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A MINIATURE MODULAR MCA FOR GAMMA-RAY SPECTROSCOPY*

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Abstract

A wide variety of user requirements in nondestructive assay field applications can be satisfied by carefully specifying a small number of standardized hardware and software modules and their interfaces. Examples of this philosophy will be presented with a novel, small multichannel analyzer (M^3CA) as the foundation. The prototype M^3CA is 10 cm by 20 cm by 9 cm and includes a detector bias supply, amplifier, and battery /1/.

1. Introduction

In-field measurements are generally more challenging than measurements made in a controlled laboratory environment. It is more difficult to get good results if the instrument is brought to the item to be measured rather than if the item is brought to a well-designed measurement station. In addition, field measurements suffer from poor control over the sample geometry and chemical form; often even the sample location is not well known. However, certain needs can only be satisfied with in-field measurements, and in-field measurements can be attractive to the facility operator.

Current technology offers a choice between multiperson operation and simple, primitive operation. Existing compact multichannel analyzer (MCA) technologies are portable but typically require additional personnel or transportation aids or both to hold the detector, the data reduction and storage capability, and the miscellaneous items that are needed. The alternative hardware systems for portable operation by a single person tend to be of the "go/no go" or rate meter type that are susceptible to bias effects. The simple alternative cannot distinguish which isotope causes the signal. Temperature and battery level changes can cause instabilities that lead to unpredictable biases in the measurement results.

Meanwhile, user needs for holdup measurements, process monitoring, inventory verification, and environmental surveys are growing in an environment of increasing concern for health and safety. Facility operators are attracted to in-field measurements that generate less mixed waste and require less handling and radiation exposure than traditional count room analyses. Our goal is to provide hardware and software building blocks that users who are not technically expert in the internal details can use to solve a variety of problems.

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2. Evolving Technologies

The advances in electronics and software are more rapid and more impressive every year. The M^3CA development effort is benefitting from spin-offs from this market-driven advancement. Some of the specific hardware developments are smaller and faster processors, low-power requirements, and compact storage and controller units. These readily available pieces can be interconnected with miniature, standardized interfaces and all of this capability is becoming available at continually decreasing unit costs.

Compact low-resolution detectors with shielding that weighs only 2 kg are available from commercial sources /2/. Bar-code-reader technology is being widely used for items that must be inventoried on a regular basis, and some bar-code readers can perform simple control and storage functions.

Software developments are proceeding at a commensurate pace. New commercial tools, such as powerful and flexible databases, exhibit enhanced features that take advantage of the hardware improvements. Many products can be used across several hardware platforms and with different operating systems. The data files of the better software can be accessed by different programs, thus helping to reduce the scourge of transcription errors.

3. Integration: User Requirements vs Modern Technology

We developed a multidimensional user needs matrix for portable gamma-ray assays and compared it to the hardware and software possibilities. Our goal was to design requirements for a few simple modules that could be assembled into solutions addressing the various needs. The measurement needs ranged from criticality safety to accountability measurements. Different isotopes are of interest to different facilities, sometimes more than one isotope is measured in a given application. Needs common to all applications were stable hardware response and compact, robust field modules. Each user requires assurance that the data are valid as taken, but detailed reduction and evaluation of the data usually occur later, off line. Operational simplicity is essential. In general, the less equipment carried into the field and the less carried into potential contamination areas, the better.

All equipment carried into the field must be reliable. The mean time between hardware failures must be as good as or better than the time for modern nuclear instrument module electronics and desktop computers. It is not acceptable for maintenance and repair costs to be a significant fraction of the installation cost. Facility operators minimize the time spent inside the facility measuring items or maintaining instruments. Repeating measurement campaigns because of equipment failures is not a popular activity. Modern, low-power electronics exhibit vastly better reliability than predecessor electronics.

Software modules are becoming available that are independent of computer platform and operating system. These programs have identical user interfaces independent of the systems they run on. This philosophy should be extended to new hardware units as much as possible. This philosophy can be assisted by defining simple interfaces that require compatibility with several systems. The advantages of modules that are independent of computer platform and operating system are that less training is required for new users, new modules can be used with existing equipment, and it is easier to assemble the modules into new instruments.

