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TITLE: THE MINI-MCA: AN INTELLIGENT INSPECTION INSTRUMENT

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THE MINI-MCA: AN INTELLIGENT INSPECTION INSTRUMENT*

ABSTRACT

The small portable multichannel analyzer (Mini-MCA) designed at Los Alamos National Laboratory is an intelligent safeguards instrument developed for the IAEA under the United States Aid Program. The Mini-MCA is a basic 1-k channel MCA that features a high degree of user friendliness and portability. Its history, use, and future applications are discussed.

I. INTRODUCTION

In less than 30 years, nuclear technology has changed the design of multichannel analyzers (MCAs) dramatically from vacuum-tube-type 100-channel analyzers that nearly filled a room, required almost continuous maintenance, and relied on mechanical calculators for hand analysis to today's 16-k channel MCAs that are linked to and controlled by mainframe computers that perform amazing feats of analysis, automated data acquisition, and experiment control. Along with this remarkable increase in sophistication, the reliability of the analyzers has increased and the size has decreased such that the components can be contained in one or two instrumentation racks. However,

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these systems are still too large to be hand-carried for use in a typical field inspection.

A new generation of portable battery-operated instruments with built-in intelligence is emerging, which will make some advantages and features of the large systems available for field use. When properly designed and implemented, these instruments can be tailored to aid the International Atomic Energy Agency (IAEA) inspector during specific inspection measurements. The instruments provide--in the field at the finger tips of the inspectors--a level of procedure prompting and calculating power and speed never before available.

Because an inspector's time at a facility is limited, the instruments he uses should help him obtain dependable and traceable data with minimal effort and should eliminate errors in operating procedures and calculations. In addition, the inspector should be able to determine if an instrument is malfunctioning.

II. INTELLIGENT INSTRUMENTS

Advances in microprocessor technology have made possible a new generation of intelligent instruments. All intelligent instruments contain microprocessors, but not all instruments containing microprocessors are intelligent. An intelligent instrument uses the programmed-in intelligence made possible by the microprocessor to tailor the instrument to aid the inspector during specific inspection measurements.

The intelligent instrument must be able to make some decisions independent of the inspector, such as determining an optimum gain range or determining whether a sample is high-enriched ^{235}U, weapons- or reactor-grade plutonium, or a mixture of uranium and plutonium.

Intelligent instruments should be able to automate specific inspection measurements and should feature built-in or automated calibration. They should do all calculations internally, independent of the user, and these calculations should include error propagation. Thus, the chances of error in reading or recording data or in miskeying data into a calculator are eliminated. The instruments must be able to log both raw and reduced data.

An intelligent instrument can carry on a dialogue with the inspector. If the inspector knows the basics of a measurement and an instrument, the instrument should make it easy for the inspector to perform the measurement without an instruction manual by providing prompting for the basic instrument functions. This is not necessary for the professional experimentalist working daily in a laboratory environment, but it is important to the inspector because the typical inspector is not an everyday user of the instrument and he must use the instrument under conditions that are often less than ideal.

Whenever possible, hardware settings in intelligent instruments should be accomplished through software control rather than internal hard-wired switches. Thus, the instrument settings can be automated, and the operational state of the instrument may be sensed for diagnostic or data logging purposes.

internal self-diagnostics should be implemented. The instrument should be able to control, be controlled by, and communicate with a second instrument or intelligence.

III. MINI-MCA

A. Development History

In 1978, the International Safeguards Group at Los Alamos National Laboratory embarked on a program to develop intelligent, portable instruments for their programs. The goal was to use current technology to design instruments that automatically correct for electronic offsets, select optimal gain ranges, average data in a transparent manner, make internal calculations of results (including error propagation), and provide procedure prompting.

The first such instrument designed was an ion or neutron detector spent-fuel measurement package, ION-1, which pulse counts the neutrons emitted from spent-fuel assemblies and measures the gamma-ray dose in the vicinity of an assembly using a gas-filled ion chamber operating in the current mode.[1-3] The instrument automatically corrects for electronic offset, prompts for and takes background measurements, and uses the background results to correct data taken later. The instrument monitors all supply and bias voltages and alerts the user if the voltages drift out of tolerance. In addition to being a useful tool, ION-1 provided the basis for the development of an inspector-instrument interface[4] that was being designed for use in an intelligent MCA that was in the planning stages.

