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THE INSPECTOR-INSTRUMENT INTERFACE IN PORTABLE NDA INSTRUMENTATION*

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Recent electronics technology advances make it possible to design sophisticated instruments in small packages for convenient field implementation. An inspector-instrument interface design that allows communication of procedures, responses, and results between the instrument and user is presented. This capability has been incorporated into new spent-fuel instrumentation and a battery-powered multichannel analyzer.

Introduction

An International Atomic Energy Agency (IAEA) inspector may use several different types of instruments in his inspections. Obtaining the data and arriving at results of a specific measurement are complicated by the fact that the inspector may seldom use a particular instrument; this increases the probability of mistakes in operating procedures or in calculating results. Unfamiliarity with the instrument makes it difficult for the inspector to determine if the instrument is malfunctioning. Because the inspector has limited time at a facility, these errors must be minimized so the inspector can concentrate on the measurement.

An important feature of inspector-oriented instruments that minimizes these errors is the proper design and use of an inspector-instrument interface. This interface includes the hardware and protocol that allow the instrument and inspector to communicate during a measurement. While different instruments are used to make different measurements, the interface hardware and protocol of all instruments should be similar so that the inspector can comfortably move from one instrument to another and use each one effectively with little experience. Properly written user-oriented software uses the interface to allow an inspector to focus his concentration on the measurement's meaning with minimal distraction due to remembering detailed procedures, checking hand calculations, and worrying if an instrument is operating properly during an inspection. The instrument prompts him through the correct measurement steps, and calculations are done internally, eliminating incorrect results caused by a wrong keystroke or miscopied number.

Two instruments that use the inspector-instrument interface have been delivered to the IAEA by the Los Alamos National Laboratory Safeguards Assay Group. One is a battery-operated 1000-channel analyzer that can display and record spectra obtained from NaI or high-resolution detectors. The 28-cm-wide by 18-cm-long by 24-cm-high analyzer features built-in high-voltage and preamplifier power supplies and an internal spectroscopy amplifier. The other instrument is the portable spent-fuel gamma-ray and neutron detector electronics that provides digital readout of the current mode response produced by gamma rays in an ion chamber and amplification and scaling of pulses received from a neutron detector. The primary application is the measurement of gamma-ray and neutron activity of irradiated reactor fuels stored at a reactor or at an away-from reactor storage pond. Each instrument's front panel contains a 32-character display used to communicate instructions, options, and results to the

user and a keypad used to command the instrument or to enter responses. In this paper the underlying design philosophy of the inspector-instrument interface is discussed. Examples are given to illustrate key features.

Additionally, each instrument has standard communications interface hardware and the software capability to support a specified communications protocol. This allows them to be adapted for use in a distributed data-acquisition system, which may be found in larger nuclear facilities.

Goals and Philosophy

The goal of the interface development activities at Los Alamos is to provide an intelligent instrument "assistant" that prompts the user through procedures. In a simple and straightforward manner it carries out programmed steps of a measurement, prompting for external information when required. It calculates results and error estimates. This type of instrument also performs internal diagnostics and reports malfunctions to the user.

While the physical interface is not unique, from the user standpoint it is important to have the same well-defined philosophy of interaction for all instruments. Once the user learns this philosophy, he has a basic understanding of all the instruments that use the standard interface. Therefore, he can effectively use an instrument even if he has not used it recently or frequently.

Each valid user action must have a unique response; that is, the result of a legal key push is always the same and not dependent on the sequence of proceeding key pushes. It is important that each action is followed by a definite response. Our interface provides tactile feel and visible response on a liquid crystal display (LCD) or cathode-ray tube (CRT). Some designs limit response to only tactile feel or an audio beep; tactile feel alone can be misleading, and a beep may not be heard in high-noise environments.

The state of control should always be known. At any time, the user should be able to determine the current command being executed in a nondestructive manner, without losing information already acquired or aborting an action in progress. It should be obvious when the instrument is waiting for a response.

Proper interface design defines which actions are valid at all states of control. The instrument must not execute requests that are not valid at a particular time. It must inform the user of the invalid request and must recover from such a request with minimal inconvenience to the user. For example, dumping spectrum data to tape while the unit is acquiring data is an invalid request. If this condition occurs, the instrument responds with INVALID ACTION REQUESTED and continues to acquire data ignoring the request to dump to tape. To store the data to tape the user halts the data acquisition and then requests the data dump. This enables the instrument to write a consistent set of spectral data and status to tape.