We are implementing a modular concept around a new miniature modular MCA (M^3CA) /1/. A small number of hardware and software modules will form a tool kit. This tool kit will use simple, standardized interfaces that can couple to different controllers. The simple serial interfaces will allow a variety of platforms to be coupled to the M^3CA. Each application will start with primary modules from the tool kit, which should satisfy most of the application's needs. The relatively small amount of application-specific development will be done as required on a customized basis.

4. Applications of a M^3CA

The choice of which modular building blocks to use with the M^3CA is determined by the specific applications and the available hardware. Holdup measurements, verification measurements, and process monitoring are three applications described below.

Portable Holdup Measurements

Holdup is residual nuclear material retained by process equipment after operation. Holdup accumulations can be significant because small amounts per unit area distributed throughout large facilities generally add up to large amounts /3/. Periodic nondestructive assay (NDA) of holdup provides measured nuclear material quantities for inventory records and for criticality safety /4/. Retention of safe quantities of nuclear materials in equipment avoids unnecessary and costly cleanouts and minimizes radiation doses to operators.

A viable program for quantitative measurements of holdup requires thousands of gamma ray measurements in a short time, frequently with limited access in challenging environments. Figure 1 shows a user simulating a typical measurement. The user requires equipment that is rugged, reliable, compact, lightweight, and simple to use. In general, commercially available, shielded, low resolution detectors are used, as shown in Fig. 1. However, it is desirable to have the hardware capability to support high resolution detectors when the application requires them. The quality of the spectral data obtained from these measurements must be assured automatically, and the data from each measurement must be matched to the specific process equipment.

Fig. 1. A user simulating a measurement of the nuclear material holdup in ventilation piping.

Assay of holdup takes place in three steps as follows:

(1) calibration of the hardware,
(2) acquisition and storage of data from holdup deposit measurements, and
(3) archiving and quantitative analysis.

Both the M^3CA and the gamma ray detector are required in steps (1) and (2) using different control modules.

For the holdup measurement calibration, a serially interfaced PC is used to set up and control the M^3CA, to automate the analysis for the generalized geometry calibration /5/, and to display the gamma ray spectra. New, stable hardware does not require frequent calibration. Calibration uses long count times in controlled, clean locations remote from the process areas. Calibrations are performed by NDA experts. The use of sophisticated menu driven software and spectral display/manipulation capabilities is desirable in this calibration. Los Alamos software developed in the C programming language has been implemented for operation of the M^3CA with full keypad based PC control of hardware and spectral display /1/. An applications software package entitled HMSII /6/, written in dBase IV automates the calibration of the holdup measurement application. A compiled version of this software has been downloaded and tested on palm sized PC's communicating with the M^3CA. The product of the calibration is a parameter file that contains the

M^3CA setup and spectrum analysis information, the reference information for the daily measurement-control and quality-assurance tests, and the generalized-geometry calibration constants.

To acquire holdup data, a palm-size, commercial, programmable bar-code reader/data-logger replaces the PC as the M^3CA controller. The miniature control unit is programmed to set up and control the M^3CA, automate the acquisition of gamma-ray spectra, store the reduced spectral data, and perform certain tests to assure spectrum quality. The palm-size control unit becomes enabled for service when the NDA expert transfers the parameter file to the control unit by serial link. The software program for the bar-code reader is a truncated version of HMSII. Holdup field measurements must be performed in rapid succession in a hostile environment with all equipment carried by a single user who is relatively unfamiliar with NDA methodology. Bar codes affixed to each measurement location are located and scanned by the user who then initiates the corresponding measurement. The bar code is stored with the reduced spectral data in the bar-code-reader memory. Later analysis, outside the potentially contaminated area, uses the bar code to match the data with a specific process location and with equipment details that are required to calculate a result. The user performs holdup measurements at bar-coded locations until time or the memory allocated for storage of data has been exhausted. The user returns the bar-code reader/data logger to the NDA expert who serially transfers the data (typically several hundred measurements) to the PC, which can remain outside the hostile environment. Following data transfer, the serial link between the M^3CA and the palm-size control unit is reestablished, and the user resumes measurements until all locations have been measured.

