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The IAEA Neutron Coincidence Counting (INCC) and the DEMING Least-Squares Fitting Programs†

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Abstract

Two computer programs are described: (1) the INCC (IAEA or International Neutron Coincidence Counting) program and (2) the DEMING curve-fitting program. The INCC program is an IAEA version of the Los Alamos NCC (Neutron Coincidence Counting) code. The DEMING program is an upgrade of earlier Windows® and DOS codes with the same name. The versions described are INCC 3.00 and DEMING 1.11. The INCC and DEMING codes provide inspectors with the software support needed to perform calibration and verification measurements with all of the neutron coincidence counting systems used in IAEA inspections for the nondestructive assay of plutonium and uranium.

1. Introduction

1.1 Purpose

The INCC (IAEA or International Neutron Coincidence Counting) program is a general purpose code intended for use with nuclear material nondestructive assay (NDA) verification systems using thermal neutron coincidence counters. Although the INCC code was written for the IAEA, it is available for use by others; it is then called the International Neutron Coincidence Counting program and does not contain the IAEA logo. The DEMING program is a least-squares fitting code written for the development of neutron coincidence counting calibration curves. The DEMING program can be used independently of INCC or can be called directly from INCC. INCC and DEMING are normally used together to collect calibration data, determine calibration curves, and perform assay and verification measurements.

† The revisions of the NCC and DEMING codes to produce INCC version 3.00 and DEMING version 1.11 were supported by the US Program for Technical Assistance to IAEA Safeguards (POTAS).

1.2 Overview

INCC covers the full range of thermal neutron coincidence and multiplicity counting applications. It performs passive assays for plutonium items, active assays for uranium items, and active/passive assays for mixed uranium/plutonium items.

Passive assays of plutonium can be performed with several techniques, including the use of (1) conventional calibration curves (coincidence rate vs. effective ^{240}Pu mass) for pure or slightly impure materials with similar densities and geometries, (2) known-alpha multiplication correction for pure materials with various densities and geometries, (3) known-multiplication alpha correction for highly impure materials with similar densities and geometries, (4) multiplicity analysis for impure materials with various densities and geometries, and (5) add-a-source analysis for drum-sized items with various matrix materials.

Active assays of uranium are usually performed with calibration curves (coincidence rate vs. ^{235}U mass). An important special category is the active assay of light-water-reactor, fresh-fuel assemblies with the uranium neutron coincidence collar (UNCL); in addition to the calibration curves, these assays require sets of calibration parameters to account for poison rods, enrichment effects, etc. Active multiplicity analysis can be performed to verify an item's neutron multiplication, but not the ^{235}U mass.

Active/passive assays are performed with calibration curves of net coincidence rate (active minus passive) vs. ^{235}U mass. Different calibration curves are needed for different uranium/plutonium ratios.

In addition, analysis methods are included for special situations such as add-a-source analysis for drum assay systems and glove box analysis for holdup measurements.

All of the neutron coincidence counter applications used by the IAEA are covered by the INCC code. The IAEA counter types include the HLNC, AWCC, UNCL, PSMC, PCAS, UFBC, PWCC, PNCL, PLBC, MAGB, LNMC, HBAS, DRNC, CNCM, and BCNC. Implementation of INCC in the IAEA is just beginning. Potentially, the code could be used about 200 times a year at approximately 30 facilities using 50 neutron counters (1996 estimates).

The INCC code supports all of the coincidence electronics packages commonly used by the IAEA and in the US: (1) the Canberra JSR-11, JSR-12, JSR-14, and model 2150, (2) the Aquila PSR-B, and (3) the Los Alamos MSR4 (the multiplicity prototype for the 2150, JSR-14, and PSR-B).

The DEMING program can be used for general purpose curve fitting tasks, but its main purpose is to provide a convenient tool for the development of NDA calibration curves. A special feature of DEMING is the capability of simultaneously analyzing errors on both variables (such as effective ^{240}Pu mass and coincidence rate) using a technique developed by Deming [1].

