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A SOPHISTICATED GAMMA-RAY DATA ACQUISITION SYSTEM BASED ON AN IBM PC/XT COMPUTER

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Abstract

It is easy to assemble and program an automated gamma-ray data acquisition system consisting of an IBM PC/XT computer and several computer-controllable modules. Our system features pattern recognition to determine the energy calibration, automatic gain setting, automatic efficiency calibration, detector-positioner control, and source-changer control in addition to the more conventional operations.

Introduction

Traditionally, gamma-ray data acquisition systems have been based on hardwired multichannel analyzers. A few allowed some programming for data analysis, often in a language that was limited in capability or difficult to use. Interfaces for control of external equipment had to be custom built. A few users resorted to CAMAC, which is the rather complicated system used in high-energy physics. Thus, users were discouraged from automating their systems and only used what the analyzer vendors provided. The situation is more favorable now because many systems are based on personal computers with which users are familiar; moreover, some vendors are beginning to offer instrumentation with standard NIM/GPIB (IEEE-488) or RS-232-C interfaces. This paper describes a gamma-ray data acquisition system based on a personal computer and several computer-controllable modules.

Equipment

All the equipment in the system (Figs. 1 and 2), except for the detector positioner and source changer, is commercially available. The computer is an IBM PC/XT with a high-resolution color graphics card, a 10-Mbyte cartridge drive for archival storage and a 1200-baud modem for connection to the Central Computing Facility in Los Alamos. The unusual capabilities of the system derive from its computer-controllable instrumentation. An 8192-channel analog-to-digital converter (ADC) with a buffer memory acquires pulse-height distributions independent of the computer once the computer sets the ADC's parameters. A spectroscopy-grade amplifier with computer-setable gain and time constant processes the analog signals to the ADC. A computer-controllable counter/scaler scales a pulser for deadtime corrections. A general purpose interface/controller module controls the detector positioner, source changer, and an automatic liquid-nitrogen filling system for a high-purity germanium (HPGe) detector. All of these modules are controlled via an electronic switch.

Electronic Switch

The electronic switch is connected to communications port 1 (COM 1) on the IBM PC/XT. The switch has one RS-232-C input port and five RS-232-C output ports. Electronic switches can be placed in series if more output

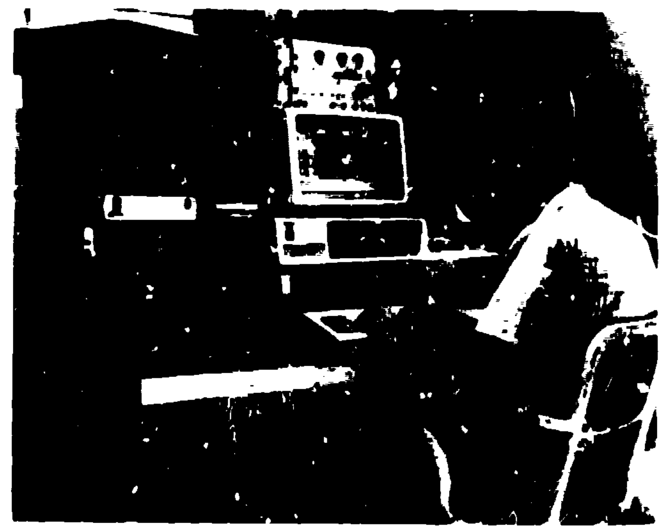

Fig. 1.
IBM PC/XT computer and electronics. The NIM bin contains an ADC with buffer memory, a computer-controllable amplifier, a spectrum stabilizer, a pulser, a computer-controllable counter/timer, and a computer-controllable general purpose interface/controller. An electronic switch and a modem are on top of the NIM bin. A cartridge drive is behind the keyboard.

Fig. 2.
Detector positioner and liquid nitrogen filling system. A high-purity germanium detector in an all-attitude dewar is mounted on the trolley.

ports are needed. When power is supplied, the input port is connected to the internal microprocessor. Transmitting the number of an output port, such as "2," will connect the input port to the output and make the switch transparent to the data. Sending a special sequence such as "escape, escape, X" will reconnect the input port to the microprocessor. Then another output port can be selected. A potential problem in this design is the possible presence of the special sequence in the data, but so far this has not occurred. Electronics switches with two separate input ports, one for control and one for data, avoid this potential problem.

