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AUTHOR(S) J.R. Hurd, C.A. Bonner, MST-10
C.A. Ostenak, PDSA
R.E. Morrison, H.C. Staley, MEE-3
J.G. Fleissner, T.W. Coressel, D.C. Yee, Rockwell International,
Rocky Flats Plant, Golden, CO

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ROBOCAL: GAMMA-RAY ISOTOPIC HARDWARE/SOFTWARE INTERFACE

J.R. Hurd, C.A. Bonner, C.A. Ostenak, R.E. Morrison, and H.C. Staley
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

J.G. Fleissner, T.W. Coressel, and D.C. Yee
Rockwell International, Rocky Flats Plant
Golden, Colorado 80402

ABSTRACT

ROBOCAL, presently being developed at the Los Alamos National Laboratory, is a full-scale prototypical robotic system for remotely performing calorimetric and gamma-ray isotopics measurements of nuclear materials. It features a fully automated vertical stacker-retriever for storing and retrieving packaged nuclear materials from a multi-drawer system, and a fully automated, uniquely integrated gantry robot for programmable selection and transfer of nuclear materials to calorimetric and gamma-ray isotopic measurement stations. Since ROBOCAL is to require almost no operator intervention, a mechanical control system is required in addition to a totally automated assay system. The assay system must be a completely integrated data acquisition and isotopic analysis package fully capable of performing state-of-the-art homogeneous and heterogeneous analyses on many varied matrices. The TRIFID assay system being discussed at this conference by J.G. Fleissner of the Rocky Flats Plant has been adopted because of its many automated features. These include: MCA/ADC setup and acquisition; spectral storage and analysis utilizing an expert system formalism; report generation with internal measurement control printout; user friendly screens and menus. The mechanical control portion consists primarily of two detector platforms and a sample platform, each with independent movement. Some minor modifications and additions are needed with TRIFID to interface the assay and mechanical portions with the CimRoc 4000 software controlling the robot.

INTRODUCTION

Nondestructive assay (NDA) plays an essential role in nuclear materials processing and safeguards at the Los Alamos Plutonium Facility. Prompt, high-quality NDA measurements are needed to monitor and control the movement, processing, and storage of nuclear materials and to detect their misplacement or unauthorized use. Currently, NDA measurements are performed "hands-on" resulting in chronically high personnel radiation exposures despite various administrative and engineered radiation controls. Moreover, we are experiencing a steady increase in demand for NDA measurements, especially calorimetric and gamma-ray isotopics assay[1], resulting in still higher personnel radiation exposures. These increased measurement demands are now exceeding capacity by factors of two or more which suggests at least doubling the present number of calorimeters and gamma-ray isotopics instruments. Alternatively, the capacity of the existing instruments could be increased by adopting a 2-3 shifts per day, 7-day work week. Either of these approaches would result in yet higher radiation exposures for the countroom technicians.

In order to solve both the exposure and increased measurement demand problems simultaneously, as well as minimize personnel access to nuclear materials, "ROBOCAL", a Robotic Calorimetry System, is being developed at the Los Alamos National Laboratory. ROBOCAL is a full-scale prototypical robotic system for remotely performing calorimetric and gamma-ray isotopics measurements of nuclear materials. Originating in 1987, ROBOCAL is presently undergoing testing and evaluation in Room 38 of the PF-4 basement at the Los Alamos Plutonium Facility and is scheduled for full operation later this calendar year. ROBOCAL features a fully automated vertical stacker-retriever for storing and retrieving packaged nuclear materials from a multi-drawer system consisting of 144 item locations, and a fully automated, uniquely integrated gantry robot for programmable selection and transfer of packaged nuclear materials from their drawers to NDA measurement stations comprising five on-line calorimeters and two on-line gamma-ray isotopics instruments (see Figures 1 and 2).