1.3 History

The INCC code is a modification and extension of the Los Alamos NCC code [2], which has been under development for many years — first as a DOS code for industry-standard personal computers and later as a Windows® code. Three major changes that were made to NCC were 1) redesigning the user interface to largely comply with the IAEA Instrumentation Standard User Interface Model, 2) adding the Uranium Neutron Coincidence Collar (UNCL) to the supported detector types, and 3) adding input/output files according to IAEA file specifications. The INCC code uses essentially the same algorithms as the IAEA's HLNC neutron coincidence counting code [3] to the extent that their operations overlap. The HLNC code was developed in 1988 as a joint project between the IAEA (code structure, user interface, and database) and Los Alamos (algorithms and analysis modules); it remains in active use.

The DEMING code began as a stand-alone DOS program [4] for least-squares fitting of calibration data. A Windows® version of DEMING was written in 1994 to improve the user interface and to provide a mechanism for automated data transfer between the NCC and DEMING codes. This version of DEMING was very convenient, but lacked many of the features of the original DOS version. In 1997 DEMING was upgraded to its present form, which includes most of the features of the DOS code, runs under Windows®, and has an added provision for plotting two calibration curves on the same graph.

1.4 Software development

Both INCC and DEMING are written in C and C++ and use a Los Alamos graphical user interface library (GUI LIB). The INCC code also uses the Raima Database Manager® database library. The INCC program has 80,000 lines of code, excluding the libraries, and has a 3.4 MB executable file. The DEMING program has 10,500 lines of code, excluding the libraries, and has a 1.3 MB executable file. This paper refers to version 3.00 of INCC and version 1.11 of DEMING.

1.5 Hardware and software requirements

The INCC and DEMING programs will run on any modern, industry-standard personal computer. The minimum requirements are a 33 MHz 486 processor, 8 MB RAM, 100 MB fixed drive, 1.44 MB floppy drive, a serial port, and a Microsoft Windows® 3.1, 95, or NT operating system.

2. INCC

The following overview summarizes many of the features of INCC and is organized by items in the main menu of INCC. Some of the submenu items appear only in maintenance mode, which is described in section 2.2.

2.1 File

Submenu:

- Save As/Export
  - PSA/Logsheet File
  - Performance Monitoring File
  - Transfer
  - Initial Data (maintenance mode only)
- Get External Data
  - Stratum Authority File
  - Item Relevant Data File
  - Transfer
  - Initial Data (maintenance mode only)
- Back Up All Data
- Restore All Data
- Printer Setup
- Exit INCC

Verification results are exported in the 'PSA/Logsheet File' and normalization (detector stability test) results are exported in the 'Performance Monitoring File'; these are output-only text files in comma-separated-variable (CSV) format. Measurement data files (binary) can be saved and restored to the same or different computer using 'Transfer'. Detector and calibration data files (binary) can be saved and restored to the same or different computer using 'Initial Data'. Item (sample) data can be entered using the 'Item Relevant Data File' and stratum acceptance limits can be entered using the 'Stratum Authority File'; these are input-only text files in CSV format.

The entire INCC database can be saved ('Back Up All Data') and restored ('Restore All Data') to any drive or directory; this is very convenient for transferring a measurement campaign from one computer to another or for keeping different databases for different tasks.

Measurement results are also stored in output-only text files in the subdirectory C:\INCC_300\DATA. A results file is produced automatically at the end of each measurement.

2.2 View

'View' is used to switch between the normal and maintenance modes of INCC. The transition is not password protected. Maintenance mode provides access to calibration parameters, test limits, and other parameters not needed during routine verification measurements.