Languages

The languages BASIC, FORTRAN, and PASCAL are used in our system. BASIC is convenient for the computer-controlled modules because it was assumed for most of the examples and instructions supplied by the vendors. FORTRAN is most familiar to us. PASCAL was the language used for some of the software we purchased and modified.

Automatic Energy Calibration

The system is easily calibrated when the source changer can be used to position sources with simple spectra in front of the detector, and the energy calibration is known to be approximately linear with channel number. The system first inserts a ^{137}Cs source that has a 662-keV line (Fig. 3) and searches for a strong peak using a modification of the method developed by Mariscotti.[1] If it does not find one, it assumes that the line is off scale and tries ^{203}Hg (279 keV) and then ^{241}Am (60 keV). If a strong peak can not be located with any of these sources, an error message is printed. If a strong peak is located, the system inserts other sources such as the mixed source from the National Bureau of Standards (NBS) containing ^{125}Sb, ^{152}Eu, and ^{154}Eu to span the on-scale energy range. Because the gain is now approximately known from the location of the strong peak, the peaks from these sources are easily located. The system calculates the centroids of selected peaks and performs a least-squares fit of a quadratic function to determine an energy calibration. Points with large deviations are dropped and the fit is repeated to determine a final energy calibration.

The system is more difficult to calibrate if sources with simple spectra are not used. This can happen, for example, when spectra are acquired in the field and transferred to the IBM PC/XT for analysis. Suppose that the uncalibrated spectrum is from an environmental sample (Fig. 4). The system assumes that the highest energy gamma-ray line is the 2615-keV line from ^{208}Tl, but it might be off scale if the gain is too high. First the system performs a modified Mariscotti peak search.[1] Under the hypothesis that the highest energy peak found on scale is the 2615-keV line, the system looks for background lines at 609 keV (^{214}Bi), 911 keV (^{228}Ac), 1461 keV (^{40}K), and 1765 keV (^{214}Bi). If at least three are found, it calculates the centroids and performs a linear least-squares fit to determine an energy calibration. If χ^2 is acceptable, it tries to verify this calibration by locating other background peaks and performing a least-squares fit of a quadratic function to determine a final energy calibration. If χ^2 is not acceptable or other background peaks can not be located, the highest energy peak is again assumed to be the 2615-keV peak, and other possibilities for the lower energy peaks are tried. If this fails, the system assumes that the highest energy peak is not the 2615-keV peak.

The system next tries to estimate the energy of the highest energy peak by calculating the fractional resolution (FWHM/centroid where FWHM is the full width at half maximum) of the highest energy peak. Since the fractional resolution is a monotonically decreasing function of energy (Fig. 5), the calculated fractional resolution corresponds to a gamma-ray energy. If the identity of the detector is known, the function is known; if not, the system assumes that the detector is of average quality and uses an appropriate function. Once the gamma-ray energy is known, the system tries to identify strong background lines and performs a least-squares fit as above. If this fails, a more general search is required.

For the general search, the system picks 4 strong background peaks such as the 609, 911, 1461, and 2615-keV peaks and tries them against all ordered combinations of the ten strongest peaks found by the peak search above. The trial consists of an attempted linear least-squares fit. If χ^2 is less than 1000, the system calculates the probability P_1 of this value of χ^2 using known probability distributions for χ^2. Next the system performs a fit of the FWHM for these four peaks as a function of the channel number. The resulting analytical function is used to calculate the resolution at 1332 keV. If the identity of the detector is known, its resolution under good conditions is known; a normal probability distribution is used to assign a probability P_2 to the calculated resolution. If the identity is not known, the system assigns P_2 with a probability distribution for the resolution which we have determined from data on many detectors (Fig. 6). The product of these probabilities $P = P_1 * P_2$ is assigned to this identification. When P is larger than a set value, the system looks for other background peaks to confirm the fit. If they are found, the system performs a final quadratic fit as above; if not, it proceeds to other ordered combinations of the ten strongest peaks. After exhausting the search on the first four background peaks, other background peaks are tried and eventually, if necessary, weaker peaks found in the peak search. A formula limits the number of combinations to try. An attempt is made to verify the ten combinations with the highest values of P by looking for other background peaks. If an acceptable combination cannot be found, an error message is printed.