DISCUSSION

The purpose of this presentation is to discuss the gamma ray isotopics requirements of ROBOCAL including the interfacing with the robot controller. Because ROBOCAL is to be totally automated, the isotopics instrument requires a mechanical control system in addition to a totally automated assay system. The primary requirement for the assay system is that it be a completely integrated data-acquisition and isotopic analysis package fully capable of performing state-of-the-art homogeneous and heterogeneous analyses on many different matrices.[1] At present, an ideal device for the automated assay system would appear to be the TRIFID/EPICS (Transuranic Isotopic Fraction Interrogation Device / Enhanced Plutonium Isotopics "C" Software) system[2] scheduled for presentation at this conference by J.G. Fleissner of the Rocky Flats Plant (RFP). For example, some of the automated features of TRIFID include MCA/ADC (Multichannel Analyzer / Analog to Digital Converter) setup and acquisition, spectral storage, isotopic analysis, and report generation. Further, the TRIFID design even permits it to be programmed such that an entire day's counting can be done with absolutely no operator intervention. In addition, the isotopic analysis program has an expert system formalism used to detect and assay for spectral interferences, and to automatically adjust peak fitting constraints based on spectral intensity variations. Thus, the necessity for operator intervention to switch analysis files is essentially obviated! The entire software package was developed in the C language thus rendering it very versatile. For ease of operation and training, extensive use was made of user friendly screens and menus. The system has proved itself in a production mode at RFP since September, 1988. Marked decreases in training and "hands-on" operation time were noted when compared with preceeding systems.

Software/Hardware Interfacing

Some modifications and additions are needed with the present TRIFID system in order to interface with the CimRoc 4000 software which resides on the central computer (IBM-AT) and controls the ROBOCAL robot. The interface to the Canberra Series 95 Multichannel Analyzer remains unchanged. The modified TRIFID software, called ISOCODE, will be run on a Compaq 386/20 computer. The keyboard of this computer will be locked out in the normal running mode and all control will be via an RS 232C serial line from the IBM AT. This controller, referred to here as the master program, can send four different commands to the

ISOCODE program:

(1) Inform the ISOCODE program, executing on the Compaq 386/20, that a sample for measurement is on the platform and start the acquisition cycle

(2) Direct the ISOCODE program to enable the keyboard. This will permit an operator to interact directly with TRIFID in order to, e.g., change setup parameters. When the QUIT option from the TRIFID menu is selected, the keyboard will again be disabled and control will be returned to the master

(3) Request the status of the gamma isotopic system, including the existence of errors

(4) Direct the program to stop the current run. If there is no current run, no action will be taken.

The isocode program can, in turn, send the results of the analysis (see Table 1), as well as an error message if the transmission isn't received, back to the master program residing on the central computer. These results can then be immediately viewed by the operator and are automatically archived on a user-friendly, versatile data-base system (RBASE). The spectral data are permanently stored at the Compaq on removable Bernoulli Cartridges.

All messages sent to or from the master program are in the format specified in the communication protocol document[1] by Martin Kellogg of the Los Alamos National Laboratory. Some of the features of this protocal which apply here are now described. First, all information is transferred in printable ASCII characters. This allows a non-intelligent terminal to be hooked to the serial line for debugging. All numbers are formatted in printable characters (usually decimal, but possibly some other base when more compactness is desired) for transmission. Each ASCII character has 7 data bits. The 8th bit is transmitted as an even parity bit, and is checked by the receiver. There is one start bit and one stop bit. The bit rate is hardware (or software) selectable. It may range from 300 to 19200 bits per second. Next, messages are variable in length, up to some maximum. This allows short messages for acknowledgment and longer messages for transmission of assay results. Messages longer than the maximum are segmented into multiple messages, each of which is sent and acknowledged separately. All messages begin with a sync character ({ "left brace") and are terminated with a carriage return and line feed.

Any characters preceding the sync character or following the line feed are ignored. Each message contains the current date and time in case they are logged to some device. Further, each message contains a message tag, which indicates the message type (see Table 2). The receiver determines from the tag the content and format of the message. Some messages, such as acknowledge, may have no content.

