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AUTHOR(S):
T. H. Kuckertz, MEE-8
J. T. Caldwell, N-2
P. A. Medvick, MEE-8
W. E. Kunz, N-2
R. D. Hastings, N-2

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Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

MAKING TRANSURANIC ASSAY MEASUREMENTS USING MODERN CONTROLLERS*

T.H. Kuckertz, J.T. Caldwell, P.A. Medvick
W.E. Kunz, and R.D. Hastings

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Abstract

This paper describes methodology and computer-controlled instrumentation developed at the Los Alamos National Laboratory that accurately performs nondestructive assays of large containers bearing transuranic wastes and nonradioactive matrix materials. These assay systems can measure fissile isotopes with 1-mg sensitivity and spontaneous neutron-emitting isotopes at a 10-mg sensitivity. The assays are performed by neutron interrogation, detection, and counting in a custom assay chamber. An International Business Machines Personal Computer (IBM-PC) is used to control the CAMAC-based instrumentation system that acquires the assay data.

1. Introduction

This paper describes methodology and computer-controlled instrumentation developed at the Los Alamos National Laboratory that accurately performs nondestructive assays[1-4] of containers bearing transuranic wastes and nonradioactive matrix materials. Transuranic waste is defined in United States Department of Energy (DOE) Order 5820.2 and consists primarily of long-lived (half lives greater than 20 y) isotopes of uranium, plutonium, and other elements with atomic numbers greater than 92. With suitable calibrations, the assay systems described herein can measure fissile isotopes with 1-mg sensitivity and spontaneous neutron-emitting isotopes at a 10-mg sensitivity. The assays are performed by neutron detection and counting and are accurate in the presence of substantial backgrounds generated by alpha-emitting sources and substantial quantities of neutron-absorbing-and-moderating matrices.

These systems are primarily used for the assay of containers bearing plutonium-contaminated waste. United States DOE disposal regulations provide for waste having an activity level less than 100 nCi/g to be buried as low-level waste. Containers with an activity level greater than 100 nCi/g are to be treated as transuranic waste and held in retrievable storage.

2. General Schema

Assay systems have been built for 208-l barrels and 3-m^3 crates.[1-4] A 208-l assay system is shown in Figure 1. The system consists of a graphite inner liner that is 10-cm thick and an outer liner of polyethylene that is 25-cm thick, both of which are held together by aluminum structural members. These materials were chosen to provide the optimum time and energy response to neutrons detected by ^{3}He proportional counters that are present in all sides and in the top and bottom of each assay chamber.

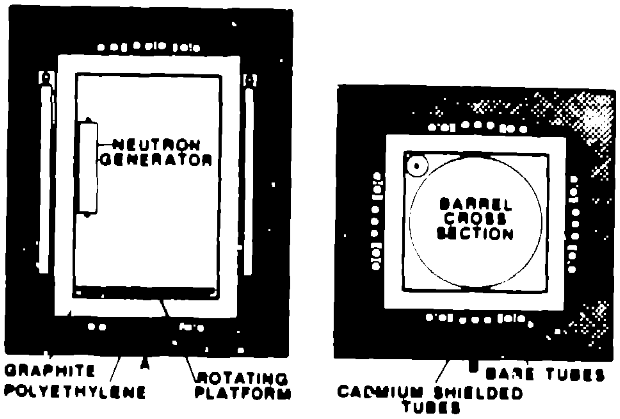

Fig. 1

Two different measurements are made in the assay systems. A pulsed neutron generator is used to interrogate a sample during an active assay. The time history of the resulting hard-fission spectrum is integrated along with the time history of the interrogating neutron flux to produce a measure of the mass of any fissile isotopes in the sample. The interrogation also produces a measure of absorbers in the matrix. During a passive assay, neutron counting and neutron-coincidence counting are used to measure the mass of spontaneous neutron-emitting isotopes. Various count statistics are used to eliminate the effects of alpha emitters, moderators, and absorbers in the matrix.