2.3 Setup

Submenu:

Facility/Inspection
Measurement Parameters
Isotopics
Composite Isotopics
Item Data Entry
Collar Item Data Entry

'Setup' is the starting point for routine use. Under 'Setup | Facility/Inspection' the user selects the facility, material balance area, detector, etc. to be used for measurements, data review, etc. Under 'Setup | Measurement Parameters' the user selects the type of shift-register electronics, selects the serial port, and enters detector parameters such as gate length, high-voltage, efficiency, etc.

Isotopic data can be entered under 'Isotopics' or 'Composite Isotopics'. The 'Composite Isotopics' option is for combining several components (different masses and isotopic compositions) into a combined mass and isotopic composition at a specified date. The isotopic data are the plutonium isotopic values, the ^{241}Am content, the plutonium and americium analysis dates, and the corresponding errors.

The user can enter isotopic and measurement-item data under 'Setup' or at the time of measurement under 'Acquire'. Under 'Setup' the user can enter measurement-item data for subsequent measurements during the current measurement. These data can also be read in from the item files under 'File | Get External Data | Item Relevant Data File'.

2.4 Maintain

The 'Maintain' option is not visible unless INCC is in the maintenance mode. This option has the most complex submenu structure in INCC (see Fig. 1). The 'Calibration' submenu option has its own submenu, which includes options to call DEMING, to select analysis methods, and to enter calibration parameters for each of the analysis methods.

Measurement data can be analyzed with one or more analysis methods. Under 'Maintain | Calibration | Analysis Methods' the user selects which methods to use. At the end of a measurement, a verification result is calculated for each method. For example, a plutonium verification measurement could be analyzed with the known-alpha multiplication correction method and the passive multiplicity method, so that two assay results are produced. When the user selects more than one analysis method, the user must also select the 'normal' method and can select a 'backup' method. The final verification results will have one result identified as the 'primary' result, which is determined by the user's priority and a statistical test.

To obtain a calibration curve by least-squares fitting to calibration data, the following procedure is followed. The user selects 'Maintain | Deming Curve Fitting', selects a material type, selects an analysis method, and selects the form of the calibration curve (e.g., polynomial). INCC then presents a list of calibration measurements that were made for this material type and analysis method. The user selects the calibration measurements to be used for the curve fit. INCC then starts DEMING and transfers the calibration data to DEMING. The user does the curve fitting and returns to INCC. The calibration parameters are transferred from DEMING to INCC and are installed in the appropriate calibration parameter file automatically.

A detector is added to or deleted from the INCC database under 'Maintain | Detector Add/Delete'. Likewise, facilities, material balance areas, strata, material types, etc. can be added or deleted.

It is usually unnecessary to use the 'Background Setup' or 'Normalization setup' options, because the background and normalization parameters are automatically saved and read by other operations in INCC. However, for special situations, these parameters can be edited.

The 'QC and Test Parameters' option is used to set the quality control and test limits for such things as the limit used in testing for outliers in a number of repeat measurement cycles, the limit for the maximum acceptable coincidence background rate, etc.

The stratum rejection limits determine whether the assay mass in a verification measurement is accepted or rejected. Each stratum has values for bias, random error, and systematic error, from which the rejection limits are calculated.

Random error calculations can be based on a theoretical model or on the sample standard deviation of a number of repeat measurement cycles. The choice is made under 'Maintain | Error Calculation Method'. The theoretical method is the default method and is accurate to 20% or better except for highly multiplying items.

Measurement results are saved for the length of time specified under 'Maintain | Archive'.