Several features are incorporated for checking the correctness of messages. Each message contains a byte count after the sync character; this count can be used to check message length. Following the message content, there is a checksum preceding the CR/LF. The checksum is a longitudinal sum of the message characters; the receiver verifies that the message characters actually received sum to the same result. Message handshaking allows for retransmission of messages when necessary. The receiver acknowledges correct receipt of a message or asks for retransmission if a message is not received correctly. If the sender receives no response within a specified time, the message is retransmitted up to a maximum of five times at which point the communication software signals an error. In addition, as an extension to the protocol, if one of the programs detects that the communications has failed or its synchronization is lost, it will send a NAK message to the other computer to indicate the loss. This indicates that both programs are to start with retransmission of the message sequence from the initial "R" message. As mentioned before, if a communication or central computer failure occurs, the isotopics instrument can be taken off-line where it does not require the link with the central computer. It can be operated in a stand-alone mode and will log the analysis results onto the disk and printer. In fact, this mode will be entered automatically when the instrument detects loss of communication. Exit may similarly be either manual or automatic.

We conclude this section by giving an example (see Table 3) of a message originating from the master and sent to the ISOCODE program. The start message contains the information required to start an assay run. The master program sends a data message of type ST that contains the necessary information. The ISOCODE program will return an acknowledge or NAK depending upon whether the message was received correctly. The fields of information will be fixed length ASCII strings separated by semicolons. All strings will be right padded with blanks if their length is shorter than the given field length.

The mechanical control portion of the gamma isotopic measurement station consists primarily of an instrument cabinet, two detector platforms and a sample platform (see figure 3). Each platform is a stand-alone mechanical apparatus that acts independently of the other platforms. The detector platforms can move 31 inches along an axis either toward or away from the sample platform and are controlled by two Anaheim Automation DPF-76 3-Axis motor controllers, communicating with the Compaq via a serial port, and two Anaheim Automation 34D311 stepper motors. The driver routines for the controllers are written in the C language and can be called by the ISOCODE software as needed. In addition, failsafe hard limit switches are provided to prevent damaging movement. If the hard limit switch is actuated, power is removed from the motor and will not be restored unless a move is requested in the opposite direction. One of the detector platforms has a second stepper motor that controls a stepped wedge containing five positions of 32 mil increments of cadmium which can be moved in front of the LEPS detector to provide necessary absorption of low-energy gamma and x-rays. The sample platform is controlled by two stepper motors and limit switches. The sample to be measured is placed on the platform by the robot and the platform is then moved along a vertical axis and simultaneously rotated. Assay height (extent of vertical motion) can be determined by monitoring the gross count rate. Control lines from all platforms are brought to a control panel which displays the status of all limit switches and houses the motor controllers. The control panel also provides for manual activation of any motor, slow or high speed, and provides an emergency shut-down switch. The panel is connected to the Compaq 386/20 via an RS-232C serial link which receives commands from the Compaq and returns status information about the mechanical system.

In order to develop the ISOCODE software for ROBOCAL, three phases of TRIFID software development were identified: (1) pre measurement, (2) acquisition cycle, and (3) effective specific power calculation. The pre measurement phase contains routines to determine the cadmium absorber thickness and optimum detector distances from the sample prior to acquisition of the gamma-ray spectrum for analysis. It also includes receipt of setup file specifications from the master computer (CimRoc 4000 IBM-AT) for the sample to be assayed. Studies are presently under way to determine the best way to develop the algorithms. Since the primary function of the cadmium absorber is to attenuate the large 60 keV Am peak to approximately the same height as the X-ray peaks in the region, a simple integral comparison should suffice. Determining the best detector distance is not quite as easy since different collimation may have to be employed depending upon the sample strength. However, since the primary goal is to achieve the maximum count rate without saturating the detectors or losing too much throughput because of deadtime,[4] studies are being performed using Ortec 994 Counter Timers to integrate the gross count rates in order to map out boundaries based on the maximum source strengths achievable. If the sample to be measured has less count rate than that boundary, then the detector is simply moved as close to the sample as possible; if not, then algorithms will have to be developed to incrementally move the detectors, always comparing with the prescribed boundary conditions.