The raw data and instrument parameters should be available with the results whether they are displayed

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on the LCD or written to magnetic tape. Putting complete information on a tape reduces the chances of logging an incorrect value. Each tape record should uniquely define the measurement. Time and date are necessary; they may be supplemented with inspector, facility, and sample identifiers.

Implementation

The first instrument designed during the development of the standard interface was an ion- or neutron-detector electronics package (ION-1) used for spent-fuel measurements. It measures the relative gamma dose using a gas-filled ion chamber in the current mode. Its current sensitivity ranges from 0.1 pA to 637 nA. The actual gamma dose is a function of the ion chamber used. Neutrons are counted when input pulses exceed a lower-level discriminator (LLD) set by the instrument. The instrument can automatically set the optimum gain for the gamma channel and the LLD for a uranium-235 fission chamber. A photo of the ION-1 is shown in Fig. 1. The detector connectors, battery charger input, and RS-232 serial connector are mounted on the rear panel. The physical interface is the front panel, which has an LCD with two rows of 16 ASCII characters to convey instructions, results, and options to the user; a 4 by 4 information entry keypad; and a 1 by 4 control keypad.

The second instrument in which this interface was implemented is a portable, battery-powered multichannel analyzer (MCA). This MCA is an extension of an MCA unit demonstrated by another group at Los Alamos.¹

Fig. 1. ION-1 electronics package.

The hardware features of the analyzer are a 1024-channel analog-to-digital converter (ADC) with a conversion oscillator frequency of 32 MHz, internal high-resolution gamma-ray (HRG) spectroscopy amplifier, NaI amplifier-stabilizer, and bias and preamplifier power for NaI and HRG detectors. The MCA operates from internal batteries or an ac charger. The front panel shown in Fig. 2 has a 3.5- by 5.5-cm CRT display, CRT vertical scale knob, 4 by 4 keypad, 2-line by 16-character ASCII LCD, magnetic recording wafer drive RS-232 serial interface connector, and the connector for detectors and

Fig. 2. Portable MCA.

preamplifiers. Only a 4 by 4 keypad is implemented due to initial design constraints.

The microprocessor-based design of both instruments is an integration of hardware and software engineering; interfaces between the hardware modules are accomplished through the software. The ION-1 functions are listed in Table I. Detailed descriptions are given

TABLE I
ION-1 COMMAND TABLE

With all commands except ACQ, the SHFT key must be pushed first.

<u>ACQ</u> :	Initiate data accumulation.
<u>DATE</u> :	Set date and time. Default values are 0000 hours, day 1 of month 1 of year 0.
<u>CTIM</u> :	Set neutron accumulation time. Default value is 200 s.
<u>LID</u> :	Set the lower-level discriminator of the neutron channel. Default value is 50.
<u>MODE</u> :	Select data accumulation mode, neutrons only, γ only, or both. Default value is both.
<u>BGND</u> :	Take background in selected mode.
<u>GAIN</u> :	Select manual or automatic gain adjustment. Default value is automatic adjustment.
<u>VOL1</u> :	Informational display showing power supply status.

in Ref. 2. The functions require 12K bytes of ROM and ~1.5K bytes of PAM; 4K bytes of ROM and ~1.5K bytes of RAM are available for expansion. The MCA performs basic analyzer functions listed in Table II in 17.5K bytes of ROM and 6K bytes of RAM. The automated uranium-235 enrichment measurement uses 3K bytes of ROM, and 35.5K bytes of RAM or ROM are available for future automated measurements.

All calculations in the instruments are done internally using a software mathematics package with 24-bit precision and a range of $10^{\pm 38}$. It performs addition, subtraction, multiplication, division, and calculates the square root. The basic operating system software of both instruments is the same.

The Inspector-Instrument Interface

The purpose of the interface is to allow the instrument and user to conveniently carry on a dialog. The instrument provides options, instructions, and information on the LCD; user responses are entered on the keypad.

The keypad is divided into an information entry and a control section. The keypad of ION-1 is reproduced in Fig. 3. The lower case of the entry keys contains the most frequently used entries such as digits, INC, DEC, and scroll lines $\uparrow$ and $\downarrow$. The upper case is used to enter commands. The upper case is enabled by pressing the SHFT key similar to the way second functions are selected on a hand-held calculator. The cross-hatch in the figure emphasizes that the upper case and the SHFT key are accented in yellow.