3. Logic Design and Instrumentation

A block diagram of the neutron counting instrumentation and the counting signals produced therein is shown in Figure 2. Four types of ^{3}He proportional counters are shown. The set of cadmium-shielded detectors measures the fission spectrum neutrons and the set of unshielded detectors boosts the efficiency of the total detector system during passive assays. A low-pressure unshielded ^{3}He detector measures the interrogating neutron flux during active assays. Also used during active assays is a collimated ^{3}He proportional counter, whose function is to determine flux inside the assay container. During active assays the pulse generator drives the neutron generator to produce 14-MeV neutron pulses of 10^6 neutrons each. The shielded detectors, flux monitor, and barrel-flux monitor measure

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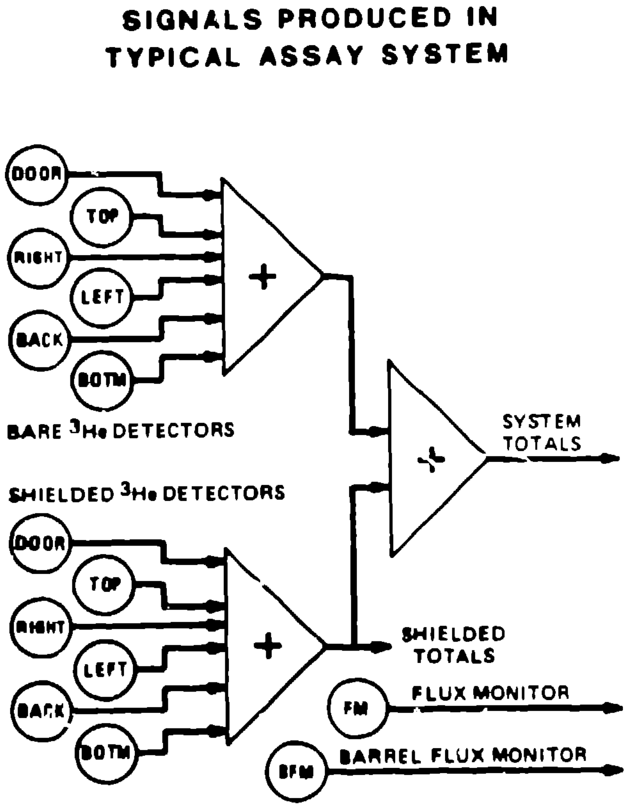

Fig. 2

quantities of interest for determining the fissile mass. During passive assays, neutrons in the cavity are counted by both the shielded and bare detectors. Data acquired by these detectors are used to determine masses of spontaneous neutron–emitting isotopes.

Figure 3 shows a typical, averaged, time history of epithermal neutrons detected by the shielded detector system. At early times, those neutrons detected can be attributed to the pulsed neutron generator. This is denoted by the sharp rise and fall of the curve shown in Figure 3. As the neutrons produced by the neutron generator become thermalized, the nuclei of fissile isotopes capture these neutrons and fission. Any such fission will produce neutrons, which are designated by the area A. The area A gets larger as the amount of fissile material in the cavity increases. The neutron population in the cavity will eventually die away to a background level designated by area B in the curve. This background level results from cosmic rays, spontaneous fission neutron emitters, and (,n) sources in the drum, and, in general, is indicative of source size. Figure 4 shows a typical, averaged, time history of the interrogating flux in the assay chamber as measured by the flux monitor. Area C in Figure 4 represents the interrogating flux during the time when induced fissions are occurring in any fissile material in the assay chamber. In general, the amount of fissile material in the cavity is proportional to (A - B)/C.