The acquisition phase includes additional routines to initialize the system, start and stop the helical scanner (rotating and translating platform), and prepare for power shutdown. For example, the routine CLEANUP initializes the serial port, sets vital motor control parameters, sends all motors to their retracted positions (platform raised, detectors back and wedge out), and verifies these limits. This routine is called several times during the course of a run: after power up to initialize the system, after an assay to prepare the unit for the next sample, and before power down. The routine SHUTDOWN lowers the sample table for power down. Otherwise, without the motor holding torque, the sample platform would lower itself under its own weight, possibly causing damage or dropping a sample. The routines SPIRAL and STOPSPIRAL initiate and stop the sample platform rotation/translation for data acquisition. Once SPIRAL returns control to the main program, the motor controller acts autonomously until the TOPSPIRAL routine is called. From previous studies[5] it has been determined that, for a one-half inch slit width collimater (the type used here), rotation rates of

10 rev./min. coupled with translation speeds of 0.33 in./min. give best results. Since data acquisition time is normally 30 minutes for most samples, this is sufficient time for one full vertical translation of a 10 inch high cannister. Thus, data will be obtained on 30 rotations per inch of vertical translation.

The last phase, effective specific power (Peff) calculation, has routines to select the proper isotopics for calculating the effective specific power and its associated uncertainty. For example, in the case of an assay of a heterogeneous salt with a non-zero beta value,[5] the ISOCODE software has algorithms to recognize this and not use the high energy (COAX) americium value in the Peff calculation.

Finally, in order to help clarify and integrate the ideas and routines incorporated in ISOCODE, we present a process flow chart illustrating the sequential flow throughout the system during a typical assay (see figures 4 and 5). "Program Self-Initialization involves a call to the CLEANUP routine. This also sets up communications between the various components. In the "Idle" mode the Compaq is waiting for either a "start" command from the CimRoc Central Computer or assumption of keyboard control by the operator. After receiving a sample and "start" command, the Compaq makes a call to the SPIRAL routine and performs the positioning sequence detailed in figure 5. Next, the Compaq instructs the sample platform motor controller to start translating by making another call to SPIRAL (rotation is already occurring from the positioning sequence). After the Canberra MCA times out (preset time attained), the data are sent to the Compaq and the analysis is performed. A call to the CLEANUP routine is then made and the CimRoc IBM-AT Central Computer is queried. If the CimRoc responds, the Compaq will print and transmit the analysis results to the CimRoc for archiving and operator viewing. If the CimRoc does not respond, the Compaq will query up to a total of five times before automatically entering the keyboard mode. Keyboard control allows the operator to fulfill the role of the CimRoc by placing/removing samples, entering/retrieving data via floppy disks, starting/ending assays while maintaining the automation afforded by the Compaq.

CONCLUSIONS

In recent years, with the advent of expert systems employing artificial intelligence and the integration with robotics, it has become possible to automate many repetitive, boring processes. In particular, the very recent development of TRIFID/EPICS by RFP personnel[2] has made it feasible to automate the very important assay procedure of calorimetry and gamma-ray isotopics. The advantages, from a practical standpoint, are that operators receive less radiation exposure, throughput is increased by about a factor of three, and safeguards is enhanced. Further, the operators' time can be better spent in more productive activities that require more thinking. From a different perspective, perhaps more speculative, one of the important accomplishments of this trailblazing endeavor is that it has set the stage for further development in this arena. For example, plans are already underway to automate the LANL PF-4 MEGAS (Multiple Energy Gamma Assay System) operation[6] in which repetitive measurements of low-level nuclear waste boxes are made. One can raise the question of just how far this concept can be pushed. It seems to us not inconceivable that eventually all packaging, unpackaging, and measuring of nuclear materials will be robotized.