In the summer of 1979, a microprocessor-based MCA prototype[5] was demonstrated that used an external amplifier and bias supply to acquire a 1-k channel spectrum. This spectrum was displayed on a 6-cm diagonal cathode-ray tube (CRT) and the data could be transferred using an internal modem to an external audio tape recorder or to a computer. This demonstration MCA was battery operated and fit into a very small package.

In December 1979, the IAEA requested that the United States Aid Program provide three small portable prototype MCAs for IAEA evaluation. Although the first priority was to provide a functioning MCA, much emphasis was placed on providing a degree of user friendliness never before seen in instruments and on tailoring the unit to the specific needs of an IAEA inspector. The prototype instruments implemented the IAEA recommendations, ideas from ION-1 and the demonstrated MCA, and designs developed at EG&G-Santa Barbara and Brookhaven National Laboratory.

In May 1981, two prototype instruments, called Mini-MCAs (Fig. 1), were delivered to the IAEA. In November 1981, a third unit with improved hardware was delivered, and the original two units were returned to Los Alamos for upgrading. These units have been returned to the IAEA to bring their total to three units. The units perform the standard MCA functions and, in addition, implement an automated NaI ^{235}U enrichment function.

Since the first delivery of the Mini-MCAs to the IAEA, we have conferred with commercial vendors about our design concepts and have focused on improving the hardware reliability of the instruments, standardizing the operating system, investigating the feasibility of higher level language programming for the Mini-MCA, and researching and implementing additional applications software.

B. Mini-MCA Features

The main innovation of the Mini-MCA is the demonstration of a truly intelligent portable instrument that is extremely simple to operate. Through the inspector-instrument interface, the inspector and the instrument carry on a dialogue that allows the instrument to become an "assistant" to the inspector. The interface is not the specific hardware of the Mini-MCA, rather it is the definition of the interaction between the user and the instrument.

The hardware features, although not equal to those of sophisticated state-of-the-art laboratory-based analyzers, are adequate for many inspector measurements. (Resolution of 0.68 keV at 186 keV was independently measured by the IAEA[6].) The hardware features contained in the Mini-MCA are listed below.

Internal Features:

- 1-k channel analog-to-digital converter with a conversion oscillator frequency of 32 MHz.
- Internal high-resolution gamma-ray (HRG) spectroscopy amplifier with pole zero adjustment, active baseline restoration, variable gain from 1 to 1023 in steps of 1, and a fixed integration time constant of 3 μs.

- Battery operated, including bias and preamplifier power for both NaI and HRG detectors (NaI bias can be stabilized when a seeded crystal is used).

Front-Panel Devices:

- 6-cm diagonal CRT that has 256 vertical by 1024 horizontal resolution, an intensified movable cursor, and capabilities for intensified regions of interest. Analog control of horizontal and vertical position and horizontal expansion is provided. There is a dedicated knob for digital vertical scale control.
- 4-by-4 keypad for control and information entry.
- 2-line by 16-character liquid crystal display (LCD).
- Magnetic-tape wafer drive capable of reading and recording at 10.8-k baud. A 75-ft tape can contain 27 files, which include 1-k channel spectra data and instrument parameters.
- Standard RS-232 serial interface connector for external communication and control.
  - Connectors for detectors, preamplifiers, and battery charger.
  - Power-on switch.

The microprocessor-based design of the Mini-MCA is an integration of hardware and software engineering; interfaces between the hardware modules are accomplished through the software. A design requirement was that in addition to performing the standard MCA functions the Mini-MCA software allow implementation of future automated measurements. The basic software consists of three parts: utilities that interface to the hardware modules, a floating-point mathematics package with 24-bit precision and a range of $10^{\pm 38}$, and the basic MCA functions. The basic MCA functions and implemented automated measurements are listed in Table I. The software is written so that automated measurements can easily use the subroutines in the basic software; thus the software for new automated measurements uses (1) the utilities to display the prompts that guide the user through the measurement, (2) the basic functions to perform the data acquisition, (3) the mathematics package to do the required calculations, and (4) the utilities to display the results. Although the basic software is written in assembly language, some calculations in the automated measurements are done in FORTRAN.

C. The Inspector-Instrument Interface

The purpose of the interface is to allow for convenient dialogue between the instrument and the user. The instrument provides options, instructions, and information on the LCD; user responses are entered on the keypad.