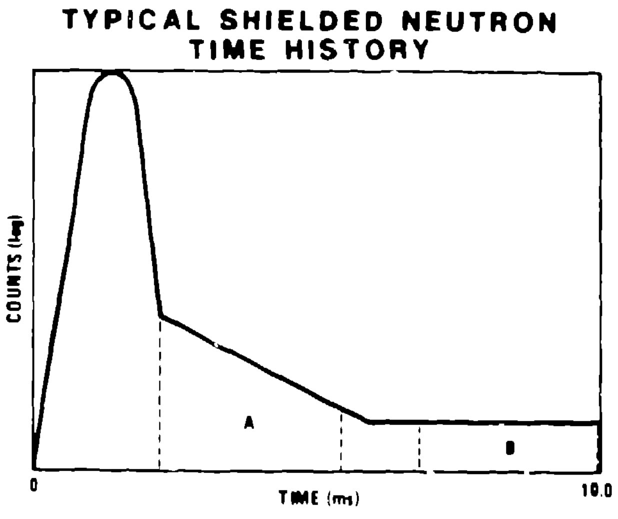

Fig. 3

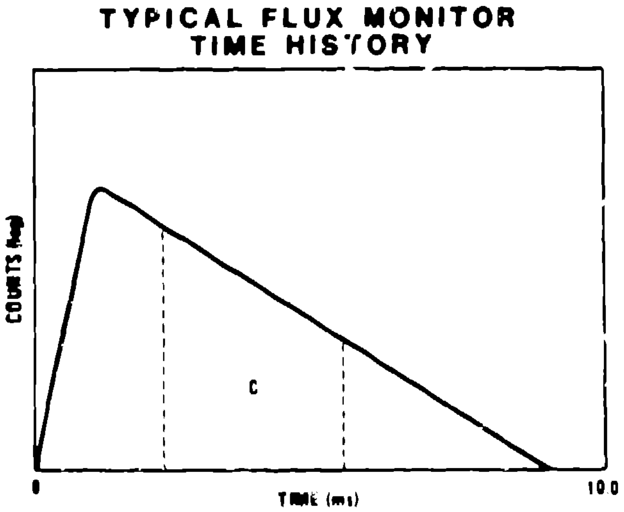

Fig. 4

The presence of neutron moderators and absorbers in the assay chamber complicates any measurement.[5] A second flux monitor, called the barrel-flux monitor, is shielded and collimated such that most of what it observes originates inside the container being assayed. The time histories observed by this detector have the same shape as those shown in Figure 4; however, as the amount of absorber in the assay chamber increases, the quantities of neutrons observed by this second flux monitor decreases. Thus, the ratio of the barrel-flux-monitor area C_B to the flux-monitor area C_F gives a measure of absorber effects for which the calibration with known sources can compensate.

Moderator effects are a function of the absorber index and the system-and-shielded-totals rates taken during passive assays. Both the absorber and moderator indices along with the calibration are unique to a particular assay chamber.

Caldwell et al.[1] detail how this information was determined for a drum assay system.

Initial versions of the assay system used a LeCroy 3500 as the system control computer. More recent versions use an International Business Machines Personal Computer (IBM-PC) as the control computer. In addition to a substantial reduction in cost from $15000 to $5000 per control computer, numerous other advantages accrue from the use of the IBM-PC. Some of these are: standard CAMAC modules can be used, data storage medium is compatible with many off-line computer systems, and system control functions are performed noticeably faster. A block diagram of the computer system with CAMAC interface is shown in Figure 5.