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TABLE 1

Archive Information Sent to Master
from TRIFID Isotopic System

Item	# ASCII Chars.	Example
Pu-238 (% total Pu)	8	0.0096
Pu-239 (% total Pu)	8	93.7634
Pu-240 (% total Pu)	8	5.9559
Pu-241 (% total Pu)	8	0.2491
Pu-242 (% total Pu)	8	0.0220
Am-241 (% total Pu)	8	0.0826
U-235 (% total Pu)	8	5.9971
Np-237 (% total Pu)	8	13.2231
Am-243 (% total Pu)	8	1.3327
Uncer. Pu-238 (%)	6	8.71
Uncer. Pu-239 (%)	6	0.16
Uncer. Pu-240 (%)	6	2.48
Uncer. Pu-241 (%)	6	0.41
Uncer. Pu-242 (%)	6	12.46
Uncer. Am-241 (%)	6	2.54
Uncer. U-235 (%)	6	11.68
Uncer. Np-237 (%)	6	1.23
Uncer. Am-243 (%)	6	33.39
Eff. Specific Power	9	0.0023879
Uncer. Eff. Sp. Power(%)	5	0.38
Collection Date	8	12/ 2/88
Collection Time	8	15:47:03
LSTAT Number	1	2
Instrument ID	2	01
Live Time	5	3600
True Time	5	3783
Beta Value	7	0.0259
Beta Uncer.(%)	6	11.29
LEPS Anal. File	4	plut
COAX Anal. File	4	hnrg
Absorber Pos.	1	3
Count Rate	5	53000

Total Characters:	196 *	

* Will require two data message segments to transmit

TABLE 2

The following types of messages are defined:

Message Tag	Description
?	Retransmission of the message just received is requested; the message content is empty.
A	Transmission of the message or segment just received is acknowledged; message content is empty. A request message is acknowledged by transmitting the requested data. The "A" message is not sent in this case.
R	Message is a request; the message content is a two-character code indicating the type of request.
D	This is the last or only segment of a data message; the message content is the type of data and the data itself.
0, 1, ...9	This is a segment other than the last of a segmented data message; the message content is the type of data and the data itself. The first segment has the message tag 0, the second 1, etc. If there are further segments after 9, the tags recycle from 0. The last segment has message tag D.

'he first two characters of the content in a data essage are a code that designates the type of ata in the message. Some examples are ST for tart assay, RA for assay results, ER for error, P for stop assay, NA for NAK (not acknowledged), A for stand-alone, i.e., return keyboard control n Compaq to operator, etc. If the message is egmented, the content of each segment starts with he data type characters.

TABLE 3

Start Message Sequence

```
        22  23-25 26-27 28 - ??
----++---++-----+-----+--------++----
... || D || ST; | #;  | Data;  || ...
----++---++-----+-----+--------++----
     COMPAC <------< ROBOT

----++---++----
... || A || ...
----++---++----
     COMPAQ >------> ROBOT
```

Start Message Contents

Name	Length	Description
System #	1	This identifies which of the two possible gamma-isotopic systems is to be started.
Lot ID	20	This is the lot identifier supplied by the operator for the sample when it is entered into the robot system.
Material	2	This is the material type supplied by the operator for the sample when it is entered into the robot system.
Account	3	This is the account number supplied by the operator for the sample when it is entered into the robot system.
Setupfile	11	This is the name of the MCA file that TRIFID is to use for performing the analysis.
Comment	58	This is a character comment that can be used as a label on the printed output. Its contents are never parsed.