The keypad (Fig. 2) contains an information entry section and a control section. The lower-case entries--the digits 0-9, INC, and DEC--are used most frequently. Commands are entered using the upper case.

The upper case is enabled by pressing the SHFT key; this procedure is similar to the way second functions are selected on a hand-held calculator. The diagonal shading in the figure indicates that the upper-case entries and the SHFT key are accented in yellow. In addition to SHFT, there are three other keys in the control section: the ENTR key, which registers an entered number; the END key, which signals the instrument that the present command is no longer needed or can be pushed to abort a command at any time; and the NEXT key, which is pushed when the user has completed an instruction and is ready to proceed with the command.

A blinking cursor indicates that the instrument is waiting for a response. During any input sequence, only certain key pushes are valid. Valid keys are generally known from the state of the LCD. A command can be entered anytime the LCD contains the standard prompt, which always contains ACTION=? on the second LCD line. It is the first prompt that appears after power-on. A digit entry is valid whenever the blinking cursor appears in a number field. The number field contains the present value for the indicated parameter. The scroll arrows in the lower-right LCD position indicate there is additional information that can be viewed by using ↑ or ↓. NX in that position indicates that NEXT can be pushed to proceed to the next step.

If there is no blinking cursor the LCD is only informational and the only valid response is scroll or NEXT.

If an invalid key is pushed, the message INVALID ENTRY PUSH VALID KEY is displayed for 1 s. After 1 s the information on the LCD returns to the information displayed immediately before the invalid key push. The user then proceeds as if he had not pushed the invalid key.

To demonstrate the user-instrument interaction in entering information, an example of the procedure for setting the upper- and lower-level discriminators is described. Figure 3 shows the LCD. The two fields, labeled for clarity, contain the present values. The range of each value is presented after each field. A blinking cursor, denoted by the underscore, appears in the left-most digit of field 1. The value can be changed to 20 in either of two ways. (1) Type 20; the digits are displayed as they are entered and the cursor moves one position to the right for each digit entered; push ENTR and the cursor moves to the left position of the next field. (2) Use the INC key to increment the number displayed to 20; then push ENTR; to enter 250 into field 2, enter 250 or use the DEC key; when the desired number occurs in the field, press ENTR. (Pushing INC or DEC for more than 1/2 s causes the number to increment or decrement continuously at an accelerating rate.)

The discriminator display is a "window" of a large display "page" of the MCA PARM command. The total page is shown in Table II. The portion of the page that actually shows through the window is controlled with the scroll arrows that move the window up and down along the display page.

An example of the decision-making dialogue follows. The example describes how a detector is chosen in the PARM command. The possible choices are presented:

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DETECTOR=1
HRG=0  NAI=1
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A blinking cursor, denoted by the underscore, indicates that the unit is awaiting a response. An NaI detector is indicated by the 1 in the input field. A 0 may be entered to choose HRG. When the desired choice is displayed, push ENTR.

D. Commercialization

It is important that there be a commercial source for the Mini-MCA for reasons of supply and repair. Furthermore, a commercial MCA vendor has expertise in the design and packaging of the electronics. To our knowledge, three units exist that are similar in size to the one described in this paper. One of these units is software compatible with the Los Alamos unit. A second provides facilities to add our application software.

IV. APPLICATIONS

The Mini-MCA can be used to make measurements that other MCAs of similar quality make. We have used it in two different plutonium facilities in the United States, at spent-fuel storage facilities, at the Three Mile Island Reactor Facility, and at training schools in Los Alamos.

Because we realized the need for tailoring the instrument for specific applications, the software was designed to minimize the effort required to add automated measurements. Automated measurements are most efficiently developed using the following steps. First, a knowledgeable user applies the basic functions of the Mini-MCA to actually do the measurement; he should note all steps, instructions, and possible options as he proceeds. He records all data and calculations. After the basic measurement has been made and documented, the user communicates with the programmer to discuss the actual implementation software and possible tradeoffs that can make the software easier to write or use. The programmer then writes the actual software and uses the sample data to test it. When the software has been tested, the instrument is returned to the user for field testing. After the user and other users have experience with the automated measurement, any necessary corrections and upgrades are communicated to the programmer. The programmer makes the necessary changes and returns the unit for more testing. The process of upgrading the software may continue through several iterations.

