



Nuclear Nonproliferation Division
Safeguards Science and Technology Group, N-1
Safeguards and Security Systems Group, N-4

INCC Software Users Manual

March 29, 2009

Original Authors:

Merlyn Krick, PhD., B. Harker

Maintaining Authors:

William Geist, PhD., J. Longo

Software Version:

This document applies to version 5.1.2.* of the INCC software.

INCC is designated as Los Alamos Computer Code 98-08 (LA-CC-10-092).

Sponsorship:

This work was supported, in part, by the United States Member State Support Program to IAEA Safeguards; the U.S. Department of Energy, Office of Nonproliferation and National Security, International Safeguards Division; and the U.S. Department of Energy, Office of Safeguards and Security.

Authorship and Disclaimer:

Copyright © Los Alamos National Security, LLC, (LANS), 2010.

The INCC software and accompanying documentation is maintained by the Safeguards Science and Technology Group (N-1) and the Safeguards and Security Systems Group (N-4).

The INCC software and accompanying documentation is produced under Contract No. DE-AC52-06NA25396 with the U.S. Department of Energy (DOE). LANS has certain rights in the software and documentation pursuant to the contract, and the software and documentation should not be copied or distributed outside your organization. All rights in the software and documentation are reserved by the DOE and LANS. Neither the U.S. Government nor LANS makes any warranty, express or implied, or assumes any liability or responsibility for the use of this software and documentation.

Contents

INTRODUCTION	10
Overview	10
This Document's Conventions	11
Windows Conventions	12
Units	12
Date format	13
GETTING STARTED	14
System Requirements	14
Installation Procedure	14
Integrated Review Installation Configuration	15
PROCEDURES	16
System Setup	16
Inspector Verification Measurement Procedure	17
Background Measurements	17
Initial Source Measurements	18
Normalization Measurements	19
Precision Measurements	19
Verification Measurements	20
Calibration Measurements	21
Calibration Procedure	22
Holdup Measurements Procedure	23

Import Operator Declarations from Operator Review and Measurements from Radiation Review	24
Display measurement corresponding to a peak in Radiation Review	28
Operations Reference	29
Startup	29
Inspection Main Menu	29
Maintenance Main Menu	30
File Submenu	31
Save As/Export	31
Get External Data	32
Backup All Data	33
Restore All Data	33
Batch Analysis	33
Database	34
Printer Setup	35
Exit INCC	35
View Submenu	35
Setup Submenu	35
Facility/Inspection	35
Measurement Parameters	36
Isotopics	37
Composite Isotopics	39
Item Data Entry	39
Collar Item Data Entry	40
Maintain Submenu	40
Calibration	41
Deming Curve Fitting	41
Analysis Methods	41
Passive Calibration Curve	42
Known Alpha	43
Known M	45
Passive Multiplicity	46
Add-a-source	47
Curium Ratio	48
Truncated Multiplicity	49
Active Calibration Curve	49
Collar	50
Active Multiplicity	52

Active/Passive	52
Background Setup	53
Normalization Setup	53
Unattended Measurements Setup	55
QC and Test Parameters	56
Stratum Rejection Limits	58
Error Calculation Method	58
Sweep	59
Archive	60
Detector Add/Delete	60
Facility Add/Delete	60
MBA Add/Delete	61
Stratum Id Add/Delete	61
Material Type Add/Delete	61
Poison Rod Type Add/Delete	62
Glovebox Add/Edit/Delete	62
Add-a-source Setup	63
Delete Measurements	63
Some Settings	64
Certain Advanced Features	64
Add/Delete Password	64
Measure High Voltage Plateau	64
Select Pu240e Coefficients	65
Acquire Submenu	67
Rates Only Acquire	69
Background Acquire	69
Initial Source Acquire	69
Normalization Acquire	69
Precision Acquire	70
Verification Acquire	70
Calibration Measurements Acquire	72
Holdup Acquire	72
Reanalyze Submenu	73
Verification Reanalysis	73
Holdup Reanalysis	74
Report Submenu	74
All Measurements Report	74
Rates Only Report	75
Background Report	75
Initial Source Report	76
Normalization Report	77
Precision Report	77
Verification Report	78

Calibration Report	78
Holdup Report	79
Measurement Summary	79
Verification Summary	80
Holdup Summary	80
Plot Normalization History	81
Plot Calibration and Verification Results	81
Tools Submenu	81
Select Another Review Tool	81
Window Submenu	82
Arrange Icons	82
Cascade	82
Tile	82
Help Submenu	82
Topics	82
Procedures	83
App Info	83
About INCC	83
FILES	84
Input files	84
Stratum Authority File Format	84
Item Relevant Data File Format	85
Operator Declaration File Format	87
Operator Declaration File Format for Curium Ratio Measurements	88
Isotopics Data File Format	89
Composite Isotopics Data File Format	90
Test Data File Format	91
Holdup Test Data File Format	92
Radiation Review Measurement Data File Format	93
Batch Script File Format	93
Output files	96
File Naming Conventions	96
PSA Operator-Inspector Measurement Database and Logsheet File Format	97
Performance Monitoring File Format	99
Isotopics Data File Format	100
Composite Isotopics Data File Format	101
INCC ANALYSIS ALGORITHMS	102
Introduction	102

Raw Data	102
Quality Control (QC) Tests	102
High Voltage Test	103
Raw Data Checksum Tests	103
Measured Count Rates	104
Accidentals/Singles Test	105
Theoretical and Sample Standard Deviations	106
Calculated Accidental Coincidence Counts	107
Outlier Tests	107
Errors of Measured Singles and Doubles Rates	108
Count Rates Corrected for Deadtime	109
Theoretical Errors of Deadtime Corrected Singles and Doubles Rates	110
Theoretical Error of Deadtime Corrected Triples Rate	111
Background Subtraction	114
Normalization	114
Deadtime, Background, Normalization and QC Test Table	117
Rates Only Measurements	117
Background Measurement	117
Initial Source Measurement	118
Normalization Measurement	118
Precision measurement	120
Plutonium Isotopic Updating	121
Alpha	126
Effective ^{240}Pu Mass	126
Effective ^{239}Pu Mass	127

Calibration Measurements	127
Conventional Calibration Curve Assay	127
Conventional Multiplicity Assay	134
Weighted Point Model Multiplicity Assay	139
Multiplicity Assay with Unknown Efficiency	140
Dual Energy Passive Multiplicity Assay	141
Multiplicity Assay with Known Alpha	147
Known Alpha Assay	150
Known Multiplication Assay	152
Active Multiplicity Assay	154
Add-a-Source Assay	155
Truncated Multiplicity Assay	158
Plutonium Assay Mass	164
LWR Fuel Collar Assay	166
Table of Symbols	174
 DATABASE RECOVERY PROCEDURE	177
 Database corrupted	177
 TECHNICAL SUPPORT	177
 Physics technical support	177
 Software technical support, issue reporting and resolution	178
 APPENDIX	178
 Data Processing	178
Data processing - raw data	178
Data processing - checksum test	178
Data processing - accidentals/singles test	179
Data processing - outlier test	179

Data processing - deadtime corrected count rates and errors	179
Data processing - average rates	180
Data processing - background subtraction	180
Measurements	180
Rates Only	180
Background	180
Initial Source	181
Normalization	181
Precision	181
Verification measurements - general	181
Verification measurements - passive calibration curve	182
Verification measurements - known alpha	182
Verification measurements - known M	182
Verification measurements - passive multiplicity	183
Verification measurements - add-a-source	183
Verification measurements - curium ratio	184
Verification measurements - truncated multiplicity	184
Verification measurements - active calibration curve	184
Verification measurements - collar	185
Verification measurements - active multiplicity	185
Verification measurements - active/passive	185
Holdup measurements	185
Calibration	185
Command Line Flags	185
/IMPORT	186
/INITIALIZE	186
Command line examples	188
References	190

Introduction

Overview

INCC is a general purpose neutron coincidence counting program that runs on personal computers running any Microsoft Windows operating system. It is intended for nondestructive passive and active neutron verification applications. Passive neutron verification techniques include calibration curve, known alpha, known multiplication, add-a-source, multiplicity, curium ratio and truncated multiplicity. Active techniques include calibration curve, multiplicity, collar and active/passive. You can use all of these techniques with INCC. Active multiplicity presently determines the neutron multiplication of a uranium item, but does not determine the uranium mass.

You can verify items using multiple verification techniques at the same time by selecting multiple analysis methods. For example, you might verify plutonium items using the passive calibration curve and the known alpha techniques simultaneously. Collar verifications cannot be combined with other verification techniques. You can group verification measurements by inspection number.

You can use any of the common coincidence electronics packages: the Canberra JSR-11 and JSR-12, the Canberra JSR-14 in either PSR or JSR-12 mode, the Los Alamos MSR4 multiplicity module, the Canberra 2150 multiplicity module (a commercial version of the MSR4), the Los Alamos and Aquila portable shift register (PSR), the Los Alamos intelligent shift register (ISR), the Advanced Multiplicity Shift Register (AMSR) and the Los Alamos dual gated shift register (DGSR). To use the Canberra JSR-14, you must use the Canberra program to set the high voltage mode to “portable”.

All measurement results are stored in both database and text files. You can save and restore the entire database or measurement data, measurement (detector) parameters and calibration parameters for transfer between computers. You can import Stratum Authority and Item Relevant Data files from IFSS, SPAN and NMAX. You can export files for the Operator-Inspector Measurement Database and Logsheet and you can export Performance Monitoring files. You can review, create reports and print any measurement data and results at any time.

When the program is started you will be warned if the hard disk is more than 90 percent full. If you see this warning you need to free up some disk space. If the hard disk becomes 95 percent full, measurement data acquisition will be disabled in order to protect the database from becoming corrupted when the hard disk is completely full.

You can develop calibration curves with the INCC program. To do this, collect data from calibration standards and fit the data with the Deming least squares fitting program which can be called by the INCC program. The resulting calibration coefficients are automatically transferred to calibration files and you are ready for verification measurements. You can only use Deming for the passive and active calibration curve, known alpha, and add-a-source analysis methods.

You can plot calibration curves with the calibration and verification measurement data to produce graphical summaries of calibration and verification results.

You can write a summary of verification results or all measurement results, one measurement per line, in comma separated variable format for input to a spreadsheet program such as EXCEL.

Measurement control options are included for quality control tests. They include normalization and precision tests to check the detector efficiency and stability, and raw data tests and outlier tests to check for data consistency.

You can calculate the mass and display results for verification measurement data files imported from Radiation Review. You can also process and display results for background and normalization measurement data files imported from Radiation Review. These files are created from measurements made by Shift Register Collect or Multi-Instrument Collect (MIC) running in unattended mode. The results will remain in the database, and can be reviewed or reanalyzed at any time.

If the mass has previously been calculated using the import function, you can display the results for the verification or normalization measurement corresponding to a peak on a graph in Radiation Review by simply clicking on or near the peak and requesting INCC data display.

Clicking on *Tools / Select Another Review Tool* will provide the user with the ability to have Radiation Review display the peak corresponding to the most recently displayed INCC verification measurement.

This Document's Conventions

1. Italics are used to denote menu selections to be made by the user, for example, select *Measurement Parameters*.

2. A sequence of operations is indicated by using a vertical bar to separate the individual operations, for example, select *File | Exit INCC* means select the File menu and then the Exit option from that menu.
3. File names and file path names are specified with the Courier New font, for example, `c:\INCC\data`.
4. Character strings displayed on the screen are surrounded by double quotes, for example, you would see the message “System Error Cannot read from drive A.” if you attempted to do a save without a disk in drive A.
5. Square brackets are used to denote single keystrokes that cannot be represented by a single character, for example, [Enter].
6. Character strings that are to be typed in by the user are in boldface type, for example, **a:install[Enter]**.
7. Warnings for functions that may inadvertently cause a loss of data or parameters are in boldface type.
8. By convention, the INCC installation location will be referred to as `\INCC` in this document.

Windows Conventions

1. The underlined character in a menu item is called a hot key. Selection of a menu item or button can be accomplished by using the mouse to click where desired or by typing **[Alt] [hot key]** for main menu and button selections, and simply typing the **[hot key]** for all other menu selections.
2. Typing **[Enter]** from within a dialog box usually has the same effect as selecting the “OK” button, and will result in exiting the dialog box. Use **[Tab]** and **[Shift][Tab]** to move down and up respectively between dialog box fields. The mouse can be used to move to a non-contiguous field.
3. Selection of multiple lines, for example when selecting measurements to delete, follows the windows standard.

Using the mouse:

- a. Click on the first line you want to select.
- b. Press and hold down the **[Shift]** key while you click on the last line you want to select.
- c. To select lines out of sequence, press and hold down the **[Ctrl]** key while you click on each line you want to select.

Using the keyboard:

- a. Use the arrow keys to move to the first line you want to select.
- b. Press and hold down the **[Shift]** key while you select the remaining lines you want.

Units

Unless otherwise stated, time is in seconds, mass is in grams, rates are in counts per second, lengths are in centimeters and isotopic composition is in weight percent. To convert from parts per million (ppm) to weight percent, divide by 10,000.

Date format

The format in a date edit field will always be whatever you have chosen for your computer. You will get an error message that tells you the correct format if you try to enter an invalid date. You may use “Regional Settings” in the “Control Panel” group to change the date format. The date format for results will always be YY.MM.DD, regardless of what format you have chosen for your computer. The years 52 through 99 represent 1952 through 1999. The years 00 through 51 represent 2000 through 2051. All arithmetic involving years, such as the decay correction of isotopes, is done in Julian time so that the two digit year is not a problem.

Getting started

System Requirements

This software requires:

- Pentium II or better CPU
- 64 MB RAM minimum
- 500 MB available space on the fixed disk
- USB port, 1.44 MB floppy disk, or CD-ROM reader
- One serial port. When using add-a-source, two serial ports are required
- Mouse or other pointing device
- VGA color monitor or better with at least 1024x768 pixels
- Microsoft Windows Operating Systems: Windows 2000, Windows XP Home, or Professional are preferred and provide the best performance. The author believes INCC functions correctly (when properly configured) on all Windows 32 and 64-bit operating systems, including Windows Vista, Windows Server 200 n , and the upcoming Windows 7, but no unassailable proof yet exists.

Installation Procedure

This installation procedure may overwrite your existing version of INCC and its database. Be sure to make a backup of your current version and all the subdirectories before you proceed. A backup can be made using your current INCC installation. See the section titled “Backup All Data” on page 32. All data in your current database may be overwritten. When installing INCC 5.0.5.5 (or newer) over an existing INCC installation location, the installation procedure will attempt to make a copy of your existing INCC database.

One way to create a backup (in the new subdirectory INCC_bac) is to type **xcopy c:\INCC*.* c:\INCC_bac /s /e** from a DOS prompt.

To perform the installation:

1. Click on Start. Then click on Accessories. Then click “Windows Explorer”.
2. Using the Windows Explorer, find the file named *incc511DoE.exe* (or *incc511IAEA.exe*, *incc511Eur.exe*, where 511 corresponds to the major release version 5.1.1, or the equivalent) on your delivery media. The software was provided to you on a CD, or on some other type of removal media.
3. Double-click on the named file to run the INCC installation,, and follow the instructions. The installation software will guide you through the required steps.
4. The default installation location is C:\incc. But you may choose a location other than the default to install the software.
5. When the installation has completed, click on Start, then click on Programs, then click on the INCC file folder and then click on the INCC 5 icon. The program should start up, and display the main menu in Inspection mode.

Integrated Review Installation Configuration

INCC normally uses contextual locations for runtime assets. These asset locations and names may be modified using entries in the InccCfg.ini file. When installed as a supporting tool within a LANL Integrated Review Software installation, INCC may optionally use the asset location features of the Facility Manager application. The Facility Manager maintains locations of data and configuration paths for the use of tools such as INCC. To use the Facility Manager features, create or edit the file InccCfg.ini; said file must reside in the same folder as the INCC executable, incc.exe. Disable the existing configuration entries by prefixing the entries with using # characters, and add the two lines below. The next time INCC runs, INCC resource asset locations will be determined using the current facility defined for the Facility Manager.

```
[DEFAULT_FACILITY_INFO]
bUSEIRS=y
```

Procedures

System Setup

1. Start the INCC program, select *View* and click on *Maintain* to get into the Maintenance Menu.
2. Select *Maintain / Material Type Add/Delete*, and prepare a list of material types to match your items. You can change this list at any time.
3. Select *Maintain / Calibration / Analysis Methods*, and check the analysis methods you want to use for each material type. You can change the selections at any later time.
4. Select *Maintain / Background Setup*, and set all background rates to zero.
5. Select *Maintain / Normalization Setup*, select the type of normalization and set the normalization constant to one and the error to zero. Enter the reference ^{252}Cf doubles rate or the reference AmLi singles rate and its measurement date. Check the box if you are using an add-a-source ^{252}Cf source as the reference source, and enter the measurement position. If you do not know these values yet, enter arbitrary values temporarily. You cannot do a normalization test until these values are known and entered here.
6. Select *Setup / Measurement Parameters*.
 - a. Select the type of shift register electronics used by your system and the serial port to which the shift register is connected.
 - b. Enter the predelay, gate length, and high voltage. Some of these may be manual settings (outside the program), depending on the type of shift register electronics used.
 - c. Enter the detector die-away time and the deadtime coefficients A and B.
 - d. If any of your planned measurements involve multiplicity analysis, enter the efficiency, multiplicity deadtime, and the doubles and triples gate fractions.
7. Select *Maintain / QC and Test Parameters*. Set the entries to their default values: (from top to bottom) 1000, 0.1, 4, 3, 100, 10, box checked, 3, 1, 1, 99 and 1.
8. Select *Maintain / Archive*, and make sure that your database and data sets will be saved as long as you need them.

9. If you are using an add-a-source system, select *Maintain / Add-a-source Setup*, and enter the add-a-source parameters for either the CompuMotor or PLC.
10. You will need a set of calibration parameters for each analysis method for each material type that you will verify. If you already have these values, select *Maintain / Calibration* and select an analysis method and enter your parameters for each material type. Repeat for all other analysis methods you will use. If you do not have these values yet, you can not verify until you get the calibration parameters.

Inspector Verification Measurement Procedure

1. Turn on the computer, start INCC and select *View / Maintain* to get into maintenance mode.
2. Go to *Setup / Facility Inspection* and enter information as appropriate.
3. Go to *Setup / Isotopics* and enter all the isotopics you will need.
4. Go to *Setup / Item Data Entry* and enter the information for all the items you will measure.
5. Go to *Acquire / Background* and enter information as required and do the background measurement. Print a background report.
6. Go to *Acquire / Normalization* and enter information as required and do the normalization measurement. Print a normalization report.
7. Go to *Acquire / Verification* and follow the Online Help under Procedures - Verification measurements.
8. After each measurement, print a measurement report for that measurement.
9. When all measurements are finished go to *Report / Verification Summary* and print a summary report by instrument and by stratum. You can also back up the summary data at the same time.
10. Go to *File / Backup All Data* and backup all data (the entire database) to a floppy disk.

Background Measurements

1. Select *Acquire / Background*.
2. Enter any comment you want to make.
3. Enter the count time per cycle in seconds and the number of cycles, or using measurement precision, enter the percent precision and the lower and upper limits on the number of cycles.
4. Select "Shift register" as the data source.
5. Select quality control (QC) tests on, that is, check the box.
6. Check the print box if you want printed results at the end of the measurement. You can always print results later under *Report / Background* if you do not want to print now. Check the ending

comment box if you want to be able to add a description of the measurement when it has completed.

7. Select the "OK" button and you will get a choice of passive or active well configurations. Select passive for normal room background measurements and active for background measurements in active systems when the AmLi sources are in the detector.
8. Select the "OK" button and the background measurement will start.
9. You can end the measurement early, if desired, by selecting "Quit measurement with results" or "Abort measurement" button. If you choose the quit option, the results will be calculated with the data from the cycles completed so far. If you choose the abort option all the data from the current measurement will be destroyed.
10. When the measurement is finished, you will get two results windows, one for the cycle data and one for the final results. The last twenty results windows will stay on the screen unless you close them manually.

Initial Source Measurements

1. Select *Acquire / Initial Source*. You must be in Maintenance mode.

Note: Initial source measurements are not made for UNCL detectors because they have been pre-calibrated and cross-referenced.

2. Select ^{252}Cf or AmLi as the source type.

Note: If you have an add-a-source system and want to use the add-a-source as the normalization source, click on the box "Use add-a-source Cf252 source for normalization test measurements" and enter the desired source position.

3. Enter the source id and a comment if desired.
4. Select "Shift register" as the data source.
5. Select "Use number of cycles" or "Use measurement precision" to determine the measurement time. If you select the number of cycles, enter the count time per cycle; if you select precision, enter the measurement precision and the minimum and maximum number of runs.
6. Check the "QC tests" box.
7. Check the "Print results" box if you want the results printed automatically at the end of the measurement. You can always print the results manually at the end of the measurement and you can always recall the results under *Report / Initial Source* if you want to print the results later.
8. Check "Comment at end of measurement" if you want to enter a comment after the measurement is completed.
9. Click OK to start the measurement.
10. You can end the measurement early, if desired, by selecting "Quit measurement with results" or "Abort measurement" button. If you choose the quit option, the results will be calculated with the

data from the cycles completed so far. If you choose the abort option, all the data from the current measurement will be destroyed.

11. When the measurement is finished, you will get two results windows, one for the cycle data and one for the final results. The last twenty results windows will stay on the screen unless you close them manually. The reference rate and date are transferred to the database. You can check this by looking at the rate and date under *Maintain / Normalization* setup.

Normalization Measurements

1. Select *Acquire / Normalization*.
2. Enter any comment you want to make.
3. Enter the count time per cycle in seconds and the number of cycles, or using measurement precision, enter the percent precision and the lower and upper limits on the number of cycles. If you are using the sample standard deviation error calculation method, the number of cycles should be at least ten.
4. Select "Shift register" as the data source.
5. Select quality control (QC) tests on, that is, check the box.
6. Check the print box if you want printed results at the end of the measurement. You can always print results later under *Report / Normalization* if you do not want to print now. Check the ending comment box if you want to be able to add a description of the measurement when it has completed.
7. Select the "OK" button and the normalization measurement will start.
8. You can end the measurement early, if desired, by selecting "Quit measurement with results" or "Abort measurement" button. If you choose the quit option, the results will be calculated with the data from the cycles completed so far. If you choose the abort option all the data from the current measurement will be destroyed.
9. When the measurement is finished, you will get two results windows, one for the cycle data and one for the final results. The last twenty results windows will stay on the screen unless you close them manually. The results for the normalization measurement are the ratio of expected to measured doubles rates for the reference ^{252}Cf source and the standard deviation of the ratio. If the ratio is more than three standard deviations from unity or more than 4% from unity, you will get a "Fail" message.

Precision Measurements

1. Select *Acquire / Precision*. You must be in Maintenance mode.
2. Enter any comment you want to make.

3. Enter the count time per cycle in seconds and the number of cycles, or using measurement precision, enter the percent precision and the lower and upper limits on the number of cycles.
4. Select "Shift register" as the data source.
5. Select quality control (QC) tests on, that is, check the box.
6. Check the print box if you want printed results at the end of the measurement. You can always print results later under *Report / Precision* if you do not want to print now. Check the ending comment box if you want to be able to add a description of the measurement when it has completed.
7. Select the "OK" button and the precision measurement will start.
8. You can end the measurement early, if desired, by selecting "Quit measurement with results" or "Abort measurement" button. If you choose the quit option, the results will be calculated with the data from the cycles completed so far. If you choose the abort option all the data from the current measurement will be destroyed.
9. When the measurement is finished, you will get two results windows, one for the cycle data and one for the final result. The last twenty results windows will stay on the screen unless you close them manually. The results for the precision test are the number of cycles, the chi-square lower and upper limits, the sample and theoretical variance and the chi-square value. If this value falls outside the lower or upper limits, you will get a "Fail" message.

Verification Measurements

1. Select *Acquire / Verification*.
2. Select an item id from the drop down list or type in a new item id and any comment you want to make.
3. Enter the count time per cycle in seconds and the number of cycles, or using measurement precision, enter the percent precision and the lower and upper limits on the number of cycles.
4. Select "Shift register" as the data source.
5. Select quality control (QC) tests on, that is, check the box.
6. Check the print box if you want printed results at the end of the measurement. You can always print results later under *Report / Verification* if you do not want to print now. Check the ending comment box if you want to be able to add a description of the measurement when it has completed.
7. Select the material type, material balance area, stratum id, inventory change code and I/O code for your verification item.
8. If you want to do a verification measurement, that is, if you want to compare the assay mass with a declared mass, enter the declared mass. Otherwise, enter zero for the declared mass.
9. Select the "Isotopics" button and enter the isotopic composition for Pu items. For uranium items, select "Default" for the isotopic composition.

10. Select the "OK" button and the verification measurement will start.
11. You can end the measurement early, if desired, by selecting "Quit measurement with results" or "Abort measurement" button. If you choose the quit option, the results will be calculated with the data from the cycles completed so far. If you choose the abort option all the data from the current measurement will be destroyed.
12. When the measurement is finished, you will get two results windows, one for the cycle data and one for the final results. The last twenty results windows will stay on the screen unless you close them manually. The final results for an verification measurement are the assay mass and standard deviation for each analysis method that you selected. The results from the "normal" (primary) analysis method will be highlighted. In addition, if you entered a declared mass, you will get a comparison between the assay and declared mass for each analysis method that you selected.

Calibration Measurements

1. Select *Acquire / Calibration*. You must be in Maintenance mode.
2. Select the material type for your calibration standard.
3. Select an item id from the drop down list or type in a new item id, type in the known mass of your standard.
4. Enter any comment you want to make.
5. Enter the count time per cycle in seconds and the number of cycles, or using measurement precision, enter the percent precision and the lower and upper limits on the number of cycles.
6. Select "Shift register" as the data source.
7. Select quality control (QC) tests on, that is, check the box.
8. Check the print box if you want printed results at the end of the measurement. You can always print results later under *Report / Calibration* if you do not want to print now. Check the ending comment box if you want to be able to add a description of the measurement when it has completed.
9. Select the "Isotopics" button and enter the isotopic composition for your calibration standard.
10. Analysis methods for which you want to calibrate must have already been selected from *Maintain / Calibration / Analysis Methods*. There are four analysis methods that you can use for calibration in this program: passive calibration curve, active calibration curve, known alpha, and add-a-source. The calibration procedures for the other analysis methods are not as simple and are not part of the INCC program.

The add-a-source calibration is used to get calibration data for the doubles rate from the item versus the effective ^{240}Pu mass of the item. You must get the calibration coefficients for the add-a-source correction factor outside this program.

Be certain that the measurement (detector) parameters are set the way you want them in *Setup / Measurement Parameters* because the calibration results depend on these parameters, and you must use the same parameters for the verification measurements.

In addition, if you want to do calibration measurements using the known alpha method, you must enter the alpha weight and the rho-zero values in *Maintain / Calibration / Known Alpha*.

11. Select the "OK" button and the calibration measurement will start.
12. You can end the measurement early, if desired, by selecting "Quit measurement with results" or "Abort measurement" button. If you choose the quit option, the results will be calculated with the data from the cycles completed so far. If you choose the abort option all the data from the current measurement will be destroyed.
13. When the measurement is finished, you will get two results windows, one for the cycle data and one for the final results. The last twenty results windows will stay on the screen unless you close them manually. Final results are produced for each analysis method selected. For the active calibration curve method, the results are the doubles rate and standard deviation. For the passive calibration curve and add-a-source methods, the results are the effective ²⁴⁰Pu mass and the doubles rate with its standard deviation. For the known alpha method, the results are the effective ²⁴⁰Pu mass and the doubles rate, with its standard deviation, corrected for multiplication .

Calibration Procedure

1. Select *Maintain / Calibration / Deming Curve Fitting*.
2. Select the material type for which you want to generate a calibration curve.
3. Select the analysis method you want to use. If you want to use more than one analysis method, you must repeat this procedure for each analysis method.
4. Select the "OK" button.
5. For all analysis methods except known alpha, select the curve type you want to use. The choices are:

$$D = a + bm + cm^2 + dm^3$$

$$D = am^b$$

$$D = am/(1 + bm)$$

$$D = a(1 - e^{-bm})$$

Where D is the doubles rate, m is the mass, and a, b, c, and d are calibration coefficients.

The known alpha method always uses the curve type: $D = a + bm$

6. Select the "OK" button. You will get a list of all calibration measurements made with the material type and analysis method you selected.
7. Click on each measurement that you want to include in the curve fit. Select the "OK" button and you will get the Deming curve fitting program with the calibration data sets already loaded.

8. Do the least squares fit to your data. If needed, see the Deming user's manual or Deming online help for instructions.
9. Select the "OK" button and the calibration parameters will be transferred to the INCC program.
10. Check that the transfer of the calibration parameters was successful: select the appropriate analysis method under *Maintain / Calibration* and observe the calibration parameters.

Holdup Measurements Procedure

1. With INCC in maintenance mode select *Maintain / Glovebox Add/Edit/Delete* and enter the number of measurement positions for the glovebox to be assayed.
2. Set the passive background rates to zero. Background corrections are usually not made with holdup measurements.
3. Select *Acquire / Holdup*.
4. Select a glovebox id, an MBA, a stratum id, and the item material type.
5. Select an item id from the drop down list or type in a new item id. If the item id is new, the isotopics dialog box will appear. Enter the isotopics for the item being assayed at this time.
6. If you want to do a verification measurement, that is, if you want to compare the assay mass with a declared mass, enter the declared mass. Otherwise, enter zero for the declared mass.
7. Type in any comment you want to make.
8. Enter the count time per cycle in seconds and the number of cycles.
9. Select "Shift register" as the data source.
10. Select quality control (QC) tests on, that is, check the box.
11. Check the print box if you want printed results at the end of the measurement. You can always print results later under *Report / Holdup* if you do not want to print now.
12. Check the ending comment box if you want to be able to add a description of the measurement when it has completed.
13. Select the "Isotopics" button and enter the isotopic composition for your item if it has not already been entered.
14. Select the "OK" button, and the holdup measurement position screen will be displayed.
15. Click on the box that corresponds to the location of the detector relative to the glovebox. The selected box will change color and display the message "Measure Next". Select the "Measure selected glovebox position" button and the measurement will begin. When the measurement for the position starts, a single results window is displayed showing the cycle data at this position. You can end the measurement early, if desired, by selecting "Quit measurement with results" or "Abort measurement" button. If you choose the quit option, the measurement will stop with the data from the cycles completed so far. If you choose the abort option the data from the current measurement position will be destroyed.

16. Once the measurement finishes, move the detector to the next location and select the next position to be measured in the software. Repeat this process until all the positions are measured. A cycle results window is generated for every position measured or remeasured.
17. A previously measured position can be remeasured by clicking on the box that corresponds to the location to be remeasured and selecting the “Measure selected glovebox position” button. The new data will replace the old data in the analysis.
18. Once all the positions have been measured, select the “Quit measurements with results” button on the measurement position screen. A final results window is opened showing all the count rate results from the individual measurement positions, the calculated average count rates for the whole glovebox, and assay mass and standard deviation for each analysis method that you selected. In addition, if you entered a declared mass, you will get a comparison between the assay and declared mass for each analysis method that you selected. If the “Abort measurement” button is selected, all the data for the entire glovebox will be destroyed.

Import Operator Declarations from Operator Review and Measurements from Radiation Review

INCC can calculate the mass and display results for verification measurement data files, and display results for background and normalization measurement data files imported from Radiation Review. These files were created from measurements made by Shift Register Collect or Multi-Instrument Collect running in unattended mode. These results will remain in the database, and can be reviewed or reanalyzed at any time, just as you would with any other measurement. The results from background and normalization measurements will replace previously existing values in the database and should be used with caution.

The measurement data files created by Radiation Review must reside in the common database directory. The format of these binary files is described in “Radiation Review Measurement Data File format” under the Input Files section of this document.

Each file includes all the cycles for one verification, background or normalization measurement. Note: All cycles in a verification or normalization measurement must have the same count time. Background measurements may have cycles with different count times because all the cycles will be summed into one cycle.

Import procedure:

1. The INCC import function is initiated by Integrated Review.
2. The operator declaration file created by Operator Review for INCC is read. Isotopic data sets are created for each unique set of isotopics and an entry is made in the item data entry table for each unique item id. Composite isotopics cannot be created from multiple sets of isotopics. This file contains the following parameters:

Material balance area

Item id
 Stratum id
 Inventory change code
 I/O code
 Material type
 Declared mass (g)
 Isotopics source code
 Isotopics id
²³⁸Pu %
²⁴⁰Pu %
²⁴¹Pu %
²³⁹Pu %
²⁴²Pu %
 Pu date (YYYYMMDD)
²⁴¹Am %
 Am date (YYYYMMDD)
²³⁸Pu error
²³⁹Pu error
²⁴⁰Pu error
²⁴¹Pu error
²⁴²Pu error
²⁴¹Am error

3. The header for each Radiation Review file in the common database directory with an extension of .NCC is read. The files are sorted chronologically.
4. If no detector id has been created for a measurement, a warning message is displayed, and that measurement is skipped. In other words, **you must go into INCC and create the detector before you import any measurements from that detector**. This is necessary because there are several detector parameters such as gate length, dead time, efficiency ,etc. and calibration parameters that are needed to calculate mass.
5. Each measurement that passes step 4 is displayed in chronological order, one line per measurement, in a selection screen with the following information:

Detector id	Item id	Meas. Type	Date	Time	Filename
-------------	---------	------------	------	------	----------

6. The user selects as many measurements as desired, and they are processed in chronological order. The default is to select all measurements. The last processed background and normalization measurements will be saved in the database and used with subsequent verification measurements.
7. At this point there are two options. If the detector dependent “auto import” box was **not** checked, as each measurement is processed, the appropriate acquire dialog box is displayed, enabling the user to specify the desired details for that measurement. Steps 7, 8 and 9 only apply if “Auto import” was not checked.

Background measurements
 Enter a comment if desired

From a checkbox select to use or not use QC tests
From a checkbox select to print or not print results
From a checkbox select to enter or not enter an ending comment
From a separate dialog box choose whether this is a passive or active measurement

Normalization measurements

Enter a comment if desired
From a checkbox select to use or not use QC tests
From a checkbox select to print or not print results
From a checkbox select to enter or not enter an ending comment
Source id (display only)

Verification measurements

Select Material Balance Area (defaults to current MBA)
Select or enter Item Id (defaults to the one in the file header)
Select Stratum Id (defaults to one corresponding to the item id in the file header if previously set through the *Item Data Entry* dialog box)
Select Material Type (defaults to the one corresponding to the item id in the file header if previously set through the *Item Data Entry* dialog box)
Enter declared mass (defaults to the one corresponding to the item id in the file header if previously set through the *Item Data Entry* dialog box)
Select Inventory Change Code (defaults to the one corresponding to the item id in the file header if previously set through the *Item Data Entry* dialog box)
Select I/O Code (defaults to the one corresponding to the item id in the file header if previously set through the *Item Data Entry* dialog box)
Select isotopics or composite isotopics by clicking on the button (defaults to the one corresponding to the item id in the file header if previously set through the *Item Data Entry* dialog box)
Enter a comment if desired
From a checkbox select to use or not use QC tests
From a checkbox select to print or not print results
From a checkbox select to enter or not enter an ending comment

If the “Auto import” checkbox has been checked, then as each measurement is processed only the dialog box for selecting active or passive is displayed for background measurements, no dialog boxes are displayed for normalization measurements, and if the item data for the item id of the current measurement have been previously entered then no dialog boxes are displayed for verification measurements. The “Auto import” checkbox is accessible in maintenance mode by selecting *Maintain / Unattended Measurements Setup*.