Format of Messagebody Data

Index	Code	Format	Description
01-02	ST	%2s	Start
03	,	:	Separator
04		%1d	System #

Table 3 (continued

05	;	;	Separator
06-25		%20s	Lot ID
26	;	;	Separator
27-28		%2s	Material
29	;	;	Separator
30-32		%3s	Account #
33	;	;	Separator
34-44		%11s	Setupfile
45	;	;	Separator
46-103		%58s	Comment
104	;	;	Separator

Fig. 1. View of the ROBOCAL work envelope as seen looking toward the KARDEX Stacker-Retriever. A large 7-inch calorimeter with a slightly protuding sample can is visible just in front of the KARDEX. The robot arm is located above and to the right of the calorimeter. One of the light curtain units is just visible in the far-left foreground; in the far-right foreground part of the back of the control rack for the calorimeters can be seen.

Fig. 2. View of the gamma isotopics station at the end of the ROBOCAL work envelope (looking away from the stacker-retriever). The LEPS detector, with its shielding not yet in place, can be seen resting on its horizontally movable platform. Just in front is the rotating and translating platform holding a sample can for measurement. In the background on the left is a rack containing the motor controllers and isotopics electronics; on the top right is the Canberra Series 95 MCA and just underneath is the Compaq 386/20. This entire system is discussed fully in the text of the paper.

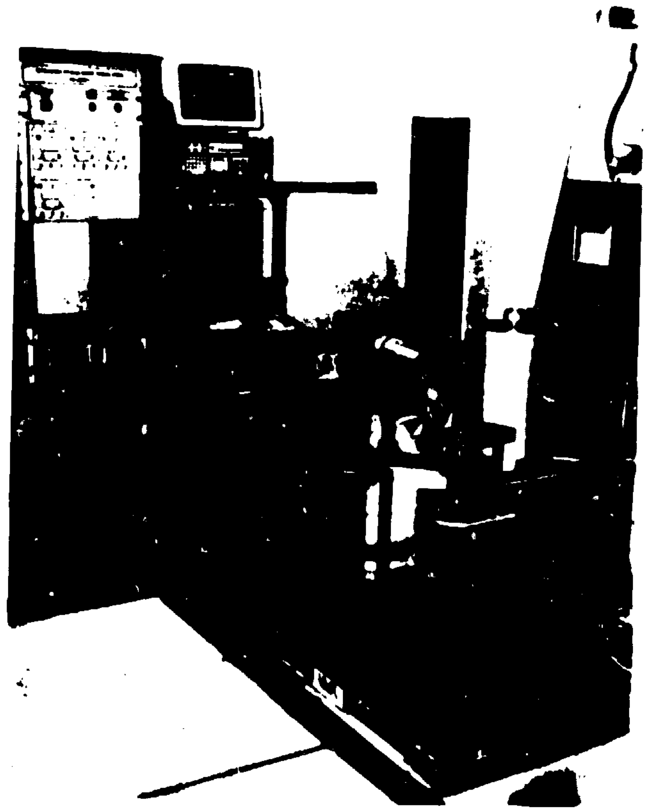

Fig. 3. A schematic sketch of the gamma isotopics system showing the various possible movements of the detectors, sample, and cadmium stepped wedge as well as their interconnections. Not shown is the connection from the Compaq to the CimRoc 4000 Central Computer (IBM-AT).