2.5 Acquire

Submenu:

Rates Only
Background
Initial Source (maintenance mode only)
Normalization
Precision (maintenance mode only)
Verification
Calibration Measurements (maintenance mode only)

A 'Rates Only' measurement is a general purpose measurement used to get count rates only; nothing is done with the results. A 'Background' measurement can be passive or active; passive background is room background and active background is background from AmLi sources. An 'Initial Source' measurement is used to establish the reference count rate for future normalization measurements. Either ^{252}Cf or AmLi can be selected as the normalization source; normally ^{252}Cf is used with passive systems and AmLi is used with active systems. A normalization (or detector stability test) measurement is used to check the efficiency of the detector and to produce a correction factor (normalization constant), if needed; the normalization constant is then applied to future measurements, as appropriate. The normalization constant is almost always 1. A 'Precision' measurement tests the short-term stability of the system by comparing the observed scatter in a series of measurement cycles with that expected theoretically. 'Calibration' measurements are used to obtain the measurement data from NDA standards for the construction of calibration curves. A 'Holdup' measurement is a special measurement designed to measure glove-box holdup.

Each type of measurement has a dialog box into which the user enters data needed for the measurement; e.g., the dialog box for a verification measurement is shown in Fig 2. Measurements can be performed for a fixed count time (e.g., 10 cycles of 60 s each) or for a fixed precision (e.g., 60-s cycles until the precision of the coincidence rate is 0.5% or less).

Normally raw data are acquired from the shift-register coincidence electronics. However, raw data can also be obtained from previous measurement data stored in the database, entered manually, read from specially formatted disk files, or read from a shift-register-review disk file (a file made by a program that reviews shift-register data acquired from unattended systems). Regardless of the data source, INCC treats the raw data as though they came from the shift-register electronics.

2.6 Reanalyze

'Reanalyze' is used primarily to correct data-entry errors in verification and holdup measurements. When a measurement is selected for reanalysis, a dialog box appears and gives the user an opportunity to change values (such as declared mass, isotopic composition, and item type) that might have been entered incorrectly when the measurement was done. The raw data are reanalyzed with the new parameters and the result, optionally, replaces the original results file and thereby corrects the error.

2.7 Report

Under the 'Report' menu option any measurement in the database can be recalled at any time for review or printing. Also, the calibration curves can be plotted and printed with the calibration and verification data points for a specified material type and analysis method.

Verification and holdup summaries can be created as text files in CSV format for use with commercial spreadsheet software. The user can select which measurement results and which data elements are included in the summary file. These summary files provide a very convenient way to do custom processing of the measurement data and results.

2.8 Window

The 'Window' menu option can be used to arrange icons or to cascade or tile the windows that display the measurement results.

2.9 Help

The entire user manual is contained in the on-line help system. The user can select from the table of contents or search for specific words. Topics are cross-referenced for easy navigation. Context-sensitive help is available in the dialog boxes.

3. DEMING

The following overview summarizes many of the features of DEMING and is organized by items in the main menu of DEMING. A typical DEMING window is shown in Fig. 3. This example shows the results of fitting plutonium calibration data using the calibration curve technique and the known-alpha multiplication correction technique. On the right side of the window the coincidence rate is plotted vs. the effective ^{240}Pu mass. The coincidence rates, with and without multiplication correction, are plotted with their error bars; the masses do not have assigned errors, so only vertical error bars are shown. Also shown in the plot are the fitted curves (the calibration curves) and their error bands. On the left side of the window is the data table, which shows data for the known-alpha calibration. DEMING only handles one data set at a time, but results can be stored for overlay plotting, as shown in Fig. 3. The data table shows the X and Y values and errors on the Y values; errors can be added for the X values also. The data points selected in the 'Use' column are used for the least-squares fit. The type of fitting function is shown above the plot. The 'Fit' button above the function type initiates the fit. At the top left of the window a data table (display only) shows the fitted coefficients and errors. After a successful fit, the residuals can be plotted by clicking on the 'Plot Residuals' button above the function type.

3.1 File

Submenu:

New Data
Open Data

Save Data
Save Data As
Save Results
Save Results As
Print
Printer Setup
Exit

The X,Y data can be saved and restored ('Open Data'), and the fitting results (coefficients and errors) can be saved; these save and restore operations all use text files in CSV format. The data, results, and plot can be printed (one page for the plot and one page for everything else).