TABLE II

MCA COMMAND TABLE

With all commands except STRT, the SHFT key must be pushed first.

STRT	Acquire data for time specified by livetime.
ROI	Assign or change regions of interest. A maximum of 99 regions can be assigned. Regions may overlap.
CALC	Total or background-subtracted areas of assigned regions and their associated uncertainties are calculated and displayed.
STAT	Examine or change instrument parameters. The parameters included in the STAT function are pre-set 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-level discriminators, memory subgroup, and battery and digital supply voltages.
TAPE	Read spectra from the tape, write spectra to the tape, position the tape, erase 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 cassette along with an inspector identifier. The identifier and the date and time serve to uniquely identify the spectrum.
DUMP	Write the current spectrum and instrument setting to the serial port.
ENRH	Perform ^{235}U enrichment measurement. The calibration constants used in the calculation are obtained either by entering previously determined constants from the keypad or prompting the user through a calibration procedure using two known samples. Once the calibration constants are known, the user is prompted through the steps to determine the enrichment of an unknown. Once the calibration constants are entered, each measurement of an unknown is accomplished by a single button push. The results include the enrichment estimate with its calculated uncertainty.

In addition, the number of counts in any channel is available when the MCA is waiting for a new command to be entered.

In addition to SHFT, there are three other keys on the control pad. The ENTR key registers an entered number. That is, the instrument displays the number as it is typed, but it does not use the number until ENTR is used. The END key signals the instrument that

Fig. 3. ION-1 keypad labels.

the present command is no longer needed. The instrument ends the command, displays a standard prompt requesting another command, then waits for the next command. The END key can also be pushed to abort a command at any time. For example, if during a 15-min acquire, the user needs to make a detector placement change, he pushes END, repositions the detector, and then pushes ACQ. The final key on the control pad is NEXT, which is pushed when the user has completed an instruction and is ready to proceed with the command. For example, when the user is instructed to CONNECT THE CABLE, he connects the cable and then pushes NEXT to proceed.

A blinking cursor indicates 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. 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 NX.

If an invalid key is pushed, the LCD contains INVALID ENTRY PUSH VALID KEY 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 to set the upper- and lower-level discriminators of the MCA is described. The LCD appears as:

Field 1	Range
LLD = <u>15</u>	(0-255)
ULD = 255	(0-255):
Field 2	

The two fields, labeled for clarity, contain the present values. The range of the value is presented after each field. A blinking cursor, denoted by the underscore, appears in the left-most digit of field 1. The LLD can be changed to 20 in one of two ways. Type 20. The digits are displayed as they are entered and the cursor moves one position to the right. If the field is full the cursor will not move to the right. Push ENTR and the cursor moves to the left position of the next field. The other way is to 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 continuously increment or decrement at an accelerating rate.) The cursor will return to field 1. To change the upper-level discriminator (ULD) to 245, push ENTR to get the cursor to move to field 2. Make the change to 245 and press ENTR. When the display is correct, move on to the next options using the scroll arrows.

The display shown above is a "window" of a large display "page" of the MCA STAT command. The total page is shown in Table III. The information that actually

shows through the window is controlled with the scroll arrows that move the window up and down along the display page.

TABLE III

MCA STATUS PAGE

```

CT TIME= 100 S
E TIME =      S  +
RATE=      C/S  +
DEAD TIME=  %    +
DETECTOR=1
NAI=1 GER=0      +
INPUT POLARITY=0 +
POS=1 NEG=0      +
GAIN=8
GAINS 2,4,8,16  +
SET HV= 0
HV (0-4095)     +
LLD=10 (0-255)  +
ULD=255 (0-255) +
MGRP=1 OF 1     +

BATT=15.00
+5= 5.00        +
+12= 12.00
-12=-12.00      +

```

An example of the decision-making dialogue is the MODE command of ION-1. This command allows the user to specify which type(s) of data are to be collected. The possible choices are presented:

```

GAMMAS=0 BOTH=2
NEUTRONS=1 DO=2

```

A blinking cursor, denoted by the underscore, indicates the unit is awaiting a response. The present mode is indicated by the 2 in the input field. A 0 or 1 may be entered. When the desired choice is displayed, push ENTR.