8. In manual mode a results text window is optionally printed for each selected measurement in the same format as for other measurements. The data source will be “Review disk file”.
9. In manual mode, if ‘Ending comment’ was selected then a dialog box will be displayed with the measurement results and a box for entering the ending comment.

10. If this is a verification measurement then the following data for this measurement will be appended to the file for Integrated Review to reconcile and display:

Pass/Fail status (pass specified as green, fail specified as yellow)
Detector id
Item id
Measurement start time
Measurement start date
Calculated mass (g) from the primary analysis method
Calculated mass error
Declared - assay mass (g)
Declared - assay mass (%)
Isotopics source code

If the analysis method is curium ratio, the following data for this measurement will be appended to the file for Integrated Review to reconcile and display:

Pu Pass/Fail status (pass specified as green, fail specified as yellow)
Total U Pass/Fail status (pass specified as green, fail specified as yellow)
²³⁵U Pass/Fail status (pass specified as green, fail specified as yellow)
Detector id
Item id
Measurement start time
Measurement start date
Calculated Pu mass (g)
Calculated Pu mass error
Declared - assay Pu mass (g)
Declared - assay Pu mass (%)
Calculated total U mass (g)
Calculated total U mass error
Declared - assay total U mass (g)
Declared - assay total U mass (%)
Calculated ²³⁵U mass (g)
Calculated ²³⁵U mass error
Declared - assay ²³⁵U mass (g)
Declared - assay ²³⁵U mass (%)

11. The import files created by Operator Review and Radiation Review for INCC will be deleted so that these operator declarations and measurements will not get imported again the next time there is an import.
12. When all measurement files have been processed, INCC automatically will exit.

Display measurement corresponding to a peak in Radiation Review

If the measurement has previously been imported, INCC can display the results for the verification measurement corresponding to a click on or near a peak on a graph in Radiation Review which will cause a data matching message to be sent to INCC. Any other installed review tool may also request the display of a verification measurement by using the data matching message.

When a data matching message is received from another review tool, usually Radiation Review, INCC displays the verification measurement for the detector specified in the data matching message that most closely matches the requested date and time according to the following algorithm:

If the requested date and time falls within the time interval of a verification measurement, that measurement will be displayed. The duration of a measurement is defined as the beginning of the first cycle through the end of the last cycle.

Otherwise the date and time of the end of the preceding measurement and the beginning of the following measurement are compared. Whichever is closest to the requested date and time will be displayed unless:

The time difference between the requested date and time and the measurement date and time exceeds the maximum time specified by a parameter that can be entered from the “Unattended Measurement Parameters” dialog box. If this time difference is exceeded then a message will be displayed indicating no match was found for the requested verification measurement date and time.

An error message will be displayed if there are no verification measurements for the requested detector.

The INCC standard menu (operator mode) will be displayed when processing has completed. All functions that are available in standalone mode will now be available.

The requested verification measurement will be displayed in a text window and printed if print was selected the last time a measurement result was displayed.

NOTE: INCC always assumes the currently selected facility. If you want to import files from a different facility, you must first go into INCC and select (first create if it does not already exist) the desired facility.

Operations Reference

Startup

To start INCC using a Windows user interface, click on Start, then click on Programs, then click on the INCC file folder and then click on the INCC 5.xx icon.

Inspection Main Menu

The major software controls, as listed below, are usually referred to as the Main Menu. The following are provided by INCC when in Inspection mode:

File

Contains options for exporting PSA, Logsheet and Performance Monitoring files, importing Stratum Authority and Item Relevant Data from files, transfer of measurement files, backing up and restoring the entire database, batch script execution, quick database switch, printer setup and program exit.

View

Provides the ability to switch between Inspection and Maintenance modes.

Setup

Contains options for facility, inspection, measurement parameter, isotopics, composite isotopics, item data entry and collar data entry.

Acquire

Contains rates only, background, normalization, verification and holdup measurement data acquisition methods.

Reanalyze

Contains options for reanalyzing verification and holdup measurements with selected parameters changed.

Report

Contains all options for review and reporting of previously acquired measurement data, options to create a summary of measurements and export the summary to a comma separated variable format file, an option to plot a history of normalization measurements and an option to plot measurement data with their calibration curve.

Tools

Contains an option providing the user with the ability to have Radiation Review display the peak corresponding to the most recently displayed INCC verification measurement.

Window

Contains options for arranging measurement data text windows.

Help

Contains online help, access through WordPad to user written procedures and information about copyright restrictions and the date and version number of INCC being used.

Maintenance Main Menu

The major software controls, as listed below, are usually referred to as the Main Menu. The following are provided by INCC when in Maintenance mode:

File

Contains options for exporting PSA, Logsheet and Performance Monitoring files, importing Stratum Authority and Item Relevant Data from files, transfer of measurement files, saving and restoring measurement (detector) parameters and calibration parameters (initial data), backing up and restoring the entire database, printer setup and program exit.

View

Provides the ability to switch between Inspection and Maintenance modes.

Setup

Contains options for facility, inspection, measurement parameter, isotopics, composite isotopics, item data entry and collar data entry.

Maintain

Contains all other parameter entry and setup, including calibration, background, normalization, measurements acquired in unattended mode, QC, stratum rejection limits, error calculation method, archive, and add-a-source. Contains options for adding and deleting detectors, facilities, material balance areas, strata, material types, poison rod types and gloveboxes. Provides a way of deleting unwanted measurements from the database. This menu collects new advanced features, *e.g.* selectable effective ^{240}Pu coefficients for mass calculations.

Acquire

Contains all measurement data acquisition methods.

Reanalyze

Contains options for reanalyzing verification and holdup measurements with selected parameters changed.

Report

Contains all options for review and reporting of previously acquired measurement data, options to create a summary of measurements and export the summary to a comma separated variable format file, an option to plot a history of normalization measurements and an option to plot measurement data with their calibration curve.

Tools

Contains an option providing the user with the ability to have Radiation Review display the peak corresponding to the most recently displayed INCC verification measurement.

Window

Contains options for arranging measurement data text windows.

Help

Contains online help, access through WordPad to user written procedures and information about copyright restrictions and the date and version number of INCC being used.

File Submenu

Contains options for exporting PSA, Logsheet and Performance Monitoring files, importing Stratum Authority and Item Relevant Data from files, transfer of measurement files, saving and restoring measurement (detector) parameters and calibration parameters (initial data), backing up and restoring the entire database, bulk batch analysis, quick database switch, printer setup, and program exit.

Measurement and calibration parameters can only be saved and restored in Maintenance mode. The bulk batch analysis, quick database switch, and printer setup are only available in maintenance mode.

Save As/Export

File / Save As/Export / PSA/Logsheet File provides a way of exporting data to the PSA Operator-Inspector Measurement Database. The user will be presented with the standard Windows Save As dialog box for selecting the disk drive, path and file name. The default file name is NCC_PSA.dat.

File / Save As/Export / Performance Monitoring File provides a way of exporting Performance Monitoring data which includes information about normalization measurements. The user will be presented with the standard Windows Save As dialog box for selecting the disk drive, path and file name. The default file name is NCC_perf.dat.

File / Save As/Export / Transfer provides a way to save measurement data sets on a disk and later restore them either on the same computer or another computer running INCC. The measurement data sets are written in a binary format that INCC can read using *File / Get External Data / Transfer* which is a complementary function. Through a dialog box with

radio buttons you must next select whether to save measurements only from the current detector or all detectors. If the current detector is chosen, you will then be asked to select an inspection number. In either case, you will be presented with the standard Windows Save As dialog box for selecting the disk drive and path where the measurement data are to be written. For the inspection number, select "All" to be able to choose from all measurements of any type; otherwise select the desired verification measurement inspection number. You will then be able to select which measurement data sets are to be saved. Click on a line to select that measurement data set. Selected lines will be highlighted in blue.

File / Save As/Export / Initial Data provides a way to save measurement (detector) parameters and calibration parameters on a disk and later restore them either on the same computer or another computer running INCC. The parameters are written in a binary format that INCC can read using *File / Get External Data / Initial Data* which is a complementary function. Measurement and calibration parameters can only be saved and restored in Maintenance mode. You must next select which type of parameters to save. There will be a dialog box with radio buttons for "Save detector parameters for the current detector", "Save detector parameters for all detectors", "Save calibration parameters for the current detector" and "Save calibration parameters for all detectors". You will be presented with the standard Windows Save As dialog box for selecting the disk drive and path where the parameters are to be written. Select the "OK" button to cause the selected parameter sets to be written to disk files.

Get External Data

File / Get External Data / Stratum Authority File provides a way of importing stratum ids and historical bias, random uncertainty and systematic uncertainty. The user will first be prompted to select a file name using the Windows standard file selection process. The default file name is NCCstrat.dat. The file will be read in as soon as you select "OK" after selecting a file. New facilities and strata will automatically be created if necessary. Already existing strata will automatically be overwritten.

File / Get External Data / Item Relevant Data File provides a way of importing item ids and all the parameters associated with an item. This information will typically come from IFSS, SPAN or NMAX. The user will first be prompted to select a file name using the Windows standard file selection process. The default file name is NCC_PSA.dat. The file will be read in as soon as you select "OK" after selecting a file. New facilities, MBAs, strata, inventory change codes, I/O codes, material types, isotopics, collar data and item ids will automatically be created if necessary. Already existing items will automatically be overwritten.

File / Get External Data / Transfer provides a way to restore measurement data previously saved on a disk. *Transfer* may be used on either on the same computer where the data were saved or another computer running INCC. The data must have been written in a binary format using *File / Save As/Export / Transfer*. The user will be presented with the standard Windows File Open dialog box to select the disk drive and path from where the measurement data are to be read. The user will then be able to select which measurement data sets are to be

restored. Click on a line to select that measurement data set. Selected lines will be highlighted in blue. The selected files will be read in as soon as you select “OK”. All parameters needed to support the selected measurements will be automatically restored to the database. These parameters are facility, material balance area, detector, calibration, isotopics, stratum and stratum rejection limits. If there is a conflict with already existing parameters, the user will have the choice of always overwriting, never overwriting or being prompted to overwrite.

File / Get External Data / Initial Data provides a way to restore measurement (detector) parameters and calibration parameters. The user will select the desired file from the standard windows file selection dialog box. Only one set of detector or calibration parameters can be restored at a time. A set will include all of the detector or calibration parameters for a particular detector. The selected file will be read in as soon as you select “OK”.

Warning: there is only one set of measurement (detector) parameters, and one set of calibration parameters for each material type and analysis method. Restoring detector or calibration parameters will overwrite your existing parameters.

Backup All Data

File / Backup All Data provides a way of saving the entire database to a disk file in zip (compressed) format. The user will be presented with the standard Windows Save As dialog box to select the disk drive and path where the database is to be saved. As soon as you select “OK” the database will be written file by file using the pkzip utility. You will be notified when the backup has completed.

Restore All Data

File / Restore All Data provides a way of restoring the entire database from a zipped (compressed) disk file created using *File / Backup All Data*. The user will be presented with the standard Windows File Open dialog box to select the disk drive and path from where the database is to be restored. **As soon as you select “OK” the existing database will be overwritten file by file using the pkunzip utility.** You will be notified when the restore has completed.

Batch Analysis

File / Batch Analysis offers a partially automated approach to analyzing multiple sets of existing measurements with new declaration values. This operation expects a batch script prepared earlier as input. See Batch Script Generation and Input files - Batch Script File Format for details on batch script preparation and content. The operation locates a batch script file on the file system using a file dialog, parses the script for analysis entries, runs the analysis entries found in the script, producing analysis results for each script entry.

The new analyses created by executing the batch script do not modify or change any previous analyses present in the INCC database.

Invoking the *File / Batch Analysis* command opens a file dialog. Use the file dialog to locate a batch script file. When the batch script file is located, select “Open” on the file dialog. The selected batch script file is then opened by INCC, and parsed for measurement commands. No errors or warnings are generated when the script is parsed for batch processing. Malformed script entries are unceremoniously skipped.

For each valid measurement entry discovered in the batch script file, the existing measurement data is retrieved and then analyzed using the new values provided in the script entry. You should see the successive analysis results pop up as each valid batch script line is processed. Each newly analyzed measurement produces a standard results window. A log window recording the progress of the processing results is also created.

Database

File / Database provides a quick way to switch databases in INCC, without replacing the primary default INCC database. The menu command opens a list dialog. The current database path is the first entry in the list. The additional entries in the list are for adding paths to other databases. To change a database, 1) check the box to the left of the desired database, 2) select the “OK” button to switch to the new INCC database.

To add a database to the list of database choices, 1) select the list entry to hold the path to the new database, 2) use the “Select” button to navigate to the database folder of an INCC database, 3) then when the folder with the correct filename is found, select “Open”, 4) the new database location will be placed in the list entry selected. Note that an INCC database folder must contain the database file `ncc_db.dbd`, the file dialog operation in step 3 will not accept a database folder section without the presence of this file. Additional checking occurs to detect if the selected database is compatible with current INCC software. The operation in step 3 will not open an INCC database from version prior to 5.00. Attempting to open an INCC database version prior to 5.00 generates an informational warning message. Please refer to see *File / Restore All Data* above for the correct procedure for accessing an INCC database version prior to INCC 5.00.

In a standalone INCC installation, the selected databases and last current database information is retained across INCC invocations. The last database accessed using the database switch feature will be the default database for INCC the next time INCC is started.

Note: when INCC runs under the control of a LANL Integrated Review System (IRS) configuration, database choices are temporary, changes are *not* retained after INCC is closed. INCC will restart using the IRS configured INCC database. The location of the earlier database choice is retained for convenience.

Printer Setup

To use this feature, select *File / Printer Setup*. *Printer Setup* provides the user with a means of configuring the printer, such as selecting between portrait and landscape mode. This is the standard windows Print Manager, Printer Setup screen.

Exit INCC

Selecting *File / Exit INCC* is one way of exiting the INCC program. Clicking on the System menu button and then selecting Close will also cause INCC to exit. When you exit INCC a dialog box will be displayed asking if you want to back up the database. It is a good practice to frequently back up the database in case you need to recover from a subsequent problem.

View Submenu

View / Maintain provides the ability to switch between Inspection and Maintenance modes. Clicking on *View / Maintain* toggles between the two modes. A check mark by *Maintain* indicates that you are in Maintenance mode.

Setup Submenu

Contains options for setting up facility and general inspection parameters, measurement (detector) parameters, isotopics, composite isotopics, item data and collar item data. Isotopics, composite isotopics, item data and collar item data can be entered while acquiring measurement data from the shift register.

Facility/Inspection

Setup / Facility/Inspection provides a dialog box for selecting the facility, material balance area and detector id. When the detector id is selected the detector type and electronics id will also be selected, but may be changed here if necessary. The inspection number and inspector name are also entered here. There is a button that will allow you to change the system date, time and time zone.

The amount of information included in results displays and printouts is controlled here by a series of check boxes. Listed below are the choices and their default values. Selected values remain in effect until specifically changed here or in one of the report dialog boxes.

Detector parameters	On
Calibration parameters	On
Isotopics	On
Individual cycle raw data	Off

Individual cycle rate data	On
Summed raw coincidence data	Off
Summed multiplicity distributions	Off
Individual multiplicity distributions	Off

All measurement data sets are written to an ASCII file created using the file naming convention described in “File naming conventions”. The default directory for these files is \INCC\DATA. The “Change ASCII results data directory” button allows the user to specify a different directory, for example a JAZ drive, so that the measurement data files can be taken to a different computer. The archive subdirectory will automatically be created. For more about the data and archive subdirectories, see "Archive". The user will be presented with a dialog box for typing in the disk drive and path for writing ASCII measurement data files.

Measurement Parameters

To use this feature, select *Setup / Measurement Parameters*. You must select the shift register type that matches the electronics used in your system. The choices are MSR4 or 2150, JSR-11, JSR-12, PSR or ISR, DGSR and AMSR. MSR4 refers to the Los Alamos multiplicity shift register nuclear instrument module and the commercial version of the circuit, the Canberra model 2150. The JSR-11 and JSR-12 are Canberra coincidence electronics packages that do not have multiplicity electronics. The PSR is the Los Alamos and Aquila portable shift register that has multiplicity electronics. The DGSR is the Los Alamos portable shift register that utilizes two gates to decrease the statistical error, thereby reducing the count time required to achieve the same precision with a single gate. The AMSR is the Los Alamos advanced multiplicity shift register.

Depending on which shift register type you select, in Inspection mode some of the parameters will be grayed out in this dialog box to indicate that they cannot be set from the computer by the shift register type selected. The parameters are not grayed out in Maintenance mode so that you can enter the correct values for display.

The serial port that connects the computer to the coincidence electronics can vary from system to system. You must select the port that matches the configuration of your system. The choices are COM Port 1 through COM Port 10. In simple systems the shift register port is usually COM Port 1.

The predelay can be set from 0 to 1023.75 microseconds in 0.25 microsecond steps. The usual predelay is 4.5 microseconds for conventional coincidence counting and 3 microseconds for multiplicity counting.

The gate length can be set from 0.25 to 1024 microseconds in 0.25 microsecond steps. The most common gate length is 64 microseconds for conventional coincidence counting and 32 microseconds for multiplicity counting. The second gate length applies only to the DGSR, and functions the same as the first gate length.

The most common high voltage is 1680 volts. A recommended value should be given in the detector manual or indicated with a label at the high voltage connector of the detector.

The die-away time depends on the detector design and is typically 40 to 70 microseconds. The detector manual usually gives the value. If you cannot determine the die-away time, use 50 microseconds.

The singles rates are corrected with a deadtime, where S is the measured singles rate, and A is the deadtime coefficient. The doubles rates are corrected with a deadtime, where D is the measured doubles rate, and B is the deadtime coefficient. See the detector manual for values of A and B. Deadtime coefficient A is given in units of microseconds and B is given in units of microseconds squared.

The neutron detection efficiency is typically 0.15 to 0.60. See the detector manual for the value or measure it using a calibrated ^{252}Cf source.

The multiplicity deadtime is used to correct the triples counting rate. The value is typically 30 to 200 nanoseconds. See the detector manual for the deadtime value.

The deadtime coefficients A and B are used to correct the singles and doubles rates. For a six-channel Amptek system, A is typically 0.6 to 0.8 μs and B is typically 0.20 to 0.26 $(\mu\text{s})^2$. See the detector manual for the deadtime values.

The deadtime coefficient C is used for an additional deadtime correction factor for the triples rate. The value for C is typically 0 to 1×10^{-32} seconds. Get the value for C from the detector manual, if specified. Otherwise, set C = 0.

The doubles gate fraction accounts for the effect of the finite length of the coincidence gate on the doubles rate. The doubles gate fraction is typically about 0.4. Get the value from the detector manual.

The triples gate fraction accounts for the effect of the finite length of the coincidence gate on the triples rate. The triples gate fraction is approximately the square of the doubles gate fraction. Get the value from the detector manual.

The efficiency, multiplicity deadtime, doubles gate fraction, and triples gate fraction are used only for multiplicity analysis and can be ignored for conventional coincidence counting.

Isotopics

To use this feature, select *Setup / Isotopics*. The plutonium isotopic composition of the verification item can either be entered from the keyboard or read in from a disk file by using the "Read isotopics from file" button. Enter the ^{241}Am content as the weight percent of the total plutonium. Enter isotopics errors as the weight percent of the total plutonium. The normal form for displaying isotopics is the mass of Pu = 100% and the mass of ^{241}Am is a

percentage of total Pu mass. However, there is a radio button to allow entering isotopics as the mass of Pu + ^{241}Am = 100%. This option is only for isotopics entry from the dialog box. Isotopics displays in reports and entry from disk files is always in the form Pu = 100% and the mass of ^{241}Am as a percentage of total Pu mass.

If you use a disk file for the plutonium isotopic composition, the file must first contain the isotopics id, then the isotopics source code, and then the isotopic data in the same order as shown in the dialog box, with the errors at the end. The dates must be in the format chosen for your windows system. You can change the date format through the control panel by clicking on the "Regional settings" icon. The disk file must be a text (ASCII) file, with the data elements separated by commas. If the isotopics id contains spaces, it must be enclosed in double quotes. For a complete description of the isotopics file format, see "Isotopics data file format".

The possible isotopics source codes are:

OD	Operator declared
IA	Inspector analyzed
IM	Inspector measured
OA	Operator analyzed
OC	Operator calculated
OE	Operator estimated
OS	Other source
CO	Composite

If the isotopics source code is CO, all the isotopic composition values and dates will be grayed out because composite isotopics can only be changed by selecting *Setup / Composite Isotopics*. Selecting the "Add isotopics data set" button, and then typing in the isotopics id in the dialog box that will appear will allow you to enter a new set of isotopics even if the previously displayed isotopics were grayed out because the isotopics source code was CO.

Multiple isotopic data sets may be stored in the database simultaneously, and a particular set may be selected by its isotopics id. The selected isotopics data set will be used by all verifications until another one is selected. An isotopics data set may be written to a disk file by selecting the "Write isotopics to file" button, and then selecting the disk drive, path and file name from the standard Windows Save As dialog box that will appear. A new isotopics data set may be created by typing in the desired isotopics values, then selecting the "Add isotopics data set" button, and then typing in the isotopics id in the dialog box that will appear. The isotopics values for an already existing isotopics data set may be changed by selecting the desired isotopics id, typing in the new values, and then selecting the "Save isotopics data set" button. The isotopics id for an existing isotopics data set may be changed by selecting the desired isotopics id, selecting the "Edit isotopics id" button, and then typing in the new isotopics id in the dialog box that will appear. An isotopics data set may be deleted from the database by selecting the desired isotopics id and then selecting the "Delete

isotopics data set" button. This will be necessary when the maximum of 1000 isotopics data sets is reached.

Composite Isotopics

To use this feature, select *Setup / Composite Isotopics*. The composite plutonium isotopic composition, consisting of up to 20 sets of isotopics, for the verification item can either be entered from the keyboard or read in from a disk file. Enter the ^{241}Am content as weight percent of plutonium. When you have all the isotopic compositions entered correctly, select the "Calculate and Store Isotopics" button. This will cause the composite isotopics, weighted by mass, to be calculated and stored in the isotopics database using the composite isotopics id. Only isotopic compositions with a mass greater than zero will be included in the composite isotopics calculation. The composite isotopic composition is weighted by mass. If you forget to select the "Calculate and Store Isotopics" button, you will be reminded when you select OK to exit the composite isotopics dialog box.

If you use a disk file for the composite plutonium isotopic composition, the file must contain first the composite isotopics id, then the mass in grams Pu, and then the isotopic data in the same order as shown in the dialog box, with the errors at the end. Repeat the mass, isotopic data and errors for each set that makes up the isotopic composition. The dates must be in the format chosen for your windows system. You can change the date format through the control panel by clicking on the "Regional settings" icon. The disk file must be a text (ASCII) file, with the data elements separated by commas. If the composite isotopics id contains spaces, it must be enclosed in double quotes. For a complete description of the composite isotopics file format, see "Composite isotopics data file format".

Multiple composite isotopic data sets may be stored in the database simultaneously, and a particular one may be selected by its composite isotopics id. A composite isotopics data set may be written to a disk file by selecting the "Write composite isotopics to file" button, and then selecting the disk drive, path and file name from the standard Windows Save As dialog box that will appear. A new composite isotopics data set may be created by typing in the desired composite isotopics values, then selecting the "Add composite isotopics data set" button, and then typing in the composite isotopics id in the dialog box that will appear. The composite isotopics values for an already existing composite isotopics data set may be changed by selecting the desired composite isotopics id, typing in the new values, and then selecting the "Save composite isotopics data set" button. The composite isotopics id for an existing composite isotopics data set may be changed by selecting the desired composite isotopics id, selecting the "Edit composite isotopics id" button, and then typing in the new composite isotopics id in the dialog box that will appear. A composite isotopics data set may be deleted from the database by selecting the desired composite isotopics id and then selecting the "Delete composite isotopics data set" button. This will be necessary when the maximum of 1000 composite isotopics data sets is reached.

Item Data Entry

To use this feature, select *Setup / Item Data Entry*. You can enter item ids to be measured, along with their material balance area, material type, isotopics, stratum id, inventory change code, I/O code, declared mass, heavy metal declared uranium mass and heavy metal declared length. You can only select a material type, isotopics id and stratum id from a drop down list. Therefore, you must have already entered the desired material types from the *Material Type Add/Delete* dialog box, the desired isotopics from the *Isotopics* dialog box and the desired stratum ids from *Stratum id Add/Delete* dialog box. You may also enter item from a disk file through the *File / Get External Data / Item Relevant Data File* option.

The possible values for the Inventory change code are:

Blank field	PIV or IIV
RD	Received during interim (domestic)
RF	Received during interim (foreign)
RN	Received during interim
SD	Shipped/measured during interim inspection (domestic)
SF	Shipped/measured during interim inspection (foreign)
SN	Shipped/measured during interim inspection

The possible values for the I/O code are:

Blank field	PIV
X	IIV
I	Received during interim
A	Received/measured during PIV and before PIV date
C	Received/measured during PIV and after PIV date
O	Shipped/measured during interim inspection
B	Shipped/measured during PIV and before PIV date
D	Shipped/measured during PIV and after PIV date
F	Flow measurement
T	Test measurement
Z	Other

Collar Item Data Entry

To use this feature, select *Setup / Collar Item Data Entry*. You can enter collar item ids to be measured, along with their rod length, rod length error, total ^{235}U , total ^{235}U error, total ^{238}U , total ^{238}U error, total number of rods, total number of poison rods, poison percent, poison percent error and poison rod type. You can only select a poison rod type. Therefore, you must have already entered the desired poison rod type from *Poison Rod Type Add/Delete*. For each collar item you must also have used *Item Data Entry* to create a corresponding entry.

Maintain Submenu

The *Maintain* submenu is only available in Maintenance mode. It contains options for setting up calibration, background, normalization, QC and test parameters, stratum rejection limits, error calculation method, archive parameters and add-a-source parameters. It also provides the ability to add and delete detectors, facilities, material balance areas, strata, material types, poison rod types and gloveboxes. Finally, it provides a way of deleting unwanted measurements from the database.

Calibration

Calibration contains calibration parameter edit options for each analysis method, and an option to call the Deming Curve Fitting program to calculate and automatically store calibration parameters in the INCC database.

Deming Curve Fitting

To use this feature, select *Maintain / Calibration / Deming Curve Fitting*. You can fit your calibration data with the Deming least squares fitting program starting from this dialog box. First select the material type and the analysis method for which you want to obtain calibration parameters. If you want to verify items of a certain type using more than one analysis method, you must determine the calibration parameters for each analysis method separately. Calibration for multiplicity, active/passive, or known multiplication analysis is more complex than fitting a curve, and cannot be done within this program.

After you select the "OK" button you will get a list of calibration measurement data sets for the material type and analysis method you chose. Select the data sets you want to include in the least squares fit and then select the "OK" button. This program will now start the Deming least squares fitting program and load your data sets. Do the least squares fit using a function appropriate for the selected analysis method. See the Deming user's manual or Deming online help for information on the Deming code. When you are finished with the Deming fit, the calibration parameters will be automatically installed in the INCC database, and you will be returned to this program. You can check the results by selecting your analysis method under *Maintain / Calibration* and then selecting your material type. The calibration parameters obtained from the Deming program should be displayed in the dialog box.

Analysis Methods

To use this feature, select *Maintain / Calibration / Analysis Methods*. A set of verification measurement data can be analyzed with many different analysis methods. Seven passive methods (calibration curve, known alpha, known M, multiplicity, add-a-source, curium ratio and truncated multiplicity) and four active methods (calibration curve, collar, multiplicity and active/passive) are provided. For each material type that you will verify, select the analysis methods you want to use by clicking in their boxes. Except for the collar analysis method, any material type can be analyzed with one or more analysis methods.

You will get as many results sets as you have selected analysis methods. For passive verification measurements there is an automatic comparison of different analysis methods when two or more have been selected. The accepted verification result will be the “normal” method unless the result from the “backup” method differs by more than n standard deviations from the normal method, where n is a test parameter that can be set by selecting *Maintain / QC and Test Parameters*. If the two methods differ by more than the test limit then the backup result is accepted. The accepted result will be highlighted. If a user selects two or more passive analysis methods an additional dialog box will be displayed for the user to select one “normal” and one “backup” analysis method.

For each material type and analysis method you select, you must enter appropriate calibration parameters under *Maintain / Calibration* in the main menu.

Passive Calibration Curve

To use this analysis method select *Maintain / Calibration / Passive Calibration Curve*. There is a calibration parameter set for each material type. A set consists of the upper and lower mass limits, the curve type, the coefficients, the variances, the covariances, and an extra error term (σ_x).

The curve types are:

1. $D = a + bm + cm^2 + dm^3$
2. $D = am^b$
3. $D = am / (1 + bm)$
4. $D = a (1 - e^{-bm})$

Where D is the doubles rate, m is the mass of effective ^{240}Pu or ^{235}U , and a , b , c , and d are calibration coefficients.

You can enter the parameters from the keyboard or use the Deming code to enter the parameters automatically. The extra error term (σ_x) is always zero unless you change it from the keyboard. This error is used to account for extra error sources, for example, error sources not accounted for by the curve fitting process. The extra error is expressed as percent relative standard deviation; the corresponding mass error is combined quadratically with the mass error calculated from the calibration curve variances and covariances and the doubles rate standard deviation.

The polynomial curve type can have more than one solution for a specified doubles rate. In this case the software selects the smallest mass that is within the upper and lower mass limits. If there is no solution within the mass limits, then the software selects the smallest positive mass. If there is no positive mass, then the least negative mass is selected.

There are also two heavy metal correction parameters for MOX "collar" measurements and a checkbox to enable these parameters which are usually not used. The correction factor is applied to the doubles as follows:

$$K4 = 1 + \text{heavy metal weighting factor} * (\text{heavy metal reference} - \text{declared heavy metal content})$$

Where:

$$\text{Declared heavy metal content} = (\text{declared Pu} + \text{declared U}) / \text{declared length}$$

Then:

$$\text{Doubles} = K4 * \text{doubles}$$

$$\text{Doubles error} = K4 * \text{doubles error}$$

The calibration parameters can be printed with the measurement (detector) parameters by selecting the "Print calibration parameters" button.

Known Alpha

To use this analysis method select *Maintain / Calibration / Known Alpha*. There is a calibration parameter set for each material type. A set consists of the alpha weight, the rho-zero value, the extra error term (sigma x), and the coefficients a and b, their variances and covariance:

$$D = a + bm$$

Where D is the doubles rate corrected for multiplication and m is the effective ^{240}Pu mass.

The alpha value is the ratio of neutrons from (alpha, n) reactions to neutrons from spontaneous fissions. For pure plutonium metal, alpha is zero because there are no (alpha, n) reactions. For pure plutonium oxide, alpha can be calculated from the plutonium isotopic composition because the (alpha, n) yield for oxygen is known for each of the plutonium isotopes. This calculation is performed by the software. The alpha value used for the multiplication-correction calculation is the alpha value for pure plutonium oxide multiplied by a weighting factor called the alpha weight. For pure plutonium metal the alpha weight is zero, For pure plutonium oxide, the alpha weight is one. If items have uniform impurities that change the alpha value for pure oxide by a known amount, the alpha value for these items can be calculated by using the appropriate alpha weight.

Rho-zero is the ratio of the doubles to singles rates times $(1 + \alpha)$ for a nonmultiplying item of ^{240}Pu . Rho-zero is used as a reference value for the multiplication correction calculation. It depends on the detector parameters. Get the recommended value for rho-zero from the user's manual for the detector.

You can enter the calibration coefficients a and b and their variances and covariance from the keyboard or use the Deming code to enter the values automatically. The alpha weight, rho-zero, and the extra error term (sigma x) must be entered from the keyboard. The extra error

term (sigma x) is always zero unless you change it from the keyboard. This error is used to account for extra error sources, for example, error sources not accounted for by the curve fitting process. The extra error is expressed as percent relative standard deviation; the corresponding mass error is combined quadratically with the mass error calculated from the calibration curve variances and covariances and the doubles rate standard deviation.

The constant k is used in the equation that determines the neutron multiplication. It depends on the moments of the spontaneous fission neutron distributions of ^{240}Pu and on the induced fission neutron distributions of ^{239}Pu . The default value is 2.166.

There are two heavy metal correction parameters for MOX "collar" measurements, and a radio button to enable these parameters which are usually not used. The correction factor is applied to the singles and doubles as follows:

$$K4 = 1 + \text{heavy metal weighting factor} * (\text{heavy metal reference} - \text{declared heavy metal content})$$

Where:

$$\text{Declared heavy metal content} = (\text{declared Pu} + \text{declared U}) / \text{declared length}$$

Then:

Singles	=	$\text{sqrt}(K4) * \text{singles}$
Singles error	=	$\text{sqrt}(K4) * \text{singles error}$
Doubles	=	$K4 * \text{doubles}$
Doubles error	=	$K4 * \text{doubles error}$

There are two moisture correction algorithms implemented in the known-alpha analysis. One method applies a correction to the calculated "dry" alpha and the other method applies a correction to the multiplication corrected doubles rate (*i.e.*, the mass).

Moisture Correction #1. There is a set of calibration coefficients for a moisture correction on alpha, and a radio button is available to enable these (infrequently used) parameters. The ring ratio (RR) is used to calculate a correction (CF) to the dry alpha calculated from isotopics:

$$RR = \text{inner ring} / \text{outer ring}$$

where:

$$\begin{aligned} \text{inner ring} &= 1^{\text{st}} \text{ scaler rate} \\ \text{outer ring} &= \text{singles rate} \end{aligned}$$

The curve types that can be used for calculating the correction factor are:

1. $RR = a + b * CF + c * CF^2 + d * CF^3$
2. $RR = a * CF^b$
3. $RR = a * CF / (1 + b * CF)$
4. $RR = a (1 - e^{-b * CF})$

$$\text{wet alpha} = \text{dry alpha} * \text{CF}$$

The wet alpha is then used in the standard known alpha analysis.

Moisture Correction #2. Alternatively, the same set of calibration coefficients can be used for a moisture correction on the multiplication corrected doubles rate, and a radio button is available to enable these (infrequently used) parameters. The ring ratio (RR) is used to calculate a correction (CF) to the multiplication corrected doubles rate:

$$\text{RR} = \text{inner ring} / \text{outer ring}$$

where:

$$\text{inner ring} = 1^{\text{st}} \text{ scaler rate}$$

$$\text{outer ring} = \text{singles rate}$$

The curve types that can be used for calculating the correction factor are:

1. $\text{RR} = a + b * \text{CF} + c * \text{CF}^2 + d * \text{CF}^3$
2. $\text{RR} = a * \text{CF}^b$
3. $\text{RR} = a * \text{CF} / (1 + b * \text{CF})$
4. $\text{RR} = a (1 - e^{-b * \text{CF}})$

$$\text{moisture corrected } D_c = D_c * \text{CF}$$

The moisture corrected D_c is then used in the multiplication corrected calibration curve to determine the effective ^{240}Pu mass.