3.2 Edit

Submenu:

Delete Row
Insert Row

The 'Edit' menu option is used for editing the data table.

3.3 Options

Submenu:

Plot Setup
Error Setup
Interpolation

'Plot Setup' allows the user to select the X and Y ranges, set the X and Y labels, select X and Y errors, format the data-entry table, and select overlay plotting. 'Error Setup' gives the user the option to (1) plot error curves using Student's t, Scheffe, or Miller limits and to set the confidence limit for the error curves, (2) select the type of X and Y weighting (absolute, percent, square root, and equal weighting), and (3) select Y residuals or Studentized residuals and set the outlier test limit for the residuals table. 'Interpolation' allows the user to calculate X at Y or Y at X for an arbitrary point or for all data points.

3.4 Results

The results are displayed with high precision in a results window. The information is the same as that printed under 'File | Print'.

3.5 Sort

The data table can be sorted in order of increasing X values.

3.6 Help

The complete users manual is available on-line under 'Help'. The user can select from the table of contents or search for specific words. Context-specific help is available in the dialog boxes.

4. Conclusions

The INCC and DEMING programs have passed formal acceptance testing by the IAEA and have been used reliably under inspection, training, and R&D conditions. The executable codes will probably be commercially available in the near future. The DEMING code is not expected to be changed much in the near future, but the INCC code will probably undergo a series of upgrades, mostly to add new analysis methods, new data handling methods, and new coincidence electronics packages. Anticipated changes to INCC will have little effect on the menu structures or dialog boxes, so a user should have no difficulty adjusting to a new version. Version 3.10 is already well developed, but its formal testing has not yet started.

5. Acknowledgments

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The authors contributed to the INCC 3.00 and DEMING 1.11 versions as follows: (1) W. C. Harker, software design and programming, (2) M. S. Krick, INCC algorithms, (3) P. M. Rinard and P. De Ridder, DEMING algorithms and data analysis routines, (4) T. R. Wenz, INCC test plan, (5) P. Pham, INCC specifications, (6) P. De Ridder, DEMING specifications and testing, and (7) M. S. Krick, P. Pham, and W. Lewis, project management.

6. References

[1] W. E. Deming, *Statistical Adjustment of Data*, 1st edition (John Wiley & Sons, Inc., New York, 1948).