The LCD and keypad are the basic physical elements of the interface, but certain applications may require additional devices. For example, CRT display and controls and a magnetic tape storage unit were added for the MCA interface. The CRT is a self-scanning display with 256 vertical by 1024 horizontal resolution. It has a single cursor controlled by a software register that is changed using the integer entry routine. Vertical scale is determined by a vertical scale knob. (While we strive for standardization in our manner of input, changing the CRT vertical scale through the keypad was deemed too inconvenient as opposed to using rotary knob.) The vertical scale knob position is read and the CRT display memory is updated continuously in a loop. The magnetic tape provides a means to log the spectral data; approximately 18 spectral records can be stored on a 50-ft tape. Each record includes the instrument parameters for the measurement along with the spectral data. It takes 14.5 s to read or write a single record. Further details are found in Ref. 3. Measurement logging using the tape will be enhanced to fill the needs of specific users.

Automated Measurements

The first automated measurement implementer for the MCA is a uranium-235 enrichment measurement.⁴ The user must remember only to push the ENRH key to start the instrument stepping through the measurement procedure. The user is given the option of entering or measuring the necessary calibration constants (A and B) and is prompted through the entry or calibration

measurement procedures, and then through the unknown measurement procedures. All calculations are performed by the instrument and the results along with uncertainties are reported with 7-digit precision.

The following example demonstrates an enrichment measurement where the calibration constants are entered. Push SHFT, ENRH to begin the measurement. The message

```
MEAS=0, ENTR AB=1
DETERM AB=2, DO=0
```

on the LCD presents the measurement options:

ENTR AB --to enter values for constants A and B,

DETERM AB--to determine these constants by measuring standards, or

MEAS --to retain constants that were established in a previous measurement and proceed to measure an unknown.

The measure option is defaulted and the blinking cursor indicates that a user response is necessary. To choose the enter constants option, type 1, then ENTR. The prompt for defining regions of interest appears next:

```
SET WINDOWS=0
PRESET=1 DO=1
```

One can select option 0 to manually set the windows. The resident ROI command is invoked to accomplish this. If option 1 is selected, the windows and gain are preset to predefined values without further user interaction. To register this choice, press ENTR. After the windows and gain are set, the LCD contains:

```
A= 4.499E-02
B=-3.956E-02 +
```

where A and B are the previously established values (they are set to 0 at power up). Use the digit keys and ENTR to enter the desired values. The integer, fraction, and exponent part of the number are treated as separate fields for number entry. When the correct values are entered, push SHFT, + to continue to the next display which shows the count time:

```
CT TIME = 100 S +
```

Make any needed changes and continue to the next step by pushing SHFT, +. The display directs the user to:

```
PREPARE UNKNOWN
PUSH STRT
```

When the sample is properly positioned, push STRT; the memory is erased and data acquisition begins. During acquisition, an approximate enrichment is calculated, and the display, which contains the enrichment, time remaining, and count rate, is continuously updated. When count time is complete, the following summary page is available to the user:

```
W1= 215 TO 313
W2= 323 TO 421 +
E TIME= 100S
GAIN= 8
Z1= 96935
±311.4
Z2= 37969
±194.9
A= 4.499E-02
B=-3.956E-02
E= 3.02±.0101
NEXT RDY?, STRT +
```

The LCD window is placed as shown by the dashes. To view the other information one must use the + or - keys. To make another measurement, push STRT. As with any of the functions, push STOP to end the function. It should be emphasized, the user need only remember to invoke the ENRH command to gain the assistance of the instrument in making the enrichment measurement. After all parameters are set, the enrichment measurement of an unknown is made by simply pushing STRT.

Anticipated Additions

In the ongoing development of these instruments, we found that additional capabilities may be desirable.

Alphanumeric input is needed to enter facility and sample identifiers. Possibly the INC and DEC keys will be used for this purpose. When an alphanumeric field is active, pushing the INC key will cause the entry character to scroll from 0-9, then A-Z. When the proper character is displayed, press ENTR to register the character and move the cursor to the next position.

Consideration must be given to entering floating point numbers. Currently, a floating point number is treated as having two fields, one before and one after the decimal point. A change-sign key may be necessary, and a decimal point and enter exponent may be desirable.

Acknowledgments

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