A. NaI ^{235}U Enrichment

An NaI ^{235}U enrichment measurement[7] was implemented in the original unit. The method uses calibration constants that can be entered or determined at the time of the measurement. After the constants are contained in the Mini-MCA the user is prompted to ready the sample; then a single button push results in data acquisition, data analysis, and display of the calculated enrichment. Table III shows the results obtained from enrichment measurements on 1-kg cans of powdered oxide.

B. UF_6 Cylinder Enrichment Using HRG Spectroscopy

This application determines the net area of the 186-keV peak (Fig. 4) and uses a calibration constant and a container wall absorption correction to provide a value of the enrichment of the material inside the container.*

The automated measurement leads the user through the procedure. It instructs the user to set a region of interest on the 186-keV peak; prompts the user for the calibration constant, attenuation coefficient, count time, cylinder wall thickness, and cylinder identifier; and then acquires data. On completion of the acquisition, the final enrichment results with associated uncertainties are calculated and displayed. The software for the procedure prompting is written in assembly language, and the calculations are done in FORTRAN.

C. Plutonium Isotopics

We are approaching the plutonium isotopics measurement at two levels. The simpler level is plutonium isotopic identification. The goal is to lend a degree of verification to inventory samples. Without doing a total assay, one can use simple ratios and corrections to determine that a sample is roughly what it is declared to be. One can grossly determine among a collection of samples the particular samples that are weapons-grade, reactor-grade, or ^{238}Pu. To some degree, this method can provide the $^{239}Pu/^{241}Pu$ isotopic weight ratio.

The more difficult level is a more detailed plutonium isotopic analysis. Isotopic analysis programs† have been written for the HP-97 calculator, which uses data collected with a 1-k

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*The principal investigator of this application in Los Alamos is R. H. Augustson.
†T. D. Reilly of Los Alamos is the author of the isotopic analysis programs.

channel Silena analyzer. The Los Alamos Mini-MCA could be used for this application (a plutonium spectrum acquired with the Mini-MCA is shown in Fig. 5); however, a 0.5-k channel offset or a 2-k channel analyzer would make the treatment of the regions of interest easier.

Either of these methods could be used in conjunction with a neutron measurement. The neutron results are used with the isotopic results of the Mini-MCA to calculate total plutonium. The Mini-MCA can be programmed to control the neutron electronics package,[8] and to calculate the results of both neutron and gamma-ray data, or the Mini-MCA and the neutron electronics could both be controlled by an external controller.*

D. Authentication of In-Plant Instrumentation

The authentication of in-plant instruments is another application of the Mini-MCA.† The Mini-MCA can be programmed so that the signal normally input to an in-plant analysis system can be input to the Mini-MCA; the unit can then make the calculations necessary to check the basic results of the in-plant instrument. Initially, no control of the hardware by the Mini-MCA is planned; however, the Mini-MCA does lend itself to such control.

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*The Mini-MCA and the neutron electronics package have both been interfaced to an HP-85 calculator by G. E. Bosler and M. S. Krick of the IAEA.

†The principal investigator of the project in Los Alamos is C. R. Hatcher.

E. MTR Fuel Enrichment Verification Using NaI

The first implementation of this application will be simple and straightforward. It will rely on a previous calibration and assemble specific correction factors to determine the mass of ^{235}U in a materials testing reactor (MTR) fuel assembly. The Mini-MCA has the capability to enter data on the specific MTR fuel assembly and detection system to predict the count rate, if such implementation is required by the IAEA.

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TABLE I

MCA [illegible] AND AUTOMATED MEASUREMENTS

ACQ	Acquire [illegible] r a specified livetime.
ROI	A [illegible] nge regions of interest. A maximum of 99 re[illegible]s [illegible] assigned. Regions may overlap.
CALC	Tota[illegible] or background-subtracted areas of assigned regions and their associated uncertainties are calculated and displayed.
PARM	Examine or change instrument parameters. The parameters included in the PARM function are preset count time and elapsed time in livetime seconds, count rate, per cent deadtime, detector being used (HRG or NaI), amplifier input polarity, amplifier gain, high-voltage setting, upper- and lower-lever discriminators, memory subgroup, and battery and digital supply voltages.
TAPE	Read spectra from the tape, write spectra to the tape, position the tape, and examine instrument settings for the last spectrum read. The full spectrum and all parameters--high voltage, gain, count time, etc.--are recorded on the tape along with an inspector identifier. The identifier and the date and time uniquely identify the spectrum.
DUMP	Write the current spectrum and instrument settings to the serial port.
ENRH	Perform NaI ^{235}U enrichment measurement.
UF_6	Perform HRG ^{235}U enrichment measurement of material inside a UF_6 product cylinder.
MTR	Perform verification of enrichment of materials testing reactor (MTR) fuel assemblies using NaI detector.