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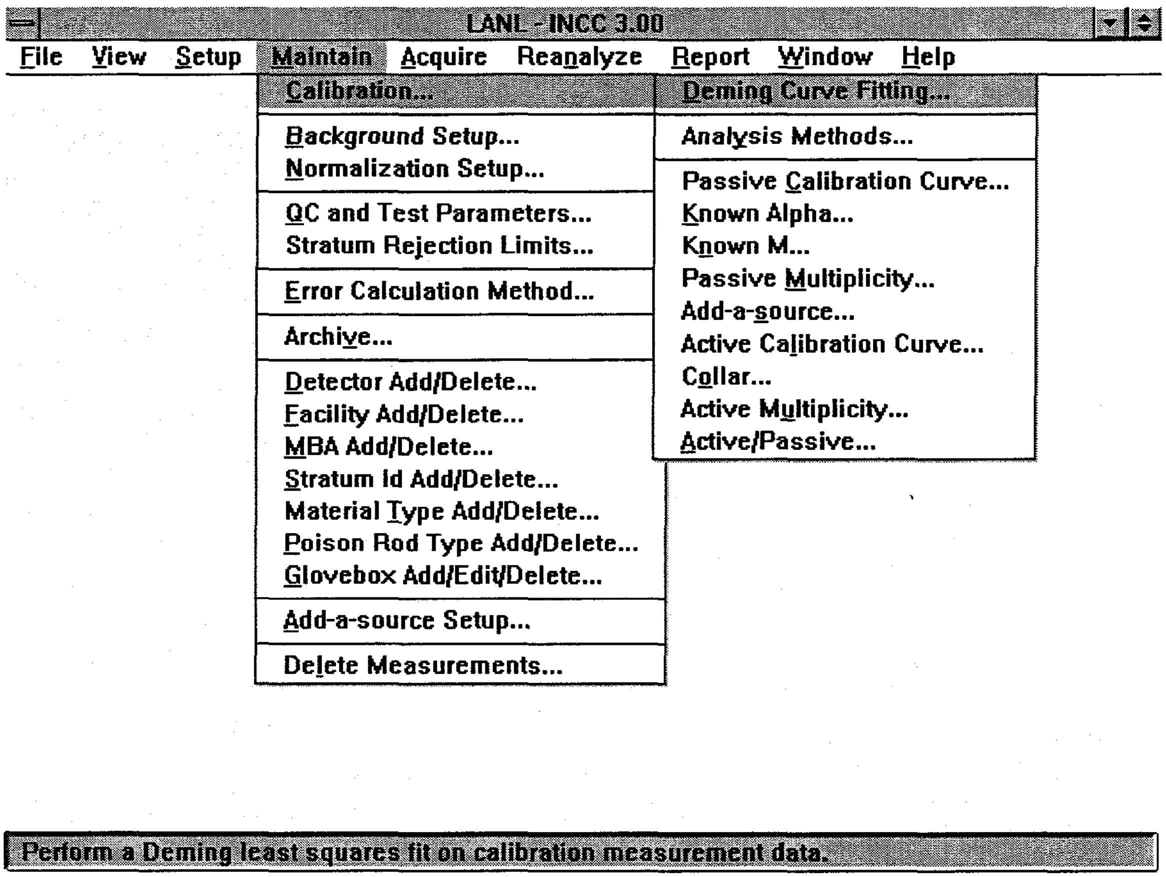
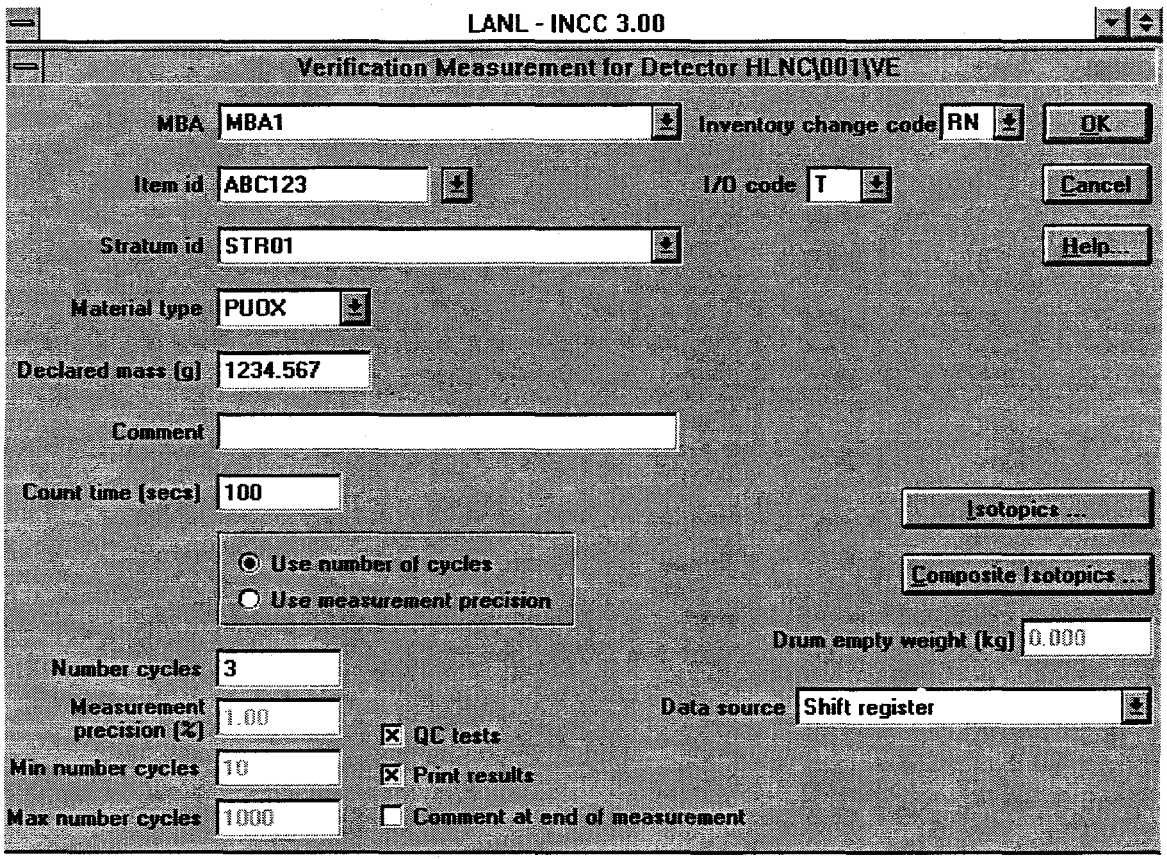
[3] M. S. Krick, "Algorithms and Software for Data Acquisition and Analysis Using Thermal Neutron Coincidence Counters Within the IAEA's IFSS/NCC System," Los Alamos National Laboratory report LA-UR-88-1301 (1988).