Although the M^3CA is not used in the third step, this step is essential in using the M^3CA for holdup measurements. A single user might perform as many as 1000 holdup measurements in an 8 hour shift. The third step quantifies and archives holdup values based on measurements by several users. The HMSII software uses a data base developed for each facility that links the reduced measurement data with physical and mechanical details at individual measurement locations in the processes. The HMSII software corrects the data for various geometry and attenuation effects, quantifies the individual holdup assay results and uncertainties, and combines contiguous quantitative results appropriately to give the holdup quantity and its uncertainty for each piece of equipment, process line, or material balance area. Without data management, these volumes of data would be of little use.

Verification Measurements

Nuclear material verification measurements are performed to corroborate declared (accountability) values with quantitative assays. Item declarations can be verified in storage vaults or in process rooms. Verification measurements are sometimes indistinguishable, in method as well as purpose, from holdup measurements, thereby both require rugged, reliable, compact, lightweight, simple to use equipment that automatically assures the quality of the data.

Examples of verification of nuclear material quantities in process or storage locations by portable gamma-ray measurements have been documented /7,8/. These examples have involved hyperpure germanium as well as NaI(Tl) detectors, each with different electronics to acquire and reduce spectral data. Because of the modular and flexible design, the new M^3CA linked to the appropriate control unit satisfies the needs of all of these applications and significantly reduces size without compromising other features.

Process Monitoring

Continuous, unattended gamma-ray and neutron measurements have been performed on-line for real-time assay of nuclear materials in process streams /7,9,10/. These measurements monitor process operations primarily to control the process. Production benefits of continuous process monitoring include optimized products, minimized waste and reagents, and minimized delays (from remote analysis of process samples) in processing. Unattended quantitative assays reduce nuclear materials handling and transfer requirements associated with the removal of process samples, thereby contributing to radiation dose minimization and improved safeguards. The real-time readout of nuclear material quantities can also contribute to near-real-time nuclear material accountability.

In common with requirements for holdup and verification measurements, assay equipment for process monitoring must be rugged, reliable, and compact. Normal operation must be independent of user intervention; in the existing M^3CA design, user input is required only to identify a new measurement location or sample. The monitoring function applies to a fixed location so that intervention is not required after initial start up. A further requirement for the monitoring function, the automated assurance of the quality of data obtained during continuous operation, is also built into the M^3CA. The M^3CA module has been designed to include only essential generic features. Application specific features become modular plug in or remote additions. Therefore, the M^3CA is optimized for process monitoring because maximized reliability and minimized complexity are expected of instrumentation installed on the process line. The sophistication (visual readouts, for example) required to implement process control functions will reside with interfaced hardware that is remote from the M^3CA.

5. Future Needs and Applications

Enhanced Miniaturization

The prototype M^3CA addresses the requirements of portability and compactness for holdup measurements, verification measurements, and process monitoring; it is significantly smaller and lighter than previous instruments with equivalent features. Additional miniaturization planned for 1993 /1/ will make the M^3CA even more useful by providing room for even more functions.

Enhanced Functionality: Memory and Storage

Measurement needs such as portable holdup assays and quantitative process monitoring involve rapid acquisition of large numbers of gamma-ray spectra that must be evaluated in near-real-time. The prototype M³CA transfers reduced spectral data because it has a limited memory and storage capability and is currently limited by serial data transfer rates. Therefore, each spectrum is first subjected to diagnostic tests (spectral data can be subsequently adjusted) to assure the quality of the reduced and transferred data. The test program resides in the controller unit, but the M³CA calculates the spectrum-quality parameters and transfers these to the controller unit for the diagnostic testing. Adjustments (such as digital-gain-drift compensation /11/) are performed in the M³CA, upon command from the controller unit, before the transfer of the reduced spectral data. Increased M³CA programmable memory will enable additional calculations of generic spectrum quality parameters for enhanced spectrum-quality-assurance diagnostics. PC compatibility will allow downloading of any standard PC program into the M³CA. Increased data storage capability, by modular addition of miniaturized storage media such as thin magnetic card drives, will permit archival storage of raw spectral data.

Enhanced Functionality: Indicators

The hardware status of the prototype M³CA is verified through the controller unit; it sends commands to the M³CA and reads out parameters from it. But the status of the hardware could be verified without the controller unit if a visual readout of such things as voltages, temperatures, and power status is added along with audio or visual indicators of alarm limit violations.