The calibration parameters can be printed with the measurement (detector) parameters by selecting the "Print calibration parameters" button.

Known M

To use this analysis method select *Maintain / Calibration / Known M*. There is a calibration parameter set for each material type. A set consists of five nuclear data constants, calibration coefficients b and c, and the excess error, sigma(x). You will probably not need to change the nuclear constants from their default values:

Spontaneous fission rate of ^{240}Pu (fissions/g/s):	473.5
1st factorial moment of ^{240}Pu spontaneous fission neutron distribution:	2.154
2nd factorial moment of ^{240}Pu spontaneous fission neutron distribution:	3.789
1st factorial moment of ^{239}Pu 2-MeV induced fission neutron distribution:	3.163
2nd factorial moment of ^{239}Pu 2-MeV induced fission neutron distribution:	8.240

The calibration coefficients b and c relate the neutron multiplication (M) to the effective ²³⁹Pu mass (m) through the calibration equation:

$$M = 1 + bm + cm^2$$

All parameters must be entered from the keyboard. The calibration of M versus m must be done outside this program. The extra error is expressed as percent relative standard deviation; the corresponding mass error is combined quadratically with the mass error calculated from the calibration curve variances and covariances and the doubles rate standard deviation.

The calibration parameters can be printed with the measurement (detector) parameters by selecting the "Print calibration parameters" button.

Passive Multiplicity

To use this analysis method select *Maintain / Calibration / Passive Multiplicity*.

There are five types of analysis: (1) conventional multiplicity, (2) weighted point model multiplicity, (3) solve for efficiency, (4) dual-energy model, and (5) known alpha. Only one type can be used at a time. Radio buttons are used to make the selection. Conventional multiplicity analysis solves for effective ²⁴⁰Pu mass, neutron multiplication, and alpha from the singles, doubles, and triples rates using energy-independent, point model equations and using the detection efficiency and gate fractions entered as measurement parameters. The weighted point model multiplicity analysis allows the coefficients of the point model equations to be modified. If the detection efficiency is unknown, but the plutonium mass is very small (*e.g.*, waste measurements in moderated drums), then the neutron multiplication can be neglected and the point-model equations can be solved for effective ²⁴⁰Pu mass, alpha, and efficiency. The dual-energy model is an extension of the energy independent, point-model equations that uses two neutron energies: one to approximate the average energy of the (alpha,n) neutrons and one for the fission-spectrum neutrons. The known alpha option calculates alpha from isotopics and solves for multiplication, efficiency and ²⁴⁰Pu effective mass. For this case, the error analysis is simplified by only using the triples error, and ignoring the singles and doubles error.

There is a calibration parameter set for each material type. A set consists of seven nuclear data constants, three calibration coefficients (a, b, c), and the excess error, sigma(x). In addition, for dual-energy analysis, the calibration parameters include a table of energy-dependent values for (1) the detection efficiency for (alpha,n) neutrons, (2) the ratio of the efficiency of the inner ring of ³He tubes to that of the outer ring for (alpha,n) neutrons, and (3) the ratio of the induced-fission probability for (alpha,n) neutrons to that for fission-spectrum neutrons.

You will probably not need to change the nuclear constants from their default values:

Spontaneous fission rate of ²⁴⁰ Pu (fissions/g/s):	473.5
---	-------

1st factorial moment of ^{240}Pu spontaneous fission neutron distribution:	2.154
2nd factorial moment of ^{240}Pu spontaneous fission neutron distribution:	3.789
3rd factorial moment of ^{240}Pu spontaneous fission neutron distribution:	5.211
1st factorial moment of ^{239}Pu 2-MeV induced fission neutron distribution:	3.163
2nd factorial moment of ^{239}Pu 2-MeV induced fission neutron distribution:	8.240
3rd factorial moment of ^{239}Pu 2-MeV induced fission neutron distribution:	17.321

Coefficients a, b, and c determine a correction factor (CF1) for the effective ^{240}Pu assay mass that depends on the neutron multiplication (M) through the equation:

$$\text{CF1} = a + b (M - 1) + c (M - 1)^2$$

For no correction, set $a = 1$ and $b = c = 0$.

The efficiency correction factor (ECF) is used to make small adjustments to the detection efficiency for different material types. The value used in the code in passive multiplicity analysis is the product of the detector efficiency (from the Measurement Parameters dialog) multiplied by the ECF. This allows samples with significantly different properties (size, shape, isotopic composition etc.) to be analyzed without changing the detector in INCC. The default value is 1.0.

The known alpha model uses the alpha weight value. The (alpha, n) yield is calculated assuming the plutonium is pure oxide. The alpha weight is a weighting factor that can be used to adjust the calculated yield as needed. For pure oxide alpha weight is 1; for pure metal alpha weight is 0. This parameter is only used for known alpha multiplicity analysis. All parameters must be entered from the keyboard. The coefficients a, b and c must be determined outside this program. The extra error is expressed as percent relative standard deviation; the corresponding mass error is combined quadratically with the mass error calculated from the calibration curve variances and covariances and the doubles rate standard deviation.

The calibration parameters can be printed with the measurement (detector) parameters by selecting the "Print calibration parameters" button.

Add-a-source

To use this analysis method select *Maintain / Calibration / Add-a-source*. There is a calibration parameter set for each material type. The parameters for the add-a-source technique consist of parameters for the calibration of the doubles rate versus effective ^{240}Pu mass and parameters for the add-a-source correction. The parameters for the calibration of doubles rate versus effective ^{240}Pu mass have the same meaning as those used for the passive calibration curve method. The parameters for the add-a-source correction consist of the number of add-a-source cycles, the add-a-source correction coefficients, the add-a-source reference date, and the add-a-source reference rates.

The add-a-source measurement consists of the measurement of an item followed by the measurement of the item plus the add-a-source located at one to five positions in the assay chamber. The number of positions is set in the dialog box for "CompuMotor Setup" or "PLC Setup" under *Maintain / Add-a-source Setup*. The add-a-source parameter "Number of cycles" is the number of cycles for the add-a-source at each of the add-a-source positions.

The add-a-source correction factor (cf) for the doubles rate is:

$$cf = 1 + a + b \cdot \delta + c \cdot \delta^2 + d \cdot \delta^3$$

Where a, b, c, and d are calibration coefficients and:

$$\delta = r - 1$$

Where r is the ratio of the add-a-source reference doubles rate to the measured add-a-source doubles rate. The calibration coefficients a, b, c, and d must be determined outside this program.

The add-a-source reference doubles rate (D0 average) is the average of the reference doubles rates for up to five add-a-source positions. As you enter the reference doubles rates for the add-a-source positions, the average is displayed. You cannot enter the average directly. The add-a-source reference date (D0 reference date) is the date when the reference doubles rates were measured at the add-a-source positions.

The calibration coefficients for the passive calibration curve can be transferred automatically from the Deming program or can be entered from the keyboard. All add-a-source parameters must be entered from the keyboard. The extra error is expressed as percent relative standard deviation; the corresponding mass error is combined quadratically with the mass error calculated from the calibration curve variances and covariances and the doubles rate standard deviation.

The calibration parameters can be printed with the measurement (detector) parameters by selecting the "Print calibration parameters" button.

Curium Ratio

To use this analysis method select *Maintain / Calibration / Curium Ratio*. There is a calibration parameter set for each material type. A calibration parameter set consists of the curve type, coefficients, variances, covariances, an extra error term (sigma x), and a button choice for using either single or doubles rates for the analysis.

The curve types are:

1. $D = a + bm + cm^2 + dm^3$
2. $D = am^b$

3. $D = am / (1 + bm)$
4. $D = a (1 - e^{-bm})$

Where D is the count rate (doubles or singles, depending upon the selected button option), m is the mass of ²⁴⁴curium, and a, b, c, and d are calibration coefficients.

The parameters are entered from the keyboard. The extra error term (sigma x) is always zero unless you change it. This error is used to account for extra error sources, for example, error sources not accounted for by the curve fitting process (errors in the facility supplied curium mass ratios are not entered here). The extra error is expressed as percent relative standard deviation; the corresponding mass error is combined quadratically with the mass error calculated from the calibration curve variances and covariances and the count rate standard deviation.

The calibration parameters can be printed with the measurement (detector) parameters by selecting the "Print calibration parameters" button.

Truncated Multiplicity

The truncated multiplicity analysis method is used for the measurement of very small Pu items when the cosmic ray background interferes with the measurement. Truncated multiplicity analysis uses only the first three multiplicity values (the zeros, ones, and twos) in the multiplicity distributions and thus ignores the higher multiplicities that are produced primarily by cosmic rays; this improves the precision of the assay mass.

To use this analysis method, select *Maintain / Calibration / Truncated Multiplicity*. Each material type has its own set of parameters. The truncated multiplicity parameters are the two calibration coefficients (a and b) and the choice of analysis methods. The analysis can be done using the known efficiency method, the unknown efficiency method, or both. In the known efficiency method, the efficiency is taken from the measurement parameters for the detector (under *Setup / Measurement Parameters*). In the unknown efficiency method the efficiency is calculated from the measured twos/ones ratio. If you select both analysis methods, you will get two verification results; the software does not try to select the preferred result. However, if you select truncated multiplicity with other analysis methods, such as passive multiplicity or calibration curve, then only the known efficiency solution from truncated multiplicity analysis is used to determine the primary result.

The calibration coefficient 'a' is a correction factor for the measured ones rate in the known-efficiency solution. Select 'a' so that the assay mass is correct for a small Pu standard. The calibration coefficient 'b' is a correction factor for the measured ones rate in the unknown-efficiency solution. Select 'b' so that the assay mass is correct for a small Pu standard.

Active Calibration Curve

To use this analysis method select *Maintain / Calibration / Active Calibration Curve*. There is a calibration parameter set for each material type. A set consists of the curve type, the coefficients, the variances, the covariances, and an extra error term (sigma x).

The curve types are:

1. $D = a + bm + cm^2 + dm^3$
2. $D = am^b$
3. $D = am / (1 + bm)$
4. $D = a (1 - e^{-bm})$

Where D is the doubles rate, m is the mass of ^{235}U , and a, b, c, and d are calibration coefficients.

You can enter the parameters from the keyboard or use the Deming code to enter the parameters automatically. The extra error term (sigma x) is always zero unless you change it from the keyboard. This error is used to account for extra error sources, for example, error sources not accounted for by the curve fitting process. The extra error is expressed as percent relative standard deviation; the corresponding mass error is combined quadratically with the mass error calculated from the calibration curve variances and covariances and the doubles rate standard deviation.

The calibration parameters can be printed with the measurement (detector) parameters by selecting the "Print calibration parameters" button.

Collar

To use this analysis method select *Maintain / Calibration / Collar*. Select the material type (PWR, BWR, etc.) and the mode [Thermal (no Cd)] or [Fast (Cd)]. Then select the Next button to enter the calibration coefficients. You can set upper and lower mass limits, if desired; after a verification measurement is completed, a warning is given if the assay mass is outside of the mass limits.

A recent enhancement to the Collar Calibration parameters increases the specificity of the poison absorption factor (PAF) for a given poison rod type. Normally, a PAF value is globally associated with a single rod type, and specified in the global Poison Rod Type Add/Delete feature. Specific PAF values may now be assigned to each thermal mode, for a single material type. On the first dialog of the Collar Calibration parameters, a rod type selector is shown. The corresponding PAF for the selected rod type is also shown. To override the default PAF for the selected rod type, enter a new PAF value in the edit box. The new value will be associated with the currently selected detector, material type and thermal mode. On the third dialog, a table entry is provided for entering coefficients for each rod type. The active PAF value for each rod is shown. A new PAF value may be entered from this dialog. These new unique PAF values are used in analyses and retained in measurement results.

The only calibration curve type used for the collar so far is $D = am/(1 + bm)$, where D is the doubles rate, m is the ^{235}U mass, and a and b are calibration coefficients. You can enter the calibration coefficients and errors from the keyboard or read them from a disk file under *File / Get External Data / Initial Data*. The extra error term (sigma x) is normally zero. This error is used to account for error sources not accounted for by the curve-fitting process and is expressed as percent relative standard deviation; the corresponding mass error is combined quadratically with the mass error calculated from the calibration curve variances and covariances and the doubles rate standard deviation.

The number of calibration rods is the number of rods in the fuel assembly used to determine the calibration parameters.

The poison correction factor k3 has the form:

$$k3 = 1 + n * N0 / N * a * [1 - \exp(-\text{lambda} * \text{poison})] * (b - c * E)$$

where:

n	=	number of poison rods in the measured fuel assembly
N0	=	number of rods in reference fuel assembly
N	=	total number of rods in the measured fuel assembly
lambda	=	poison absorption factor
poison	=	weight-percent poison in the poison rods
E	=	^{235}U enrichment in percent
a, b, c	=	calibration constants

Lambda depends on the type of poison rod. You can enter new poison rod types under *Maintain / Poison Rod Type Add/Delete*.

The uranium mass correction factor k4 has the form:

$$k4 = 1 + a * (b - U)$$

where:

U	=	total uranium mass in grams
a, b	=	calibration constants

The extra item correction factor k5 accounts for other sample effects such as protective bagging and cardboard around a fuel assembly. The k5 correction factor can be composed of up to 20 separate factors and their absolute errors which can be enabled on an individual measurement basis. The final k5 correction factor is the product of all the k5 components selected for a particular measurement.

You can find details about collar calibration in the Los Alamos report “Neutron Collar Calibration and Evaluation for Assay of LWR Fuel Assemblies Containing Burnable Neutron Absorbers”, LA-11965-MS (1990). This report gives calibration parameters for PWR and BWR fuel assemblies containing gadolinium poison rods.

You can print all of the collar calibration parameters by clicking on “Print calibration parameters” in either the “Collar Calibration” or “Correction Factors” dialog box.

Active Multiplicity

To use this analysis method select *Maintain / Calibration / Active Multiplicity*.

There is a set of calibration parameters for each material type. For active multiplicity verification the only quantity determined at present is the neutron multiplication; verification ^{235}U mass is not determined. The neutron multiplication can be determined from the measured triples and doubles rates and six nuclear data constants. You will probably not need to change these constants from their default values:

1st factorial moment of thermal neutron induced fission of ^{235}U :	2.414
2nd factorial moment of thermal neutron induced fission of ^{235}U :	4.638
3rd factorial moment of thermal neutron induced fission of ^{235}U :	6.818
1st factorial moment of fast neutron induced fission of ^{235}U :	2.637
2nd factorial moment of fast neutron induced fission of ^{235}U :	5.623
3rd factorial moment of fast neutron induced fission of ^{235}U :	9.476

The calibration parameters can be printed with the measurement (detector) parameters by selecting the "Print calibration parameters" button.

Active/Passive

To use this analysis method select *Maintain / Calibration / Active/Passive*.

The active/passive technique is used for the active verification of items which have a passive neutron yield. At present this technique simply subtracts the passive count rates from the active count rates and calculates the effective ^{235}U mass from the calibration curve.

There is a calibration parameter set for each material type. A set consists of the curve type, the coefficients, the variances, the covariances, and an extra error term (sigma x).

The curve types are:

1. $D = a + bm + cm^2 + dm^3$
2. $D = am^b$
3. $D = am / (1 + bm)$
4. $D = a (1 - e^{-bm})$

Where D is the doubles rate, m is the mass of effective ^{240}Pu or ^{235}U , and a, b, c, and d are calibration coefficients.

You can enter the parameters from the keyboard or use the Deming code to enter the parameters automatically. The extra error term (sigma x) is always zero unless you change it from the keyboard. This error is used to account for extra error sources, for example, error sources not accounted for by the curve fitting process. The extra error is expressed as percent relative standard deviation; the corresponding mass error is combined quadratically with the mass error calculated from the calibration curve variances and covariances and the doubles rate standard deviation.

The calibration parameters can be printed with the measurement (detector) parameters by selecting the "Print calibration parameters" button.

Background Setup

You can inspect and change the background count rates under *Maintain / Background Setup*. The background rates are the passive singles, doubles, and triples rates with errors (room background), the active background singles rate and error (AmLi source background), and the passive and active background rates in scaler 1 and scaler 2 (the extra scalers on the PSR, MSR4, 2150 and AMSR shift-register units). Normally you do not need to use the Background Setup option. After a background measurement has completed, the background rates are automatically stored.

Normalization Setup

There are four options under *Maintain / Normalization Setup*:

- Use Cf252 source doubles rate for normalization test
- Use Cf252 source singles rate for normalization test
- Use AmLi source for normalization test
- Collar normalization test

Normally AmLi is used for normalization measurements with active systems such as the AWCC and Cf252 is used with passive systems such as the HLNC. Normalization measurements with the UNCL are always done with the fourth option.

If you select “Use AmLi source for normalization test”, you will get a dialog box with the following items:

- AmLi source id
- Normalization constant
- Normalization constant error
- AmLi reference singles rate
- AmLi reference singles date
- Acceptance limit (%)

Enter the id of your AmLi source. The normalization constant and error are initially 1 and 0, respectively. When you make a normalization measurement, the new normalization constant and error are displayed here. You can enter the normalization constant and error from the keyboard here, if necessary for special situations. When you make an initial source measurement with an AmLi source, the singles rate and date are stored as the AmLi reference rate and date and are displayed here. You can enter the reference rate and date from the keyboard, if necessary. The acceptance limit in percent determines whether the result of a normalization measurement is accepted. If the measurement produces a normalization constant that differs from 1 by more than the acceptance limit, then the constant is saved as the new normalization constant; otherwise, the normalization constant is set to 1 and the error is set to 0.

If you select “Use Cf252 source doubles rate for normalization test”, you will get a dialog box with the following items:

- Cf252 source id
- Normalization constant
- Normalization constant error
- Cf252 reference doubles rate
- Cf252 reference doubles rate error
- Cf252 reference doubles date
- Precision limit (%)
- Acceptance limit (std dev)
- Acceptance limit (%)

This is similar to the dialog box for AmLi normalization. The Cf252 reference rate error is included here because the counting-statistics error of the doubles rate is not necessarily negligible. Likewise, a precision limit is included. If an initial source or normalization measurement produces a precision for the doubles rate that is greater (*i.e.*, worse) than the precision limit, then the result is not accepted. There are two acceptance limits. If a normalization measurement produces a normalization constant that differs from 1 by more than the acceptance limit in percent and by more than the acceptance limit in standard deviations, then the constant is saved as the new normalization constant; otherwise, the normalization constant is set to 1 and the error is set to 0.

If you are using an add-a-source system, you can use the add-a-source as the normalization source. If you want to do this, check the add-a-source box at the bottom of the window and enter the desired position for the add-a-source during initial-source and normalization measurements.

If you select “Use Cf252 source singles rate for normalization test”, you will get a dialog box with the following items:

- Cf252 source id
- Normalization constant
- Normalization constant error
- Cf252 reference singles rate
- Cf252 reference singles rate error
- Cf252 reference singles date
- Precision limit (%)
- Acceptance limit (std dev)
- Acceptance limit (%)

This is very similar to the dialog box for Cf252 source doubles rate. The only difference is that singles rates are used instead of doubles rates and there is no choice to use add-a-source. This option should only be used if the doubles rates are very low.

If you select “Collar normalization test”, you will get a dialog box with the following items:

- AmLi source id
- Neutron yield relative to MRC-95
- Normalization constant
- Normalization constant error
- MRC-95 reference singles rate
- MRC-95 reference singles date
- Acceptance limit (%)

All the AmLi sources and collars have been cross-calibrated and are referenced to the AmLi source MRC-95. You can use any AmLi source for collar verification if you know its yield relative to MRC-95. Many AmLi relative source yields are listed in Table II of the Los Alamos report “Neutron Collar Calibration and Evaluation for Assay of LWR Fuel Assemblies Containing Burnable Neutron Absorbers”, LA-11965-MS (1990), p. 4. Many reference singles rates and dates for MRC-95 in UNCL detectors are listed in Tables XII-XV of this report [columns “T0 (empty)” and “T0 date”, respectively]. The acceptance limit is the same as described above.

Unattended Measurements Setup

To use this feature, select *Maintain / Unattended Measurements Setup*. This will bring up the “Unattended Measurement Parameters” dialog box which is detector dependent.

INCC can be used in conjunction with Radiation Review to analyze measurements acquired in unattended mode by either Shift Register Collect or Multi-Instrument Collect. In this case, Radiation Review can send a data matching message to INCC requesting the display of the previously imported verification measurement for the detector specified in the message that most closely matches the requested date and time. If the time difference between the requested date and time and the measurement date and time exceeds (plus or minus) the maximum time in seconds specified by a parameter entered from the “Unattended Measurement Parameters” dialog box, then a message will be displayed indicating no match was found for the requested verification measurement date and time.

When importing measurements from Radiation Review you have the option of being presented with an acquire dialog box for checking and possibly changing parameters as each measurement is imported or you can check the “Auto import” box here and have INCC use whatever parameters were previously entered for the item id of the current measurement. If no item id parameters were previously entered then you will be presented with an acquire dialog box regardless of whether or not the “Auto import” box was checked.

QC and Test Parameters

To use this feature, select *Maintain / QC and Test Parameters*. The program performs several quality control tests on the measurement data. One of these is a checksum test that is always applied to multiplicity data to check for internal consistency. There are no test parameters for this test, because exact agreement is required.

When you start a measurement of any type under *Acquire*, you can select whether or not to use the optional quality control tests. If you use the quality control (QC tests), the program will perform the accidentals/singles test and outlier test.

Measurements normally consist of repeat cycles, for example, 10 cycles of 100 seconds each. The accidentals/singles test compares the singles rate with the accidental coincidence rate at the end of each cycle. If the neutron source rate is constant during the cycle, then, within statistical errors, the accidentals rate should equal the square of the singles rate times the gate length. If the rates do not agree within statistical errors and the quality control tests are turned on, then the cycle is rejected and another is made automatically. The limit of acceptance is set by the parameter "Accidentals/singles test outlier limit (sigma)", which is the limit expressed in standard deviations. The usual limit is 4 standard deviations.

There are two additional limits used by the accidentals/singles test. The first of these is the "Accidentals/singles test rate limit (1/seconds)", which is usually set to 1000 1/second. The accidentals/singles test is not done if the singles rate is below this limit. The reason for this limit is that, at low count rates, room background variations can make the test fail, even though the system is working normally. For the same reason, the test is never done for passive background measurements.

The other additional limit is the "Accidentals/singles test precision limit (%)", which is usually set to 0.1%. If the accidentals and singles rates agree within this limit, the accidentals/singles statistical test is not done and the cycle is accepted. The reason for this limit is that the test can fail for cycles with excellent precision even though the accidentals/singles agreement is satisfactory.

The outlier test compares the results of individual cycles with the average of all the cycles and rejects cycles that fall outside the test limit. Additional cycles are then made automatically, if needed, to replace any rejected cycles. The parameter is "Outlier test limit (sigma)", which is the test limit expressed in standard deviations. The usual limit is 3 standard deviations. For verification measurements, the outlier test is done on the assay mass calculated for each of the cycles. For most other measurements, the outlier test is done on the doubles and triples rates. The outlier test is not done for precision measurements, because the purpose of the precision test is to compare the observed and theoretical standard deviations.

The measurement control chi-squared limit, expressed in percent, determines the upper and lower bounds for the chi-squared test; the limit is the probability that the measured chi-squared value will be between the upper and lower limits in the ideal case where the system is perfectly stable and the theoretical standard deviation is known exactly. The default value for the chi-squared limit is 99%.

To prevent a series of bad measurements from continuing indefinitely, there is a test parameter called "Max # of checksum or accidentals/singles failures", which is normally set to 10. If the number of cycles that fail these tests exceeds the limit, the measurement is stopped and the results are calculated, if possible, from any good cycles in the data set. To effectively disable this test, set this value to a large number, for example 1000.

If two or more passive analysis methods have been selected, then an automatic comparison of the verification results is made. The accepted verification result will be the "normal" analysis method unless it differs from the "backup" method by more than n standard deviations, where n is the "Normal/backup verification test limit (sigma)".

A comparison of the requested and actual high voltage is made after each cycle to insure that the high voltage has not drifted. If the "High voltage test limit (%)" is exceeded, that cycle is marked as having failed the HV test. The default value is 1 percent. To disable the test, set this value to 1000. It may occasionally be of interest to know what the high voltage is for each cycle. This can be done by setting this parameter to zero which will cause the high voltage to be displayed for every cycle.

A checkbox is provided for disabling consistency tests between shift register and multiplicity data if a multiplicity shift register is being used. These tests should only be turned off (box not checked) for very high counting rates where the multiplicity counter will overflow. The singles rate at which overflow will occur is dependent on gate length, and is approximately 1.5 million singles per second for a gate length of 64 microseconds. A smaller gate length will allow counting at higher rates before overflow occurs. The checksum test is never

performed, regardless of whether this box is checked, if an AMSR is being used because fast accidentals will cause the test to fail most of the time.

Two radio buttons are provided for choosing how to calculate the doubles rate. If you choose “Measure accidentals count rates” from the shift register then the following equation is used:

$$\text{Doubles rate} = ((\text{Reals} + \text{Accidentals}) - \text{Accidentals}) / \text{count time}$$

If you choose “Calculate the accidentals count rates (T^2G)” then the following equation is used:

$$\text{Doubles rate} = ((\text{Reals} + \text{Accidentals}) - (\text{singles} * \text{singles} * \text{gate length})) / \text{count time}$$

If you choose to calculate the accidentals rates then the error analysis will automatically be set to the sample standard deviation method. The default is to use the measured accidentals rates. When the doubles rate is obtained from the calculated accidentals coincidence rate, the doubles rate for a complete measurement is calculated as the average of the doubles rates for the individual cycles and differs slightly from the doubles rate calculated from the summed raw data; this method was chosen because the calculation assumes that the singles rate is constant during the data collection, and this is more likely to be true for each cycle than for the entire measurement.

Stratum Rejection Limits

To use this feature, select *Maintain / Stratum Rejection Limits*. For each stratum id you can enter a historical bias, historical random uncertainty and historical systematic uncertainty for the current detector. These values may also be obtained from Stratum Authority disk files by using *File / Get External Data / Stratum Authority File*. For verification measurements the mass acceptance test is as follows:

$$\text{Total uncertainty (delta)} = \text{sqrt}(\text{random}^2 + \text{systematic}^2)$$

Then the acceptance range is:

$$\text{bias} - 3 * \text{delta} \leq ((\text{declared mass} - \text{measured mass}) / \text{declared mass}) \leq \text{bias} + 3 * \text{delta}$$

If the measured mass is outside this acceptance range, then the measurement will be marked as having failed the quality test on all results displays and printouts and the discrepancy/anomaly flag will be set to “Y” and the delta value will be reported as the relative standard deviation in the PSA/Logsheet output file.

Error Calculation Method

To use this feature, select *Maintain / Error Calculation Method*.

There are two choices for calculating the measurement errors that result from counting statistics fluctuations: theoretical standard deviation and sample standard deviation. The theoretical standard deviations are calculated from error models that approximate the true errors; these errors are accurate to within about $\pm 15\%$ and can be calculated from any number of cycles. The sample standard deviations are calculated from the observed scatter of repeated cycles; the accuracy of these errors is determined by the number of cycles. The relative error of the sample standard deviation is $1/\sqrt{2n}$, where n is the number of cycles.

The default selection is theoretical standard deviations. For highly multiplying items, the theoretical error models underestimate the true errors by 50% to 100%, so sample standard deviations are recommended for this kind of material.. If an AMSR is being used then the sample standard deviation is always used regardless of which error method is chosen because the theoretical models will overestimate the errors.

Sweep

To configure and control the activation of this feature, select *Maintain / Sweep*. The Sweep Data Feature dialog is displayed. Configure the 'Sweep' features and select "OK".

'Sweep' is an automatic backup feature for analysis results. An INCC analysis creates text report using a time and date naming scheme (see Output files - File Naming Conventions below). INCC can also export a complete binary copy of all analysis results for a specific detector. INCC creates a separate file for each analysis which include the original measurement data, the calibration parameters used for the analysis, and the complete analysis results (see *Maintain / Transfer Save As/Export* for transfer file details). 'Sweep', when activated, takes advantage of these two types of INCC output files by automatically copying a text result and a binary transfer file to a user determined location. When activated, 'Sweep' will create these copies for each measurement analysis performed.

To activate 'Sweep', select the "Use the Sweep Feature" check box on the Sweep Feature Data dialog. To choose a sweep location, select the "Select Location:" button, and use the presented file dialog to navigate to the desired location, the folder to place the 'swept' copies of measurement results. Select "OK" to save the settings and close the dialog. Subsequent measurement analyses will use these 'Sweep' settings.

Because both the transfer binary file and the text results files share the same measurement file name and type file suffix, the 'Sweep' feature adds the .TXT suffix to the test results file. For example, suppose the 'Sweep' location is set to `d:\Sweep\helvetii\`, and the 'Sweep' feature has been activated. A Verification measurement is performed, with results file name `57605502.VER`. The transfer file name will also be `57605502.VER`. The 'Sweep' feature simply appends a `.txt` to the test results file `57605502.VER.txt`. Two files are copied to the sweep location: `57605502.VER` and `57605502.VER.txt`.

Archive

To use this feature, select *Maintain / Archive*.

The Archive dialog box provides the user with the ability to control the number of days before an automatic file archive or automatic file deletion action is taken in each of three cases:

1. For each measurement, ASCII results files are created in the \DATA subdirectory, and then automatically moved to the \DATA\ARCHIVE subdirectory after a specified number of days. The default is 90 days.
2. **After the specified number of days, ASCII measurement results files are automatically deleted from both the \DATA subdirectory and the \DATA\ARCHIVE subdirectory.** The default is 1000 days.
3. **After the specified number of days, measurement results are automatically deleted from the INCC database..** The default is 10000 days, effectively disabling this option.

To effectively disable some or all of these features, simply set the number of days to a very large number. However, automatic archive and deletion prevent the \DATA directory and the database from becoming very large and thus degrading performance.

Warning: INCC and all other applications will be unable to execute if the database becomes so large that it uses all the available hard disk space.

Detector Add/Delete

To use this feature, select *Maintain / Detector Add/Delete*. A default detector id of XXXX/XXX/YY is provided with INCC when it is installed. The first four characters are the detector type, for example AWCC, the middle three characters identify the detector, and the last two characters are the configuration id.

To add a new detector, select “Add detector” from the dialog box, and then a dialog box will be displayed for you to type in the new detector (maximum of 11 characters in the form XXXX/XXX/YY) which will be placed in the detector id list. There is a maximum of 100 detectors. The detector type will automatically be converted to all uppercase letters.

To delete a detector, select “Delete detector” from the dialog box, and then a dialog box will be displayed for you to select the detector to be deleted from a drop down list.

Facility Add/Delete

To use this feature, select *Maintain / Facility Add/Delete*. A default facility of XXXX is provided with INCC when it is installed.

To add a new facility, select “Add facility” from the dialog box, and then a dialog box will be displayed for you to type in the new facility (maximum of 12 characters) and facility description (maximum of 20 characters) which will be placed in the facility list. There is a maximum of 50 facilities. The facility will automatically be converted to all uppercase letters.

To delete a facility, select “Delete facility” from the dialog box, and then a dialog box will be displayed for you to select the facility to be deleted from a drop down list.

MBA Add/Delete

To use this feature, select *Maintain / MBA Add/Delete*. A default Material Balance Area (MBA) of XXXX is provided with INCC when it is installed.

To add a new MBA, select “Add material balance area” from the dialog box, and then a dialog box will be displayed for you to type in the new MBA (maximum of 4 characters) and MBA description (maximum of 20 characters) which will be placed in the MBA list. There is a maximum of 50 material balance areas. The MBA will automatically be converted to all uppercase letters.

To delete an MBA, select “Delete material balance area” from the dialog box, and then a dialog box will be displayed for you to select the MBA to be deleted from a drop down list.

Stratum Id Add/Delete

To use this feature, select *Maintain / Stratum Id Add/Delete*.

To add a new stratum id, select “Add stratum id” from the dialog box, and then a dialog box will be displayed for you to type in the new stratum id (maximum of 12 characters) and description (maximum of 20 characters) which will be placed in the stratum id list. There is a maximum of 100 stratum ids. The stratum id will automatically be converted to all uppercase letters. You must use *Maintain / Stratum Rejection Limits* to enter a historical bias, historical random uncertainty and historical systematic uncertainty for each detector.

To delete a stratum id, select “Delete stratum id” from the dialog box, and then a dialog box will be displayed for you to select the stratum id to be deleted from a drop down list.

Material Type Add/Delete

To use this feature, select *Maintain / Material Type Add/Delete*. A default material type of Pu is provided with INCC when it is installed.

To add a new material type, select “Add material type” from the dialog box, and then a dialog box will be displayed for you to type in the new material type (maximum of 5 characters) which will be placed in the material type list. There is a maximum of 100 material types.

To delete an material type, select “Delete material type” from the dialog box, and then a dialog box will be displayed for you to select the material type to be deleted from a drop down list.

Poison Rod Type Add/Delete

To use this feature, select *Maintain / Poison Rod Type Add/Delete*. A default poison rod type of G for gadolinium is provided with INCC when it is installed.

To add a new poison type, select “Add poison rod type” from the dialog box, and then a dialog box will be displayed for you to type in the new poison rod type (maximum of one character) and its poison absorption factor (default is .647) which will be placed in the poison rod type list. There is a maximum of 10 poison types.

The default poison absorption factor for each rod type may be overridden for select Detector, Material Type and Thermal Code settings in Collar Calibration parameters. See the description in the Collar Calibration section.

To delete a poison rod type, select “Delete poison rod type” from the dialog box, and then a dialog box will be displayed for you to select the poison rod type to be deleted from a drop down list.

Glovebox Add/Edit/Delete

To use this feature, select *Maintain / Glovebox Add/Edit/Delete*.

This feature is used only for holdup measurements performed using the *Acquire / Holdup* option. It allows glovebox measurement geometries to be defined, edited, or removed from the database. The existing glovebox configurations can also be printed from here. In order to perform a measurement with *Acquire / Holdup*, it is necessary to have at least one glovebox defined. Four pieces of information are required to define a glovebox: (1) a glovebox identification number, (2) the number of rows (*i.e.* the number of vertical measurement positions), (3) the number of columns (*i.e.* the number of horizontal measurement positions), and (4) the distance between the detector and the glovebox. Item 4 is only for information purposes and is not required. The maximum number of rows allowed is 2 (minimum is 1), and the maximum number of columns allowed is 6 (minimum is 1).

To add a new glovebox, select “Add glovebox” from the dialog box, and then a dialog box will be displayed for you to type in the new glovebox id (maximum of 20 characters) and its dimensions (1 or 2 rows and 1 to 6 columns) which will be placed in the glovebox id list. There is a maximum of 100 glovebox ids.

To delete a glovebox, select “Delete glovebox” from the dialog box, and then a dialog box will be displayed for you to select the glovebox id to be deleted from a drop down list.

To change the dimensions of an existing glovebox, select “Edit an existing glovebox” from the dialog box.

To display and optionally print all the defined gloveboxes and their configuration, select “Display glovebox configuration” from the dialog box.

Add-a-source Setup

To use this feature, select *Maintain / Add-a-source Setup*. *Add-a-source Setup* is only used for systems with either a manual or automated add-a-source. It provides the method for setting up the manual add-a-source placement or setting up a CompuMotor 4000, CompuMotor 3000, JCC21 series PLC, WM3100 series or Canberra counter PLC to be used to move the ^{252}Cf source into position for verification measurements. First select which type of hardware is to be used to control movement of the ^{252}Cf source by clicking on the appropriate radio button. Then select the “OK” button.