TABLE III

NaI ENRICHMENT MEASUREMENT RESULTS[a]

Sample ID	Declared Value	Measured Value[b] (15 s)		Measured Value[b] (30 s)		Measured Value[b] (60 s)	
14	10.2	10.6	(0.25)	10.0	(0.18)	10.2	(0.13)
11	11.9	12.4	(0.26)	12.1	(0.18)	11.7	(0.13)
16	13.4	13.4	(0.26)	13.5	(0.19)	13.2	(0.13)
x1	3.06	3.02	(0.21)	3.20	(0.15)	3.01	(0.10)
x1	3.06	3.33	(0.21)	3.38	(0.15)	2.82	(0.10)
11	11.9	12.2	(0.25)	12.2	(0.18)	12.1	(0.13)
16	13.4	13.8	(0.27)	13.4	(0.19)	13.2	(0.13)
x2	10.2	10.1	(0.25)	10.1	(0.18)	10.3	(0.13)
14	10.2	10.5	(0.25)	10.3	(0.18)	10.2	(0.13)
13	17.5	17.3	(0.29)	17.7	(0.18)	17.8	(0.14)
12	1.96	1.93	(0.21)	2.07	(0.15)	1.84	(0.10)

Calibration: Source 13 150 s.
Source 12 600 s.

[a]Values shown are per cent ^{235}U.
[b]Measurements were made with 15-, 30-, and 60-s acquisition times.

FIGURE CAPTIONS

Fig. 1. Mini-MCA.

Fig. 2. Mini-MCA keypad.

Fig. 3. Liquid crystal display.

Fig. 4. Uranium-235 HRG spectrum.

Fig. 5. Plutonium HRG spectrum.