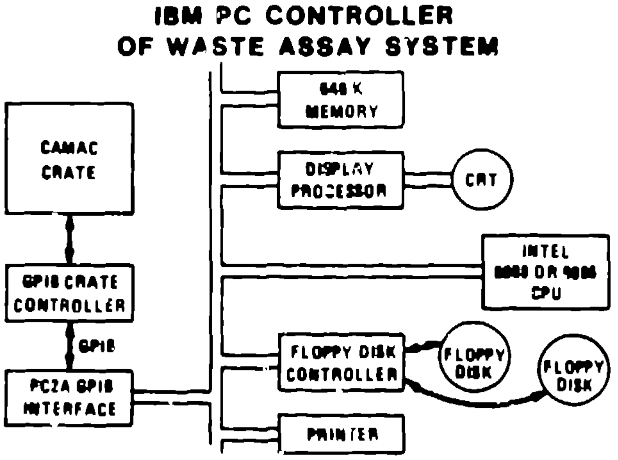

Fig. 5

A block diagram of the data acquisition and control system for active assays is shown in Figure 6. A single CAMAC crate is controlled via a National Instruments PC2A to GPIB interface and a LeCroy 8901A GPIB interface to Type U crate controller. LeCroy 2323 programmable gate generators are used to generate the integration gates for the shielded totals, the flux monitor and the barrel-flux monitor. The integrals associated with areas A, B, and C in Figures 2 and 3 are accumulated in Kinetic Systems 3610 hex scalers under control of these gates.

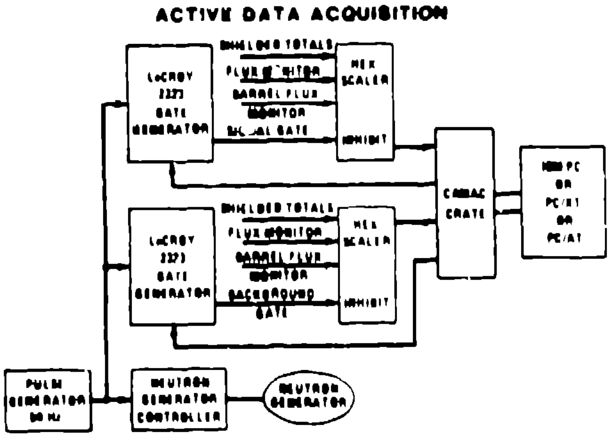

Fig. 6

The LeCroy 2323 gate generators are driven by the same pulse generator, which fires the neutron generator. Thus, average integrals are accumulated in part each time the pulse generator is fired. Typically 2000 pulses are required to assay a barrel and 5000 pulses are required to assay a crate. The integrals are read directly into the IBM-PC for further processing.

Spontaneous fission neutron-emitting isotopes produce neutrons at a rate proportional to mass of any such isotope. Because each fission produces on the average more than one neutron, the neutrons produced by fission are clustered. The neutrons produced by an (α,n) source appear randomly and not in groups. To separate the effects of (α,n) sources from spontaneous neutron-emitting sources, net coincidence rates must be measured accurately. A block diagram of signal-processing electronics for acquiring data during passive assays is shown in Figure 7. The shielded totals and system totals are used to drive coincidence gate generators. The coincidence gates so generated are typically delayed 2 to 5 μs and have lengths of 35 μs and 250 μs for shielded totals and system totals, respectively. If the time that the coincidence gates are active is typically less than 10% of the entire count time, the first neutron in a group will open the gate and the remainder of neutrons in the group will occur during the open gate and be counted in gated scalers (Standard Engineering QS-450). Coincidence rates proportional to spontaneous neutron-emitting masses are determined in this fashion. Additionally, system-gate counts and accurate clocks are used to determine accurate gate lengths. LeCroy 2551 12-channel/scalers perform both this counting and diagnostic counting for monitoring each detector module. We process the systems totals coincidence data (detector efficiency = 12.5%, dieaway time = 100 μs) and the shielded totals data (detector efficiency = 2.8%, dieaway time = 20 μs) separately. The latter is used for high sensitivity assays of low source drums and the former for more accurate assays of high (α,n) source drums.