Enhanced Functionality: Pulse Height Analysis

New compact detectors are being tested for performance and reliability. M³CA hardware and software might have to be adapted to be compatible. Adaptations might include gain stabilization, pulse rejection or pulse height defect compensation, digital control of external detector bias supplies, and "wireless" detector connections. Compatibility with new detector technologies might also extend beyond gamma-ray detectors to applications with neutron detectors.

6. Summary

Our goal is to provide MCA hardware and software building blocks that technical users can use to solve a variety of problems. The M³CA will be independent of computer platform and operating system and can be used by technical personnel who have limited experience with internal MCA operation.

7. References

/1/ J. K. Halbig, S. F. Klosterbuer, P. A. Russo, J. K. Sprinkle, Jr., M. M. Stephens, L. G. Wing, and K. D. Ianakiev, "Recent Miniature MCA Technology Developments at Los Alamos," presented at ESARDA 15th Symposium on Safeguards and Nuclear Material Management, Rome, Italy, May 11-13, 1993.

/2/ P. A. Russo, C. W. Bjork, M. M. Stephens, and D. A. Close, "Elimination of Gain Instability in Compact NaI(Tl) Detectors," in "Safeguards and Security Progress Report, January-September 1990," D. B. Smith and G. R. Jaramillo, Comps., Los Alamos National Laboratory report LA-12095-PR (August 1991), p. 18.

/3/ T. Brumfield, C. Gunn, S. E. Smith, and D. Watson, "Estimates Used for Enriched Uranium Accountability," Martin Marietta Energy Systems report Y/DG-17057 Rev. 6 (December 1989).

/4/ S. E. Smith and J. A. Kreykes, "A Holdup Measurement System for Enriched U at the Oak Ridge Y-12 Plant," submitted to the 19th WATTec Conference in Knoxville, Tennessee, February 18-21, 1992, Y/MA 7177.

/5/ "Nondestructive Assay of Special Nuclear Materials Holdup," Los Alamos National Laboratory manual for DOE-sponsored training (Safeguards Assay Group N-1, Los Alamos, New Mexico, May 4-8, 1992).

/6/ S. E. Smith, J. S. Gibson, J. K. Halbig, S. F. Klosterbuer, P. A. Russo, R. Siebelist, J. K. Sprinkle, Jr., "The Holdup Measurement System II (HMSII)," Martin Marietta Energy Systems Y-12 Plant report Y/MA-7208 (January 1993) to be presented at the 34th Annual Meeting of the INMM, Scottsdale, Arizona, July 18-21, 1993.

/7/ P. A. Russo, R. B. Strittmatter, E. L. Sandford, M. M. Stephens, T. L. Brumfield, S. E. Smith, E. E. McCullough, J. W. Jeter, and G. L. Bowers, "Automated Instruments for In-Line Accounting of Highly Enriched Uranium at the Oak Ridge Y-12 Plant," Los Alamos National Laboratory report LA-10243-MS (February 1985).

/8/ T. R. Wenz, P. A. Russo, M. C. Miller, H. O. Menlove, S. Takahashi, Y. Yamamoto, and I. Aoki, "Portable Gamma-Ray Holdup and Attributes Measurements of High- and Variable-Burnup Plutonium," in *Proceedings of the Fourth International Conference on Facility Operations - Safeguards Interface* (American Nuclear Society, Inc., La Grange Park, Illinois, 1992) ANS Order No. 700168, pp. 226-236.

/9/ P. A. Russo, J. K. Sprinkle, Jr., M. M. Stephens, T. L. Brumfield, C. S. Gunn, S. E. Smith, and D. R. Watson, "Stationary and Portable Instruments for Assay of HEU Solids Holdup," in *Proceedings of the Third International Conference on Facility Operations - Safeguards Interface* (American Nuclear Society, Inc., La Grange Park, Illinois, 1988) ANS Order No. 700132, pp. 101-115.

/10/ P. A. Russo, Q. D. Appert, R. S. Biddle, T. A. Kelley, M. M. Martinez, and M. H. West, "Quantitative Monitoring of the Fluorination Process by Neutron Counting," Los Alamos National Laboratory document LA-UR-92-3852 (November 1992).

/11/ P. A. Russo, T. R. Wenz, and J. A. Painter, "Experimental Evaluation of Software-Driven Digital Gain-Drift Compensation in Scintillator Gamma-Ray Spectroscopy," Los Alamos National Laboratory report LA-12390-MS (September 1992).