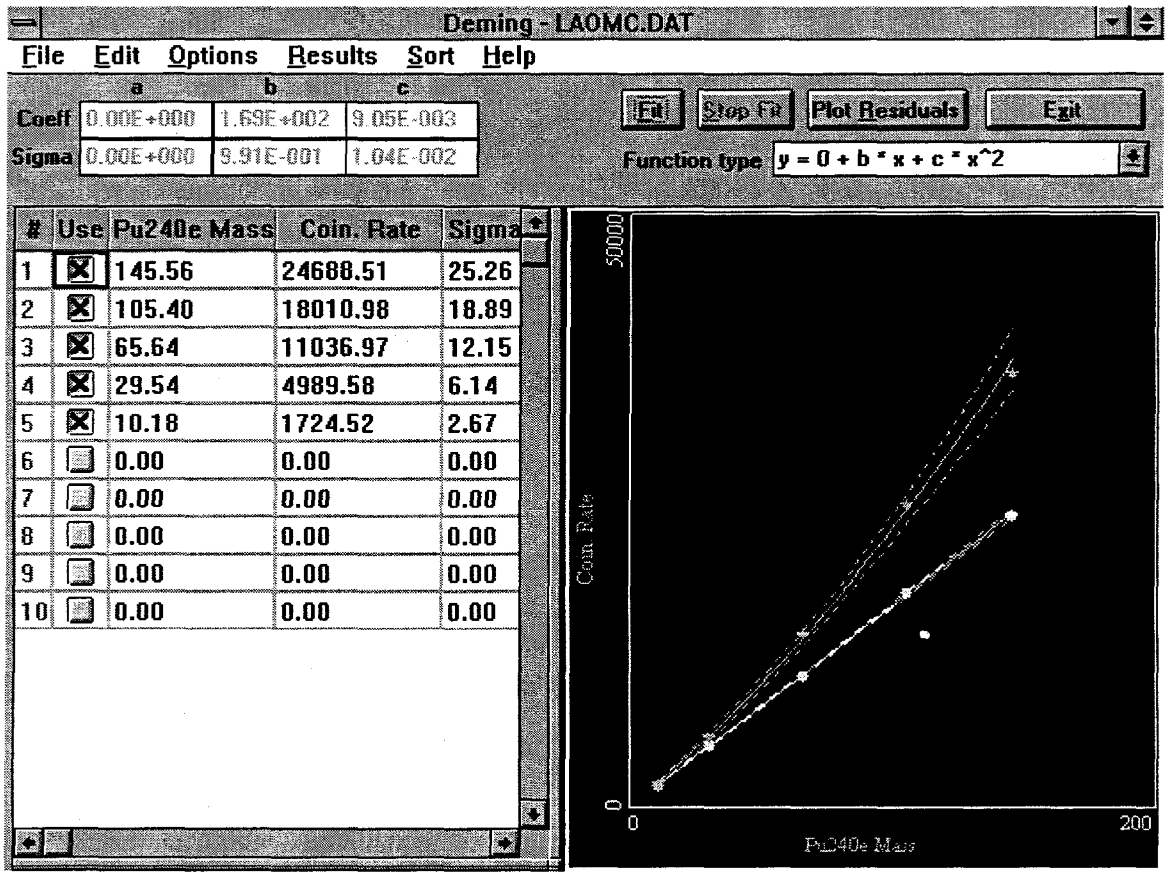
[4] P. M. Rinard and A. Goldman, "A Curve-Fitting Package for Personal Computers," Los Alamos National Laboratory report LA-11082-MS, Rev. 1 (March, 1988).