If CompuMotor 4000 or CompuMotor 3000 is selected, the CompuMotor setup screen will be displayed. You can select COM Port 1 through COM Port 10. The distance to the over travel switches, the CompuMotor steps per inch, the bit mask settings, the axis number and the bit state when the CompuMotor is in an over travel switch depend upon how the CompuMotor was installed, and should only have to be set once. The number of and distances to measurement positions depend upon the physical configuration of the detector and the type of material being measured. Select the CompuMotor serial port that matches the hardware setup.

If JCC21 Series PLC, WM3100 series PLC or Canberra counter PLC is selected, the PLC setup screen will be displayed. You can select COM Port 1 through COM Port 10. The number of and distance to measurement positions depend upon the physical configuration of the detector and the type of material being measured. The WM3100 series PLC will automatically control opening and closing the door and turning the drum rotator on and off.

If manual is selected, the Manual Add-a-source Setup screen will be displayed. Enter the number of ^{252}Cf source positions to be measured. The first measurement will be without the ^{252}Cf source, and the remaining measurements will be with the ^{252}Cf source. A message will be displayed when the ^{252}Cf source should be moved to a new position.

Delete Measurements

To use this feature, select *Maintain / Delete Measurements*. This feature allows the user to delete measurements from the database that are no longer needed. An inverse chronological list (most recent first) of all measurements is displayed, one per line. Click on the line for

each measurement to be deleted, and it will be highlighted in blue. When you have selected all the measurements you want to delete, select the “OK” button.

Some Settings

To use this feature, select *Maintain / Some Settings*. This menu item provides access to some miscellaneous INCC settings.

Selecting “Clear ‘Ask Once’ Settings” resets the affirmation dialog prompt state to ‘Ask’ (the default for INCC). Some INCC affirmation dialogs can be hidden permanently after the user has responded to the dialog at least once. Clearing the ‘Ask Once’ settings causes dialog affirmations that have been presented to the user, and subsequently hidden, to be presented to the user again for affirmation.

The “Control DB Vista Popups” setting is used to suppress internal warning and error popup dialogs that may occur when an INCC database is disrupted. *Caution: this feature should not be used under normal operating circumstances. Use this feature only for diagnostic and recovery procedures.* An INCC database is also known as a “DB Vista” database. The internal DB Vista database management system will notify an INCC user with popup dialogs when low-level problems with an INCC database are encountered during processing. Database disruption can occur in unusual conditions, such as hard disk failure, surpassing hard disk space limits or power cycling the machine while an INCC database operation is in progress. When diagnosing or working to recover data from a disrupted INCC database, use the “Suppress DB Error Notifications” setting to suppress internal DB Vista database popups.

Certain Advanced Features

Certain advanced features may appear after the *Some Settings* menu. Features found here depend upon the INCC variant (one of US, IAEA, or EURATOM), and include *Add/Delete Password*, *Measure High Voltage Plateau* and *Select Pu240e Coefficients*.

Add/Delete Password

To use this feature, select *Maintain / Add/Delete Password*. Access to the Maintain menu and advanced features may be controlled using a password. Activate password use, and enter a password, using this feature. Similarly, an active password may be removed using this feature. The password feature provides a light barrier to unauthorized or inadvertent tampering of important calibration settings, and should be used together with complementary user training and administrative controls.

Measure High Voltage Plateau

To use this feature, select *Maintain / Measure High Voltage Plateau*. This feature is a method for observing the behavior of a particular detector across several voltage levels.

INCC performs a sequence of measurement runs with a detector. The number of runs is based on the entered parameters. At successively higher voltage levels, singles are measured and recorded. INCC presents a results report, updated after each successive run. The report is saved in a file, using a predefined name; the file name is shown on the face of the report.

The method comprises the steps of

Retrieving four parameters values from the plateau entry dialog:

$^{\min}V$ minimum voltage limit
 $^{\max}V$ maximum voltage limit
 $^{\text{step}}V$ voltage step size, range is 2 to 100 volts
 t step count time

Initializing three control variables

$\text{number of runs} = (^{\max}V - ^{\min}V) / ^{\text{step}}V + 1$
 $\text{voltage} = ^{\min}V$
 $i = 0$

Performing a sequence of measurements, where each measurement uses a higher voltage level, increased by $^{\text{step}}V$, the level not going over the maximum voltage level $^{\max}V$ and the run count not going over *number of runs*:

for $i \leq \text{number of runs}$ and $\text{voltage} < ^{\max}V$
 $\text{voltage} = ^{\min}V + i * ^{\text{step}}V$;
 set the detector's voltage;
 take one measurement for t seconds (a run);
 $i = i + 1$;

Select Pu240e Coefficients

To use this feature, select *Maintain / Select Pu240e Coefficients*. The standard coefficients for ^{240}Pu -effective, used in INCC plutonium mass calculations, are known from the PANDA book [20], (and see Effective ^{240}Pu Mass). These standard values for coefficients may be substituted for others in INCC mass calculations. This feature provides three additional choices for these coefficients, based on the accumulated work described in ESARDA 1999 [35].

The four choices:

Source	Gatewidth in μs	^{238}Pu	^{242}Pu
PANDA 1991	--	2.520	1.680
ESARDA 1999	64	2.707	1.658

ESARDA 1999	128	2.714	1.667
N95 HENCC	88	2.718	1.664

Acquire Submenu

In maintenance mode *Acquire* contains all measurement data acquisition methods. In Inspection mode only rates only, background, normalization, verification and holdup are available.

The data acquisition methods are rates only, background, initial source, normalization, precision, verification, calibration and holdup. Each of these data acquisition methods has at least one setup dialog box that you must fill in to acquire data. The following data entry elements are common to all data acquisition methods:

- Comment

- Count time

- Option to acquire using number of cycles or measurement precision

- Number of cycles

- Precision, minimum and maximum number of cycles for measurement precision acquisition

- Data source

- QC tests

- Print results

- Display results options

- Ending comment option

Comments are optional.

A measurement consists of the number of good cycles requested, for example, 10 cycles of 100 seconds each or the number of cycles needed to achieve the requested precision.

The data source can be shift register, database, disk file or manual entry. For background, normalization and verification measurements only, the data source can be 'review disk file', indicating that the data came from either the Shift Register Review or Radiation Review program:

- "Shift register" is the normal data acquisition mode from shift register electronics.

- "Database" refers to the database of previously acquired measurement data.

- "Disk file" refers to specially formatted disk files that allow arbitrary measurement data sets to be analyzed.

“Manual entry” allows the user to type in a count time, measurement date and up to 200 sets of totals (singles), reals plus accidentals and accidentals.

"Review disk file" refers to measurement data files that have been exported from the Shift Register Review or Radiation Review program in NCC format.

If you select "Database" as the data source, you will get an inverse chronological list (most recent first) of previous measurements of the same data acquisition method. When you select one of the previous measurements, the raw measurement data for that measurement are read from the database and are processed as though they came from the shift register. All of the parameters that are used to process the data are the current parameters in the database. This allows you, for example, to reanalyze old measurement data with different background, deadtime, calibration coefficients, etc. Measurements can only be reanalyzed one at a time.

Disk files are primarily intended for software diagnostics, but can also be used to import measurement data that were acquired without the use of this program. You can find the required format for these disk files in “Test data file format”. If you select "Disk file" as the data source, you will be asked to enter or select the filename for the file that contains your data. Each measurement must be in a separate file.

Manual entry is primarily intended for software diagnostics, but can also be used to import measurement data that were acquired without the use of this program.

You can acquire data with or without the quality control tests on. You should have the quality control tests on unless there is a special need to turn them off. The quality control tests that you can turn off are the accidentals/singles test and the outlier test. These are explained in “QC and Test parameters”. If the box labeled "QC tests" is checked, the quality control tests are turned on.

If the box labeled "Print results" is checked, the results will be printed at the end of each measurement. While a results text window is displayed, you can print it by clicking in the upper left corner of the window and then selecting “Print” from the drop down menu. If you do not print the results at the end of each measurement, you can print them later by selecting *Report*.

Check the ending comment box if you want to be able to add a description of the measurement when it has completed.

You can select the detail to display and print by checking boxes for the desired options *under Setup / Facility/Inspection*.

When the doubles rate is obtained from the calculated accidentals coincidence rate, the doubles rate for a complete measurement is calculated as the average of the doubles rates for the individual cycles and differs slightly from the doubles rate calculated from the summed raw data; this method was chosen because the calculation assumes that the singles rate is

constant during the data collection, and this is more likely to be true for each cycle than for the entire measurement.

Rates Only Acquire

To use this feature, select *Acquire / Rates only*. A "Rates only" measurement is a general purpose measurement used simply to get singles, doubles, triples and scaler count rates. You can enter an item id to identify the measurement. The program does nothing with the results except save them in the database. This measurement method corrects the raw data for deadtime and normalization, and subtracts background. These measurements can later be reanalyzed as verification measurements by selecting "Database" as the data source after selecting *Acquire / Verification*.

Background Acquire

To use this feature, select *Acquire / Background*. You can make two kinds of background measurements: passive and active. The passive background is room background only. The active background is room background plus the background from the AmLi interrogating sources in active systems. When you make a passive background measurement, the background singles and error, doubles and error, triples and error, and scaler rates are saved and are subtracted from the measured rates of future measurements. When you make an active background measurement, only the singles and error and scaler rates are saved and subtracted from the singles and scaler rates of future active measurements. Every time you make a background measurement, the previous background rates are replaced with the new background rates. You can also change the background rates manually by selecting *Maintain / Background Setup*. A background measurement will replace any rates entered manually. Background measurements are corrected for deadtime.

Initial Source Acquire

To use this feature, select *Acquire / Initial Source*. Except for UNCL detectors, you use the initial source measurement to obtain the reference count rate and date for normalization measurements. If you use an AmLi source, then the singles rate is the reference rate. If you use a ^{252}Cf source, then either the singles or doubles rate is the reference rate and the precision of the singles or doubles rate must be better than the precision limit specified in *Maintain / Normalization Setup* for the result to be accepted. After the successful completion of the initial source measurement, the reference rate and date are saved in the database; you can view these values under *Maintain / Normalization Setup*. For ^{252}Cf sources, the standard deviation of the singles or doubles rate is also saved, because this error might not be negligible.

Normalization Acquire

You use the normalization measurement to determine whether the detector efficiency has changed since the initial source measurement. The type of source (AmLi or ^{252}Cf) and the source id are specified under *Maintain / Normalization Setup*. If ^{252}Cf is the source type, then the precision of the measured singles or doubles rate must be better than the precision limit set in *Maintain / Normalization Setup* for the result to be accepted. For ^{252}Cf sources the normalization constant is the expected singles or doubles rate divided by the measured singles or doubles rate; for AmLi sources the normalization constant is the square of the ratio of the expected singles rate to the measured singles rate. For AmLi sources, if the normalization constant thus calculated differs from 1 by less than the acceptance limit specified in *Maintain / Normalization Setup*, then it is set to 1 and its error is set to 0. For ^{252}Cf sources, if the normalization constant thus calculated differs from 1 by less than either of the acceptance limits specified in *Maintain / Normalization Setup*, then it is set to 1 and its error is set to 0.

Precision Acquire

There are two kinds of measurement control, normalization and precision. To use this feature, select *Acquire / Precision*. You can use the precision test to verify that the scatter in the doubles rate in a series of cycles is the result of counting statistics only rather than counting statistics plus detector instability or electronic instability. The precision test compares the observed scatter to the theoretical scatter (the sample standard deviation to the theoretical standard deviation) using a chi-square test. The chi-square test value is the square of the ratio of sample to theoretical standard deviations. If the test ratio falls outside these limits, you will get a "Fail" message. Because there is a 1% chance of failing the test with a properly operating system, you should repeat the test if you get a failure. If you get consistent failures, the system needs repair.

Note, however, that the theoretical standard deviation is calculated from an approximate error model. You can force the precision test to fail by using a large number of cycles such that the error of the sample standard deviation is smaller than the error in the statistical error model. A reasonable range for the number of cycles is 15 to 30.

Verification Acquire

To use this feature, select *Acquire / Verification*. You can use the verification measurement to get the assay mass and error for an item using one or more analysis methods. Enter the id of your item and select the material type most appropriate for the item. The analysis methods for the material type selected must have already been set up by selecting *Maintain / Calibration / Analysis Methods*.

Select the "Isotopics" button to enter the isotopic composition of your item. The dialog box is the same as that obtained by selecting *Setup / Isotopics*, so you can enter the isotopic composition either here or there. Composite isotopics may also be entered by selecting the "Composite isotopics" button. The dialog box is the same as that obtained by selecting *Setup*

/ *Composite Isotopics*, so you can enter the composite isotopic composition either here or there.

There is an entry labeled "Declared total Pu or ^{235}U mass (g)". If you enter a declared mass for the verification item, the program will compare the assay mass with the declared mass in the results. If you set the declared mass to zero, then the comparison of assay and declared masses is not done.

You will get as many results sets as you have selected analysis methods. For passive verification measurements there is an automatic comparison of different analysis methods when two or more have been selected. The accepted verification result will be the "normal" method unless the result from the "backup" method differs by more than n standard deviations from the normal method, where n is a test parameter that can be set by selecting *Maintain / QC and Test Parameters*. If the two methods differ by more than the test limit then the backup result is accepted. The accepted result will be highlighted.

If the Curium Ratio analysis method is selected, a second dialog box will appear after the 'Verification Measurement' dialog box. This is the Curium Ratio dialog box. The following facility supplied parameters should be entered into their respective cells:

Monthly batch identification	Monthly batch id
Input batch identification	Input batch id
Value of declared total uranium mass in grams (if provided)	Declared U (g)
Value of declared ^{235}U mass in grams (if provided)	Declared U235 (g)
Curium-to-plutonium mass ratio	Cm (g) / Pu (g) ratio
Curium-to-plutonium mass ratio error	Cm/Pu ratio error
Curium-to-plutonium mass ratio analysis date	Cm/Pu ratio date
Curium-to-uranium mass ratio	Cm (g) / U (g) ratio
Curium-to-uranium mass ratio error	Cm/U ratio error
Curium-to-uranium mass ratio analysis date	Cm/U ratio date

If the plutonium isotopics are known, an effective half-life for the Pu can be entered (*Pu effective half-life (yr)*). The default value is the half-life of ^{240}Pu . The effective half-life can be calculated using the following equation:

$$t^{1/2} = 87.7 * f_{238} + 24100 * f_{239} + 6564 * f_{240} + 14.4 * f_{241} + 376000 * f_{242}$$

where:

$t^{1/2}$ is the effective half-life of the sample in years
 f_{238} is the isotopic fraction of ^{238}Pu
 f_{239} is the isotopic fraction of ^{239}Pu
 f_{240} is the isotopic fraction of ^{240}Pu
 f_{241} is the isotopic fraction of ^{241}Pu
 f_{242} is the isotopic fraction of ^{242}Pu

Note: The date format is determined by the computer settings which may be accessed through the control panel by clicking on the “Regional settings” icon.

Calibration Measurements Acquire

To use this feature, select *Acquire / Calibration Measurements*. You can use calibration measurements to collect data to obtain calibration curves for verification measurements. The calibration option is useful for passive verification using the calibration curve, known alpha, and add-a-source methods, and for active verification using the calibration curve technique. The calibration option is not useful for the other verification methods such as holdup, collar and multiplicity, because the calibration procedures for them are not as simple and must be done outside this program.

For passive verifications the calibration curve relates doubles rate to effective ^{240}Pu mass. For active verifications the calibration curve relates doubles rate to ^{235}U mass. The result of a calibration measurement is the doubles rate and the effective ^{240}Pu or the ^{235}U mass. After several calibration measurements are done for a particular material type, the calibration results can be used to generate a calibration curve using the Deming least squares program.

The doubles rate for the known alpha method is the doubles rate corrected for neutron multiplication. The program will calculate the doubles rate corrected for multiplication from the measured singles and doubles rates and from the alpha weight and rho-zero values entered by selecting *Maintain / Calibration / Known Alpha*. You should be certain, therefore, that the alpha weight and rho-zero values for your material type are entered in the calibration parameters before you make calibration measurements for the known alpha analysis method. If you forget to do this, all is not lost. You can enter the values later and then acquire calibration data using "Database" as the data source. This way you can reanalyze your calibration measurement data with the correct alpha weight and rho-zero values.

Holdup Acquire

To use this feature, select *Acquire / Holdup*. You can use the holdup acquire measurement option to determine the assay mass and error for a glovebox that is composed of i rows and j columns for a total of $i * j$ measurement positions. The count data are collected for each measurement position, and then averaged together to obtain a single measurement value. This single value is then used to calculate the mass of the holdup material from the calibration data. Only two analysis methods are valid for the holdup acquire feature: passive calibration curve and known alpha.

At the holdup dialog screen, enter the glovebox id, item id (which maybe the same as the glovebox id), and material type. Select any other acquire options as desired from the dialog screen. Enter the count time in seconds and the number of cycles that will be used for each glovebox measurement position.

Select the "Isotopics" button to enter the isotopic composition of your item. The dialog box is the same as that obtained by selecting *Setup / Isotopics*, so you can enter the isotopic composition either here or there. Composite isotopics may also be entered by selecting the "Composite isotopics" button. The dialog box is the same as that obtained by selecting *Setup / Composite isotopics*, so you can enter the composite isotopic composition either here or there.

There is an entry labeled "Declared total Pu or ^{235}U mass (g)". If you enter a declared mass for the verification item, the program will compare the assay mass with the declared mass in the results. If you set the declared mass to zero, then the comparison of assay and declared masses is not done.

After pressing "OK" from the holdup dialog screen, a second screen appears showing the measurement positions for the glovebox selected. Click on the corresponding position to be measured, and then click "Measure selected glovebox position" to start the measurement. Each measurement cycle is displayed on the screen with the corresponding statistical error for the doubles rate. The position measurement can be stopped prematurely by clicking on "Quit measurement with results" to save the data acquired or by clicking on "abort measurement" if the data are to be discarded. Once the measurement finishes, the "Select next holdup measurement position" screen reappears. The position just measured turns a different color and displays the doubles count rate and its statistical error. Another position can now be measured or remeasured by clicking on the appropriate location.

Once all the positions have been measured, click on "Quit measurement with results" from the "Select next holdup measurement position" screen. This ends the measurement for the glovebox and saves the data. The results of the measurement are displayed on the screen.

Reanalyze Submenu

Provides the ability to analyze any previous verification or holdup measurement in the database, and only change one or a few selected parameters.

Verification Reanalysis

There are two ways to reanalyze previously acquired verification measurements.

One is by selecting *Acquire / Verification*, and then selecting "Database" as the data source. If you do this, only the raw data from the original measurement will be used, and all the parameters currently in effect, for example calibration, background, detector, etc., will be used to analyze the data and calculate a mass.

The other way is to use this feature by selecting *Reanalyze / Verification*. Using this technique, you can analyze a previous measurement, and only change one or a few selected parameters. The parameters you can change are shown in the "Verification Measurement

Reanalysis” dialog box, and are material type (which would also affect the calibration), item id, stratum id, declared mass, normalization constant and error, inventory change code, I/O code, comment, ending comment, isotopics and background. You can also choose whether to use the original calibration or the current calibration for the selected material type and analysis methods. You also have the option of creating a new measurement and saving the original, or overwriting the original measurement.

Holdup Reanalysis

There are two ways to reanalyze previously acquired holdup measurements.

One is by selecting *Acquire / Holdup*, and then selecting “Database” as the data source. If you do this, only the raw data from the original measurement will be used, and all the parameters currently in effect, for example calibration, background, detector, etc., will be used to analyze the data and calculate a mass.

The other way is to use this feature by selecting *Reanalyze / Holdup*. Using this technique, you can analyze a previous measurement, and only change one or a few selected parameters. The parameters you can change are shown in the “Holdup Measurement Reanalysis” dialog box, and are material type (which would also affect the calibration), item id, stratum id, declared mass, normalization constant and error, comment, ending comment, isotopics and background. You can also choose whether to use the original calibration or the current calibration for the selected material type and analysis methods. You also have the option of creating a new measurement and saving the original, or overwriting the original measurement.

Report Submenu

Report contains all options for review and reporting of previously acquired measurement data, an option to write a summary of verification or holdup measurements in spreadsheet format, and an option to plot measurement data with their calibration curve.

In Inspection mode you can only review rates only, background, initial source, normalization, verification and holdup measurements.

All Measurements Report

To use this feature, select *Report / All Measurements*. This feature allows you to review any measurement of any type. It functions the same way as the other report options except that you get a list of all the measurements.

Batch Script Generation

The Batch Script Generation feature is applied from the All Measurements Report selection list dialog. The button “Gen script” prepares and saves an initial batch script file for use by the Batch Analysis feature. (See File - Batch Analysis.) The file created by this operation is used as a batch script template. The user edits the batch script template to modify input values for the measurement, in anticipation of performing new measurement analyses with the modified input values. Values available for modification are the item id, the measurement type, the declared mass, a comment field, the isotopics code, and source code. The batch script is used to analyze multiple measurements during one processing session.

The batch script file may be edited using Microsoft Excel, or, with care, a text editor. See Input files - Batch Script File Format for details on the batch script file syntax.

Once the script is modified, the batch script is executed using the *File / Batch Analysis* command, see File - Batch Analysis for details. The new analyses created by executing the batch script do not modify or change any previous analyses present in the INCC database.

Rates Only Report

To use this feature, select *Report / Rates Only*. This feature allows you to review the raw data and results from previous *Rates Only* data acquisitions. You will get a dialog box to select the desired report options, a print option and the type of report desired.

The types of reports are “Display results in text” and “Plot singles, doubles and triples”.

If you select “Plot singles, doubles and triples”, all other options will be grayed out. When you select the “OK” button, the next screen will be a list, in inverse chronological order (most recent first), of all rates only results. Click on all the results you want to report. The selected lines will be highlighted in blue. Then select the “OK” button. A graphical plot of the singles, doubles and triples will be displayed for each results set selected. The display contains options for printing the graph, zooming both the x and y axes, and manual scaling. The graphed results will remain in display windows until you manually close each one.

If you select “Display results in text”, you can check the "Print" box to have the report data printed exactly as displayed. You can also select which results are to be displayed by checking the appropriate boxes. The next screen will be a list, in inverse chronological order, of all rates only results. Click on all the results that you want to report. The selected lines will be highlighted in blue. Then select the "OK" button. All of the selected results will be displayed in cascaded windows and also printed, if the "Print" box was checked. The displayed results will remain in display windows until you manually close each one. The results displayed are the same as those displayed at the end of a rates only data acquisition.

Background Report

To use this feature, select *Report / Background*. This feature allows you to review the raw data and results from previous *Background* data acquisitions. You will get a dialog box to select the desired reports options, a print option and the type of report desired.

The types of reports are “Display results in text” and “Plot singles, doubles and triples”.

If you select “Plot singles, doubles and triples”, all other options will be grayed out. When you select the “OK” button, the next screen will be a list, in inverse chronological order (most recent first), of all background results. Click on all the results you want to report. The selected lines will be highlighted in blue. Then select the “OK” button. A graphical plot of the singles, doubles and triples will be displayed for each results set selected. The display contains options for printing the graph, zooming both the x and y axes, and manual scaling. The graphed results will remain in display windows until you manually close each one.

If you select “Display results in text”, you can check the "Print" box to have the report data printed exactly as displayed. You can also select which results are to be displayed by checking the appropriate boxes. The next screen will be a list, in inverse chronological order, of all background results. Click on all the results that you want to report. The selected lines will be highlighted in blue. Then select the "OK" button. All of the selected results will be displayed in cascaded windows and also printed, if the "Print" box was checked. The displayed results will remain in display windows until you manually close each one. The results displayed are the same as those displayed at the end of a background data acquisition.

Initial Source Report

To use this feature, select *Report / Initial Source*. This feature allows you to review the raw data and results from previous *Initial Source* data acquisitions. You will get a dialog box to select the desired report options, a print option and the type of report desired.

The types of reports are “Display results in text” and “Plot singles, doubles and triples”.

If you select “Plot singles, doubles and triples”, all other options will be grayed out. When you select the “OK” button, the next screen will be a list, in inverse chronological order (most recent first), of all initial source results. Click on all the results you want to report. The selected lines will be highlighted in blue. Then select the “OK” button. A graphical plot of the singles, doubles and triples will be displayed for each results set selected. The display contains options for printing the graph, zooming both the x and y axes, and manual scaling. The graphed results will remain in display windows until you manually close each one.

If you select “Display results in text”, you can check the "Print" box to have the report data printed exactly as displayed. You can also select which results are to be displayed by checking the appropriate boxes. The next screen will be a list, in inverse chronological order, of all normalization results. Click on all the results that you want to report. The selected lines will be highlighted in blue. Then select the "OK" button. All of the selected results will be displayed in cascaded windows and also printed, if the "Print" box was checked. The

displayed results will remain in display windows until you manually close each one. The results displayed are the same as those displayed at the end of an initial source data acquisition.

Normalization Report

To use this feature, select *Report / Normalization*. This feature allows you to review the raw data and results from previous *Normalization* data acquisitions. You will get a dialog box to select the desired report options, a print option and the type of report desired.

The types of reports are “Display results in text” and “Plot singles, doubles and triples”.

If you select “Plot singles, doubles and triples”, all other options will be grayed out. When you select the “OK” button, the next screen will be a list (most recent first), in inverse chronological order, of all normalization results. Click on all the results you want to report. The selected lines will be highlighted in blue. Then select the “OK” button. A graphical plot of the singles, doubles and triples will be displayed for each results set selected. The display contains options for printing the graph, zooming both the x and y axes, and manual scaling. The graphed results will remain in display windows until you manually close each one.

If you select “Display results in text”, you can check the "Print" box to have the report data printed exactly as displayed. You can also select which results are to be displayed by checking the appropriate boxes. The next screen will be a list, in inverse chronological order, of all normalization results. Click on all the results that you want to report. The selected lines will be highlighted in blue. Then select the "OK" button. All of the selected results will be displayed in cascaded windows and also printed, if the "Print" box was checked. The displayed results will remain in display windows until you manually close each one. The results displayed are the same as those displayed at the end of a normalization data acquisition.

Precision Report

To use this feature, select *Report / Precision*. This feature allows you to review the raw data and results from previous *Precision* data acquisitions. You will get a dialog box to select the desired report options, a print option and the type of report desired.

The types of reports are “Display results in text” and “Plot singles, doubles and triples”.

If you select “Plot singles, doubles and triples”, all other options will be grayed out. When you select the “OK” button, the next screen will be a list, in inverse chronological order (most recent first), of all precision results. Click on all the results you want to report. The selected lines will be highlighted in blue. Then select the “OK” button. A graphical plot of the singles, doubles and triples will be displayed for each results set selected. The display contains options for printing the graph, zooming both the x and y axes, and manual scaling. The graphed results will remain in display windows until you manually close each one.

If you select “Display results in text”, you can check the "Print" box to have the report data printed exactly as displayed. You can also select which results are to be displayed by checking the appropriate boxes. The next screen will be a list, in inverse chronological order, of all precision results. Click on all the results that you want to report. The selected lines will be highlighted in blue. Then select the "OK" button. All of the selected results will be displayed in cascaded windows and also printed, if the "Print" box was checked. The displayed results will remain in display windows until you manually close each one. The results displayed are the same as those displayed at the end of a precision data acquisition.

Verification Report

To use this feature, select *Report / Verification*. This feature allows you to review the raw data and results from previous *Verification* data acquisitions. You will get a dialog box to select the desired report options, a print option and the type of report desired. You must also select the desired inspection number or select "All" if you want to be able to report any verification measurement.

The types of reports are “Display results in text” and “Plot singles, doubles and triples”.

If you select “Plot singles, doubles and triples”, all other options will be grayed out. When you select the “OK” button, the next screen will be a list, in inverse chronological order (most recent first), of all verification results. Click on all the results you want to report. The selected lines will be highlighted in blue. Then select the “OK” button. A graphical plot of the singles, doubles and triples will be displayed for each results set selected. The display contains options for printing the graph, zooming both the x and y axes, and manual scaling. The graphed results will remain in display windows until you manually close each one.

If you select “Display results in text”, you can check the "Print" box to have the report data printed exactly as displayed. You can also select which results are to be displayed by checking the appropriate boxes. The next screen will be a list, in inverse chronological order, of all verification results. Click on all the results that you want to report. The selected lines will be highlighted in blue. Then select the "OK" button. All of the selected results will be displayed in cascaded windows and also printed, if the "Print" box was checked. The displayed results will remain in display windows until you manually close each one. The results displayed are the same as those displayed at the end of a verification data acquisition.

Calibration Report

To use this feature, select *Report / Calibration*. This feature allows you to review the raw data and results from previous *Calibration* data acquisitions. You will get a dialog box to select the desired report options, a print option and the type of report desired.

The types of reports are “Display results in text” and “Plot singles, doubles and triples”.

If you select “Plot singles, doubles and triples”, all other options will be grayed out. When you select the “OK” button, the next screen will be a list, in inverse chronological order (most recent first), of all calibration results. Click on all the results you want to report. The selected lines will be highlighted in blue. Then select the “OK” button. A graphical plot of the singles, doubles and triples will be displayed for each results set selected. The display contains options for printing the graph, zooming both the x and y axes, and manual scaling. The graphed results will remain in display windows until you manually close each one.

If you select “Display results in text”, you can check the "Print" box to have the report data printed exactly as displayed. You can also select which results are to be displayed by checking the appropriate boxes. The next screen will be a list, in inverse chronological order, of all calibration results. Click on all the results that you want to report. The selected lines will be highlighted in blue. Then select the "OK" button. All of the selected results will be displayed in cascaded windows and also printed, if the "Print" box was checked. The displayed results will remain in display windows until you manually close each one. The results displayed are the same as those displayed at the end of a calibration data acquisition.

Holdup Report

To use this feature, select *Report / Holdup*. This feature allows you to review the raw data and results from previous *Holdup* data acquisitions. A dialog box appears so you can select the results to display and the print option. You must select the desired inspection number or select “All” if you want to be able to select any holdup measurement for a report. Next, the “Measurement selection” screen shows the available holdup measurement files available. More than one file can be selected for displaying and printing at one time. The list of available files can also be printed from the “Measurement selection” screen.

Measurement Summary

To use this feature, select *Report / Measurement Summary*. This feature allows the user to create a disk file in comma separated variable (CSV) spreadsheet format for a selected set of measurement values and selected analysis methods. Check the boxes for the measurement values you want to include. You may also check the print box if you want a hard copy of what is written to the disk file. You must also select the desired inspection number or select "All" if you want to be able to include any measurement in the summary. Select the starting and ending date and time for the measurements you want to be able to include in the summary. The initial default starting date is 00/01/01 and the initial default ending date and time is the current date and time so that if you make no changes you will automatically get all verification measurements. You can use the radio buttons to choose between getting the current ending date time or the last entered ending date and time the next time you use the verification summary feature. The starting date and time will always be the last one entered.

When you select the "OK" button, you will be presented with a list of all measurements for the selected interval in inverse chronological order (most recent first). Click on all the measurements you want to have included in the CSV spreadsheet format disk file. They will

be highlighted in blue. Then select the "OK" button to write the file. The contents of the file will also be displayed on the screen. The first line contains all the column headers. Following the column header line is one line of values for each measurement selected. Fields that do not apply, such as Pu mass for a background measurement, will be blank.

Verification Summary

To use this feature, select *Report / Verification Summary*. This feature allows the user to create a disk file in comma separated variable (CSV) spreadsheet format for a selected set of verification measurement values and selected analysis methods. Check the boxes for the measurement values you want to include. You may also check the print box if you want a hard copy of what is written to the disk file. You must also select the desired inspection number or select "All" if you want to be able to include any verification measurement in the summary. Select the starting and ending date and time for the measurements you want to be able to include in the summary. The initial default starting date is 00/01/01 and the initial default ending date and time is the current date and time so that if you make no changes you will automatically get all verification measurements. You can use the radio buttons to choose between getting the current ending date time or the last entered ending date and time the next time you use the verification summary feature. The starting date and time will always be the last one entered.

When you select the "OK" button, you will be presented with a list of all verification measurements for the selected interval in inverse chronological order (most recent first). Click on all the verification measurements you want to have included in the CSV spreadsheet format disk file. They will be highlighted in blue. Then select the "OK" button to write the file. The contents of the file will also be displayed on the screen. The first line contains all the column headers. Following the column header line is one line of values for each verification measurement selected.

Holdup Summary

To use this feature, select *Report / Holdup Summary*. This feature allows the user to create a disk file in comma separated variable (CSV) spreadsheet format for a selected set of holdup measurement values. Check the boxes for the measurement values you want to include. You may also check the print box if you want a hard copy of what is written to the disk file. You must also select the desired inspection number or select "All" if you want to be able to include any holdup measurement in the summary. Select the starting and ending date and time for the measurements you want to be able to include in the summary. The initial default starting date is 00/01/01 and the initial default ending date and time is the current date and time so that if you make no changes you will automatically get all holdup measurements. You can use the radio buttons to choose between getting the current ending date time or the last entered ending date and time the next time you use the holdup summary feature. The starting date and time will always be the last one entered.

When you select the “OK” button, you will be presented with a list of holdup measurements in inverse chronological order (most recent first). Click on all the holdup measurements you want to have included in the CSV spreadsheet format disk file. They will be highlighted in blue. Then select the “OK” button to write the file. The contents of the file will also be displayed on the screen. The first line contains all the column headers. Following the column header line is a single line of the values for each holdup measurement selected.

Plot Normalization History

To use this feature, select *Report / Plot Normalization History*. A plot is displayed of all normalization measurements in chronological order. Each normalization measurement is plotted as a yellow point with error bars. The x axis is the count rate for each normalization measurement. The reference count rate (made with an initial source measurement) is plotted as a solid cyan line across the entire plot. Clicking on the Print button will produce a hard copy of the plot.

Plot Calibration and Verification Results

To use this feature, select *Report / Plot Calibration and Verification Results*. For a selected material type and analysis method, a list of verification measurements with a declared mass is presented for user selection. The selected verification measurements will be plotted in yellow as individual data points. The calibration curve will be plotted in cyan, and the individual data points used to create the calibration curve will also be plotted in cyan if they are available (the calibration curve was created using Deming called from INCC). The plotted data may also be printed by clicking on the "Print plot of calibration and verification results" check box.

When you select the “OK” button you will be presented with a list of all verification measurements for the selected material type and analysis method, in inverse chronological order. Click on all the verification measurements you want to have included in the plot. They will be highlighted in blue. Then select the "OK" button to plot the data.

Tools Submenu

Tools Contains an option providing the user with the ability to have Radiation Review display the peak corresponding to the most recently displayed INCC verification measurement.

Select Another Review Tool

1. When *Tools / Select Another Review Tool* is clicked, a dialog box containing a button for each installed review tool is displayed unless there are no other review tools installed, in which case an error message is displayed.

2. The user clicks on the button for the desired review tool.
3. A data matching message is sent to the selected review tool containing the date, time and detector id corresponding to the start of the last verification or normalization measurement displayed.

Steps 2 and 3 may be repeated for additional review tools.

Window Submenu

Window contains options for arranging measurement data windows.

