the displayed energy spectra curve, one of the markers reading out directly in keV energy units. Time of day, day of year and sample number, along with peak energy, the integral, live elapsed time and preset live time were all displayed on light-emitting diodes (LEDs) near the CRT so that the instrument's Polaroid camera could record the curve and all important digital information at one time. The instrument would operate 10 to 20 hours on its internal rechargeable gel cell batteries, and was completely self-contained in a waterproof aluminum case.

Almost all operation was performed via a 24-button keyboard to minimize knob turning which may be difficult if an operator must wear gloves in a cold climate.

The detector was a 50x50 mm NaI (Tl) crystal with photomultiplier, mounted in shock- and temperature-insulating foam. The detector was housed in a protective well along the side of the instrument, and could be used in place or removed and hung on a tripod which was carried in the cover of the instrument.

The digital logic of the instrument consisted of 300 integrated circuits of the Complementary Metal Oxide Semiconductor (CMOS) type of medium-scale integration (MSI). This is equivalent to approximately 10,000 transistors.

Second-Generation Spectrometer

As this paper is being written, a second-generation portable gamma-ray analyzer is under construction. This was started to provide more features not available in the first instrument, and to make a well-packaged, easily accessible unit as compared with the first instrument which was one-of-a-kind. The second-generation will have the ability to digitize and store one 1024-channel spectrum or four 256-channel spectra. The 256-channel spectra may be moved, added or subtracted. Integration as before is available. The display will be larger, consisting of 46 characters of LED information, six status indicators, and the same 50x75 mm cathode-ray tube for plotting. The entire display as before can be photographed by an automatically controlled Polaroid SX-70* camera which can be used as a conventional camera when not needed for the display. The data will also be telemetered out in a NRZ teletype format using a 1200- and 2200-Hz VCO. This allows the data to be recorded on a conventional audio tape recorder or sent via phone to a remote viewer or computer. A 36-button keyboard allows many more analyzing, computing and display features not found in the first instrument. Some of the features are:

- Linear or log display.
- The ACQUIRE mode can be programmed to stop on preset time, on preset counts, on overflow, or on preset counts in a specific channel.
- Three markers read out energy, with two of them also reading out counts.
- Pushbutton control in binary steps of amplifier gain which also reads out on the display.
- The energy scale can be offset (scale may read from 1 MeV to 2 MeV).
- Automatic vertical CRT scale expansion or compression.
- Ability to overlap two spectra on the CRT.
- Power-conserving display turns off when not needed.
- Blinking "warning" light on display which indicates Operator has typed in invalid or incomplete command.

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*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exlusion of others that may be suitable.

Electronics

The instrument will run for 10 to 20 hours on rechargeable gel cell batteries which can be removed and replaced easily in emergency situations. The digital logic consists of 500 CMOS MSI integrated circuits configured into a 32-bit, special-purpose computer design. Five controllers provide most of the mathematical operation, while several other controllers handle peripherals such as the LED multiplexing, the CRT plotting, and time keeping and marker moving. Although the instrument does not use a microprocessor (which in CMOS was not available early enough) the logic and flow charts can be converted to a microprocessor in later designs to conserve chip space and save weight. The present controllers, however, run at high speed, and this makes replacement with one microprocessor unlikely until the speeds are increased. The time of day plus day of year clocks are run permanently from the batteries to provide correct time when the unit is turned on. All important registers and memory are controlled by a memory protect switch which will allow it to be nonvolatile if desired, while not allowing quite as long a battery shelf life.

The preamplifier and analog-to-digital converter are low-power designs using operational amplifiers. The ADC runs at 8 MHz and is a Wilkinson-type design. All linear circuitry is designed to provide negligible drift over a 100°C operating temperature range (-30 to +70°C). The six peripheral printed circuit boards and special wire wrap plane are all designed for high reliability using the best of components. All circuitry is designed to draw minimal power, thus raising costs. An example of this is the use of a converter to lower the 12-V battery to 5 V to run the light-emitting diodes. Overall, this saves 50% power to the lamps. The logic runs from a regulated +10 V off batteries while the linear circuitry uses $\pm$ 12.250 Volts from a dc/dc converter and dual high-stability regulator. An internal 1-kV regulated supply is present for the shock-mounted NaI(Tl) detector which is carried in a front panel well similar to that located on the side of the previous model.