In the example above, the system searches for background lines. Since much of our work involves uranium and plutonium, the system is programmed to also search for characteristic lines from these materials

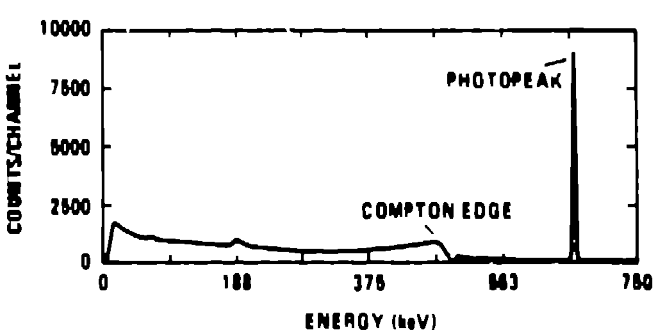

Fig 3.
Pulse-height distribution for a ^{137}Cs source. This simple distribution with a single line at 662 keV is useful in automatic energy calibrations.

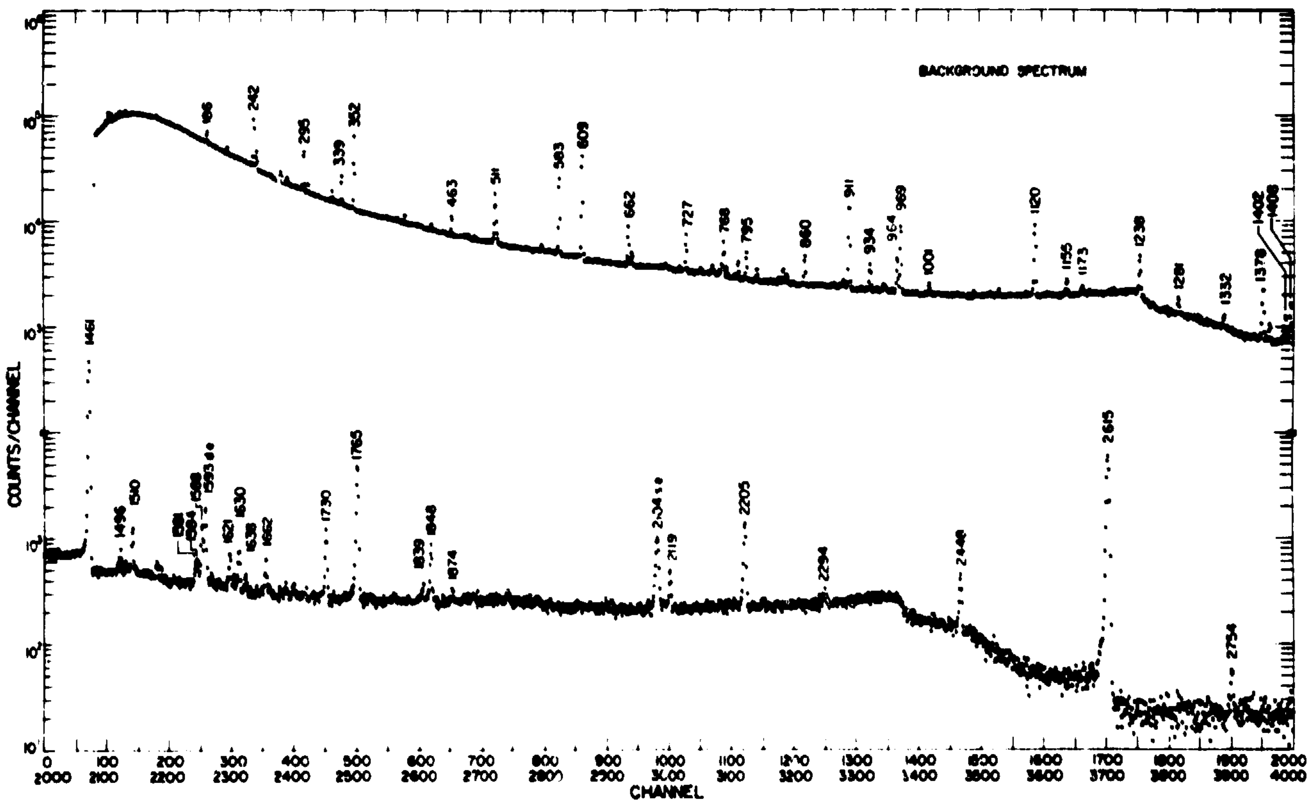

Fig. 4.
Typical background pulse-height distribution. The peaks are labelled with their energies in keV. Background lines visible in most of our distributions can be used for automatic energy calibrations.

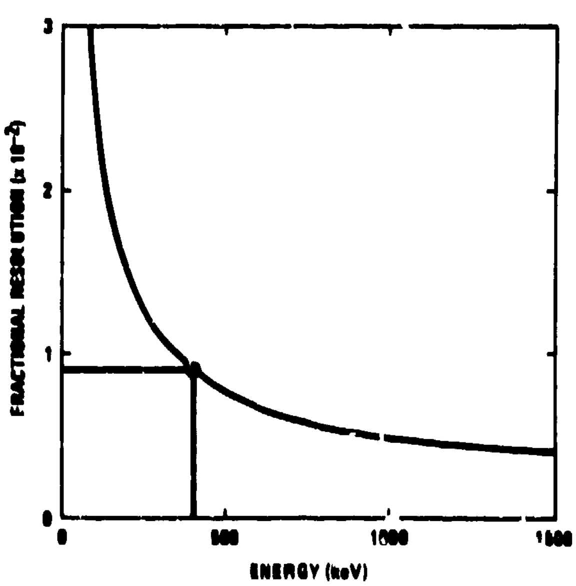

Fig. 5.
Fractional resolution (FWHM/centroid) as a function of gamma-ray energy for a detector of average quality. On this curve a fractional resolution of 0.009 corresponds to an energy of 400 keV. Different detectors will have different curves.