Arrange Icons

To use this windows arrangement feature, select *Window / Arrange Icons*. If measurement data display forms have been minimized, selecting *Arrange Icons* will arrange them in rows.

Cascade

To use this windows arrangement feature, select *Window / Cascade*. Selecting *Cascade* will cause the most recent measurement results data display form to be fully in view, and all other forms to be arranged descending one on top of the other, with only the left edge and title exposed. Clicking on a partially hidden form will bring it to the front. INCC will automatically delete the oldest measurement results display if there are more than 20 that have not been manually deleted.

Tile

To use this windows arrangement feature, select *Window / Tile*. Selecting *Tile* will cause all the measurement data display forms to be in view as much as possible. This feature is useful when you want to compare two or more measurement results.

Help Submenu

Help contains two options, *Topics* which has most of the information contained in this manual, and *About INCC* which contains copyright information, the date and version number of INCC being used and authorship credits.

Topics

To use this feature, select *Help / Topics*. This feature has most of the information contained in this manual. It is structured in the standard windows help format, including a table of contents, topic search and hypertext links.

Procedures

To use this feature, select *Help / Procedures*. When *Procedures* is selected a WordPad window will be opened, and the readme file for INCC will be displayed. The default directory will be \INCC\PROCEDUR. Users can add their procedures to this directory manually or they can be put on the last INCC install disk, and then the install process will automatically put the user's procedures in the \INCC\PROCEDUR directory. If the procedures are added to the last INCC install disk then the file names must be no more than eight characters plus the three character suffix. The suffix must be either .TXT or .DOC.

App Info

Help / App Info displays an informational list of INCC installation and runtime internal settings. This information is useful for diagnostic purposes. The information may be copied to the Windows Clipboard as text with the “Copy to Clipboard” button. Once the information is copied to the Windows Clipboard, the text may be pasted into an email message or other document. Conventional Windows applications routinely use the Clipboard for this purpose. Clipboard paste operations are typically applied using the [Ctrl-V] keystroke combination, or the “Paste” entry on the applications “Edit” menu.

About INCC

To use this feature, select *Help / About INCC*. When *About INCC* is selected, a screen will appear showing copyright information and the current INCC version number and release date. Selecting the “Credits” button will display a dialog box listing the authors of this software.

Files

Input files

Stratum Authority File Format

All **values within a record** must be separated by commas and there must not be any carriage return and line feed (CRLF). If a text string contains a space, tab or comma , it must be enclosed in double quotes. All fields must always be present. Each **record** must be terminated by a carriage return and line feed (CRLF), but no comma. The exception is the last record which must not have either a comma or CRLF terminator.

The default file name is NCCstrat.dat

Stratum Authority files are entirely in text (ASCII).

Record format:

Facility code	12 characters
Stratum id	12 characters
Stratum description	20 characters
Historical bias	floating point number
Historical random uncertainty	floating point number
Historical systematic uncertainty	floating point number

Item Relevant Data File Format

All **values within a record** must be separated by commas and there must not be any carriage return and line feed (CRLF). If a text string contains a space, tab or comma , it must be enclosed in double quotes. All fields must always be present. Each **record** must be terminated by a carriage return and line feed (CRLF), but no comma. The exception is the last record which must not have either a comma or CRLF terminator.

The default file name is NCC_Item.dat

Item Relevant Data files are entirely in text (ASCII).

Record format:

Facility code	12 characters
MBA code	4 characters
Item id	12 characters
Stratum id	12 characters
Inventory change code	2 characters
I/O code	1 character
Material type	5 characters
Isotopics source code	2 characters
possible values: OD, IA, IM, OA, OC, OE, OS, CO	
Item type	1 character
blank	normal item
P	component item
C	composite item
L	LWR fuel assembly
Isotopics id	12 characters
Declared fuel rod length (cm)	floating point
Declared fuel rod length error	floating point
Declared total Pu (g)	floating point
Declared total Pu error	floating point
Declared depleted U (g)	floating point
Declared depleted U error	floating point
Declared natural U (g)	floating point
Declared natural U error	floating point
Declared enriched U (g)	floating point
Declared enriched U error	floating point
Declared total U235 (g)	floating point
Declared total U235 error	floating point
Declared total U238 (g)	floating point
Declared total U238 error	floating point
Pu 238 %	floating point
Pu 239 %	floating point

Pu 240 %	floating point
Pu 241 %	floating point
Pu 242 %	floating point
Pu isotopics measurement date	YYYYMMDD
Am 241 %	floating point
Am isotopics measurement date	YYYYMMDD
Pu 238 error	floating point
Pu 239 error	floating point
Pu 240 error	floating point
Pu 241 error	floating point
Pu 242 error	floating point
Am 241 error	floating point
Isotopics type	1 character
P = permanent, do not ever delete from database (not currently used)	
Declared total rods	integer
Declared total poison rods	integer
Declared poison %	floating point
Declared poison % error	floating point
Declared rod type	1 character

Operator Declaration File Format

All **values within a record** must be separated by commas and there must not be any carriage return and line feed (CRLF). If a text string contains a space, tab or comma , it must be enclosed in double quotes. All fields must always be present. Each **record** must be terminated by a carriage return and line feed (CRLF), but no comma. The exception is the last record which must not have either a comma or CRLF terminator.

Operator declaration files are entirely in text (ASCII).

Record format:

Normalization measurement flag “Cf” if a Normalization measurement, otherwise empty

MBA code	4 characters
Item id	12 characters
Stratum id	12 characters
Inventory change code	2 characters
I/O code	1 character
Material type	5 characters
Declared mass (g)	floating point
Isotopics source code	2 characters
possible values: OD, IA, IM, OA, OC, OE, OS, CO	
Isotopics id	12 characters
Pu 238 %	floating point
Pu 239 %	floating point
Pu 240 %	floating point
Pu 241 %	floating point
Pu 242 %	floating point
Pu isotopics measurement date	YYYYMMDD
Am 241 %	floating point
Am isotopics measurement date	YYYYMMDD
Pu 238 error	floating point
Pu 239 error	floating point
Pu 240 error	floating point
Pu 241 error	floating point
Pu 242 error	floating point
Am 241 error	floating point

Operator Declaration File Format for Curium Ratio Measurements

All **values within a record** must be separated by commas and there must not be any carriage return and line feed (CRLF). If a text string contains a space, tab or comma , it must be enclosed in double quotes. All fields must always be present. Each **record** must be terminated by a carriage return and line feed (CRLF), but no comma. The exception is the last record which must not have either a comma or CRLF terminator.

Operator declaration files are entirely in text (ASCII).

Record format:

Item id	12 characters
Label for id	12 characters
Id	12 characters
Input batch id	12 characters
Declared Pu mass (g)	floating point
Declared U mass (g)	floating point
Declared ²³⁵ U mass (g)	floating point
Cm/Pu ratio	floating point
Cm/Pu ratio error	floating point
Cm/Pu ratio date	YYYYMMDD
Cm/U ratio	floating point
Cm/U ratio error	floating point
Cm/U ratio date	YYYYMMDD

Isotopics Data File Format

All **values within a record** must be separated by commas and there must not be any carriage return and line feed (CRLF). If a text string contains a space, tab or comma, it must be enclosed in double quotes. All fields must always be present. Each **record** must be terminated by a carriage return and line feed (CRLF), but no comma. The exception is the last record which must not have either a comma or CRLF terminator. There can be up to 1000 sets of isotopics in the INCC database.

Isotopics data files are entirely in text (ASCII).

Record format:

Isotopics id, Isotopics source code, ²³⁸Pu, ²³⁹Pu, ²⁴⁰Pu, ²⁴¹Pu, ²⁴²Pu, Pu date, ²⁴¹Am, Am date, ²³⁸Pu error, ²³⁹Pu error, ²⁴⁰Pu error, ²⁴¹Pu error, ²⁴²Pu error, ²⁴¹Am error

Only the first 12 characters of the isotopics id will be used. If the isotopics id contains a space or other white space character, it must be enclosed in double quotes.

The possible two character isotopics source codes are: OD, IA, IM, OA, OC, OE, OS, CO.

All isotopic values are in weight % Pu.

All error values are in weight % Pu.

The date format is: YYYYMMDD

Composite Isotopics Data File Format

All **values within a record** must be separated by commas and there must not be any carriage return and line feed (CRLF). If a text string contains a space, tab or comma, it must be enclosed in double quotes. All fields must always be present. Each **record** must be terminated by a carriage return and line feed (CRLF), but no comma. The exception is the last record which must not have either a comma or CRLF terminator.

Composite isotopics data files are entirely in text (ASCII).

First record format

Isotopics id, Isotopics source code, Pu mass, ²³⁸Pu, ²³⁹Pu, ²⁴⁰Pu, ²⁴¹Pu, ²⁴²Pu, Pu date, ²⁴¹Am, Am date, ²³⁸Pu error, ²³⁹Pu error, ²⁴⁰Pu error, ²⁴¹Pu error, ²⁴²Pu error, ²⁴¹Am error

Format of all records except the first:

Pu mass, ²³⁸Pu, ²³⁹Pu, ²⁴⁰Pu, ²⁴¹Pu, ²⁴²Pu, Pu date, ²⁴¹Am, Am date, ²³⁸Pu error, ²³⁹Pu error, ²⁴⁰Pu error, ²⁴¹Pu error, ²⁴²Pu error, ²⁴¹Am error

Only the first 12 characters of the isotopics id will be used. If the isotopics id contains a space or other white space character, it must be enclosed in double quotes.

The possible two character isotopics source codes are: OD, IA, IM, OA, OC, OE, OS, CO.

Mass is in grams Pu. Composite isotopics are weighted by mass.

All isotopic values are in weight % Pu.

All error values are in weight % Pu.

The date format is: YYYYMMDD

Repeat the mass, isotopic values and error values for each set of isotopics up to a maximum of six.

Test Data File Format

Test data files are entirely in text (ASCII), and all values must be separated by white space:

Number of cycles (n)
Count time per cycle in seconds

Repeat the following lines for each of n cycles:

Singles 1st Scaler 2nd Scaler Reals + Accidentals Accidentals
Number of multiplicity values (m)
1st multiplicity reals + accidentals 1st multiplicity accidentals
2nd multiplicity reals + accidentals 2nd multiplicity accidentals
.
.
.
mth multiplicity reals + accidentals mth multiplicity accidentals

If add-a-source data, append the following for each add-a-source position:

Number of cycles for add-a-source position i (n)
Count time for add-a-source position i

Repeat the following lines for each of n add-a-source position i cycles:

Singles 1st scaler 2nd scaler Reals + Accidentals Accidentals
Number of multiplicity values (m)
1st multiplicity reals + accidentals 1st multiplicity accidentals
2nd multiplicity reals + accidentals 2nd multiplicity accidentals
.
.
.
mth multiplicity reals + accidentals mth multiplicity accidentals

Holdup Test Data File Format

Holdup test data files are entirely in text (ASCII), and all values must be separated by white space. The number of rows must be 1 or 2, and the number of columns must be between 1 and 6, inclusive:

Number of glovebox rows (i)
Number of glovebox columns (j)

Repeat the following lines for each glovebox row and column (i,j):

Number of cycles (n)
Count time per cycle in seconds

Repeat the following lines for each of n cycles:

Singles	Reals + Accidentals	Accidentals
---------	---------------------	-------------

Radiation Review Measurement Data File Format

Radiation Review Measurement Data File format (binary), file extension is always .NCC:

Header

“IREV” 4 characters specifying the file type

1 character B = background, N = normalization, V = verification

11 character detector id (XXXX/YYY/ZZ)

where:

XXXX = detector type, *e.g.* PCAS

YYY = detector identifier, *e.g.* 004

ZZ = configuration id, usually 01

12 character item id (filled with trailing blanks if less than 12 characters)

yy.mm.dd, 8 characters, date of first cycle

hh:mm:ss, 8 characters, time of first cycle

unsigned short, number of cycles

Repeated for each cycle in the measurement

yy.mm.dd, 8 characters, date of cycle i

hh:mm:ss, 8 characters, time of cycle i

unsigned short, count time in seconds for cycle i

double, totals for cycle i

double, R+A for cycle i

double, accidentals for cycle i

double, scaler 1 for cycle i

double, scaler 2 for cycle i

unsigned short, number of multiplicity values for cycle i (n = 0 to 128)

n unsigned longs, non-zero R+A multiplicity distributions for cycle i

n unsigned longs, non-zero accidentals multiplicity distributions for cycle i

Note: All cycles in a verification or normalization measurement must have the same count time. Background measurements may have cycles with different count times because all the cycles will be summed into one cycle.

Batch Script File Format

The analysis batch script file extension is .xls, normally assigned to Microsoft Excel spreadsheets. However, any other file suffix will suffice. An important detail of script file syntax is that each of the nine fields must be separated by tab characters. Excel is the best tool for editing tab-delimited file content.

A measurement for analysis is identified by a single row of tab-delimited fields. One measurement is assigned per line. There are currently nine tab-delimited fields in a script entry. Names in the batch script fields cannot contain tab characters, because tab characters are used for syntactic separation.

To keep a script line in the file, but prevent it from being batch processed, place a # character at the beginning of the line. Notice that the header line has a leading # character, making it a comment. The # character does not change Excel's ability to parse the header into a convenient set of nine columns for editing.

Blank lines are acceptable, and are skipped during processing.

Details on the content of each field.

Names in the batch script cannot contain tabs.

Each field must have an entry, if it is left blank (space, tab or non-printable characters), the line will be parsed with errors and subsequently skipped during the batch processing.

The **MType** (*Measurement Type*) field is the measurement type, one of B, C, V, N, and R. Batch analysis is restricted to Background, Calibration, Verification, Normalization (Bias) and Rates Only measurements.

Users may modify the fields for **ItemId**, **MType**, **DeclaredMass(g)**, **EndComment**, **ISO** (isotopics code), and **code** (source code) fields.

If a measurement does not have an item id, the placeholder text **<no-id>** is added. Similarly for the ending comment, using the text **<end comment>**. Change the item id and comment fields to contain useful identifiers and comments that can assist in tracking and identifying the analysis results. Note that the end comment can be up to 50 characters long.

When an entry is prepared for analysis by the batch processing operation, the processing looks for the correct isotopics using the name in the ISO field. If the correct isotopics cannot be found in the database by that name, the analysis will use the default isotopics of INCC.

The **Date**, **Time** and **OrigFileName** fields should not be changed. These three fields identify the originating measurement, providing the original calibration parameters and measurement data values. Those values are used as the basis for the new analysis. The modified values of the script entry override the original values in the new analysis.

Each line may be commented by preceding it with the '#' character. Commenting a line causes batch file script processing to skip processing of the line. To keep a script line in the file, but prevent it from being batch processed, place a # character at the beginning of the line.

Below is sample batch script file.

- The first line of the file is nine column headers, prefixed by #.
- Each successive line identifies an existing measurement.
- The accented field entries have been modified, or may be modified, for batch processing to produce new analysis results.

- The third measurement entry is commented out with a # character.

#Date	Time	Mtype	ItemId	DeclaredMass(g)	EndComment	ISO	code	OrigFileName
12.06.15	12:54:49	<u>B</u>	<u>mote</u>	<u>1.01</u>	<u>your comment here</u>	<u>Default</u>	<u>OD</u>	26FM5449.BKG
12.06.15	10:51:45	R	bifstek	3.1416	try this	Test	OD	26FK5145.RTS
#12.06.15	10:51:39	<u>C</u>	<u>pescado</u>	<u>0.123</u>	<u>with comment</u>	<u>Another</u>	<u>OD</u>	26FK5139.CAL
10.06.15	10:51:37	<u>N</u>	<u>habanero</u>	<u>6.54321</u>	<u>a comment</u>	<u>Special</u>	<u>OD</u>	06FK5137.NOR
11.06.15	10:50:45	<u>V</u>	<u>puccini</u>	<u>1.234</u>	<u>some thing</u>	<u>Unusual</u>	<u>OD</u>	16FK5045.VER

Output files

File Naming Conventions

The text (ASCII) data file naming convention for measurement results is based on the date and time of day of the measurement as follows:

YMDHMMSS

Y = last digit of the year

M = month (0-9, A-C)

D = day (0-9, A-V)

H = hour (A-X)

MM = minutes (00-59)

SS = seconds (00-59)

Rates only files have a suffix of .RTS

Background files have a suffix of .BKG

Initial source files have a suffix of .INS

Normalization files have a suffix of .NOR

Precision files have a suffix of .PRE

Verification files have a suffix of .VER

Calibration files have a suffix of .CAL

Holdup files have a suffix of .HUP

PSA Operator-Inspector Measurement Database and Logsheet File Format

All values will be separated by commas. If a text string contains a space or other white space character, it will be enclosed in double quotes. All fields will always be present. NULL strings (“”) or zeros will be used when a field is not applicable. All floating point values will have six digits to the right of the decimal point.

The default file name is NCC_PSA.dat

Facility code	12 characters
MBA code	4 characters
Stratum id	12 characters
Item id	12 characters
Material type	5 characters
Inspection year	YYYY
Inspection number	12 characters
Measurement date	YYYYMMDD
Measurement time	HHMMSS
Detector type	11 characters
Detector id	8 characters
Configuration id	2 characters
Electronics id	8 characters
Measurement number	integer
Inventory change code	2 characters
I/O code	1 character
Operator's declarations:	
Isotopics id	12 characters
Pu total (g)	floating point
U total (g)	floating point
U235 total (g)	floating point
U235 %	floating point
Pu 238 %	floating point
Pu 239 %	floating point
Pu 240 %	floating point
Pu 241 %	floating point
Pu 242 %	floating point
Pu isotopics measurement date	YYYYMMDD
Am 241 %	floating point
Am isotopics measurement date	YYYYMMDD
Inspector's measurements:	
Isotopics id	12 characters
Isotopics source code	2 characters
Pu total, uncorrected (g)	floating point
Pu total, known alpha (g)	floating point

Pu total, multiplicity (g)	floating point
Pu total, known M (g)	floating point
Pu total, add-a-source (g)	floating point
Pu total, primary analysis method (g)	floating point
Primary analysis method	1 character
U	uncorrected
C	known alpha (multiplication corrected)
K	known M
M	multiplicity
A	add-a-source
R	curium ratio
T	truncated multiplicity
NULL	none
U total (g)	floating point
U235 total (g)	floating point
U235 %	floating point
Pu 238 %	floating point
Pu 239 %	floating point
Pu 240 %	floating point
Pu 241 %	floating point
Pu 242 %	floating point
Pu isotopics measurement date	YYYYMMDD
Am 241 %	floating point
Am isotopics measurement date	YYYYMMDD
Relative standard deviation	floating point
(total uncertainty for the stratum)	
Discrepancy/anomaly (Y/N)	1 character
(Y = primary analysis method failed stratum RSD uncertainty test)	
(N = primary analysis method passed stratum RSD uncertainty test)	

Performance Monitoring File Format

All values will be separated by commas. If a text string contains a space or other white space character, it will be enclosed in double quotes. All fields will always be present. NULL strings (“”) or zeros will be used when a field is not applicable. All floating point values will have six digits to the right of the decimal point.

This file contains only initial source and normalization measurements.

The default file name is NCC_perf.dat

Facility code	12 characters
MBA code	4 characters
Inspection year	YYYY
Inspection number	12 characters
Measurement date	YYYYMMDD
Measurement time	HHMMSS
Measurement type	1 character
(S = initial source, N = normalization)	
Detector type	11 characters
Detector id	8 characters
Configuration id	2 characters
Electronics id	8 characters
Normalization source id	12 characters
Measurement, total good count time	integer
Singles sum	integer
R + A sum	integer
Reals sum	integer
Normalization constant	floating point
Ratio expected/measured singles or doubles rate	floating point
Ratio expected/measured singles or doubles rate error	floating point
Normalization test pass (Y/N)	1 character

Isotopics Data File Format

All **values within a record** must be separated by commas and there will not be any carriage return and line feed (CRLF). If a text string contains a space, tab or comma , it will be enclosed in double quotes. All fields will always be present. Each **record** will be terminated by a carriage return and line feed (CRLF), but no comma. The exception is the last record which will not have either a comma or CRLF terminator.

Isotopics data files are entirely in text (ASCII).

Record format:

Isotopics id, Isotopics source code, ²³⁸Pu, ²³⁹Pu, ²⁴⁰Pu, ²⁴¹Pu, ²⁴²Pu, Pu date, ²⁴¹Am, Am date, ²³⁸Pu error, ²³⁹Pu error, ²⁴⁰Pu error, ²⁴¹Pu error, ²⁴²Pu error, ²⁴¹Am error

Only the first 12 characters of the isotopics id will be used. If the isotopics id contains a space or other white space character, it must be enclosed in double quotes.

The possible two character isotopics source codes are: OD, IA, IM, OA, OC, OE, OS, CO.

All isotopic values are in weight % total Pu.

All error values are in weight % total Pu.

The date format is: YYYYMMDD

Composite Isotopics Data File Format

All **values within a record** will be separated by commas and there will not be any carriage return and line feed (CRLF). If a text string contains a space, tab or comma, it will be enclosed in double quotes. All fields must always be present. Each **record** will be terminated by a carriage return and line feed (CRLF), but no comma. The exception is the last record which will not have either a comma or CRLF terminator.

Composite isotopics data files are entirely in text (ASCII).

First record format

Isotopics id, Isotopics source code, Pu mass, ²³⁸Pu, ²³⁹Pu, ²⁴⁰Pu, ²⁴¹Pu, ²⁴²Pu, Pu date, ²⁴¹Am, Am date, ²³⁸Pu error, ²³⁹Pu error, ²⁴⁰Pu error, ²⁴¹Pu error, ²⁴²Pu error, ²⁴¹Am error

Format of all records except the first:

Pu mass, ²³⁸Pu, ²³⁹Pu, ²⁴⁰Pu, ²⁴¹Pu, ²⁴²Pu, Pu date, ²⁴¹Am, Am date, ²³⁸Pu error, ²³⁹Pu error, ²⁴⁰Pu error, ²⁴¹Pu error, ²⁴²Pu error, ²⁴¹Am error

If the isotopics id contains a space or other white space character, it will be enclosed in double quotes.

The possible two character isotopics source codes are: OD, IA, IM, OA, OC, OE, OS, CO.

Mass is in grams Pu. Composite isotopics are weighted by mass.

All isotopic values are in weight % total Pu.

INCC Analysis Algorithms

Introduction

This section of the User's Manual presents the data analysis techniques used by the International Neutron Coincidence Counting (INCC) software. The underlying principles of neutron coincidence and multiplicity counting, both of which are routine techniques for the nondestructive assay of plutonium, are discussed in detail in Refs. 19 and 20. The add-a-source technique is described in Ref. 11 and the truncated multiplicity technique is described in Ref. 17.

With the exception of routine error propagations, references are provided for the derivations of the analysis equations.

The INCC software has many test parameters that can be changed by the user. When default values are specified here, they refer to the INCC initial values that can be edited by the user from dialog boxes.

Unless otherwise specified in this report, mass is in units of grams, time in units of seconds, and rate in units of 1/seconds. Also, unless otherwise specified, “error” is equivalent to “standard deviation”. The standard deviation of x is written equivalently as $\sigma(x)$ or σ_x .

Raw Data

The raw data depend on the type of shift register electronics used. All shift register electronics provide the counting time in seconds, singles (totals) counts, real-plus-accidental (R+A) coincidence counts and accidental (A) coincidence counts. In addition, multiplicity electronics provide two multiplicity distributions, the (R+A) distribution and the (A) distribution. The electronics collect multiplicities from 0 to 255, but INCC only uses and saves multiplicities from 0 to 127. Some electronics also collect data from two auxiliary scalers. A measurement consists of one or more cycles, each of which produces a raw data set. All data from all cycles are individually saved for analysis.

Quality Control (QC) Tests

The tests defined as QC tests are:

High voltage test

Raw data checksum tests:

1. Singles count test
2. Accidental coincidence count test
3. Real-plus-accidental coincidence count test

Accidentals/singles test

Outlier test

These tests are described in subsequent sections.

High Voltage Test

When the shift register electronics package is able to set the high voltage under software control, the software compares the high voltage output with the high voltage requested. If the two values agree within 1% (default), the test passes. If not, the measurement cycle with the failed high voltage test is rejected; in this case, an error message is generated and the cycle data are not further processed. This test can be disabled if you are in maintenance mode by selecting *Maintain / QC and Test Parameters* from the Main Menu, and setting the "High voltage test limit" parameter to 1000.

Raw Data Checksum Tests

These tests are performed only for multiplicity electronics and the tests depend on the type of multiplicity electronics. For circuits that don't use the fast accidental sampling technique, there must be exact agreement for the following three equations.

1. Singles count test:

$$C_S = \sum_{n=0}^{127} C_n^A$$

2. Real-plus-accidental coincidence count test:

$$C_{R+A} = \sum_{n=1}^{127} n C_n^{R+A}$$

3. Accidental coincidence count test:

$$C_A = \sum_{n=1}^{127} n C_n^A$$

These tests are performed at the end of each measurement cycle. If there is exact agreement, the tests pass; otherwise, an error message is generated and the cycle data are not further processed. Failure of the checksum tests indicates an electronic failure unless the multiplicity distributions have multiplicities above 127, in which case the checksum tests can be turned off to allow conventional coincidence counting with multiplicity electronics.

For multiplicity electronics that use the fast accidental sampling technique [*e.g.*, the Advanced Multiplicity Shift Register (AMSR)] , the accidental coincidence count test (number 3 above) is not done, the real-plus-accidental coincidence count test is done as shown in test number 2 above, and the singles count test is done using the following equation:

$$C_S = \sum_{n=0}^{127} C_n^{R+A}$$

Measured Count Rates

Measured count rates are rates without deadtime, background, or normalization corrections. The measured singles, doubles, and triples rates (S_m , D_m , and T_m , respectively) are [19]

$$S_m = \frac{C_S}{t_m}$$

$$D_m = \frac{C_{R+A} - C_A}{t_m}$$

$$T_m = \frac{z}{t_m}$$

where

$$z = \sum_{n=2}^{127} \binom{n}{2} (C_n^{R+A} - C_n^A) - \frac{\sum_{n=1}^{127} n C_n^A}{\sum_{n=0}^{127} C_n^A} \left[\sum_{n=1}^{127} n (C_n^{R+A} - C_n^A) \right]$$

For electronics that do not have multiplicity circuits, T_m is set to zero.

The measured doubles rate can also be obtained by using the calculated, rather than the measured, accidental coincidence counts; this method is shown in the section titled “Calculated Accidental Coincidence Counts.” The method shown above is the default method.

The auxiliary measured count rates are

$$X_1 = \frac{C_{X1}}{t_m}$$

$$X_2 = \frac{C_{X2}}{t_m}$$

for auxiliary scalers 1 and 2, respectively.

Accidentals/Singles Test

The measured accidental coincidence rate is

$$A_m = \frac{C_A}{t_m}$$

and the accidental coincidence rate calculated from the singles rate is $S_m^2 G$ [20], where

G = coincidence gate length,

therefore the ratio

$$r_{as} = \frac{A_m}{S_m^2 G}$$

should be unity within statistical errors. Set

$$z = |1 - r_{as}|$$

The accidentals/singles test passes if

$$z < \frac{p_{as1}}{100}$$

where p_{as1} is the accidentals/singles precision limit in percent (default = 0.1 %) or if

$$z < \frac{p_{as2}}{\sqrt{C_A}}$$

where p_{as2} is the accidentals/singles outlier limit in standard deviations (default = 3) and $1 / \sqrt{C_A}$ is an empirical estimate of the standard deviation of z .

The accidentals/singles test is not done if

$$S_m < p_{as3}$$

where p_{as3} is the accidentals/singles test rate limit (default: 1000 counts/s). The test is also not done for background measurements.

Theoretical and Sample Standard Deviations

Standard deviations can be obtained from theoretical equations (default) or from the observed scatter of the determined quantities (sample standard deviations). If sample standard deviations are selected, the standard deviation of quantity x for individual cycles is [23]

$$\sigma_{ssd} = \left[\frac{\sum_{n=1}^{N_c} (x_n - \bar{x})^2}{N_c - 1} \right]^{1/2}$$

and the standard deviation of the mean is

$$\sigma_{ssd}^{mean} = \frac{\sigma_{ssd}}{\sqrt{N_c}}$$

where

N_c = number of cycles that pass the high voltage, checksum
and accidentals/singles tests

x_n = value of quantity x for cycle n

\bar{x} = average value of x over N_c cycles

If $N_c = 1$, then the sample standard deviation is set to zero.

Calculated Accidental Coincidence Counts

Calculations of the measured doubles rate can be based on the calculated, rather than the measured, accidental coincidence counts, which can be obtained from the singles counts [20]:

$$C_A^{calc} = \frac{C_S^2 G}{t_m}$$

where

C_A^{calc} = calculated accidental coincidence counts.

The measured doubles rate is then

$$D_m^{calcA} = \frac{C_{R+A} - C_A^{calc}}{t_m}$$

and the error calculation method is presently forced to sample standard deviations.

Outlier Tests

In the following description, “completed cycle” means a measurement cycle that passes the high voltage test, the checksum tests, and the accidentals/singles test. Except for verification measurements, outlier tests are performed on the doubles and triples rates of completed cycles after corrections for deadtime, background, and normalization. There are two outlier rejection procedures, depending on the number of requested cycles (N_c).

If $N_c \leq 100$ (default), this procedure is followed at the end of each cycle:

1. Calculate the average doubles and triples rates for all completed cycles.
2. Find the largest deviates from the average for both the doubles rates and the triples rates.
3. If the largest deviate for the doubles rate is greater than three standard deviations (default) from the average, tag the corresponding cycle as an outlier.

4. If the largest deviate for the triples rate is greater than three standard deviations (default) from the average, tag the corresponding cycle as an outlier.
5. Calculate the average doubles and triples rates for all completed cycles not tagged as outliers.
6. Using all completed cycles not tagged as outliers, repeat from step 2 until no new outliers are found.

If $N_c > 100$ (default), this procedure is done once at the end of the measurement:

1. Calculate the average doubles and triples rates for all completed cycles.
2. For each cycle where the doubles rate is greater than three standard deviations (default) from the average, tag the corresponding cycle as an outlier.
3. For each cycle where the triples rate is greater than three standard deviations (default) from the average, tag the corresponding cycle as an outlier.
4. Calculate the average doubles and triples rates for all completed cycles not tagged as outliers.

For verification measurements, the outlier test is performed on the effective ^{240}Pu mass rather than on the doubles and triples rates when sample standard deviations are selected as the error calculation method. However, for add-a-source measurements, the outlier test is always performed on the doubles and triples rates.

Errors of Measured Singles and Doubles Rates

The theoretical error of the measured singles rate is [3]

$$\sigma(S_m) = \left[1 + \frac{2D_m}{f_d^{theor} S_m} \right]^{1/2} \frac{\sqrt{C_S}}{t_m}$$

where the theoretical doubles gate fraction is

$$f_d^{theor} = \exp(-P / \tau) [1 - \exp(-G / \tau)]$$

where

P = predelay

τ = detector die away time

The theoretical error of the measured doubles rate is [3]

$$\sigma(D_m) = \left[1 + \frac{8\gamma D_m}{f_d^{theor} S_m} \right]^{1/2} \frac{\sqrt{C_{R+A} + C_A}}{t_m}$$

where

$$\gamma = 1 - \frac{1 - \exp(-G / \tau)}{(G / \tau)}$$

Count Rates Corrected for Deadtime

The deadtime correction for the singles and doubles rates uses the deadtime expression

$$\delta = A + BS_m$$

where A and B are deadtime coefficients. The deadtime corrected singles rate is [2]

$$S_d = S_m \exp(\delta S_m / 4)$$

and the deadtime corrected doubles rate is [2]

$$D_d = D_m \exp(\delta S_m)$$

The deadtime corrected triples rate is [21, 22]

$$T_d = \frac{\exp(\delta_{mult} S_m)(1 + CS_m)z}{t_m}$$

where

δ_{mult} = multiplicity deadtime

C = triples deadtime coefficient

$$z = \sum_{n=2}^{127} \beta_n (C_n^{R+A} - C_n^A) - \frac{\sum_{n=1}^{127} \alpha_n C_n^A}{\sum_{n=0}^{127} C_n^A} \left[\sum_{n=1}^{127} \alpha_n (C_n^{R+A} - C_n^A) \right]$$

where the multiplicity deadline coefficients α_n and β_n are given by

$$\alpha_1 = 1$$

$$\alpha_n = 1 + \sum_{k=0}^{n-2} \binom{n-1}{k+1} \frac{(k+1)^k \phi^k}{[1 - (k+1)\phi]^{k+2}} \quad (n > 1)$$

$$\beta_2 = \alpha_2 - 1$$

$$\beta_n = \alpha_n - 1 + \sum_{k=0}^{n-3} \binom{n-1}{k+2} \frac{(k+1)(k+2)^k \phi^k}{[1 - (k+2)\phi]^{k+3}} \quad (n > 2)$$

where

$$\phi = \frac{\delta_{mult}}{G}$$

$$\delta_{mult} > 0$$

If $\delta_{mult} = 0$

then

$$\alpha_n = n$$

$$\beta_n = \binom{n}{2}$$

The count rates of the auxiliary scalers are not corrected for deadline.

Theoretical Errors of Deadline Corrected Singles and Doubles Rates

The theoretical error of the deadline corrected singles rate is

$$\sigma(S_d) = S_d \left(\frac{A + 2BS_m}{4} + \frac{1}{S_m} \right) \sigma(S_m)$$

and, ignoring the correlation between S_m and D_m , the theoretical error of the deadtime corrected doubles rate is

$$\sigma(D_d) = |D_d| \left\{ \left[\frac{\sigma(D_m)}{D_m} \right]^2 + (A + 2BS_m)^2 \sigma(S_m)^2 \right\}^{1/2}$$

Theoretical Error of Deadtime Corrected Triples Rate

Before including the multiplicity deadtime parameter C, the error of the deadtime corrected triples rate is obtained [3] from the multiplicity singles, doubles, and triples variance-covariance matrix (3 x 3)

$$T_{sdt} = XU_{R+A}X^t + YU_A Y^t$$

where

U_{R+A} = variance-covariance matrix for the real-plus-accidental multiplicity distribution (128 x 128)

U_A = variance-covariance matrix for the accidental multiplicity distribution (128 x 128)

X = matrix of partial derivatives of the singles, doubles, and triples rates with respect to the real-plus-accidental multiplicities (3 x 128)

X^t = transpose of X (128 x 3)

Y = matrix of partial derivatives of the singles, doubles, and triples rates with respect to the accidental multiplicities (3 x 128)

Y^t = transpose of Y (128 x 3)

Using the multinomial model, the elements of the U_{R+A} matrix are

$$(u_{R+A})_{ij} = p_i(1 - p_i) \sum_{n=0}^{127} C_n^{R+A} \quad (i = j)$$

$$(u_{R+A})_{ij} = -p_i p_j \sum_{n=0}^{127} C_n^{R+A} \quad (i \neq j)$$

where

$$p_i = \frac{C_i^{R+A}}{\sum_{n=0}^{127} C_n^{R+A}}$$

The elements of the U_A matrix are

$$(u_A)_{ij} = p_i (1 - p_i) \sum_{n=0}^{127} C_n^A \quad (i = j)$$

$$(u_A)_{ij} = -p_i p_j \sum_{n=0}^{127} C_n^A \quad (i \neq j)$$

where

$$p_i = \frac{C_i^A}{\sum_{n=0}^{127} C_n^A}$$

The elements of the X matrix are

$$x_{si} = \frac{\exp(\delta_{mult} S_m)}{t_m} \quad (\text{all } i)$$

$$x_{di} = \frac{\alpha_i \exp(\delta_{mult} S_m)}{t_m}$$

$$x_{ti} = \frac{\exp(\delta_{mult} S_m)}{t_m} \left[\beta_i - \frac{\sum_{n=1}^{127} \alpha_n C_n^A}{\sum_{n=0}^{127} C_n^{R+A}} \left(\alpha_i - \frac{\sum_{n=1}^{127} \alpha_n (C_n^{R+A} - C_n^A)}{\sum_{n=0}^{127} C_n^{R+A}} \right) \right]$$

where the subscripts s , d , and t refer to singles, doubles, and triples, respectively, and the subscript i refers to real-plus-accidental multiplicities from 0 to 127.