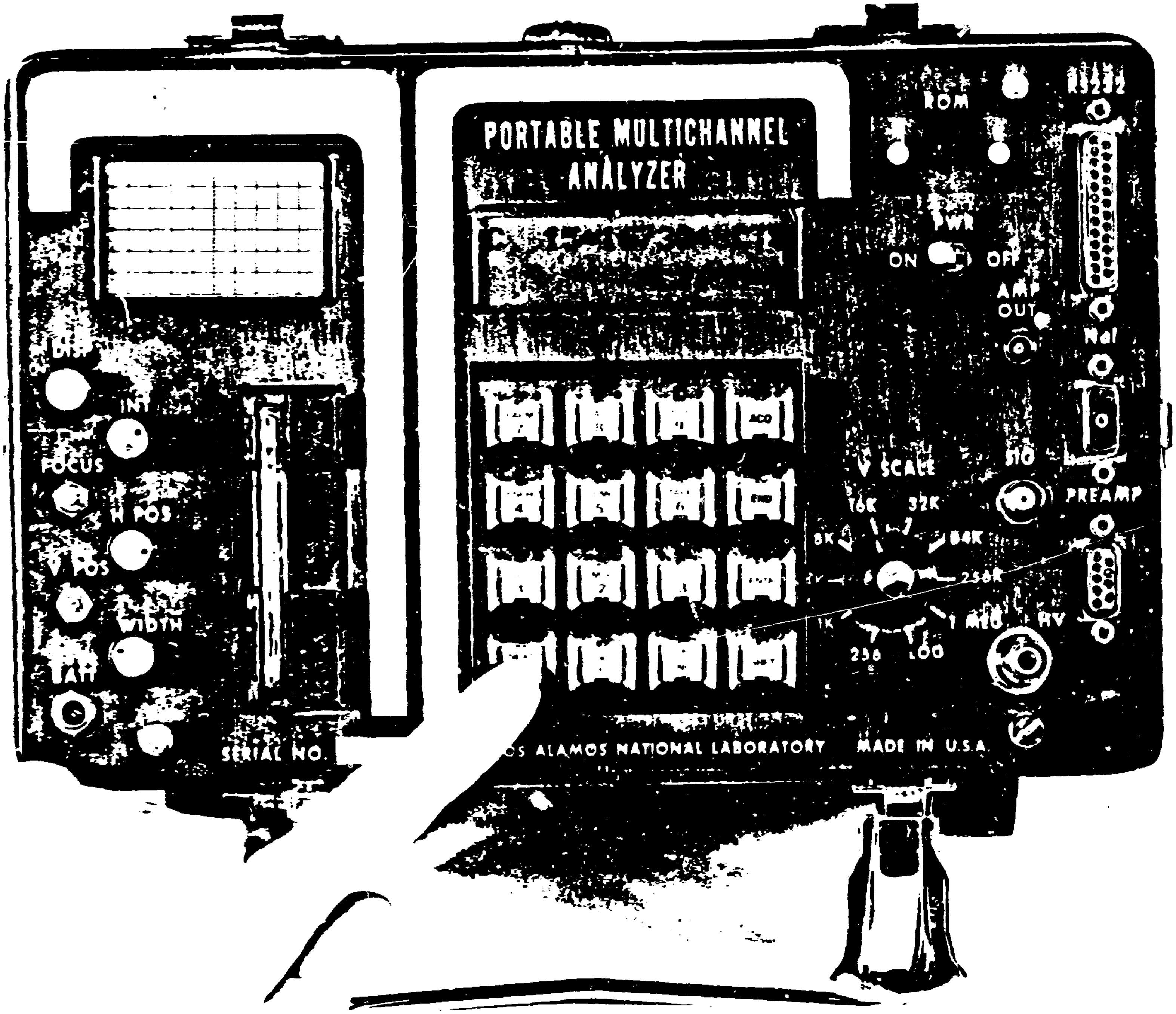

Fig. 1. Mini-MCA.

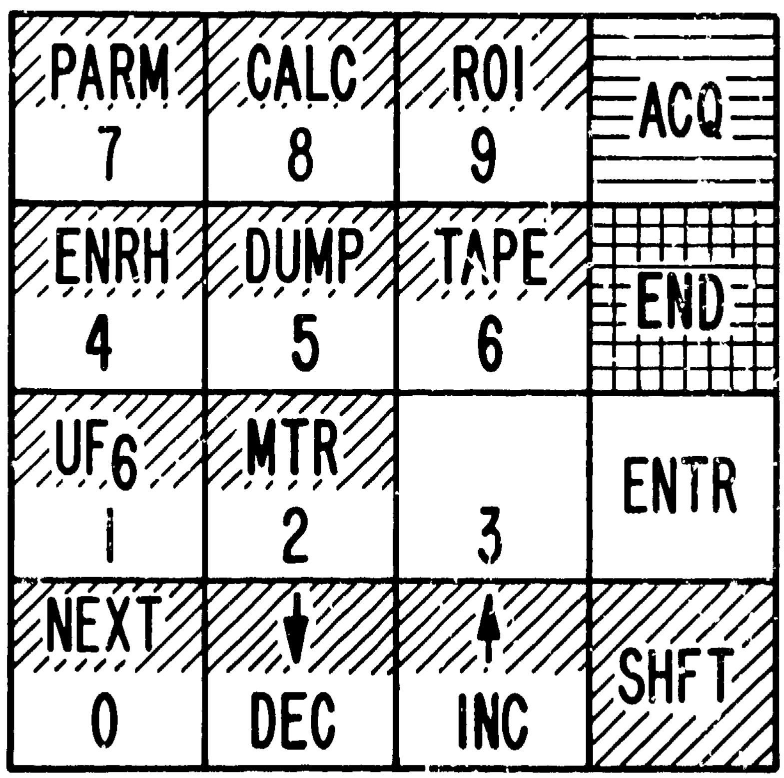

Fig. 2. Mini-MCA keypad.