GAMMA ISOTOPICS

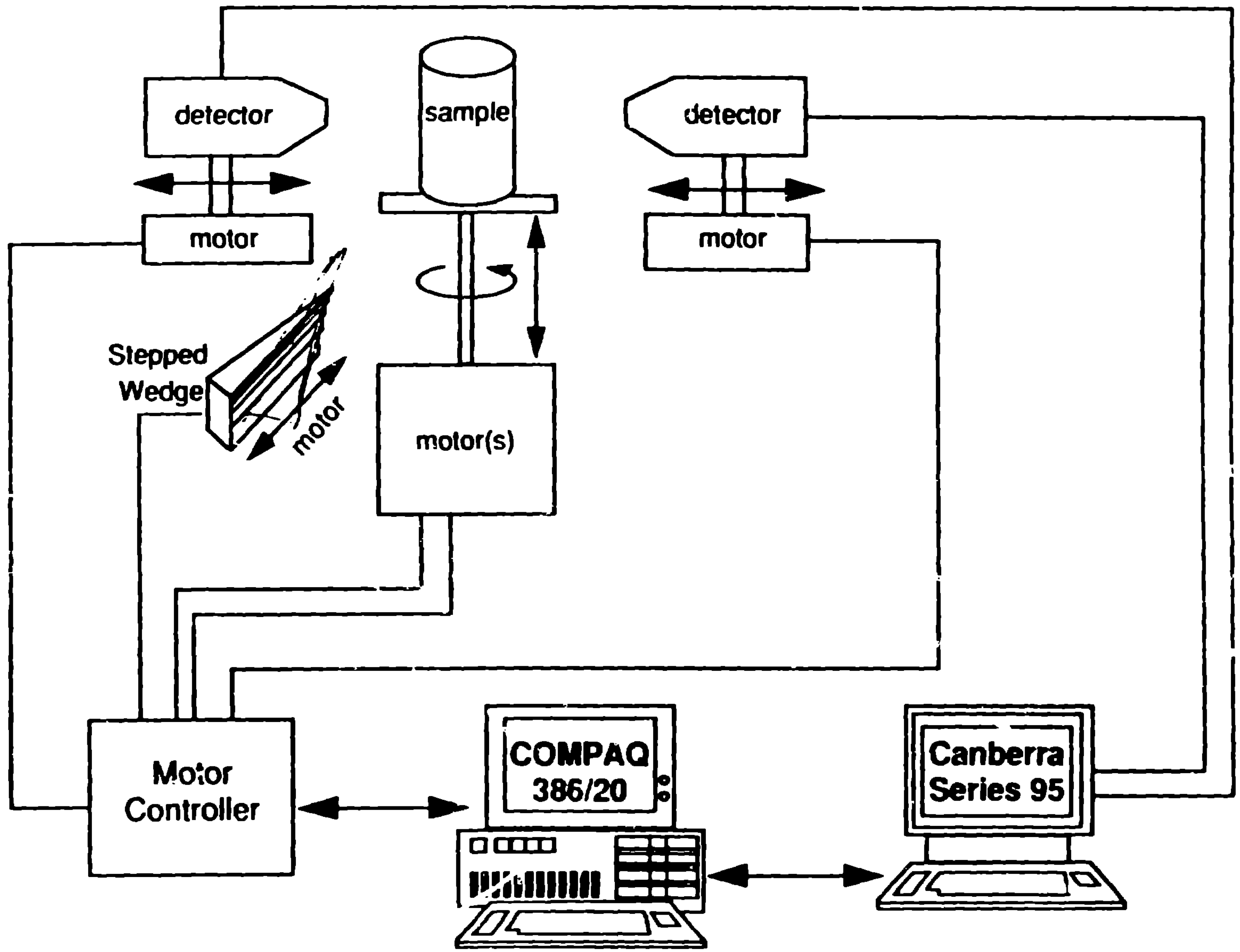

Fig. 4. Process flow chart.