Mechanical Design

The completed analyzer will be functional, environmentally protected, and esthetic. The overall shape will be that of fine luggage for ease of transportation (see Fig. 4). The waterproof cover will house either a standard SX-70 camera and accessories or a SONY TC55 tape recorder and accessories. With the cover removed, the front panel will be splash-proof and can be hosed down to remove salt if it has been used in a salt spray atmosphere. All exposed metals will be plated to resist corrosion; all switches and controls will be sealed. An additional waterproofing cover will enclose the recessed front panel controls and detector which are rarely adjusted. Normal operation can be performed using only the keyboard and three display CRT knobs below the display bezel. Recessed panel adjustments allow fine adjusting of amplifier and ADC and access to the memory-protect switch, high-voltage switch, time-setting switch and telemetry output jack. Other jacks are provided here for using other detector types. The case is built of fiberglass and aluminum. Most internal chassis parts are made from hydroformed aluminum; other parts are machined aluminum or polycarbonate. Metal parts are connected by electron-beam welding or epoxy bonding. Lock screws are used only for removable components of the chassis. The edge-lit display legend/graticule allows the legend information to be photographed. It is engraved using a Gerber computer plotter with a diamond stylus. The graticule is made from scratch-resistant polyallyldiglycol carbonate. All aluminum parts are anodized, and the front panel is painted over with a two-part epoxy. The internal chassis is cushioned by a form-fitting foam lining so that the entire chassis may move within the fiberglas shell to withstand dropping or vibration.

The majority of the digital logic is mounted on a six-board folding wire wrap plane system to eliminate connectors. The six 127- x 203-mm (5- x 8-in.) boards are held together with polypropyline hinges and unfold to about 40 in. Folded it occupies 127x203x203 mm and holds 500 integrated circuits. Conductive foam keeps the ICs from coming out of their sockets.

Two views of the prototype second-generation spectrometer before being fitted into a case are shown in Figs. 5 and 6.

The completed instrument containing batteries, line cord for 110/250-V 50/60 Hz, Polaroid SX-70 camera, camera mount for automatic photo making, viewing hood for bright sun, 50x50 mm NaI detector and cables will weigh 14 kg.

Fig. 1 A Polaroid photo made by the first-generation analyzer shows peaks made by ^{60}Co. This spectrum was not calibrated, but was only used as channel numbers (B mark energy shows 255 channels full-scale where marker is placed).

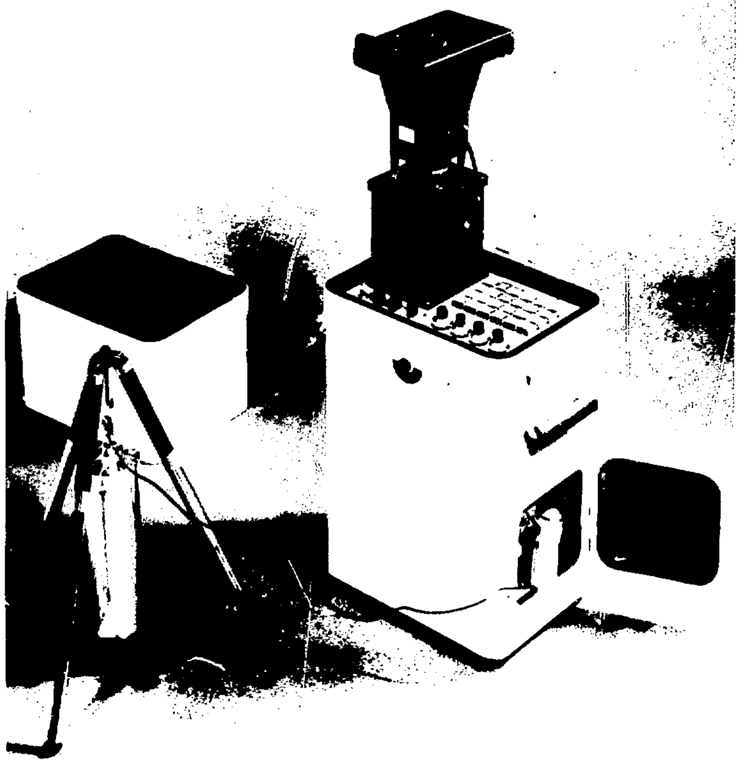

Fig. 2 The first-generation analyzer has its Polaroid camera removed from the cover and mounted on the display. The detector is removed from its carrying well and has been hung on the collapsed tripod also carried in the cover.