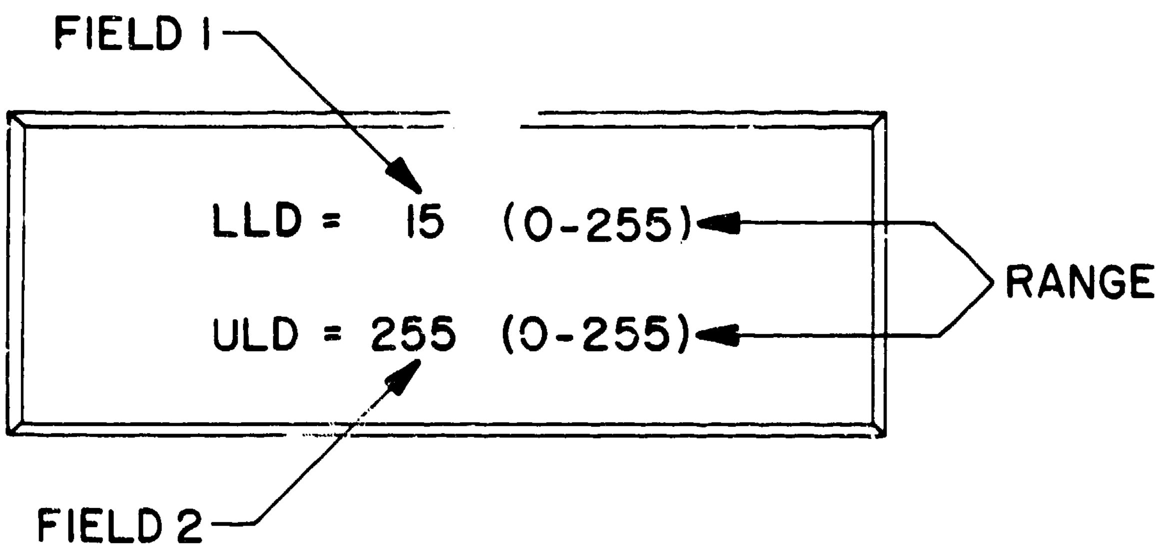

Fig. 3. Liquid crystal display.

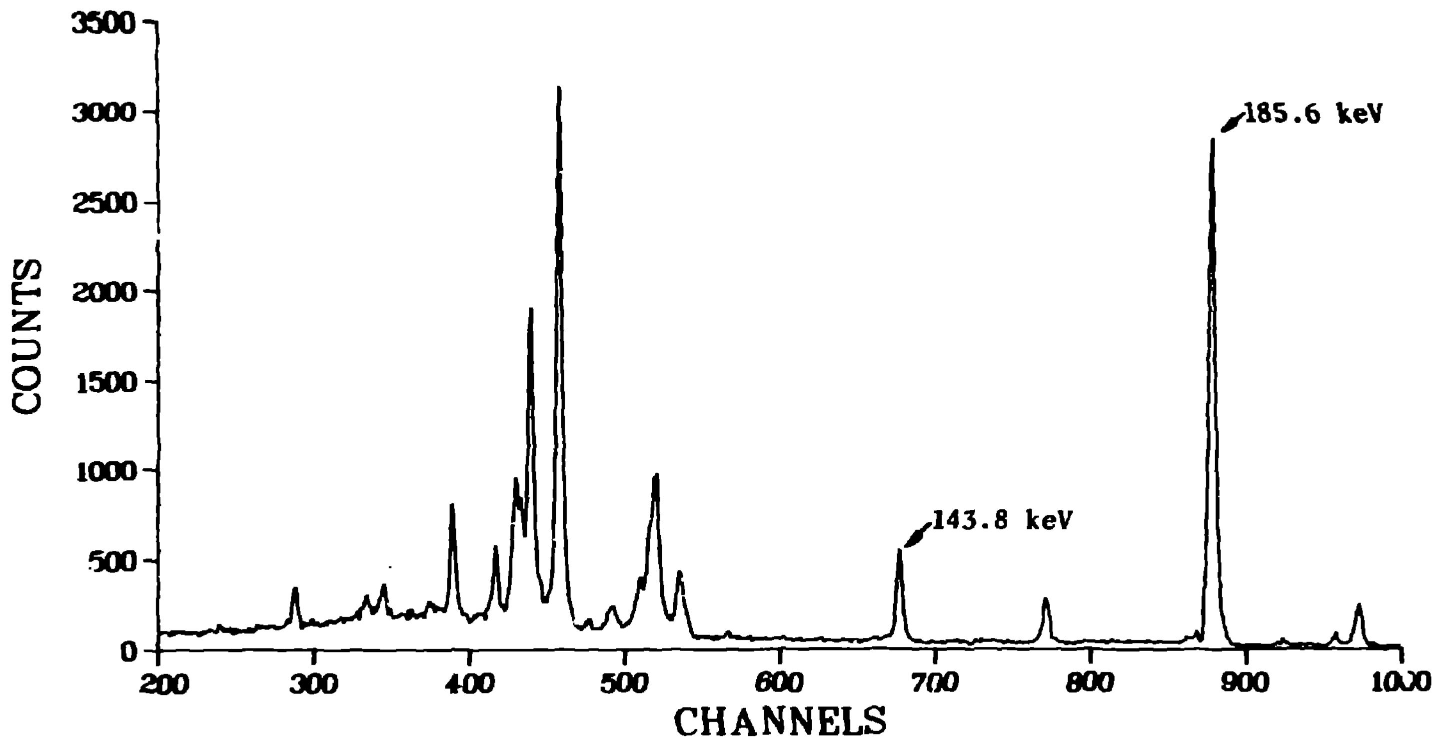

Fig. 4. Uranium-235 HRG spectrum.