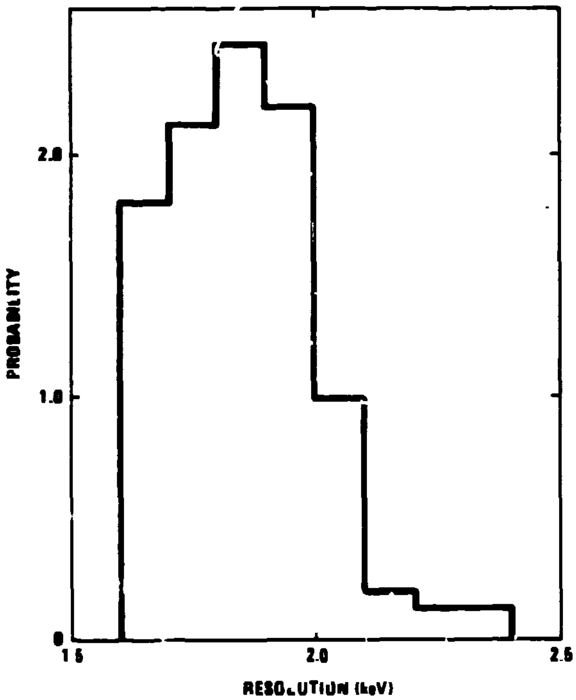

Fig. 6.
Probability distribution of high-purity germanium detector resolutions determined from data on many detectors.

The performance is what one expects. The system works quite well when the source changer is used to put in sources with simple spectra. The more general search is limited by the performance of the peak search algorithm and time constraints. If the calibration peaks dominate the spectrum, the system performs well. If the calibration peaks are weak, and there are many other peaks in the spectrum, the system performance is marginal. The system can not equal the performance of a spectroscopist who uses additional information such as the positions of Compton edges and the overall shape of the pulse-height distribution.