Figure

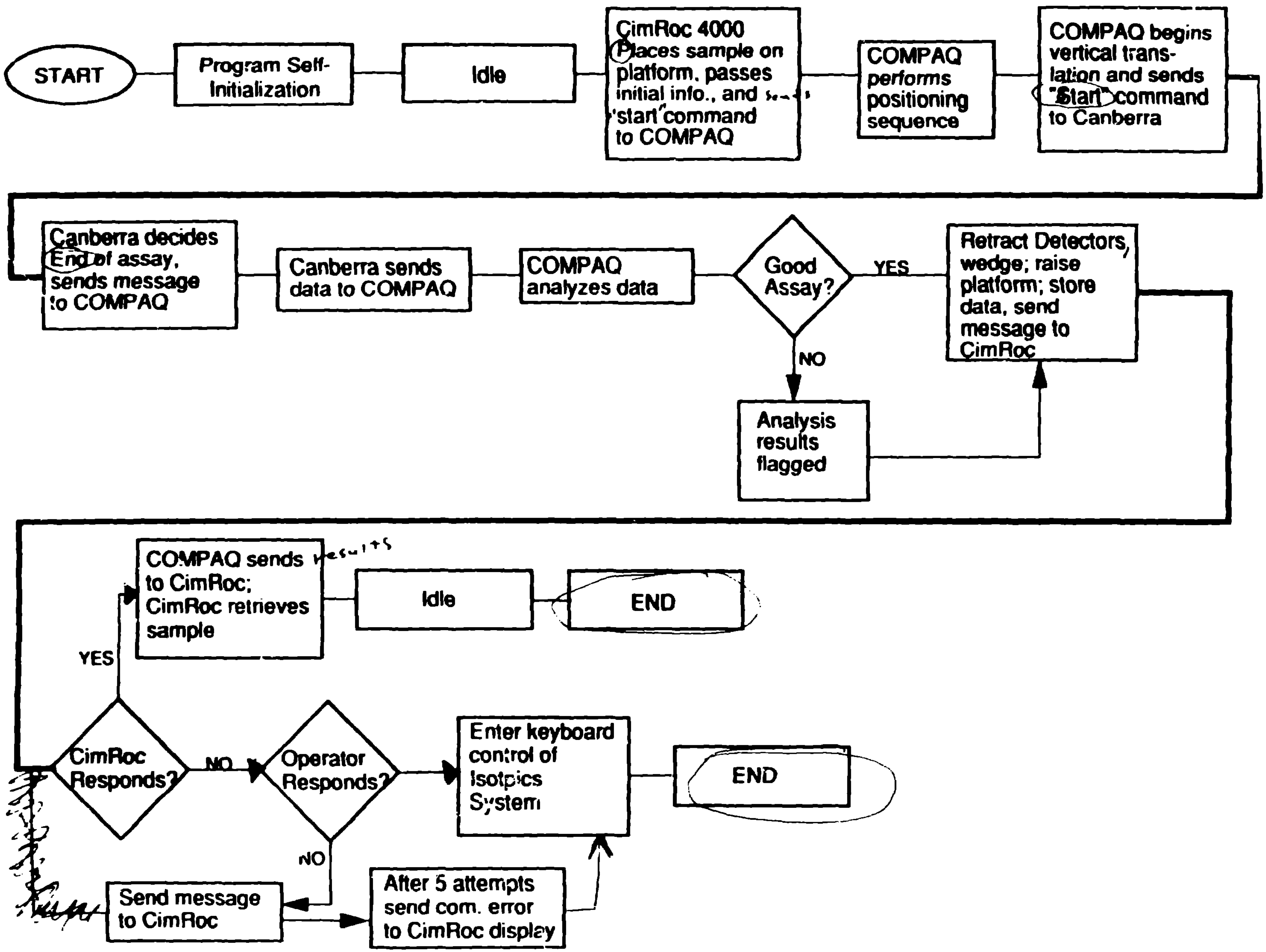
START
Program Self-Initialization
Idle
CimRoc 4000 Places sample on platform, passes initial info., and sends 'start' command to COMPAQ
COMPAQ performs positioning sequence
COMPAQ begins vertical translation and sends "Start" command to Canberra
Canberra decides End of assay, sends message to COMPAQ
Canberra sends data to COMPAQ
COMPAQ analyzes data
Good Assay?
YES
Retract Detectors, wedge; raise platform; store data, send message to CimRoc
NO
Analysis results flagged
COMPAQ sends results to CimRoc; CimRoc retrieves sample
Idle
END
YES
CimRoc Responds?
NO
Operator Responds?
Enter keyboard control of Isotpics System
END
NO
Send message to CimRoc
After 5 attempts send com. error to CimRoc display

Fig. 5. Detail of positioning sequence indicated in process flow chart.

POSITIONING SEQUENCE