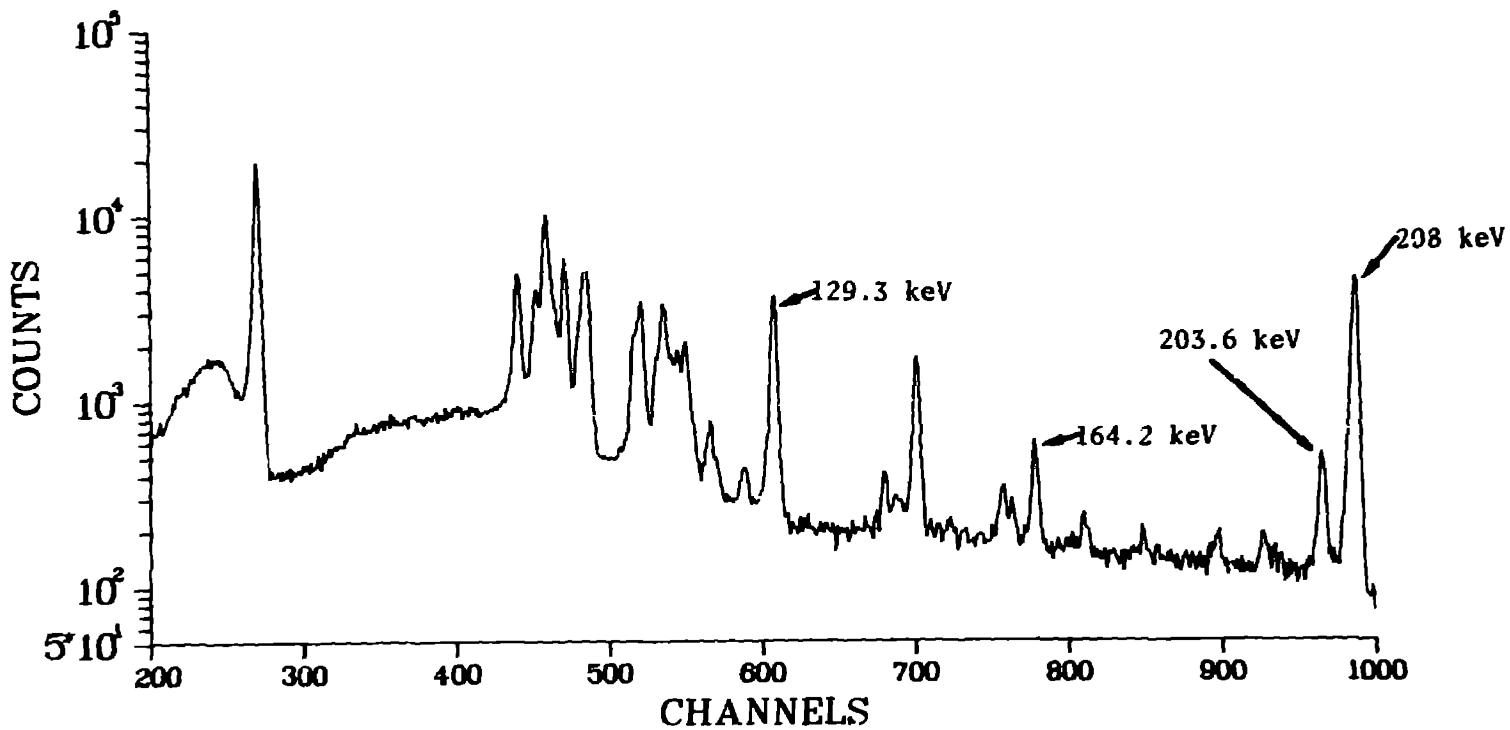

Fig. 5. Plutonium HRG spectrum.