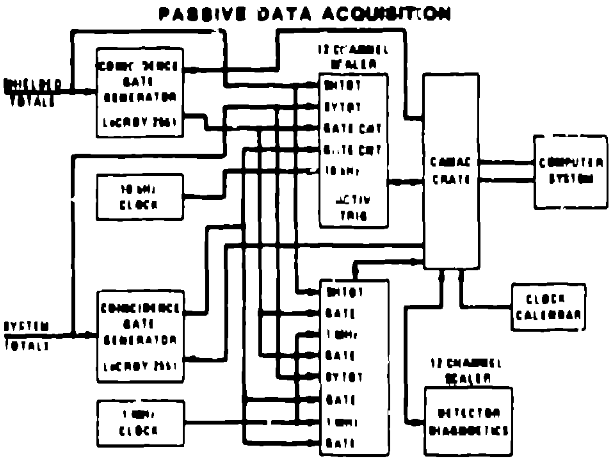

Fig. 7

4. Software

A complex software (180K bytes) code called NEUT has been produced to perform a dialogue with the operator, validate input data, archive collected data, perform active assays, perform passive assays, and generate a production report with the assay quantities in engineering units. Subsections of NEUT are the ANEUT and PNEUT subroutines, which perform the control, data acquisition, and raw data archival functions of the active assays and passive assays respectively. ANEUT and PNEUT were separate programs, which were used to perform the data acquisition for active assays and passive assays, respectively, in the LeCroy 3500 versions of the assay system. Their frequent usage consumed considerable disk-access time on the LeCroy 3500. The NEUT code and the data acquisition and control electronics were written and designed such that they can be used in a production environment with minimally skilled operators.

The NEUT code will run on any hardware configuration of an IBM-PC computer that contains at least 256K bytes of memory and a National Instruments PC2A GPIB interface. NEUT is menu driven with extensive on-line operator instructions and input data checking. NEUT will run from either a diskette system or a hard disk. All data collected either from operator input or from the data-acquisition electronics is saved in an indexed file called DBAS. The logical unit of data storage is the run, which consists of three parts, each of which pertain to the assay of a container: (1) identifying information that is entered by the operator; (2) raw data acquired during an active and passive assay; and (3) processed information such as the activity level. NEUT has the capability of using the raw data found in DBAS and recalculating the processed data quantities. This feature is useful for testing improved data-processing algorithms for computing assay quantities without having to reassay containers.

When NEUT is run, the operator is presented with twelve options that can be selected to perform assays. A list follows:

- Initial configuration
- Display data saved in summary data base
- Assay in standalone mode
- Assay in remote computer mode
- Retrieve data in remote computer mode
- Initialize summary data base
- Acquire passive background
- Recalculate assay from raw data
- Send summary data to remote computer
- ANEUT standalone mode
- PNEUT standalone mode
- Exit to MS-DOS

Several of the options allow the operator to set the environment for assays. The "Initial configuration" is used to change the counting time of passive assays (normally 200 s) and to specify the type (diagnostic, production, or none) of report produced on the printer for each assay. For accurate results, any passive data acquired are corrected to account for background levels of neutron radiation. The "Acquire passive background" option performs a passive assay on an empty container. The background so acquired is used for correcting passive assays of containers of unknown contents. One such background acquisition is performed for every 100 assays.

A single diskette (5-1/4 inch, double-density, double-sided) can contain a bootable operating system (MS-DOS), the code NEUT, and a file DBAS large enough to contain 100 assays. NEUT can be viewed as running from a single isolated diskette, which can contain as many as 100 assays or its logical equivalent (a separate directory) on a hard disk. The "Initialize summary data base" option allows the operator to set up an empty DBAS file. If such a file already exists, NEUT informs the operator of this fact and indicates which runs in the data base have not been used; the operator can then use the existing data base or continue the initialization after being warned of the consequences of overwriting an existing data base. If initialization proceeds, the operator must provide an eight-character volume serial number, which uniquely identifies the data base being created. NEUT then creates the data base with 100 dummy runs, which are replaced with real assays as containers are assayed. The size of DBAS is approximately 40000 bytes. NEUT will not allow more than 100 assays in a data base and will not permit the operator to accidently overwrite a previously completed assay.