The elements of the Y matrix are

$$y_{si} = 0 \quad (\text{all } i)$$

$$y_{di} = -\frac{\alpha_i \exp(\delta_{mult} S_m)}{t_m}$$

$$y_{ti} = \frac{\exp(\delta_{mult} S_m)}{t_m} \left[-\beta_i + \alpha_i \frac{\sum_{n=1}^{127} \alpha_n (2C_n^A - C_n^{R+A})}{\sum_{n=0}^{127} C_n^{R+A}} \right]$$

where the subscripts s , d , and t refer to singles, doubles, and triples, respectively, and the subscript i refers to accidental multiplicities from 0 to 127.

In the resulting matrix

$$T_{sdt} = \begin{pmatrix} t_{ss} & t_{sd} & t_{st} \\ t_{ds} & t_{dd} & t_{dt} \\ t_{ts} & t_{td} & t_{tt} \end{pmatrix}$$

the variance of the singles rate is set to

$$t_{ss} = \frac{\exp(\delta_{mult} S_m)}{t_m^2} \left[\sum_{n=0}^{127} C_n^{R+A} + \frac{2}{f_d^{theor}} \sum_{n=1}^{127} \alpha_n (C_n^{R+A} - C_n^A) \right]$$

Ignoring errors in the term $(1 + CS_m)$ in the equation for the deadtime corrected triples rate, the error matrix for the deadtime corrected triples rate is calculated from the scalar product

$$V_{sdt}^d = \begin{pmatrix} 1 & 1 & 1 + CS_m \\ 1 & 1 & 1 + CS_m \\ 1 + CS_m & 1 + CS_m & (1 + CS_m)^2 \end{pmatrix} \bullet T_{sdt}$$

The error of the deadtime corrected triples rate is thus

$$\sigma(T_d) = |1 + CS_m| \sqrt{t_{tt}}$$

Background Subtraction

The singles, doubles, and triples rates with deadtime correction and background subtraction are, respectively:

$$S_b = S_d - B_s$$

$$D_b = D_d - B_d$$

$$T_b = T_d - B_t$$

where B_s , B_d , and B_t are the background singles, doubles, and triples rates, respectively.

The corresponding errors of the singles and doubles rates are

$$\sigma(S_b) = \left[\sigma(S_d)^2 + \sigma(B_s)^2 \right]^{1/2}$$

$$\sigma(D_b) = \left[\sigma(D_d)^2 + \sigma(B_d)^2 \right]^{1/2}$$

respectively. The error of the background triples rate is ignored, so

$$\sigma(T_b) = \sigma(T_d)$$

The count rates of the auxilliary scalers with background subtraction are

$$X_{1b} = X_1 - B_{x1}$$

$$X_{2b} = X_2 - B_{x2}$$

where B_{x1} and B_{x2} are the background rates for auxilliary scalers 1 and 2, respectively.

There is no error analysis for the auxilliary scalers.

Normalization

The normalization constant K is a correction factor for the doubles rate that accounts for any change in detector efficiency. Because the singles, doubles, and triples rates are proportional to ε , ε^2 , and ε^3 , respectively, where ε is the detector efficiency, the normalization constants for the singles and triples rates are \sqrt{K} and $K^{3/2}$, respectively.

The normalized singles rate (following deadtime correction and background subtraction) is

$$S = \sqrt{K} S_b$$

and the error is

$$\sigma(S) = \left[\left(\frac{S}{2} \frac{\sigma(K)}{K} \right)^2 + K \sigma(S_b)^2 \right]^{1/2}$$

The normalized doubles rate (following deadtime correction and background subtraction) is

$$D = K D_b$$

and the error is

$$\sigma(D) = \left[\left(\frac{D \sigma(K)}{K} \right)^2 + K^2 \sigma(D_b)^2 \right]^{1/2}$$

The normalized triples rate (following deadtime correction and background subtraction) is

$$T = K^{3/2} T_b$$

and (ignoring the error of the normalization constant) the normalized error matrix is calculated from the scaler product

$$V_{sdt} = \begin{pmatrix} v_{ss} & v_{sd} & v_{st} \\ v_{ds} & v_{dd} & v_{dt} \\ v_{ts} & v_{td} & v_{tt} \end{pmatrix} = \begin{pmatrix} K & K^{3/2} & K^2 \\ K^{3/2} & K^2 & K^{5/2} \\ K^2 & K^{5/2} & K^3 \end{pmatrix} \bullet V_{sdt}^d$$

so the error of the triples rate is

$$\sigma(T) = \sqrt{v_{tt}}$$

The count rates for the auxiliary scalers are not normalized.

Deadtime, Background, Normalization and QC Test Table

The table below lists all the measurement types in the INCC program and indicates whether deadtime, background and normalization corrections are done, and whether the accidentals/singles (A/S) and outlier tests are performed. An “x” means that the correction is made or the test is performed.

Measurement type	Deadtime	Background	Normalization	A/S test	Outlier test
Rates only	x	x	x	x	x
Background*	x				x
Initial source	x	x		x	x
Normalization	x	x		x	x
Precision				x	
Calibration	x	x	x	x	x
Verification*	x	x	x	x	x
Truncated multiplicity background					x
Truncated multiplicity verification		x	x	x	x

*Except for truncated multiplicity measurements.

Rates Only Measurements

A rates only measurement produces the singles, doubles, and triples rates and the auxilliary scaler rates as its only results. The singles, doubles, and triples rates are corrected for deadtime, background, and normalization. The auxilliary scaler rates are corrected for background, but not for deadtime or normalization. The accidentals/singles test and the outlier test are performed.

Background Measurement

A background measurement determines the singles, doubles, and triples rates and the two auxilliary scaler rates for room background. Previous background rates are automatically replaced with the new ones. A warning message is generated if the doubles background rate exceeds 1 count/s (default) or if the triples background rate exceeds 1 count/s (default).

Background measurements of the singles, doubles, and triples rates are corrected for deadtime, but not for background or normalization.

Background measurements of the rates for the auxilliary scalers are not corrected for deadtime, background, or normalization.

The accidentals/singles test is not done, but the outlier test is performed.

Initial Source Measurement

The initial source measurement determines the doubles rate and error for a reference ^{252}Cf source. These values and the measurement date are saved automatically and are used for the analysis of future normalization measurements. The reference ^{252}Cf source must be measured long enough to reach a precision for the doubles rate of 0.3 % (default) or the results are not accepted. If the measurement does not reach the required precision, a recommended measurement time is calculated and displayed:

$$t_{rec} = 1.1 \left[\frac{\left(\frac{\sigma(D_b)}{D_b} \right)}{p_{req}} \right]^2 t_m$$

where

t_{rec} = recommended measurement time

t_m = actual measurement time

D_b = doubles rate corrected for deadtime and background

$\sigma(D_b)$ = theoretical standard deviation of the doubles rate

p_{req} = required precision (relative standard deviation of the doubles rate)

The factor of 1.1 ensures that the required precision will be reached in all practical initial source measurements. Initial source measurements are corrected for deadtime and background, but are not normalized. The accidentals/singles and outlier tests are performed.

Normalization Measurement

The normalization measurement determines whether the detection system is stable by comparing the observed doubles rate from a ^{252}Cf source with that expected from the source

based on the initial source measurement. The expected doubles rate is calculated from the reference doubles rate, the reference measurement date, and the half life of ^{252}Cf . The normalization constant is:

$$K = \frac{D_{\text{exp}}}{D_{\text{obs}}}$$

where D_{obs} is the observed doubles rate and D_{exp} is the expected doubles rate:

$$D_{\text{exp}} = D_{\text{ref}} 2^{-\Delta t/T_{1/2}}$$

where

D_{ref} = reference ^{252}Cf doubles rate,

$T_{1/2}$ = half life of ^{252}Cf (2.645 years[25]; 1 year = 365.24219 days[26]),

Δt = time from reference measurement to normalization measurement.

The error of the normalization constant is

$$\sigma(K) = \left[\left(\frac{\sigma(D_{\text{ref}})}{D_{\text{ref}}} \right)^2 + \left(\frac{\sigma(D_{\text{obs}})}{D_{\text{obs}}} \right)^2 \right]^{1/2}$$

where $\sigma(D_{\text{ref}})$ and $\sigma(D_{\text{obs}})$ are the theoretical standard deviations of D_{ref} and D_{obs} , respectively.

The reference ^{252}Cf source must be measured long enough to reach a precision for the doubles rate of 0.3 % (default) or the results are not accepted. If the measurement does not reach the required precision, a recommended measurement time is calculated and displayed:

$$t_{\text{rec}} = 1.1 \left[\frac{\left(\frac{\sigma(D_{\text{obs}})}{D_{\text{obs}}} \right)^2}{p_{\text{req}}} \right]^{1/2} t_m$$

where

t_{rec} = recommended measurement time

t_m = actual measurement time

p_{req} = required precision (relative standard deviation of the doubles rate)

The factor of 1.1 ensures that the required precision will be reached in all practical normalization measurements.

The normalization test passes if

$$\frac{|1 - K|}{\sigma(K)} < p_{k1}$$

or

$$\left| \frac{1 - K}{K} \right| < p_{k2}$$

where p_{k1} is the test limit in standard deviations (default = 3) and p_{k2} is the test limit in percent (default = 4 %). If the test passes, the normalization constant is set to 1 and its error is set to zero.

If the test fails, the recommended new normalization constant and error displayed are K and $\sigma(K)$. The user chooses whether to use the new normalization constant.

Normalization measurements are corrected for deadtime and background, but are not normalized. The accidentals/singles and outlier tests are performed.

Precision measurement

The precision measurement tests the short term stability of the detection system by determining whether the observed scatter in a series of doubles rates measurements is statistically consistent with the expected scatter. The tested value is chi squared [23]:

$$\chi^2 = \frac{\overline{D_m^2} - \overline{D_m}^2}{N_c - 1} \sum_{n=1}^{N_c} \frac{1}{\sigma_n(D_m)^2}$$

where

D_m = measured doubles rate for one cycle,

$\sigma_n(D_m)$ = theoretical standard deviation of D_m for cycle n

N_c = number of cycles

The upper and lower chi squared limits are calculated from the degrees of freedom (number of cycles - 1) and the confidence interval (default = 99 %) using the chi squared algorithm from Ref. 24.

The doubles rates are not corrected for deadtime, background, or normalization. The outlier test is not done, but the accidentals/singles tests is performed.

The precision test passes if the measured chi squared value falls between the upper and lower chi squared limits. A pass/fail message is produced.

Plutonium Isotopic Updating

The updating calculations obtain the plutonium isotopic composition and ^{241}Am content on the measurement date from the plutonium isotopic composition and ^{241}Am content at specified dates.

Single component updating

This refers to a plutonium item with a single isotopic composition. The plutonium isotopes and ^{241}Am content are given as weight percents of plutonium on specified dates. The symbol definitions are:

D^M = date of measurement

D^P = date of plutonium analysis

D^A = date of americium analysis

m_{Pu}^M = plutonium mass on measurement date

m_{Pu}^P = plutonium mass on plutonium analysis date

m_{Pu}^A = plutonium mass on americium analysis date

m_{Am}^M = ^{241}Am mass on measurement date

i = isotope index:

$i = 1$ for ^{238}Pu

$i = 2$ for ^{239}Pu

$i = 3$ for ^{240}Pu

$i = 4$ for ^{241}Pu

$i = 5$ for ^{242}Pu

$i = 6$ for ^{241}Am

m_i^M = mass of isotope i on measurement date

m_i^P = mass of isotope i on plutonium analysis date

λ_i = decay constant for isotope $i = \ln(2) / \text{half life}$:

Isotope	Half life (years)*
^{238}Pu	87.74
^{239}Pu	24119
^{240}Pu	6564
^{241}Pu	14.348
^{242}Pu	376300
^{241}Am	433.6

*Ref. 26.

f_i = decay fraction for isotope i from plutonium analysis date to americium analysis date

g_i = decay fraction for isotope i from americium analysis date to measurement date

h_i = decay fraction for isotope i from plutonium analysis date to measurement date

w_i^M = weight percent of plutonium for isotope i on measurement date

w_i^P = weight percent of plutonium for isotope i on plutonium analysis date

w_i^A = weight percent of plutonium for isotope i on americium analysis date

The plutonium isotopic masses on the plutonium analysis date are

$$m_i^P = \frac{w_i^P m_{Pu}^P}{100} \quad (i = 1 \text{ to } 5)$$

and the decay fractions are

$$f_i = \exp[-\lambda_i(D^A - D^P)] \quad (i = 1 \text{ to } 5)$$

$$g_i = \exp[-\lambda_i(D^M - D^A)] \quad (i = 4, 6)$$

$$h_i = \exp[-\lambda_i(D^M - D^P)] \quad (i = 1 \text{ to } 5)$$

The plutonium isotopic masses on the measurement date are

$$m_i^M = h_i m_i^P \quad (i = 1 \text{ to } 5)$$

the plutonium mass on the measurement date is

$$m_{Pu}^M = \sum_{i=1}^5 m_i^M$$

and the plutonium isotopic composition in weight percent on the measurement date is

$$w_i^M = 100 \frac{m_i^M}{m_{Pu}^M} \quad (i = 1 \text{ to } 5)$$

The plutonium mass on the americium analysis date is

$$m_{Pu}^A = \sum_{i=1}^5 f_i m_i^P$$

Accounting for the beta decay of ^{241}Pu to ^{241}Am and the alpha decay of ^{241}Am , the ^{241}Am mass on the date of measurement is

$$m_6^M = \frac{g_6 w_6^A m_{Pu}^A}{100} + \frac{f_4 m_4^P (g_6 - g_4) \lambda_4}{\lambda_4 - \lambda_6}$$

the 0.002% alpha decay of ^{241}Pu is ignored and the growth of ^{241}Am is calculated as shown in Ref. 29. Thus, the ^{241}Am weight percent on the measurement date is

$$w_6^M = 100 \frac{m_6^M}{m_{Pu}^M}$$

The errors of the updated plutonium isotopic weight percents are set to the approximate values

$$\sigma(w_i^M) = \frac{w_i^M}{w_i^P} \sigma(w_i^P) \quad (i = 1 \text{ to } 5)$$

and the error of the updated ^{241}Am weight percent is set to the approximate value

$$\sigma(w_6^M) = 100 \frac{\sqrt{x^2 + y^2}}{m_{Pu}^M}$$

where

$$x = \frac{g_6 m_{Pu}^A}{100} \sigma(w_6^A)$$

$$y = \frac{f_4 (g_6 - g_4) \lambda_4}{\lambda_4 - \lambda_6} \frac{m_{Pu}^P}{100} \sigma(w_4^P)$$

Multiple component updating

Composite items can be specified to have different isotopic compositions, with a plutonium mass specified for each composition. Multiple component updating calculates an isotopic composition for the entire item. The symbol definitions are

N_{comp} = number of components

m_{ij}^M = mass of isotope i (as defined above) for component j on the date of measurement

W_i^M = weight percent of plutonium for isotope i in composite item on date of measurement

M_i^M = mass of isotope i in the composite sample on the date of measurement

M_{Pu}^M = total plutonium mass for the composite sample on the date of measurement.

The values of m_{ij}^M and are calculated from the equations above. Then

$$M_i^M = \sum_{j=1}^{N_{comp}} m_{ij}^M \quad (i = 1 \text{ to } 6)$$

and

$$M_{Pu}^M = \sum_{j=1}^{N_{comp}} \sum_{i=1}^5 m_{ij}^M$$

so

$$W_i^M = 100 \frac{M_i^M}{M_{Pu}^M} \quad (i = 1 \text{ to } 6)$$

There is presently no error propagation in the composite isotopics calculation, so the composite isotopics errors are set to zero.

Alpha

The alpha value used in the known alpha multiplication correction procedure is calculated from [20]

$$\alpha = w_{\alpha} \frac{k_1 f_{238} + k_2 f_{239} + k_3 f_{240} + k_4 f_{241} + k_5 f_{242} + k_6 f_{Am241}}{k_7 (k_8 f_{238} + f_{240} + k_9 f_{242})}$$

where

w_{α} = alpha weighting factor (default = 0)

f_i = mass of plutonium isotope i as a fraction of total plutonium mass

f_{Am241} = mass of ^{241}Am as a fraction of total plutonium mass

k_i = constants ($i = 1$ to 9):

i	k_i
1	13400
2	38.1
3	141
4	1.3
5	2
6	2690
7	1020
8	2.54
9	1.69

Effective ^{240}Pu Mass

The effective ^{240}Pu mass is defined as [20]

$$m_{240e} = (2.52 f_{238} + f_{240} + 1.68 f_{242}) m_{Pu}$$

where

f_i = mass of plutonium isotope i as a fraction of total plutonium mass

m_{Pu} = total plutonium mass

The effective ^{240}Pu mass fraction is

$$f_{240e} = \frac{m_{240e}}{m_{Pu}}$$

Effective ^{239}Pu Mass

The effective ^{239}Pu mass is defined as [4]

$$m_{239e} = (0.786f_{238} + f_{239} + 0.515f_{240} + 1.414f_{241} + 0.422f_{242} + 0.545f_{Am241})m_{Pu}$$

where

f_i = mass of plutonium isotope i as a fraction of total plutonium mass

f_{Am241} = mass of ^{241}Am as a fraction of total plutonium mass

m_{Pu} = total plutonium mass

Calibration Measurements

For calibration measurements, the count rates are corrected for deadtime, background, and normalization. The accidentals/singles and outlier tests are performed. No additional analysis is done for calibration measurements except for the known alpha analysis method, where the multiplication corrected doubles rate and error are calculated as shown in the section “Known Alpha Assay.”

Conventional Calibration Curve Assay

This technique uses a calibration curve of doubles rate vs effective ^{240}Pu mass for passive assay and doubles rate vs ^{235}U for active assay. However, there is one exception. See the section on passive uranium measurements below. The assay mass and error are determined from the doubles rate and error. The doubles rate is corrected for deadtime, background, and normalization and the accidentals/singles and outlier tests are performed before the calibration curve is solved for effective ^{240}Pu mass. Four types of calibration curves can be used:

$$1. \quad D = a + bm + cm^2 + dm^3$$

$$2. \quad D = am^b$$

$$3. \quad D = \frac{am}{1 + bm}$$

$$4. \quad D = a(1 - e^{-bm})$$

where

D = doubles rate

a, b, c, d = calibration coefficients

and, to simplify the notation in this section,

m = effective ^{240}Pu mass or ^{235}U mass

The solutions of these equations are shown below.

Calibration curve type 1: $D = a + bm + cm^2 + dm^3$

Case 1: $b = c = d = 0$

There is no definite solution and an error message is generated.

Case 2: $c = d = 0; b \neq 0$

The solution is

$$m = \frac{D - a}{b}$$

Case 3: $d = 0; c \neq 0$

If

$$b^2 - 4c(a - D) < 0$$

there is no real solution and an error message is generated. Otherwise, there are two real solutions:

$$m_1 = \frac{-b + \sqrt{b^2 - 4c(a - D)}}{2c}$$

and

$$m_2 = \frac{-b - \sqrt{b^2 - 4c(a - D)}}{2c}$$

The assay mass is taken as the lower value that falls between the upper and lower mass limits (default values: 10^8 and -10^8 , respectively). If both values are outside the mass limits, an error message is generated.

Case 4: $d \neq 0$

The procedure, following Ref. 4, is as follows:

Write the cubic equation in the form

$$m^3 + pm^2 + qm + r = 0$$

where

$$p = \frac{c}{d}, \quad q = \frac{b}{d}, \quad r = \frac{a - D}{d}$$

Calculate

$$a_1 = \frac{1}{3}(3q - p^2)$$

$$b_1 = \frac{1}{27}(2p^3 - 9pq + 27r)$$

$$k = \frac{b_1^2}{4} + \frac{a_1^3}{27}$$

If

$$|k| < 10^{-12}$$

set $k = 0$; otherwise, if $b_1 \neq 0$ and

$$\left| 1 + \frac{4a_1^3}{27b_1^2} \right| < 10^{-12}$$

set $k = 0$

Case 4a: $k = 0$

There are three real solutions:

$$m_1 = -2\left(\frac{b_1}{2}\right)^{1/3} - \frac{p}{3}$$

$$m_2 = m_3 = \left(\frac{b_1}{2}\right)^{1/3} - \frac{p}{3}$$

Case 4b: $k > 0$

There is one real solution:

$$m_1 = \left(-\frac{b_1}{2} + \sqrt{k}\right)^{1/3} + \left(-\frac{b_1}{2} - \sqrt{k}\right)^{1/3} - \frac{p}{3}$$

Case 4c: $k < 0$

There are three real solutions:

Let

$$z = \left[-\frac{27b_1^2}{4a_1^3} \right]^{1/2}$$

If $b_1 > 0$, set $z = -z$

Let $\phi = \cos^{-1}(z)$

Then

$$x_1 = 2\sqrt{-\frac{a_1}{3}} \cos\left(\frac{\phi}{3}\right) - \frac{p}{3}$$

$$x_2 = 2\sqrt{-\frac{a_1}{3}} \cos\left(\frac{\phi + 2\pi}{3}\right) - \frac{p}{3}$$

$$x_3 = 2\sqrt{-\frac{a_1}{3}} \cos\left(\frac{\phi + 4\pi}{3}\right) - \frac{p}{3}$$

For case 4 the assay mass is taken as the lowest value that falls between the upper and lower mass limits (default values: 10^8 and -10^8 , respectively). If all values are outside the mass limits, there is no assay result and an error message is generated.

For cases 2, 3, and 4, the mass error is

$$\sigma(m) = \left[\frac{z}{(b + 2cm + 3dm^2)^2} \right]^{1/2}$$

where

$$z = \sigma_D^2 + \sigma_a^2 + m^2 \sigma_b^2 + m^4 \sigma_c^2 + m^6 \sigma_d^2 + 2m \sigma_{ab} + 2m^2 \sigma_{ac} + 2m^3 \sigma_{ad} + 2m^3 \sigma_{bc} + 2m^4 \sigma_{bd} + 2m^5 \sigma_{cd}$$

where

$$\sigma_D \equiv \sigma(D) = \text{doubles rate error}$$

$$\sigma_i = \text{error of calibration coefficient } i$$

$$\sigma_{ij} = \text{covariance of calibration coefficients } i \text{ and } j$$

Calibration curve type 2: $D = am^b$

If $a = 0$ or $b = 0$, there is no definite solution and an error message is generated. If $\frac{D}{a} < 0$ there is no solution and an error message is generated. Otherwise,

$$m = \left(\frac{D}{a} \right)^{1/b}$$

and

$$\sigma(m) = \left[\frac{z}{\left(abm^{b-1} \right)^2} \right]^{1/2}$$

where

$$z = \sigma_D^2 + \left(m^b \sigma_a \right)^2 + \left\{ am^b \ln(m) \sigma_b \right\}^2 + 2am^{2b} \ln(m) \sigma_{ab}$$

where $\ln(m)$ is the natural logarithm of m .

If $m = 0$, then the mass error is set to

$$\sigma(m) = \left| \frac{\sigma_D}{a} \right|^{1/b}$$

If the assay mass is outside the upper and lower mass limits (default values: 10^8 and -10^8 , respectively), there is no assay result and an error message is generated.

Calibration curve type 3: $D = \frac{am}{1 + bm}$

If $a = 0$, there is no definite solution and an error message is generated. If $a - bD = 0$ there is no solution and an error message is generated. Otherwise,

$$m = \frac{D}{a - bD}$$

and

$$\sigma(m) = m^2 \sqrt{z}$$

where

$$z = \frac{a^2}{D^4} \sigma_D^2 + \frac{1}{D^2} \sigma_a^2 + \sigma_b^2 - \frac{2}{D} \sigma_{ab}$$

If $z < 0$, an error message is generated.

Calibration curve type 4: $D = a(1 - e^{-bm})$

If $a = 0$ or $b = 0$, there is no definite solution and an error message is generated.

otherwise

$$m = \frac{-\ln\left(1 - \frac{D}{a}\right)}{b}$$

If

$$1 - \frac{D}{a} \leq 0$$

there is no solution and an error message is generated. The mass error is

$$\sigma(m) = \left[\frac{z}{\left(abe^{-bm}\right)^2} \right]^{1/2}$$

where

$$z = \sigma_D^2 + \left(1 - e^{-bm}\right)^2 \sigma_a^2 + \left(ame^{-bm}\right)^2 \sigma_b^2 + 2ame^{-bm}\left(1 - e^{-bm}\right) \sigma_{ab}$$

If $z < 0$, an error message is generated.

Heavy Metal Correction

For the measurement of MOX fuel assemblies a heavy metal correction can be applied to the measured singles and doubles rates. This correction is in the form of

$$k = 1 + HMfactor(HMref - g)$$

where $HMfactor$ and $HMref$ are empirically determined values from fits to data and g is the declared heavy metal content per unit length which includes the uranium and plutonium mass. This correction factor is then applied to the singles and doubles rate as:

$$S' = kS,$$

$$D' = \sqrt{k}D.$$

These corrected singles and doubles rates are then applied to the conventional calibration curve assay as described above.

Passive Uranium Measurements

When uranium is measured in the passive mode, the doubles rate is determined by the spontaneous fission of ^{238}U (in the absence of multiplication). The ^{238}U mass is determined from a normal passive calibration curve. The ^{235}U mass is then obtained using the entered ^{235}U enrichment of the sample:

$$U235 = U238 * e / (1 - e)$$

where e is the fractional enrichment of the material.

Conventional Multiplicity Assay

The point model multiplicity assay equations are [19]

$$S = mF_0 \varepsilon \nu_{s1} M(1 + \alpha)$$

$$D = \frac{1}{2} mF_0 \varepsilon^2 f_d \nu_{s2} M^2 \left[1 + \left(\frac{M-1}{\nu_{i1}-1} \right) \frac{\nu_{s1} \nu_{i2}}{\nu_{s2}} (1 + \alpha) \right]$$

$$T = \frac{1}{6} mF_0 \varepsilon^3 f_t \nu_{s3} M^3 \left\{ 1 + \left(\frac{M-1}{\nu_{i1}-1} \right) \left[\frac{3\nu_{s2} \nu_{i2} + \nu_{s1} \nu_{i3} (1 + \alpha)}{\nu_{s3}} \right] + \right.$$

$$\left. 3 \left(\frac{M-1}{\nu_{i1}-1} \right)^2 \frac{\nu_{s1} \nu_{i2}^2}{\nu_{s3}} (1 + \alpha) \right\}$$

where

S, D, T = singles, doubles, and triples rates, respectively

m = effective ^{240}Pu mass

M = neutron multiplication

α = (α, n) to spontaneous fission neutron ratio

\mathcal{E} = detection efficiency

f_d, f_t = doubles and triples gate fractions, respectively

$\nu_{s1}, \nu_{s2}, \nu_{s3}$ = 1st, 2nd, and 3rd factorial moments of the ^{240}Pu spontaneous fission neutron multiplicity distribution (defaults = 2.154, 3.789, and 5.211, respectively [8])

$\nu_{i1}, \nu_{i2}, \nu_{i3}$ = 1st, 2nd, and 3rd factorial moments of the ^{239}Pu neutron induced fission neutron multiplicity distribution {defaults (2 MeV values) = 3.163, 8.240, and 17.321, respectively [9]}

F_0 = ^{240}Pu spontaneous fission rate per unit mass (default = $473.5 \text{ g}^{-1} \text{ s}^{-1}$)
[(1020 neutrons per s per g ^{240}Pu [20]) / ν_{s1} = $1020 / 2.154 = 473.5$]

Eliminating m and α from these equations gives an equation for M :

$$a_M + b_M M + c_M M^2 + M^3 = 0$$

where

$$a_M = \frac{-6T\nu_{s2}(\nu_{i1} - 1)}{\mathcal{E}^2 f_t S(\nu_{s2}\nu_{i3} - \nu_{s3}\nu_{i2})}$$

$$b_M = \frac{2D[\nu_{s3}(\nu_{i1} - 1) - 3\nu_{s2}\nu_{i2}]}{\mathcal{E} f_d S(\nu_{s2}\nu_{i3} - \nu_{s3}\nu_{i2})}$$

$$c_M = \frac{6D\nu_{s2}\nu_{i2}}{\mathcal{E} f_d S(\nu_{s2}\nu_{i3} - \nu_{s3}\nu_{i2})} - 1$$

This cubic equation is solved by iteration using Newton's method with the following procedure:

1) Set $M = 1$

2) Calculate

$$z = \frac{-a_M + c_M M^2 + 2M^3}{b_M + 2c_M M + 3M^2}$$

3) Set $M = z$ and repeat from step 2 until $|M - z| < 10^{-9}$

Then

$$m = \frac{\frac{2D}{\mathcal{E}_d^f} - \frac{M(M-1)v_{i2}S}{v_{i1} - 1}}{F_0 \mathcal{E} M^2 v_{s2}}$$

and

$$\alpha = \frac{S}{m F_0 \mathcal{E} v_{s1} M} - 1$$

Let $V_{mM\alpha}$ represent the variance-covariance matrix for effective ^{240}Pu assay mass, multiplication, and alpha:

$$V_{mM\alpha} = \begin{pmatrix} \sigma_m^2 & \sigma_{mM} & \sigma_{m\alpha} \\ \sigma_{Mm} & \sigma_M^2 & \sigma_{M\alpha} \\ \sigma_{\alpha m} & \sigma_{\alpha M} & \sigma_{\alpha}^2 \end{pmatrix}$$

Then

$$V_{mM\alpha} = Z V_{sdt} Z^t$$

where V_{sdt} is the error matrix for singles, doubles, and triples

$$Z = \begin{pmatrix} m'_s & m'_d & m'_t \\ M'_s & M'_d & M'_t \\ \alpha'_s & \alpha'_d & \alpha'_t \end{pmatrix}$$

where

$$m'_s = \frac{\partial m}{\partial \mathcal{S}}$$

etc., and Z^t is the transpose of Z . Let

$$k_{z1} = \frac{-6v_{s2}(v_{i1} - 1)}{\varepsilon^2 f_t(v_{s2}v_{i3} - v_{s3}v_{i2})}$$

$$k_{z2} = \frac{2[v_{s3}(v_{i1} - 1) - 3v_{s2}v_{i2}]}{\varepsilon f_d(v_{s2}v_{i3} - v_{s3}v_{i2})}$$

$$k_{z3} = \frac{6v_{s2}v_{i2}}{\varepsilon f_d(v_{s2}v_{i3} - v_{s3}v_{i2})}$$

$$k_{z4} = \frac{2}{\varepsilon^2 f_d v_{s2} F_0}$$

$$k_{z5} = \frac{v_{i2}}{\varepsilon v_{s2}(v_{i1} - 1)F_0}$$

Then

$$\frac{\partial \mathcal{M}}{\partial \mathcal{S}} = \frac{k_{z1}T + k_{z2}DM + k_{z3}DM^2}{(k_{z2} + 2Mk_{z3})DS + (3M^2 - 2M)S^2}$$

$$\frac{\partial \mathcal{M}}{\partial \mathcal{D}} = \frac{-M(k_{z2} + Mk_{z3})}{(k_{z2} + 2Mk_{z3})D + (3M^2 - 2M)S}$$

$$\frac{\partial \mathcal{M}}{\partial \mathcal{T}} = \frac{-k_{z1}}{(k_{z2} + 2Mk_{z3})DS + (3M^2 - 2M)S}$$

$$\frac{\partial m}{\partial \mathcal{S}} = -\frac{\partial \mathcal{M}}{\partial \mathcal{S}} \left(\frac{2k_{z4}D}{M^3} + \frac{k_{z5}S}{M^2} \right) - k_{z5} \left(1 - \frac{1}{M} \right)$$

$$\frac{\partial m}{\partial D} = \frac{k_{z4}}{M^2} - \frac{\partial M}{\partial D} \left(\frac{2k_{z4}D}{M^3} + \frac{k_{z5}S}{M^2} \right)$$

$$\frac{\partial m}{\partial T} = -\frac{\partial M}{\partial T} \left(\frac{2k_{z4}D}{M^3} + \frac{k_{z5}S}{M^2} \right)$$

$$\frac{\partial \alpha}{\partial S} = (1 + \alpha) \left(\frac{1}{S} - \frac{1}{M} \frac{\partial M}{\partial S} - \frac{1}{m} \frac{\partial m}{\partial S} \right)$$

$$\frac{\partial \alpha}{\partial D} = -(1 + \alpha) \left(\frac{1}{M} \frac{\partial M}{\partial D} + \frac{1}{m} \frac{\partial m}{\partial D} \right)$$

$$\frac{\partial \alpha}{\partial T} = -(1 + \alpha) \left(\frac{1}{M} \frac{\partial M}{\partial T} + \frac{1}{m} \frac{\partial m}{\partial T} \right)$$

Thus, the errors of the effective ^{240}Pu assay mass, multiplication, and alpha are, respectively,

$$\sigma(m) = \sqrt{\sigma_m^2}$$

$$\sigma(M) = \sqrt{\sigma_M^2}$$

$$\sigma(\alpha) = \sqrt{\sigma_\alpha^2}$$

An empirical multiplication correction factor [19] is included for multiplicity assay to correct for variable multiplication that is not accounted for by the point multiplicity model. This correction factor has the form

$$f_{mc} = a_{mc} + b_{mc}(M - 1) + c_{mc}(M - 1)^2$$

where a_{mc} , b_{mc} , and c_{mc} are calibration parameters (default values = 1, 0, and 0, respectively). There is no error analysis for this correction factor, so the effective ^{240}Pu assay mass is corrected to

$$m_{240e} = f_{mc} m$$

with error

$$\sigma(m_{240e}) = f_{mc} \sigma(m)$$

Weighted Point Model Multiplicity Assay

As described in [32] and [3]], the standard point model multiplicity equations [19] are modified as shown:

$$S = mF_0 \varepsilon \nu_{s1} M(1 + \alpha),$$

$$D = \frac{1}{2} mF_0 \varepsilon^2 \nu_{s2} f_d M^2 (f_d + \alpha f_d^\alpha),$$

$$T = \frac{1}{6} mF_0 \varepsilon^3 \nu_{s3} f_t M^3 (f_t + \alpha f_t^\alpha),$$

where

$$f_d = w_d [1 + a(M - 1)],$$

$$f_d^\alpha = w_d^\alpha a(M - 1),$$

$$f_t = w_t [1 + b(M - 1) + c(M - 1)^2],$$

$$f_t^\alpha = w_t^\alpha [d(M - 1) + c(M - 1)^2],$$

where

$$a = \frac{\nu_{s1} \nu_{i2}}{\nu_{s2} (\nu_{i1} - 1)},$$

$$b = \frac{3\nu_{s2} \nu_{i2} + \nu_{s1} \nu_{i3}}{\nu_{s3} (\nu_{i1} - 1)},$$

$$c = \frac{3\nu_{s1} \nu_{i2}^2}{\nu_{s3} (\nu_{i1} - 1)^2},$$

$$d = \frac{\nu_{s1}\nu_{i3}}{\nu_{s3}(\nu_{i1} - 1)},$$

and where

S, D, T = singles, doubles, and triples rates, respectively,

m = effective ^{240}Pu mass,

M = neutron multiplication,

α = ratio of (α, n) to spontaneous fission neutrons,

F_0 = ^{240}Pu spontaneous fissions per gram per second,

ε = neutron detection efficiency,

f_d, f_t = doubles and triples gate fractions, respectively,

$\nu_{s1}, \nu_{s2}, \nu_{s3}$ = 1st, 2nd, and 3rd factorial moments of the ^{240}Pu spontaneous fission neutron distribution,

$\nu_{i1}, \nu_{i2}, \nu_{i3}$ = 1st, 2nd, and 3rd factorial moments of the neutron distribution from the neutron induced fission of ^{239}Pu ,

and where w_D, w_D^α, w_T , and w_T^α are the variable-multiplication weighting factors. The spontaneous fission and (α, n) contributions to the doubles and triples rates are all different functions of the multiplication and therefore have different weighting factors. The singles rate is proportional to the multiplication and so does not need weighting factors. When the four weighting factors are set to unity, the weighted point model equations become the standard point model equations.