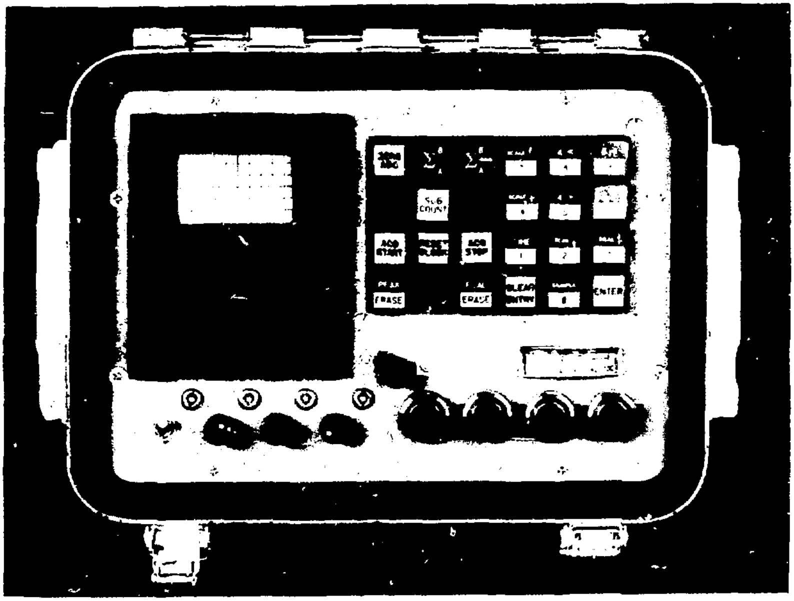

Fig. 3 The front panel of the first-generation analyzer shows a 24-button keyboard and hybrid LED, CRT display.

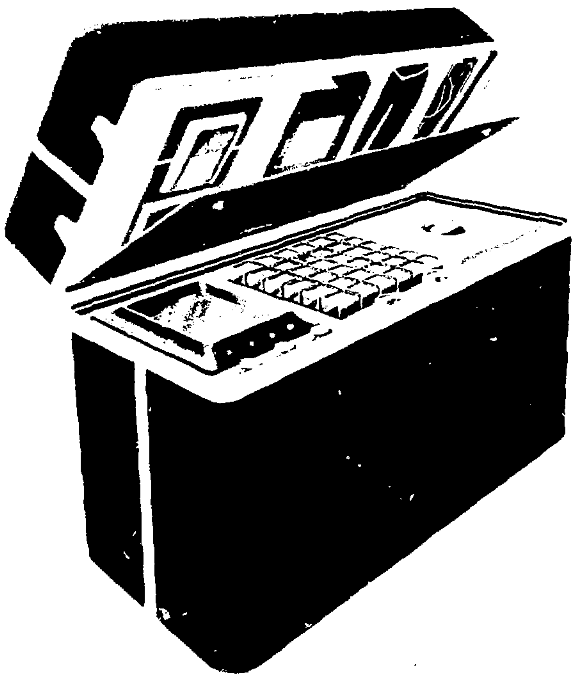

Fig. 4 An artist's conception of the second-generation is still reasonably accurate, although the latches on the case and the meters have been changed. The small lid on the right side of the front panel covers the recessed panel containing detector and seldom used controls.

Fig. 5 A prototpye second-generation analyzer under construction as of October 15, 1975 shows 36-button keyboard, Z-fold wire wrap plane in center of chassis, and printed circuit card frame at left. Front panel as yet has not been cut to fit into fiberglas box.

Fig. 6 Another view of the prototype second-generation shows detector well at left, gel cell batteries at the center, and CRT at right.