Figure captions

1. View of the INCC code main menu, the 'Maintain' submenu, and the 'Calibration' sub-submenu. The facility name active at the time of the screen capture was 'LANL', as shown in the title bar. The code is INCC version 3.00. The status bar at the bottom of the screen gives additional information about the menu option selected.
2. View of the INCC verification setup screen obtained by selecting 'Acquire | Verification'. Note that presently inactive items such as 'Measurement precision (%)' are "grayed out" and can't be changed.
3. View of the main screen of the DEMING code showing the data-entry table, the plot, the coefficients and errors, and several controls, such as 'Fit'. Results are shown in an overlay plot, where two data sets are presented on one graph; the two sets of data, the fitted curves, and the error curves are shown for plutonium oxide (passive calibration curve and known-alpha multiplication correction analysis methods), where the coincidence rate is plotted vs. the effective ^{240}Pu mass.


LANL - INCC 3.00
File View Setup Maintain Acquire Reanalyze Report Window Help
Calibration...
Background Setup...
Normalization Setup...
QC and Test Parameters...
Stratum Rejection Limits...
Error Calculation Method...
Archive...
Detector Add/Delete...
Facility Add/Delete...
MBA Add/Delete...
Stratum Id Add/Delete...
Material Type Add/Delete...
Poison Rod Type Add/Delete...
Glovebox Add/Edit/Delete...
Add-a-source Setup...
Delete Measurements...
Deming Curve Fitting...
Analysis Methods...
Passive Calibration Curve...
Known Alpha...
Known M...
Passive Multiplicity...
Add-a-source...
Active Calibration Curve...
Collar...
Active Multiplicity...
Active/Passive...
Perform a Deming least squares fit on calibration measurement data.


LANL - INCC 3.00
Verification Measurement for Detector HLNC\001\VE
MBA
MBA1
Inventory change code
RN
OK
Item id
ABC123
I/O code
T
Cancel
Stratum id
STR01
Help...
Material type
PUOX
Declared mass (g)
1234.567
Comment
Count time (secs)
100
Isotopics ...
Use number of cycles
Use measurement precision
Composite Isotopics ...
Drum empty weight (kg)
0.000
Number cycles
3
Data source
Shift register
Measurement precision (%)
1.00
QC tests
Min number cycles
10
Print results
Max number cycles
1000
Comment at end of measurement



#	Use	Pu240e Mass	Coin. Rate	Sigma
1	X	145.56	24688.51	25.26
2	X	105.40	18010.98	18.89
3	X	65.64	11036.97	12.15
4	X	29.54	4989.58	6.14
5	X	10.18	1724.52	2.67
6		0.00	0.00	0.00
7		0.00	0.00	0.00
8		0.00	0.00	0.00
9		0.00	0.00	0.00
10		0.00	0.00	0.00