Multiplicity Assay with Unknown Efficiency

This method assumes that the detection efficiency is unknown, but that the neutron multiplication is negligible ($M = 1$). Then the point model multiplicity equations are

$$S = mF_0\nu_{s1}\varepsilon(1 + \alpha)$$

$$D = \frac{1}{2} m F_0 \nu_{s2} \varepsilon^2 f_d$$

$$T = \frac{1}{6} m F_0 \nu_{s3} \varepsilon^3 f_t$$

where the symbols are defined in the section “Conventional Multiplicity Assay.” Thus,

$$\varepsilon = 3 \frac{T \nu_{s2} f_d}{D \nu_{s3} f_t}$$

$$m = \frac{2D}{F_0 \nu_{s2} \varepsilon^2 f_d}$$

$$\alpha = \frac{S}{m F_0 \nu_{s1} \varepsilon} - 1.$$

Neglecting the errors of the singles and doubles rates, the assay errors are

$$\sigma(\varepsilon) = \frac{\sigma(T)}{T} \varepsilon$$

$$\sigma(m) = \frac{2\sigma(\varepsilon)}{\varepsilon} m$$

$$\sigma(\alpha) = \frac{\sigma(\varepsilon)}{\varepsilon} (1 + \alpha)$$

Dual Energy Passive Multiplicity Assay

The dual energy technique is included in the INCC code for evaluation. It has not yet been experimentally verified. The dual energy technique allows the average (α, n) neutron energy to be different from the fission spectrum neutron energy. The ring ratio (the ratio of the singles count rate of the inner to outer ring of ^3He tubes) is used to estimate the average (α, n) neutron energy. The dual energy multiplicity equations [29] are an extension of the standard point model multiplicity equations:

$$S = m F_0 \nu_{s1} \varepsilon_f M + S_\alpha (1 - p_\alpha) \varepsilon_\alpha + S_\alpha p_\alpha \nu_{i1}^\alpha M \varepsilon_f$$

$$\begin{aligned}
D &= \frac{mF_0\varepsilon_f^2 f_d M^2}{2} \left[\nu_{s2} + \left(\frac{M-1}{\nu_{i1}-1} \right) \nu_{s1} \nu_{i2} \right] + \\
&\quad \frac{S_\alpha p_\alpha \varepsilon_f^2 f_d M^2}{2} \left[\nu_{i2}^\alpha + \left(\frac{M-1}{\nu_{i1}-1} \right) \nu_{i1}^\alpha \nu_{i2} \right] \\
T &= \frac{mF_0\varepsilon_f^3 f_t M^3}{6} \left[\nu_{s3} + \left(\frac{M-1}{\nu_{i1}-1} \right) (3\nu_{s2} \nu_{i2} + \nu_{s1} \nu_{i3}) + \right. \\
&\quad \left. 3 \left(\frac{M-1}{\nu_{i1}-1} \right)^2 \nu_{s1} \nu_{i2}^2 \right] + \frac{S_\alpha p_\alpha \varepsilon_f^3 f_t M^3}{6} \left[\nu_{i3}^\alpha + \left(\frac{M-1}{\nu_{i1}-1} \right) \bullet \right. \\
&\quad \left. (3\nu_{i2}^\alpha \nu_{i2} + \nu_{i1}^\alpha \nu_{i3}) + 3 \left(\frac{M-1}{\nu_{i1}-1} \right)^2 \nu_{i1}^\alpha \nu_{i2}^2 \right]
\end{aligned}$$

where

S, D, T = singles, doubles, and triples rates, respectively

m = effective ^{240}Pu mass

M = neutron multiplication

ε_f = detection efficiency for fission spectrum neutrons

ε_α = detection efficiency for (α, n) neutrons

f_d, f_t = doubles and triples gate fractions, respectively

$\nu_{s1}, \nu_{s2}, \nu_{s3}$ = 1st, 2nd, and 3rd factorial moments of the ^{240}Pu spontaneous fission neutron multiplicity distribution (defaults = 2.154, 3.789, and 5.211, respectively [8])

$\nu_{i1}, \nu_{i2}, \nu_{i3}$ = 1st, 2nd, and 3rd factorial moments of the ^{239}Pu fission neutron multiplicity distribution induced by 2 MeV neutrons {defaults = 3.163, 8.240, and 17.321, respectively [9]}

$\nu_{i1}^\alpha, \nu_{i2}^\alpha, \nu_{i3}^\alpha$ = 1st, 2nd, and 3rd factorial moments of the ^{239}Pu fission neutron multiplicity distribution induced by (α, n) neutrons

p_α = probability that an (α, n) neutron will induce a fission

S_α = (α, n) neutron source rate

F_0 = ^{240}Pu spontaneous fission rate per unit mass (default = $473.5 \text{ g}^{-1} \text{ s}^{-1}$)
 $[(1020 \text{ neutrons per s per g } ^{240}\text{Pu [2]}) / \nu_{s1} = 1020 / 2.154 = 473.5]$

The quantity α is the ratio of (α, n) neutrons to spontaneous fission neutrons, so

$$S_\alpha = \alpha m F_0 \nu_{s1}$$

Eliminating m and α from the equations for S , D , and T produces an equation for M for a specified (α, n) neutron energy E_n . The quantities ε_α , p_α , ν_{i1}^α , ν_{i2}^α , and ν_{i3}^α depend on the (α, n) neutron energy.

The solution of the dual energy multiplicity equations proceeds as follows:

1. Solve the standard point model multiplicity equations for m , M , and α , as shown in the section “Passive Multiplicity Assay.”
2. Calculate the total neutron source rate from fission (S_f) using the standard model:

$$S_f = m F_0 M \nu_{s1} (1 + p_f \alpha \nu_{i1})$$

where

$$p_f = \frac{M - 1}{M \nu_{i1} - 1}$$

3. Calculate the ring ratio (r_r) for (α, n) neutrons:

$$r_r = \frac{S_i - \varepsilon_i S_f}{S_o - \varepsilon_o S_f}$$

where

$\varepsilon_i, \varepsilon_o$ = neutron detection efficiencies for fission spectrum neutrons in the inner and outer detector rings, respectively

S_i, S_o = singles rates for the inner and outer rings of the detector, respectively

The singles rates S_i and S_o are obtained from the auxiliary scalars AUX1 and AUX2 of the multiplicity electronics, respectively, and are not deadtime corrected.

4. Get the (α, n) neutron energy E_n from the ring ratio using the table of ring ratio vs neutron energy. Use linear interpolation between points. If the ring ratio is below the minimum or above the maximum on the table, use the minimum or maximum energy, respectively.
5. Get ε_α from E_n using the table of neutron detection efficiency vs neutron energy. Use linear interpolation between points.
6. Get the ratio (r_p) of the first fission probability for (α, n) neutrons (p_α) to the fission probability for fission spectrum neutrons (p_f) from the table of relative fission probability vs neutron energy. Use linear interpolation between points.
7. Calculate the factorial moments of the neutron multiplicity distribution from fissions induced by (α, n) neutrons with energy E_n :

$$\nu_{i1}^\alpha = 2.872 + 0.1416E_n + 0.00188E_n^2$$

$$\nu_{i2}^\alpha = 6.726 + 0.6895E_n + 0.03463E_n^2$$

$$\nu_{i3}^\alpha = 12.516 + 1.986E_n + 0.2118E_n^2$$

These equations were obtained by least squares fitting to data from Ref. 9.

8. Solve the dual energy multiplicity equation for multiplication:

$$f(M) = g_1 g_4 - g_2 g_3 = 0$$

where

$$g_1 = \frac{3f_d T}{D} h_1 - \varepsilon_f f_t M h_3$$

$$g_2 = \varepsilon_f f_t M h_4 - \frac{3f_d T}{D} h_2$$

$$g_3 = \frac{2v_{s1}MD}{S} - \varepsilon_f f_d M^2 h_1$$

$$g_4 = \varepsilon_f f_d M^2 h_2 - \frac{2v_{s1}D}{S} \left[\frac{\varepsilon_\alpha}{\varepsilon_f} + r_p \left(\frac{M-1}{Mv_{i1}-1} \right) \left(v_{i1}^\alpha M - \frac{\varepsilon_\alpha}{\varepsilon_f} \right) \right]$$

where

$$h_1 = v_{s2} + \left(\frac{M-1}{v_{i1}-1} \right) v_{s1} v_{i2}$$

$$h_2 = r_p \left(\frac{M-1}{Mv_{i1}-1} \right) v_{s1} \left[v_{i2}^\alpha + \left(\frac{M-1}{v_{i1}-1} \right) v_{i1}^\alpha v_{i2} \right]$$

$$h_3 = v_{s3} + \left(\frac{M-1}{v_{i1}-1} \right) (3v_{s2}v_{i2} + v_{s1}v_{i3}) + 3 \left(\frac{M-1}{v_{i1}-1} \right)^2 v_{s1}v_{i2}^2$$

$$h_4 = r_p \left(\frac{M-1}{Mv_{i1}-1} \right) v_{s1} \left[v_{i3}^\alpha + \left(\frac{M-1}{v_{i1}-1} \right) (3v_{i2}^\alpha v_{i2} + v_{i1}^\alpha v_{i3}) + 3 \left(\frac{M-1}{v_{i1}-1} \right)^2 v_{i1}^\alpha v_{i2}^2 \right]$$

a. Set $M = 1$.

b. Calculate

$$f'(M) = \frac{f(M + 10^{-9}) - f(M)}{10^{-9}}$$

c. Calculate

$$M' = M - \frac{f(M)}{f'(M)}$$

d. If

$$|M' - M| > 10^{-9}$$

set

$$M = M'$$

and repeat from step b.

e. Calculate h_1, h_2, h_3, h_4, g_1 , and g_2 .

f. Calculate

$$\alpha = \frac{g_1}{g_2}$$

g. Calculate the estimated effective ^{240}Pu mass (m'):

$$m' = \frac{2D}{F_0 \varepsilon^2 f_d M^2 (h_1 + \alpha h_2)}$$

9. If

$$|m - m'| > 10^{-9}$$

calculate the estimated total neutron source rate from fission

$$S_f = m' F_0 M \nu_{s1} (1 + p_\alpha \alpha \nu_{i1}^\alpha)$$

where

$$p_\alpha = r_p \frac{M - 1}{M \nu_{i1} - 1}$$

then set $m = m'$, and repeat from step 3.

10. Let the values and errors from the solution of the standard multiplicity equations be M_0 , $\sigma(M_0)$, α_0 , $\sigma(\alpha_0)$, m_0 , and $\sigma(m_0)$ for the multiplication, alpha, and effective ^{240}Pu mass, respectively. Then set

$$\sigma(M) = \frac{M}{M_0} \sigma(M_0)$$

$$\sigma(\alpha) = \frac{\alpha}{\alpha_0} \sigma(\alpha_0)$$

and

$$\sigma(m) = \frac{m}{m_0} \sigma(m_0)$$

where M , α , and m are the corresponding values obtained from the dual energy multiplicity equations.

Multiplicity Assay with Known Alpha

This method assumes that the detection efficiency is unknown, but that the materials are pure such that the alpha value calculated from the isotopic values is correct. The point model multiplicity assay equations [19] given in the section “Conventional Multiplicity Assay” are solved from the efficiency, multiplication, and ^{240}Pu effective mass. The point model multiplicity equations are rewritten in the form:

$$\begin{aligned} S &= Am\varepsilon M, \\ D &= Bm\varepsilon^2 M^2 [1 + C(M - 1)], \\ T &= Gm\varepsilon^3 M^3 [1 + E(M - 1) + F(M - 1)^2] \end{aligned}$$

where

$$\begin{aligned} A &= F_o \nu_{s1} (1 + \alpha), \\ B &= \frac{1}{2} F_o f_d \nu_{s2}, \\ C &= \frac{\nu_{s1} \nu_{i2} (1 + \alpha)}{\nu_{s2} (\nu_{i1} - 1)}, \\ G &= \frac{1}{6} F_o f_t \nu_{s3}, \\ E &= \frac{3\nu_{s2} \nu_{i2} + \nu_{s1} \nu_{i3} (1 + \alpha)}{\nu_{s3} (\nu_{i1} - 1)}, \\ F &= \frac{3\nu_{s1} \nu_{i2}^2 (1 + \alpha)}{\nu_{s3} (\nu_{i1} - 1)^2}. \end{aligned}$$

Eliminating m and ε from these equations gives a quadratic equation for M :

$$a_x M^2 + b_x M + c_x = 0,$$

where

$$\begin{aligned} a_x &= F - \frac{TSB^2}{GD^2 A} C^2, \\ b_x &= E - 2F - \frac{TSB^2}{GD^2 A} 2C(1 - C), \\ c_x &= 1 - E + F - \frac{TSB^2}{GD^2 A} (1 - C)^2. \end{aligned}$$

The solutions for the multiplication are solved with the quadratic equation:

$$M_{\pm} = \frac{-b_x \pm \sqrt{b_x^2 - 4a_x c_x}}{2a_x},$$

where M_+ and M_- are the two solutions.

Then the two solutions for the efficiency and ^{240}Pu effective mass are:

$$\begin{aligned} \varepsilon_{\pm} &= \frac{DA}{BSM_{\pm} [1 + C(M_{\pm} - 1)]} \\ m_{\pm} &= \frac{S}{A\varepsilon_{\pm} M_{\pm}}. \end{aligned}$$

The solution with valid ranges for the M , ε , and m is chosen as the answer. The ranges are:

$$\begin{aligned} M &> 1, \\ 0 &< \varepsilon < 1, \\ m &> 0. \end{aligned}$$

For cases in which there are two valid solutions, the solution with the efficiency closest to the reported efficiency of the counter will be chosen. Also, it is possible to have cases where there will be no solutions. These may occur when the alpha value is significantly different then the alpha value calculated from the isotopic values. In this case the initial assumptions are violated and the solutions are not valid.

The calculation of the errors is very complicated. To simplify the analysis, only the triples rate will be assumed to contribute to the error. The quadratic equation for the multiplication is rewritten in the form:

$$(a + bT)M^2 + (c + dT)M + (e + fT) = 0,$$

where

$$\begin{aligned} a &= F, \\ b &= -\frac{SB^2C}{GD^2A}, \\ c &= E - 2F, \\ d &= -\frac{2SB^2C(C-1)}{GD^2A}, \\ e &= 1 - E + F, \\ f &= -\frac{SB^2(1-C)^2}{GD^2A}. \end{aligned}$$

The error in M due only to T is:

$$\sigma(M_{\pm})^2 = \left(\frac{\partial M}{\partial T} \right)^2 \sigma(T)^2.$$

$$\frac{\partial M}{\partial T} = \frac{-d(a + bT) + b(c + dT)}{2(a + bT)^2} \pm \frac{(a + bT)(cd - 2af - 2be + d^2T - 2bfT) - b\sqrt{w}}{2\sqrt{w}(a + bT)^2},$$

where

$$\sqrt{w} = \sqrt{c^2 - 4ae + 2(cd - 2af - 2be)T + (d^2 - 4bf)T^2}.$$

The error in ε is:

$$\sigma(\varepsilon_{\pm})^2 = \left(\frac{\partial \varepsilon}{\partial M} \right)^2 \sigma(M_{\pm})^2,$$

where

$$\frac{\partial \varepsilon}{\partial M} = -\frac{\varepsilon_{\pm}^2 BS}{DA} [1 + C(2M_{\pm} - 1)].$$

The error in m is:

$$\sigma(m_{\pm})^2 = \left(\frac{\partial m}{\partial \varepsilon_{\pm}} \right)^2 \sigma(\varepsilon_{\pm})^2 + \left(\frac{\partial m}{\partial M_{\pm}} \right)^2 \sigma(M_{\pm})^2.$$

$$\sigma(m_{\pm}) = m_{\pm} \sqrt{\left(\frac{\sigma(\varepsilon_{\pm})}{\varepsilon_{\pm}} \right)^2 + \left(\frac{\sigma(M_{\pm})}{M_{\pm}} \right)^2}.$$

Known Alpha Assay

The point model equations for the singles and doubles rates are

$$S = mF_0 \varepsilon \nu_{s1} M(1 + \alpha)$$

and

$$D = \frac{1}{2} mF_0 \varepsilon^2 f_d \nu_{s2} M^2 \left[1 + \left(\frac{M-1}{\nu_{i1}-1} \right) \frac{\nu_{s1} \nu_{i2}}{\nu_{s2}} (1 + \alpha) \right]$$

where the symbols are defined in the section “Conventional Multiplicity Assay.” If α is known, eliminating m from these equations produces an equation for M :

$$k_{\alpha}(1 + \alpha)M^2 + [1 - k_{\alpha}(1 + \alpha)]M - r = 0$$

where

$$k_{\alpha} = \frac{\nu_{s1} \nu_{i2}}{\nu_{s2} (\nu_{i1} - 1)} \quad (\text{default} = 2.166)$$

$$r = \frac{\frac{D}{S}(1 + \alpha)}{\rho_0}$$

where ρ_0 is the doubles/singles ratio for a nonmultiplying sample containing only ^{240}Pu . Although, theoretically,

$$\rho_0 = \frac{\varepsilon f_d \nu_{s2}}{2 \nu_{s1}}$$

ρ_0 is not restricted to this value, but is entered as one of the known alpha calibration parameters.

Solving the quadratic equation for M gives

$$M = \frac{-b_\alpha + \sqrt{b_\alpha^2 + 4a_\alpha r}}{2a_\alpha}$$

where

$$\begin{aligned} a_\alpha &= k_\alpha(1 + \alpha) \\ b_\alpha &= 1 - a_\alpha \end{aligned}$$

The multiplication corrected doubles rate is

$$D_c = \frac{D}{rM}$$

and the calibration curve is

$$D_c = a_{k\alpha} + b_{k\alpha}m$$

where $a_{k\alpha}$ and $b_{k\alpha}$ are calibration constants. Theoretically,

$$\begin{aligned} a_{k\alpha} &= 0 \\ b_{k\alpha} &= \frac{F_0 \epsilon^2 f_d \nu_{s2}}{2} \end{aligned}$$

but $b_{k\alpha}$ is usually obtained by least squares fitting, using multiplication corrected doubles rate vs effective ^{240}Pu mass for a series of pure plutonium standards.

Neglecting the correlation between S and D , the error of the multiplication corrected coincidence rate is

$$\sigma(D_c) = \left\{ \frac{\sigma_D^2}{M^4(b_\alpha^2 + 4a_\alpha r)} + \left[\frac{D}{SM^2 \sqrt{b_\alpha^2 + 4a_\alpha r}} + \frac{\rho_0}{M(1 + \alpha)} \right]^2 \sigma_S^2 \right\}^{1/2}$$

An estimate of the error of α is presently not included in the calculation of the error of D_c .

The multiplication corrected calibration curve

$$D_c = a_{k\alpha} + b_{k\alpha}m$$

is solved for effective ^{240}Pu mass and error as shown in the section “Conventional Calibration Curve Assay.”

Heavy Metal Correction

For the measurement of MOX fuel assemblies a heavy metal correction can be applied to the measured singles and doubles rates. This correction is in the form of:

$$k = 1 + HMfactor(HMref - g)$$

where *HMfactor* and *HMref* are empirically determined values from fits to data and *g* is the declared heavy metal content per unit length which includes the uranium and plutonium mass. This correction factor is then applied to the singles and doubles rate as follows:

$$S' = kS,$$

$$D' = \sqrt{k}D.$$

These corrected singles and doubles rates are then applied to the known alpha assay as described above.

Known Multiplication Assay

This method assumes that alpha is unknown, but that the multiplication is a known function of the effective ^{239}Pu mass. Presently, only a quadratic dependence of multiplication on effective ^{239}Pu mass is supported and no error analysis is done. Eliminating alpha from the point model equations for the singles and doubles rates from the section “Conventional Multiplicity Assay” gives:

$$f_M(m_{239e}) = \frac{\mathcal{E}_d M}{2} \left[k_M m_{239e} F_0 \mathcal{E} M \nu_{s2} + \left(\frac{M-1}{\nu_{i1}-1} \right) \nu_{i2} S \right] - D = 0$$

where

$$M = 1 + b_{kM} m_{239e} + c_{kM} m_{239e}^2$$

$$m_{239e} = \text{effective } ^{239}\text{Pu mass}$$

b_{kM}, c_{kM} = calibration parameters

$$k_M = \frac{m_{240e}}{m_{239e}}$$

and where the other symbols are defined in the section “Conventional Multiplicity Assay.” The factor k_M is a function of the isotopic composition only, so the known multiplicity equation can be solved for effective ^{239}Pu mass using Newton’s method as follows:

1. Set $z = 0$

2. Calculate

$$\Delta = -\frac{f_M(z)}{f'_M(z)}$$

where

$$f'_M(z) = \left(\frac{df_M(x)}{dx} \right)_{x=z} \cong \frac{f_M(z + 10^{-5}) - f_M(z)}{10^{-5}}$$

3. Set

$$m_{239e} = z + \Delta$$

4. If

$$|\Delta| > 10^{-4}$$

set $z = m_{239e}$ and go to step 2.

After the effective ^{239}Pu mass is obtained,

$$m_{240e} = k_M m_{239e}$$

$$M = 1 + b_{kM} m_{239e} + c_{kM} m_{239e}^2$$

$$\alpha = \frac{S}{m_{240e} F_0 \varepsilon M \nu_{s1}} - 1$$

Active Multiplicity Assay

Active multiplicity assay uses the measured doubles and triples rates to determine the neutron leakage multiplication of uranium samples. It does not presently determine the ^{235}U mass in the sample. In an active system the doubles (D) and triples (T) rates are given by the point model equations [30]:

$$D = \frac{F \varepsilon^2 f_d M^2}{2} \left[\nu_{t2} + \left(\frac{M-1}{\nu_{f1}-1} \right) \nu_{t1} \nu_{f2} \right]$$

$$T = \frac{F \varepsilon^3 f_t M^3}{6} \left[\nu_{t3} + \left(\frac{M-1}{\nu_{f1}-1} \right) (3\nu_{t2} \nu_{f2} + \nu_{t1} \nu_{f3}) + \right. \\ \left. 3 \left(\frac{M-1}{\nu_{f1}-1} \right)^2 \nu_{t1} \nu_{f2}^2 \right]$$

where

$F = ^{235}\text{U}$ fission rate

$\varepsilon =$ neutron detection efficiency

$M =$ neutron multiplication

$f_d, f_t =$ doubles and triples gate fractions, respectively

$\nu_{t1}, \nu_{t2}, \nu_{t3} =$ first, second, and third factorial moments of the neutron multiplicity distribution from the fission of ^{235}U induced by thermal neutrons (defaults = 2.414, 4.638, and 6.818, respectively [9])

$\nu_{f1}, \nu_{f2}, \nu_{f3} =$ first, second, and third factorial moments of the neutron multiplicity distribution from the fission of ^{235}U induced by 2 MeV neutrons (defaults = 2.637, 5.623, and 9.476, respectively [9])

Eliminating F from the equations for D and T produces the following equation for the neutron multiplication:

$$a_u + b_u M + c_u M^2 + M^3 = 0$$

where

$$a_u = \frac{1}{\varepsilon} \frac{T}{D} \frac{f_d}{f_t} \left[\frac{1}{v_{f2}} - \frac{v_{t2}(v_{f1} - 1)}{v_{t1} v_{f2}^2} \right] (v_{f1} - 1)$$

$$b_u = \frac{v_{t3}(v_{f1} - 1)^2 - (3v_{t2}v_{f2} + v_{t1}v_{f3} + \frac{3}{\varepsilon} \frac{T}{D} \frac{f_d}{f_t} v_{t1}v_{f2})(v_{f1} - 1)}{3v_{t1}v_{f2}^2} + 1$$

$$c_u = \frac{(3v_{t2}v_{f2} + v_{t1}v_{f3})(v_{f1} - 1)}{3v_{t1}v_{f2}^2} - 2$$

The cubic equation for M is solved by iteration as follows:

a) Set $M = 3$

b) Calculate

$$z = \frac{-a_u + c_u M^2 + 2M^3}{b_u + 2c_u M + 3M^2}$$

c) If

$$|z - M| > 10^{-9}$$

set $M = z$ and repeat from step b).

Add-a-Source Assay

Add-a-source assay is the same as calibration curve assay except that the doubles rate is multiplied by an add-a-source correction factor obtained from the ^{252}Cf add-a-source measurements. The add-a-source correction factor is [26]

$$k_{aas} = 1 + a_{aas} + b_{aas}\delta_{aas} + c_{aas}\delta_{aas}^2 + d_{aas}\delta_{aas}^3$$

where

$a_{aas}, b_{aas}, c_{aas}, d_{aas}$ = add-a-source calibration parameters

$$\delta_{aas} = \frac{D_{ref}^{now}}{D_{both} - D_{drum}} - 1$$

where

D_{ref}^{now} = calculated doubles rate for the add-a-source with an empty drum on the measurement date

D_{both} = doubles rate measured for the add-a-source plus the assay drum

D_{drum} = doubles rate measured for the assay drum without the add-a-source

The accidentals/singles and outlier tests are done for all measurements. Background is subtracted and the count rates are normalized.

The calculated add-a-source doubles rate for an empty drum on the measurement date is

$$D_{ref}^{now} = f_{decay} D_{ref}^{init}$$

where

D_{ref}^{init} = initial (reference) doubles rate for the add-a-source with empty drum

$$f_{decay} = \exp(-\ln(2)\Delta t / T_{1/2})$$

where

Δt = time from initial date to measurement date

$T_{1/2}$ = half life of ^{252}Cf (2.645 years [25]; 1 year = 365.24219 days [26])

The initial add-a-source doubles rate is the average of the doubles rates for up to 20 positions:

$$D_{ref}^{init} = \frac{\sum_{i=1}^{N_p} D_i^{init}}{N_p}$$

where

N_p = number of add-a-source positions

D_i^{init} = initial (reference) add-a-source doubles rate for the i -th position.

Similarly, the doubles rate for the drum plus the add-a-source is

$$D_{both} = \frac{\sum_{i=1}^{N_p} D_i^{both}}{N_p}$$

$$\sigma(D_{both}) = \frac{\left(\sum_{i=1}^{N_p} \sigma(D_i^{both})^2 \right)^{1/2}}{N_p}$$

where

$D_i^{both}, \sigma(D_i^{both})$ = background subtracted doubles rate and error for the i -th position for the add-a-source plus the assay drum.

The background error is ignored in the calculation of $\sigma(D_i^{both})$, which is always the sample standard deviation of the doubles rate measured at position i for the add-a-source plus assay drum.

The measured net add-a-source doubles rate for the i -th position is

$$D_i^{meas} = D_i^{both} - D_{drum}$$

and the error is

$$\sigma(D_i^{meas}) = \left[\sigma(D_i^{both})^2 + \sigma(D_{drum})^2 \right]^{1/2}$$

The calculated empty drum add-a-source doubles rate for the i -th position at the time of measurement is

$$D_i^{now} = f_{decay} D_i^{init}$$

so the ratio of the calculated empty drum to measured net doubles rates at the i -th position is

$$r_i^D = \frac{D_i^{now}}{D_i^{meas}}$$

The error of δ_{aas} is

$$\sigma(\delta_{aas}) = \frac{|D_{ref}^{now}|}{(D_{both} - D_{drum})^2} \left[\sigma(D_{both})^2 + \sigma(D_{drum})^2 \right]^{1/2}$$

and the error of k_{aas} is

$$\sigma(k_{aas}) = \left| b_{aas} + 2c_{aas}\delta_{aas} + 3d_{aas}\delta_{aas}^2 \right| \sigma(\delta_{aas})$$

The doubles rate and error for the calibration curve assay are

$$D = k_{aas} D_{drum}$$

and

$$\sigma(D) = |D| \left[\left(\frac{\sigma(k_{aas})}{k_{aas}} \right)^2 + \left(\frac{\sigma(D_{drum})}{D_{drum}} \right)^2 \right]^{1/2}$$

respectively.

Truncated Multiplicity Assay

The probabilities of obtaining 0, 1, or 2 real (correlated) pulses in the real-plus-accidental gate are [28]

$$r_0 = \frac{C_0^{R+A}}{C_0^A}$$

$$r_1 = \frac{C_1^{R+A} - r_0 C_1^A}{C_0^A}$$

$$r_2 = \frac{C_2^{R+A} - r_0 C_2^A - r_1 C_1^A}{C_0^A}$$

respectively, where C_n^{R+A} and C_n^A are the measured number of events with multiplicity n in the real-plus-accidental and accidental gates, respectively. The measured rates for the occurrence of real multiplicities of 0, 1, or 2 in the real-plus-accidental gate are called the measured zeros rate (M_{m0}), ones rate (M_{m1}), and twos rate (M_{m2}), respectively:

$$M_{m0} = S_m r_0$$

$$M_{m1} = S_m r_1$$

$$M_{m2} = S_m r_2$$

where the measured singles rate S_m is

$$S_m = \frac{C_S}{t_m}$$

where

$$C_S = \sum_{n=0}^{127} C_n^A$$

and t_m is the measurement time.

Deadtime corrections are not done for truncated multiplicity analysis. Approximate errors are calculated for the zeros, ones, and twos rates. If theoretical standard deviations are selected, the following equations are used; otherwise, the sample standard deviations are calculated. The zeros rate error is approximated by weighting the singles rate error by the zeros/singles ratio:

$$\sigma(M_{m0}) \cong \frac{M_{m0}}{S_m} \sigma(S_m) \cong \frac{M_{m0}}{S_m} \frac{\sqrt{C_S}}{t_m}$$

where C_S is the singles count and t_m is the measurement time. The ones rate error and twos rate error are calculated from the multiplicity distributions assuming that the multiplicity counts are Poisson distributed and uncorrelated and that the singles rate error is negligible. Then from the equations above for M_{m1} and M_{m2}

$$\sigma(M_{m1}) = S_m \frac{\sqrt{C_1^{R+A} + r_0^2 C_1^A}}{C_0^A}$$

$$\sigma(M_{m2}) = S_m \frac{\sqrt{z}}{(C_0^A)^2}$$

where

$$z = (C_1^A)^2 C_1^{R+A} + (C_0^A)^2 C_2^{R+A} + (2r_0 C_1^A - C_1^{R+A})^2 C_1^A + r_0^2 C_2^A (C_0^A)^2$$

For assay measurements, the measured singles, zeros, ones, and twos rates for an item are corrected for background as follows:

$$S = S_m^{item} - S_m^{bkgd}$$

$$M_0 = M_{m0}^{item} - M_{m0}^{bkgd}$$

$$M_1 = M_{m1}^{item} - M_{m1}^{bkgd}$$

$$M_2 = M_{m2}^{item} - M_{m2}^{bkgd}$$

where S , M_0 , M_1 , and M_2 are the background corrected rates and the superscripts *item* and *bkgd* refer to the item plus background rates and the background rates, respectively. The corresponding errors are

$$\sigma(S) = \left[\sigma(S_m^{item})^2 + \sigma(S_m^{bkgd})^2 \right]^{1/2}$$

and likewise for M_0 , M_1 , and M_2 .

The real gate multiplicity probabilities for the spontaneous fission of ^{240}Pu are [28]

$$r_i^{sf}(\varepsilon, f_d) = \frac{r_i^u}{\sum_{k=0}^5 r_k^u}$$

where

$$r_k^u = \sum_{n=k+1}^6 \sum_{m=k+1}^n \sum_{j=k+1}^m \binom{n}{m} \binom{j-1}{k} \varepsilon^m (1-\varepsilon)^{n-m} f_d^k (1-f_d)^{j-1-k} s_n$$

where

ε = neutron detection efficiency

f_d = doubles gate fraction

s_n = probability of multiplicity n from the spontaneous fission of ^{240}Pu [24]:

n	s_n
0	0.0631852
1	0.2319644
2	0.3333230
3	0.2528207
4	0.0986461
5	0.0180199
6	0.0020406

Truncated multiplicity assay with add-a-source

When truncated multiplicity is used in an add-a-source system, the ones rate is multiplied by a weighting factor to produce the doubles rate (D) used in the add-a-source calibration curve. Theoretically, the weighting factor is

$$w_{aas} = \frac{D}{M_1} = \frac{\mathcal{E}_d^{theor} v_{s2}}{2r_1 v_{s1}}$$

but w_{aas} is not restricted to this value; rather, it is an add-a-source calibration parameter (default = 1.2). The weighting factor does not have an assigned error, so

$$\sigma(D) = w_{aas} \sigma(M_1)$$

The doubles rate derived from the ones rate is used for add-a-source analysis only when this doubles rate is below a threshold value called the “Truncated multiplicity doubles rate upper limit” (default = 100 counts/s). For doubles rates above this value, the standard add-a-source analysis is done.

Assay calculation: known efficiency

This calculation assumes that the neutron detection efficiency is not significantly changed by sample moderation and absorption. The efficiency is

$$\varepsilon_c = \frac{\varepsilon}{\sqrt{K}}$$

where ε is the efficiency from the detector parameters and K is the normalization constant. Then the assay effective ^{240}Pu mass and error are

$$m_{240e} = \frac{a_{trunc} M_1}{F_0 \nu_{s1} \varepsilon_c r_1^{sf}(\varepsilon_c, f_d)}$$

$$\sigma(m_{240e}) = \left| m_{240e} \frac{\sigma(M_1)}{M_1} \right|$$

where

F_0 = ^{240}Pu spontaneous fission rate per unit mass (default = 473.5 g⁻¹ s⁻¹)

ν_{s1} = average number of neutrons emitted per spontaneous fission of ^{240}Pu
(default = 2.154)

a_{trunc} = truncated multiplicity calibration parameter (default = 1) that doesn't have an assigned error.