Two of the options are used to actually perform the assay, the "Assay in standalone mode" and the "Assay in remote computer mode". Once the "Assay in standalone mode" is selected, an operator dialogue is entered, wherein the following information is collected and verified: (1) run number (1 to 100); (2) primary identification (15 ASCII characters); (3) secondary identification (12 ASCII characters); (4) content code (10 ASCII characters); (5) container weight (kg); and (6) plutonium isotopics. After verifying the input data, NEUT instructs the operator to fire the neutron generator to start an active assay. A passive assay starts automatically when the active assay is finished. When the passive assay is finished, NEUT processes the raw data, archives both raw and processed data, and prints a report of the assay results. Assays of more containers can proceed until 100 assays have been completed. The remote computer mode allows a remote computer (via an EIA-RS232C serial interface) to perform the operator dialogue and otherwise to control program NEUT. This is a full handshake mode, wherein processed data is transferred to the remote computer.

Three options are used to examine processed data from previously performed assays. The "Display data saved in summary data base" will print a report of processed data on the printer. The "Retrieve data in remote computer mode" permits the remote computer to acquire previously processed data. Thus, if the remote computer system is not available, assaying can proceed in

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the "Assay in standalone mode;" and, when the remote computer becomes available, the assay data can be retrieved without repeating any assays. The "Send data to remote computer" dumps all data in the data base to the EIA RS-232C serial interface with no handshake from the remote computer. This mode is useful for transferring data to a remote computer in instances where control of NEUT by the remote computer is not desired.

Three diagnostic options are also available. These are for collecting, examining, and analyzing specialized raw data. Such diagnostics permit the development and improvement of data-processing algorithms and the isolation of faults in both the hardware and software. The "Recalculate assay from raw data" performs all the assay computations and data archiving that an actual assay does except that the raw data comes from the data base rather than from the assay chamber. This feature is used to test new algorithms on old data. Both the ANEUT and PNEUT standalone modes are used to perform a succession of either active or passive assays and produce a diagnostic report of raw data quantities. The data so acquired can identify system faults and verify the effect of changes in data acquisition hardware and software.

A typical assay sequence consists of the following steps in the order listed:

- Initial configuration
- Initialize summary data base
- Acquire passive background
- Assay in standalone mode
  - 1st run is of known ^{252}Cf sources
  - Up to 99 runs of unknown containers
- Exit to MS-DOS

Once the assaying of containers is started, the procedure need not be continuous. The computer can be powered off and on many times and assaying would continue at the next container to be assayed. If enough time has elapsed that the background may have changed, a new data base should be initialized on another diskette before additional assays are made.

5. Case Example

To date, three assay systems have been installed with the IBM-PC based control equipment described in this paper: a mobile unit[6], a unit at the Rocky Flats Plant in Golden, Colorado, and one in Idaho. Once a system had been set up at the Idaho National Engineering Laboratory (INEL), assay data was produced at a rate faster than could be analyzed by hand. A popular spread sheet (LOTUS 123) was used to keep track of the voluminous data from the INEL installation. A special code (IBM2LOT) was written to convert data in the DBAS files to LOTUS format and keep track of the volume serial numbers of each DBAS file. Approximately 5000 barrels have been assayed and analyzed at this time. Both skilled and unskilled operators have performed the assays. Very little if any data has been lost due to improper operator technique. Additional software has been written that permits use of a Lotus 123 spread sheet as an analysis tool for the relatively large amounts of assay data. Lotus 123 has been used not only to verify and refine the calibrations of the assay systems using the data collected by both LeCroy 3500 and IBM-PC systems from these 5000 barrels, but also to sort difficult assay cases for more sophisticated analyses.

6. Conclusion

The assay system described herein can measure fissile masses as low as 1-mg ^{239}Pu and spontaneous neutron-emitting masses as low as 10-mg ^{240}Pu. This sensitivity can be achieved with substantial quantities of absorber and moderator in the matrix and in the presence of strong alpha-emitting sources. The control-and-data-acquisition system consists of a simple and inexpensive computer system that is a de facto standard in the United States. In addition, the system archives the assay data for later retrieval and analysis. Furthermore, operation of the assay system does not require highly skilled operators.

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