Automatic Gain Setting

Since the amplifier gain can be controlled by the computer and the energy calibration can be determined automatically, the system can set any desired energy range. For example, suppose the required range is 0 to 3 MeV. The system uses the ^{137}Cs source to roughly set the gain. Then it uses ^{208}Tl and the NBS mixed source for the final adjustments.

Varying the gain under computer control makes digital stabilization possible. We have not implemented this feature because we do not believe it is required for HPGe measurements lasting less than 24 hours.

Automatic Efficiency Calibration

The capability to insert calibration sources, determine the energy calibration, and find peak areas, all under computer control makes automatic efficiency calibrations possible. The sources used are the NBS mixed source and several others such as ^{88}Y and ^{208}Tl for energies greater than 1274 keV. The system uses stored regions of interest, originally entered manually. Each area is calculated by summation above a GAMANAL-type step function.[4] The efficiency curves obtained (Fig. 7) agree to within the statistical uncertainties with those determined manually.

Detector Positioner

Because much of our work involves measuring the response functions and efficiencies at various source-to-detector distances,[2,3] we need an automatic detector positioner. Our present design (Fig. 2) uses a detector trolley moved along a rail by a chain drive. The motor for the chain drive is controlled via a relay in the general purpose interface/controller module. The trolley is stopped at fixed positions via microswitches sensed through the same interface/controller module. We hope to replace this positioning system with one in which the distance can be varied over a continuous range by the computer.

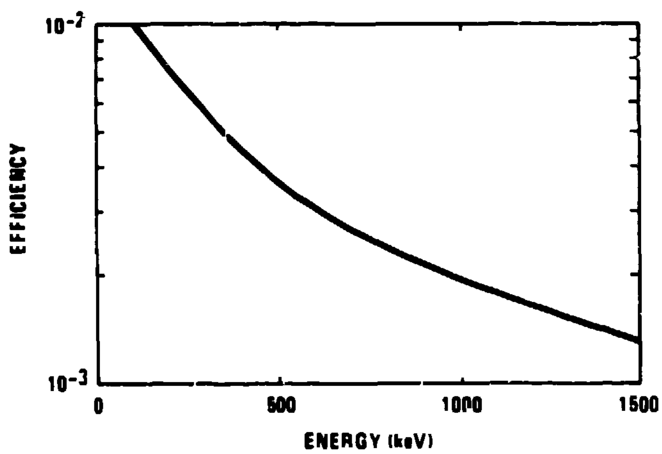

Fig. 7.
Absolute photopeak efficiency as a function of gamma-ray energy. This curve was automatically determined by our system.

Source Changer

The source changer also employs a trolley on a rail. Each of 25 sources are mounted on low mass rings and stored in a lead shield. To retrieve a source from storage, a stepping motor is used to select the source, another motor pushes it into the mounting rod on the trolley, and the trolley is moved into position by a chain drive. The stepping motor is operated by a stepping motor controller connected to an RS-232-C port on the electronic switch. The other two motors and some microswitches are connected to the interface/controller module.

Conventional Operations

The conventional operations found in a multichannel analyzer are provided by the vendor software for the multichannel buffer. They include a method of setting regions of interest, calculating peak areas and peak widths, smoothing, stripping, comparing two spectra, expanding and scrolling the display, and calibrating using two peaks. We have modified the software slightly to make some of the operations more convenient. For example the position of the marker now can be controlled with function keys or typed in.

For quantitative analysis of our germanium gamma-ray spectra, we use a program called GeLiGam (supplied by EG&G. Ortec). It features two peak-search methods. In the first, only the peaks listed in a library are located; in the second, a modified Mariscotti method[1] is used. The program provides methods for energy, peak shape, and efficiency calibration and performs deconvolution of multiplets. Again we have made a few changes.

Conclusions

Our system has sophisticated capabilities even though it was relatively easy to assemble and program. Other experimenters can easily copy and extend our methods.

Acknowledgments

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