Then

$$\alpha = \frac{S r_1^{sf}}{a_{trunc} M_1} - 1$$

and, ignoring the error of S ,

$$\sigma(\alpha) = \left| (1 + \alpha) \frac{\sigma(M_1)}{M_1} \right|$$

Assay calculation: unknown efficiency

This is the same as the assay calculation with known efficiency, except that the efficiency is determined from the measured twos/ones ratio. Let

ε_m = measured efficiency

$$r_{21}(\varepsilon_m, f_d) = \frac{r_2^{sf}(\varepsilon_m, f_d)}{r_1^{sf}(\varepsilon_m, f_d)}$$

Then ε_m is obtained by iteration using Newton's method:

1. Set $\varepsilon = 0.5$

2. Calculate

$$r_{21}' = \left[\frac{dr_{21}(x, f_d)}{dx} \right]_{x=\varepsilon} = \frac{r_{21}(\varepsilon + 10^{-8}, f_d) - r_{21}(\varepsilon, f_d)}{10^{-8}}$$

and

$$\Delta = \frac{b_{trunc} \frac{M_2}{M_1} - r_{21}(\varepsilon, f_d)}{r_{21}'}$$

where b_{trunc} is a truncated multiplicity calibration parameter (default = 1) that doesn't have an assigned error.

3. Set $\varepsilon_m = \varepsilon$

4. If $|\Delta| > 10^{-6}$ set

$$\varepsilon = \varepsilon_m + \Delta$$

and go to step 2.

Then the assay effective ^{240}Pu mass is

$$m_{240e} = \frac{a_{trunc} M_1}{F_0 \nu_{s1} \varepsilon_m r_1^{sf}(\varepsilon_m, f_d)}$$

and the value of alpha is

$$\alpha = \frac{S r_1^{sf}(\varepsilon_m, f_d)}{a_{trunc} M_1} - 1$$

For typical multiplicity detector parameters, numerical studies show that to within about 20%

$$\frac{\sigma(r_1^{sf})}{r_1^{sf}} \cong \frac{\sigma(\varepsilon_m)}{\varepsilon_m} \cong \frac{\sigma(M_2)}{M_2}$$

Because the error of M_2 dominates the error of m_{240e} , the approximate error for m_{240e} is

$$\sigma(m_{240e}) = \left| 2m_{240e} \frac{\sigma(M_2)}{M_2} \right|$$

Similarly, the approximate error of alpha is

$$\sigma(\alpha) = \left| (1 + \alpha) \frac{\sigma(M_2)}{M_2} \right|$$

Plutonium Assay Mass

Plutonium assay mass is calculated from the effective ^{240}Pu mass and the plutonium isotopic composition:

$$m_{Pu} = \frac{m_{240e}}{f_{240e}}$$

where

$$m_{240e} = \text{effective } ^{240}\text{Pu mass}$$

and the effective ^{240}Pu mass fraction is [20]

$$f_{240e} = 2.52f_{238} + f_{240} + 1.68f_{242}$$

where

f_i = mass of plutonium isotope i as a fraction of total plutonium mass.

If the plutonium assay mass is not between the upper and lower mass limits in the calibration parameter set, then a warning message is generated.

The plutonium mass error is

$$\sigma(m_{Pu}) = \left[\left(\frac{\sigma(m_{240e})}{m_{240e}} \right)^2 + z \right]^{1/2} |m_{Pu}|$$

where

$\sigma(m_{240e})$ = standard deviation of m_{240e}

$$z = \frac{2.52^2 \sigma(f_{238})^2 + \sigma(f_{240})^2 + 1.68^2 \sigma(f_{242})^2}{(2.52f_{238} + f_{240} + 1.68f_{242})^2}$$

where

$\sigma(f_i)$ = standard deviation of mass fraction of plutonium isotope i

All calibration parameter sets (except for truncated multiplicity) have a calibration parameter labeled “Sigma(x) (%)” (default = 0), which is used to account for sources of error beyond counting statistics errors and calibration errors. The extra mass error is combined quadratically with the plutonium mass error above to produce the final plutonium assay mass error:

$$\sigma(m_{Pu}) = \left[\sigma_t(m_{Pu})^2 + \left(\frac{m_{Pu}\sigma_x}{100} \right)^2 \right]^{1/2}$$

where

σ_x = Sigma(x) (%) = extra error as percent of m_{Pu}

LWR Fuel Collar Assay

The assay of light water reactor (LWR) fuel using the LWR collar detector is performed as described in Ref. 31. The calibration equation is

$$D_c = \frac{am_{235}}{1 + bm_{235}}$$

where m_{235} is the ^{235}U mass per unit length of fuel, a and b are calibration parameters, and D_c is the corrected doubles rate:

$$D_c = k_0 k_1 k_2 k_3 k_4 k_5 D$$

where D is the measured doubles rate and where the k_i are correction factors described below. In this section all rates are corrected for deadtime and background. The calibration equation is solved for m_{235} as shown in the section “Conventional Calibration Curve Assay.”

The six correction factors are:

k_0	americium-lithium (AmLi) source yield factor
k_1	efficiency factor
k_2	detector response factor
k_3	poison factor
k_4	uranium factor
k_5	miscellaneous effects factor

The source yield factor is

$$k_0 = \frac{2^{\Delta t_1 / T_{1/2}}}{r_y}$$

where

Δt_1 = assay measurement date - calibration date

$T_{1/2} = ^{241}\text{Am}$ half life (433.6 years)

$$r_y = \frac{Y}{Y_{MRC95}}$$

where

Y = neutron yield of the AmLi source used for the measurement (applied source)

Y_{MRC95} = neutron yield of the reference AmLi source MCR95

The relative yields r_y for a number of sources are listed in Table II of Ref. 31.

The standard deviation of k_0 is

$$\sigma(k_0) = \frac{k_0}{r_y} \sigma(r_y)$$

where

$$\sigma(r_y) = \sqrt{2} \bullet 0.003 \bullet r_y$$

the singles rates measured for the reference and applied AmLi sources are estimated to have standard deviations of 0.3%.

The efficiency factor is

$$k_1 = \left(\frac{S_{\text{exp}}}{S_{\text{meas}}} \right)^2$$

where S_{meas} is the measured singles rate for the applied AmLi source in the detector on the normalization measurement date and where the S_{exp} is the expected singles rate for the applied source:

$$S_{\text{exp}} = r_y S_{MRC95} 2^{-\Delta t_2 / T_{1/2}}$$

where

Δt_2 = normalization measurement date – AmLi source MRC95 reference date

S_{MRC95} = singles rate for MRC95 in the detector on the MRC95 reference date

The standard deviation of k_1 is

$$\sigma(k_1) = 2k_1 \left[\left(\frac{\sigma(S_{MRC95})}{S_{MRC95}} \right)^2 + \left(\frac{\sigma(S_{\text{meas}})}{S_{\text{meas}}} \right)^2 + \left(\frac{\sigma(r_y)}{r_y} \right)^2 \right]^{1/2}$$

where

$$\sigma(S_{MRC95}) = 0.003 \bullet S_{MRC95}$$

and $\sigma(S_{meas})$ is obtained from the normalization measurement; the measurement of MRC95 used to obtain the relative source yield is not the same measurement used to obtain the reference MRC95 singles rate for normalization measurements.

If

$$100|1 - k_1| < p_{collar}$$

where p_{collar} is the acceptance limit for the collar normalization measurement in percent, then

$$k_1 = 1$$

$$\sigma(k_1) = 0$$

The detector response factor k_2 is

$$k_2 = \frac{D_{ref_collar}}{D_{applied_collar}}$$

where

D_{ref_collar} = doubles rate for the reference collar on the cross calibration date with the reference fuel assembly.

and

$D_{applied_collar}$ = doubles rate for the applied collar on the cross calibration date with the reference fuel assembly.

The standard deviation of k_2 is estimated to be

$$\sigma(k_2) = 0.003 \bullet k_2$$

The detector response factors for a number of collars are listed for BWR and PWR assemblies with and without cadmium liners in Tables XII-XV in Ref. 31.

The poison factor is

$$k_3 = 1 + \frac{n_{poison} N_{ref}}{N_{assay}} A_c [1 - \exp(-\lambda_a G)] (B_c - C_c E_{enr})$$

where

n_{poison}	=	number of poison rods in the assay fuel assembly
N_{ref}	=	total number of rods in the reference fuel assembly
N_{assay}	=	total number of rods in the assay fuel assembly
A_c, B_c, C_c	=	calibration constants
λ_a	=	poison absorption factor (also a calibration constant)
G	=	weight percent gadolinium in the poison rods
E_{en}	=	weight percent ^{235}U enrichment of the fuel

The standard deviation of k_3 is

$$\sigma(k_3) = \left[\left(\frac{\partial k_3}{\partial A_c} \right)^2 \sigma(A_c)^2 + \left(\frac{\partial k_3}{\partial B_c} \right)^2 \sigma(B_c)^2 + \left(\frac{\partial k_3}{\partial C_c} \right)^2 \sigma(C_c)^2 + \left(\frac{\partial k_3}{\partial G} \right)^2 \sigma(G)^2 + \left(\frac{\partial k_3}{\partial E_{enr}} \right)^2 \sigma(E_{enr})^2 \right]^{1/2}$$

where

$$\frac{\partial k_3}{\partial A_c} = \frac{n_{poison} N_{ref}}{N_{assay}} (B_c - C_c E_{enr}) [1 - \exp(-\lambda_a G)]$$

$$\frac{\partial k_3}{\partial B_c} = \frac{n_{poison} N_{ref}}{N_{assay}} A_c [1 - \exp(-\lambda_a G)]$$

$$\frac{\partial k_3}{\partial C_c} = -\frac{n_{poison} N_{ref}}{N_{assay}} A_c [1 - \exp(-\lambda_a G)] E_{enr}$$

$$\frac{\partial k_3}{\partial G} = \frac{n_{poison} N_{ref}}{N_{assay}} (B_c - C_c E_{enr}) \lambda_a A_c \exp(-\lambda_a G)$$

$$\frac{\partial k_3}{\partial E_{enr}} = -\frac{n_{poison} N_{ref}}{N_{assay}} A_c [1 - \exp(-\lambda_a G)] C_c$$

The enrichment is calculated from

$$E_{enr} = 100 \bullet \frac{m_{U\ 235}}{m_{U\ 235} + m_{U\ 238}}$$

where m_{U235} and m_{U238} are the declared masses of ^{235}U and ^{238}U in the fuel, respectively.

Then

$$\sigma(E_{enr})^2 = \left(\frac{\partial E_{enr}}{\partial m_{U235}} \right)^2 \sigma(m_{U235})^2 + \left(\frac{\partial E_{enr}}{\partial m_{U238}} \right)^2 \sigma(m_{U238})^2$$

where

$$\frac{\partial E_{enr}}{\partial m_{U235}} = 100 \bullet \frac{m_{U238}}{(m_{U235} + m_{U238})^2}$$

$$\frac{\partial E_{enr}}{\partial m_{U238}} = -100 \bullet \frac{m_{U235}}{(m_{U235} + m_{U238})^2}$$

The poison absorption factor λ_a does not have an assigned error; the other errors in the poison correction factor are quantities entered with the calibration parameters or with assay item data.

The uranium factor is

$$k_4 = 1 + D_c \left(E_c - \frac{m_U}{L_{fuel}} \right)$$

where

m_U	=	total uranium mass (g)
L_{fuel}	=	fuel length (cm)
D_c, E_c	=	calibration constants

The total uranium mass and standard deviation are calculated from

$$m_U = m_{U235} + m_{U238}$$

and

$$\sigma(m_U) = \left[\sigma(m_{U235})^2 + \sigma(m_{U238})^2 \right]^{1/2}$$

respectively.

The standard deviation of k_4 is

$$\sigma(k_4) = \left[\left(\frac{\partial k_4}{\partial D_c} \right)^2 \sigma(D_c)^2 + \left(\frac{\partial k_4}{\partial E_c} \right)^2 \sigma(E_c)^2 + \left(\frac{\partial k_4}{\partial m_U} \right)^2 \sigma(m_U)^2 + \left(\frac{\partial k_4}{\partial L_{fuel}} \right)^2 \sigma(L_{fuel})^2 \right]^{1/2}$$

where

$$\frac{\partial k_4}{\partial D_c} = E_c - \frac{m_U}{L_{fuel}}$$

$$\frac{\partial k_4}{\partial E_c} = D_c$$

$$\frac{\partial k_4}{\partial m_U} = -\frac{D_c}{L_{fuel}}$$

$$\frac{\partial k_4}{\partial L_{fuel}} = \frac{D_c m_U}{L_{fuel}^2}$$

The errors needed for the uranium correction factor error calculation are quantities entered with the calibration parameters or with assay item data.

The miscellaneous effects factor is

$$k_5 = \prod_{i=1}^{N_{effects}} k_{5i}$$

where k_{5i} is the factor for the i-th effect and $N_{effects}$ is the number of effects.

The standard deviation of k_5 is

$$\sigma(k_5) = k_5 \left[\sum_{i=1}^{N_{effects}} \left(\frac{\sigma(k_{5i})}{k_{5i}} \right)^2 \right]^{1/2}$$

The total collar correction factor is

$$k_{collar} = k_0 k_1 k_2 k_3 k_4 k_5$$

For the calculation of the error of k_{collar} , the normalization measurement date is set equal to the assay date:

$$\Delta t_2 = \text{assay measurement date} - \text{AmLi source MRC95 reference date}$$

this simplifies database operations in the INCC code and has zero or negligible effect on the error in practical situations.

Let

$$k_{01} = k_0 k_1 = \left(\frac{2^{\Delta t_1 / T_{1/2}}}{r_y} \right) \left(\frac{r_y S_{MRC95} 2^{-\Delta t_2 / T_{1/2}}}{S_{meas}} \right)^2 = \frac{r_y 2^{(\Delta t_1 - 2\Delta t_2) / T_{1/2}} S_{MRC95}^2}{S_{meas}^2}$$

Then

$$\sigma(k_{01}) = \left[\left(\frac{\partial k_{01}}{\partial r_y} \right)^2 \sigma(r_y)^2 + \left(\frac{\partial k_{01}}{\partial S_{MRC95}} \right)^2 \sigma(S_{MRC95})^2 + \left(\frac{\partial k_{01}}{\partial S_{meas}} \right)^2 \sigma(S_{meas})^2 \right]^{1/2}$$

where

$$\begin{aligned} \frac{\partial k_{01}}{\partial r_y} &= 2^{(\Delta t_1 - 2\Delta t_2) / T_{1/2}} \left(\frac{S_{MRC95}}{S_{meas}} \right)^2 \\ \frac{\partial k_{01}}{\partial S_{MRC95}} &= \frac{2 \bullet 2^{(\Delta t_1 - 2\Delta t_2) / T_{1/2}} r_y S_{MRC95}}{S_{meas}^2} \\ \frac{\partial k_{01}}{\partial S_{meas}} &= \frac{-2 \bullet 2^{(\Delta t_1 - 2\Delta t_2) / T_{1/2}} r_y S_{MRC95}^2}{S_{meas}^3} \end{aligned}$$

However, if

$$k_1 = 1$$

and

$$\sigma(k_1) = 0$$

then

$$\sigma(k_{01}) = \sigma(k_0)$$

The standard deviation of k_{collar} is then

$$\sigma(k_{collar}) = k_{collar} \left[\left(\frac{\sigma(k_{01})}{k_{01}} \right)^2 + \left(\frac{\sigma(k_2)}{k_2} \right)^2 + \left(\frac{\sigma(k_3)}{k_3} \right)^2 + \left(\frac{\sigma(k_4)}{k_4} \right)^2 + \left(\frac{\sigma(k_5)}{k_5} \right)^2 + \frac{2 \bullet \text{cov}(k_3, k_4)}{k_3 k_4} \right]^{1/2}$$

where

$$\text{cov}(k_3, k_4) = \frac{\partial k_3}{\partial E_{enr}} \frac{\partial k_4}{\partial m_U} \text{cov}(E_{enr}, m_U)$$

where

$$\text{cov}(E_{enr}, m_U) = \frac{\partial E_{enr}}{\partial m_{U235}} \sigma(m_{U235})^2 + \frac{\partial E_{enr}}{\partial m_{U238}} \sigma(m_{U238})^2$$

The standard deviation of the corrected doubles rate D_c is then

$$\sigma(D_c) = D_c \left[\left(\frac{\sigma(k_{collar})}{k_{collar}} \right)^2 + \left(\frac{\sigma(D)}{D} \right)^2 \right]^{1/2}$$

where $\sigma(D)$ is the standard deviation of the measured doubles rate.

The assay ^{235}U mass per unit length of fuel and the standard deviation (m_{235} and $\sigma(m_{235})$) are then obtained from D_c and $\sigma(D_c)$ as shown in the section “Conventional Calibration Curve Assay.”

The total assay ^{235}U mass m_{235}^{total} is calculated from

$$m_{235}^{total} = m_{235} L_{fuel}$$

the standard deviation is calculated as

$$\sigma(m_{235}^{total}) = m_{235}^{total} \left[\left(\frac{\sigma(m_{235})}{m_{235}} \right)^2 + \left(\frac{\sigma(L_{fuel})}{L_{fuel}} \right)^2 \right]^{1/2}$$

where the weak correlation between m_{235} and L_{fuel} through the uranium correction factor k_4 is ignored as insignificant in practical situations.

Finally, the declared minus assay mass difference and standard deviation are

$$\Delta_{235} = m_{U\ 235} - m_{235}^{total}$$

and

$$\sigma(\Delta_{235}) = \left[\sigma(m_{U\ 235})^2 + \sigma(m_{235}^{total})^2 \right]^{1/2}$$

where the weak correlation between $m_{U\ 235}$ and m_{235}^{total} through the poison correction factor k_3 and the uranium correction factor k_4 is ignored as insignificant in practical situations. Because the k_3 and k_4 correction factors are insensitive to the ^{235}U mass, the assay solution for m_{235}^{total} is not iterated.

Table of Symbols

The following symbols are used in more than one section of this document and are not necessarily defined in each section.

A	deadtime coefficient for the singles and doubles rates
B	deadtime coefficient for the singles and doubles rates
C	deadtime coefficient for the triples rate
C_A	accidental coincidence counts
C_{R+A}	real-plus-accidental coincidence counts
C_S	singles counts (totals) counts
C_{X1}	counts in 1st auxiliary scaler
C_{X2}	counts in 2nd auxiliary scaler
C_n^{R+A}	real-plus-accidental coincidence counts with multiplicity n

C_n^A	accidental coincidence counts with multiplicity n
D	doubles rate corrected for deadtime, background and normalization
D_b	doubles rate corrected for deadtime and background
D_d	doubles rate corrected for deadtime
D_m	measured doubles rate (no corrections)
F_0	^{240}Pu spontaneous fission neutrons per second per gram of ^{240}Pu
f_{240e}	mass of effective ^{240}Pu as a fraction of plutonium mass
f_d	doubles gate fraction
f_d^{theor}	theoretical doubles gate fraction
f_i	mass of plutonium isotope i as a fraction of plutonium mass
f_t	triples gate fraction
G	coincidence gate length
K	normalization constant
m	effective ^{240}Pu mass (short notation)
M	neutron multiplication
m_{239e}	effective ^{239}Pu mass
m_{240e}	effective ^{240}Pu mass
m_{Pu}	total plutonium mass
S	singles rates corrected for deadtime, background and normalization
S_b	singles rate corrected for deadtime and background
S_d	singles rate corrected for deadtime
S_m	measured singles rate (no corrections)

T	triples rates corrected for deadtime, background, and normalization
$T_{1/2}$	half life
T_b	triples rate corrected for deadtime and background
T_d	triples rate corrected for deadtime
t_m	measurement time in seconds
T_m	measured triples rate (no corrections)
V_{sdt}	singles, doubles, and triples multiplicity error matrix with deadtime, background and normalization corrections
V_{sdt}^d	singles, doubles, and triples multiplicity error matrix with deadtime and background corrections
α	alpha value [ratio of (α,n) to spontaneous fission neutrons]
αn	multiplicity deadtime coefficient for multiplicity n
βn	multiplicity deadtime coefficient for multiplicity n
δ_{mult}	multiplicity deadtime
Δt	time difference
ε	neutron detection efficiency
v_{s1}, v_{s2}, v_{s3}	1st, 2nd, and 3rd factorial moments of the neutron emission multiplicity distribution for the spontaneous fission of ^{240}Pu
v_{i1}, v_{i2}, v_{i3}	1st, 2nd, and 3rd factorial moments of the neutron emission multiplicity distribution for the neutron induced fission of ^{239}Pu
$\sigma(x)$	standard deviation of x
σx	standard deviation of x (short notation)

Database Recovery Procedure

Database corrupted

The database may only be reinitialized by reinstalling INCC. This is a way of recovering from a corrupted database, but will result in the loss of all measurement data, calibration parameters and setup parameters. If possible, first use *File / Save As/Export / Transfer* to preserve any measurement data you do not want to lose. Use *File / Save As/Export / Initial Data* to preserve any measurement (detector) parameters and calibration parameters you do not want to lose. You must be in maintenance mode to access the *Initial Data option*. After the database has been reinitialized, you can use *Get External Data / Transfer* to try to recover the saved measurement data, and *Get External Data / Initial Data* to try to recover the saved measurement (detector) parameters and calibration parameters.

To minimize the effect of a corrupted database, it is highly recommended that you use the *File / Back Up All Data* option frequently.

Technical Support

Physics technical support

Bill Geist 505-667-2527 (telephone)
 505-665-4433 (fax)
 wgeist@lanl.gov

Software technical support, issue reporting and resolution

Joseph Longo 505-667-2452 (telephone)
505-665-4433 (fax)
longo@lanl.gov

Appendix

Data Processing

Data processing - raw data

The raw data depend on the type of shift register electronics used. All shift register electronics provide the counting time, the total counts, the real-plus-accidental ($R+A$) coincidence counts, and the accidental (A) coincidence counts. In addition, multiplicity electronics provide two multiplicity distributions, the ($R+A$) distribution and the (A) distribution. Some electronics also collect data from one or two auxiliary scalers. A measurement can consist of one or more cycles, each of which produces a raw data set. All raw data from all cycles are saved in the results file for the measurement.

Data processing - checksum test

The checksum test is a quality control test used with all multiplicity electronics except the AMSR. The sum of the counts in the accidental multiplicity distribution must equal the total neutron count. Also, the first moment of the ($R+A$) multiplicity distribution must equal the ($R+A$) coincidence counts and the first moment of the (A) distribution must equal the (A) coincidence counts. If any of these conditions are not met and the checksum test is enabled, a checksum error is generated and the measurement data from the cycle are not further processed. The multiplicity electronics can measure multiplicities from 0 to 255, but only multiplicities from 0 to 127 are used by the software; this is because the deadtime correction procedure hasn't been developed for larger multiplicities. If the measured distribution

produces multiplicities larger than 127 and the checksum test is enabled, a checksum error will occur. If the test fails, another cycle is made to replace the failed cycle. However, if n consecutive cycles (default: 10) fail, the measurement is aborted. Failure of the checksum test indicates a hardware problem unless the largest multiplicity is greater than 127. If the checksum test is enabled, it is performed even if the quality control (QC) tests are turned off.

Data processing - accidentals/singles test

The measured totals rate (or singles rate) is the totals count divided by the measurement time. The accidental coincidence rate is the accidental coincidence counts divided by the measurement time. If the neutron count rate is constant (within statistical errors) during a measurement, then the accidental coincidence rate should equal the gate length times the square of the singles rate (within statistical errors) [1]. The empirical standard deviation of the ratio of the accidental coincidence rate to the gate length times the square of the singles rate is approximately the reciprocal square root of the accidental coincidence counts. If this ratio is more than n standard deviations (default: 4) from unity, an accidentals/singles test error is generated and the measurement data from the cycle are not further processed. The accidentals/singles test is not done for background measurements and is not done when the total count rate is below some minimum value (default: 1000 counts/s). Also, the test always passes if the accidental coincidence rate and the gate length times the square of the singles rate are the same within n % (default: 0.1 %). No deadtime corrections are done for the accidentals/singles test. The test is done whenever the quality control (QC) tests are selected at the beginning of the measurement.

Data processing - outlier test

At the end of each cycle during a measurement, the outlier test compares the doubles and triples rates for each cycle in a measurement with the average doubles and triples rates for the measurement, respectively. If one or more values is at least n standard deviations (default: 3) from the average, the largest deviate is rejected as an outlier. The test is then continued until no outliers are found or until there are only two cycles left; the test is not made when there are just one or two cycles initially. If an outlier is found, an additional cycle is made automatically to replace the rejected cycle. An exception to this procedure occurs when more than n (default is 100) cycles are requested at the beginning of the measurement. In this case all the requested cycles are collected first and the outlier test is done in one pass: all cycles with a doubles or triples rate greater than n standard deviations (default: 3) from the respective average are rejected and no replacement measurements are made. The outlier test is not applied to precision measurements. The test is done whenever the quality control (QC) tests are selected at the beginning of the measurement.

Data processing - deadtime corrected count rates and errors

The singles rate and the doubles rate are corrected for deadtime using the deadtime correction equations of Ref. 2, and the deadtime corrected triples rate is calculated using the equations

of Ref. 3. The standard deviations of the count rates are determined in one of two ways as selected under *Maintain / Error Calculation Method*: theoretical standard deviations (default selection) and sample standard deviations. If theoretical standard deviations are selected, the errors for the singles and doubles rates are calculated from the equations in section 2.5 of Ref. 3 and the error for the triples rate is calculated from the equations in section 3 of Ref. 3. If sample standard deviations are selected, then the count rate errors are calculated as the sample standard deviations of the rates from the individual cycles in a measurement. If there is only one cycle, the sample standard deviations are set to zero. All measurements are corrected for deadtime except precision measurements.

Data processing - average rates

After all cycles for a measurement are finished and any outliers are rejected, the summed raw data for the individual cycles are used to calculate the final rates. The final standard deviations for the rates depend on the calculation method selected. If the errors are calculated from theory, then they are calculated from the summed raw data. If they are calculated from the sample standard deviations, then the relative error of the average rate is the sample standard deviation divided by the average rate of the individual cycles and then divided by the square root of the number of cycles.

Data processing - background subtraction

The singles, doubles, and triples rates for passive and active background measurements can either be measured or entered from the keyboard under *Maintain / Background*. The present background rates are subtracted from the deadtime corrected rates obtained in calibration, verification, holdup, initial source, normalization, and rates only measurements.

Measurements

Rates Only

Rates only measurements produce singles, doubles, and triples rates and errors as the only result. The rates are corrected for deadtime, passive background, and normalization.

Background

Passive background measurements automatically replace previous passive singles, doubles, and triples background rates with the new measured rates. In passive background measurements, a warning message is generated if the doubles rate or the triples rate exceeds n counts/s (default: 1 count/second). An active background measurement automatically replaces the previous active background singles rate. The passive doubles and triples background rates are used for the active doubles and triples background rates.

Initial Source

For AmLi initial source measurements, excluding the UNCL, the singles rate and measurement date are stored in the database as the reference values for normalization measurements. For ^{252}Cf initial source measurements the singles or doubles rate and error and the measurement date are stored in the database as the reference values for normalization measurements. These rates are corrected for deadtime and background.

Normalization

The normalization measurement determines a normalization constant to correct for a change in the detector efficiency since the initial source measurement. For ^{252}Cf normalization measurements the normalization constant is the ratio of the expected singles or doubles rate to the measured singles or doubles rate; the expected rate is calculated from the initial source data and the 2.645-year ^{252}Cf half-life. If the normalization constant is less than n standard deviations (default: 3) from unity or is less than m percent (default: 4) from unity, then the normalization constant is set to 1 and the error is set to 0. For AmLi normalization measurements the normalization constant is the square of the ratio of the expected singles rate to the measured singles rate; the expected rate is calculated from the initial source data and the 433.6-year ^{241}Am half-life. If the normalization constant is less than m percent (default: 4) from unity, then the normalization constant is set to 1 and the error is set to 0.

Precision

Precision measurements test the short term system stability by determining whether the observed scatter in a series of doubles measurements is statistically consistent with the expected scatter. The tested value is chi-square. The upper and lower acceptance limits are determined by the number of cycles and the confidence level (default: 99%). No corrections are done to the doubles rates for this test, but the checksum test and the accidentals/singles test are applied. The result is the measured chi-square value, the upper and lower limits, and a pass/fail message.

Verification measurements - general

There are seven types of passive verifications and four types of active verifications. The passive verifications determine Pu mass [1] and the active verifications (except for active multiplicity) determine ^{235}U mass. All verifications start with the measurement of count rates as described above, followed by one or more verification calculations. Each verification type has its own analysis method; the rates from an item can be analyzed with several analysis methods as selected by the user. The Pu isotopic composition is used by all of the passive methods to convert the effective ^{240}Pu mass to Pu mass [1]; it is also used with the ^{241}Am content in the known alpha method to calculate the alpha value [1] and in the known multiplication method to calculate the effective ^{239}Pu mass [4]. The Pu and Am content is decay corrected from the analysis date or dates to the verification date using the half lives

from Ref. 5; the decay of ^{241}Pu to ^{237}U with 0.002% probability is ignored. In approximation, the percent errors of the Pu isotopes after decay are set equal to the percent errors before decay and the error of the ^{241}Am mass after decay is obtained by combining the contributions from the ^{241}Am before decay and the ^{241}Pu that decays to ^{241}Am .

Each of the verification methods is covered in a separate section below.

Verification measurements - passive calibration curve

The verification is based on a calibration curve of doubles rate (after all corrections) vs. effective ^{240}Pu mass. Four curve types are provided with the general form $D = D(m, a, b, \dots)$, where D is the doubles rate, m is the effective ^{240}Pu mass, and a, b , etc. are calibration constants. The effective ^{240}Pu mass is calculated from D, a, b , etc. and the standard deviation of m is calculated using standard error propagation techniques [6]. In addition, an extra error term labeled “Sigma x (%)” is included to account for sources of error that are not included in the errors of D, a, b , etc. The quantity “Sigma x (%)”, converted to mass, is combined in quadrature with the standard deviation of m to produce the final standard deviation of m . The Pu mass is then calculated from m and the isotopic composition; the error of the Pu mass is calculated with standard error propagation techniques using the errors of m and the Pu isotopes.

The polynomial curve type can have more than one solution for a specified doubles rate. In this case the software selects the smallest mass that is within the upper and lower mass limits. If there is no solution within the mass limits, then the software selects the smallest positive mass. If there is no positive mass, then the least negative mass is selected.

Verification measurements - known alpha

The verification is based on a calibration curve of multiplication corrected doubles rate vs. effective ^{240}Pu mass [1]. The multiplication corrected doubles rate D_c is calculated from the singles and doubles rates, the alpha value, rho-zero, and a constant k . The alpha value α is calculated [1] from the Pu isotopic composition and the alpha weight. The alpha weight is a factor used to weight the alpha value calculated for pure oxide; *e.g.*, for pure oxide the alpha weight is 1 and for pure metal the alpha weight is 0. Rho-zero is the ratio of the doubles to singles rates times $(1 + \alpha)$ for a nonmultiplying item of ^{240}Pu . The constant k is 2.062 in Ref. 1; a value of 2.166 (default) makes k consistent with the multiplicity analysis parameters below. The effect of switching between 2.062 and 2.166 is small for most items. The calibration curve has the form $D_c = a + bm$, where a and b are calibration constants. Otherwise, the analysis procedure is the same as for the passive calibration curve procedure.

Verification measurements - known M

The verification is based on a calibration curve of multiplication vs. effective ^{239}Pu [4]. The equations relating the singles and doubles rates to the effective ^{240}Pu mass, multiplication

(M), and alpha are the same as for the known alpha technique. Alpha and the effective ^{240}Pu mass are the unknowns; M is determined from the calibration curve. The only function for the calibration curve presently in the software is $M = 1 + am + bm^2$, where m is the effective ^{239}Pu mass, and a and b are calibration constants. There is presently no error calculation for the effective ^{240}Pu mass; the only error assigned to the effective ^{240}Pu mass is that from the extra error component “Sigma x (%)”.

Verification measurements - passive multiplicity

For conventional multiplicity analysis the verification is based on the monoenergetic, point-model equations in Ref. 7 that relate the singles, doubles, and triples rates to the effective ^{240}Pu mass, multiplication and alpha. If theoretical standard deviations are selected, the errors of the effective ^{240}Pu mass, multiplication and alpha are calculated using the error analysis method of Ref. 3.

For multiplicity analysis with unknown efficiency, the same equations are used, but the neutron multiplication is set to unity and the equations are solved for effective ^{240}Pu mass, efficiency, and alpha.

For multiplicity analysis with the dual-energy model, the energy-dependent, point-model equations in Ref. 18 are used to determine the effective ^{240}Pu mass, multiplication, and alpha. The errors of the verification results from conventional multiplicity analysis are also used for the errors in dual-energy multiplicity analysis.

There is an empirical correction factor that is applied to the effective ^{240}Pu verification mass to account for a normalization required for items with high neutron multiplication. The correction factor f has the form $f = a + b(M-1) + c(M-1)^2$, where M is the neutron multiplication and a , b and c are calibration constants. The correction factor is usually set to 1. The verification depends on the first, second, and third factorial moments of the neutron multiplicity distribution for ^{240}Pu spontaneous fission (default values: 2.154, 3.789, and 5.211, respectively [8]) and for the 2-MeV induced fission of ^{239}Pu (default values: 3.163, 8.240, and 17.321, respectively [9]); it also depends on the spontaneous fission rate of ^{240}Pu (default: 473.5 fissions/g second [8, 10]).

Verification measurements - add-a-source

The add-a-source verification technique is described in Ref. 11. The add-a-source correction factor f has the form $f = 1 + a + b\delta + c\delta^2 + d\delta^3$, where a , b , c , and d are calibration constants and $\delta = D_{\text{ref}} / D_{\text{meas}} - 1$, where D_{ref} is the reference doubles rate decayed to the measurement date and D_{meas} is the doubles rate from the verification item with the ^{252}Cf add-a-source minus the doubles rate from the verification item alone. These doubles rates involving the add-a-source are averages over up to five positions of the source. The error on these rates is always calculated using the sample standard deviation. The measured doubles

rate from the item is multiplied by f and the Pu verification mass is then determined as described above under “Verification measurement - passive calibration curve”.

Verification measurements - curium ratio

Curium ratio analysis is an indirect method of determining the mass of plutonium and uranium from an observed curium neutron measurement. The curium ratio method was developed for the analysis of waste streams in spent fuel reprocessing facilities. In these waste streams, ^{244}Cm is the dominant neutron producing species.

This method requires a chemical analysis of the waste stream, after extraction of the plutonium and uranium has been completed, to determine the concentrations of ^{244}Cm , plutonium, and uranium. Ratios of grams curium per gram plutonium and grams curium per gram uranium can then be formed. These ratios are used as input parameters for the curium ratio analysis. It has been shown that these ratios remain constant throughout the waste treatment process (concentration, vitrification) [14,15,16].

The actual neutron measurement is an observation of ^{244}Cm spontaneous fission neutrons. Using a typical passive calibration curve analysis, the mass of curium can be determined. The values of the Cm/Pu and Cm/U ratios are then applied to determine the mass of Pu and U from the observed Cm mass. The ratios are decay corrected from the chemical analysis date to the measurement date within the INCC program. Errors in these ratios are propagated and included in the error ascribed to the determined masses. The ^{235}U mass is also calculated by INCC, but this mass obtained from the ratio of the operator declared masses for ^{235}U and U.

In the case of analysis of vitrified wastes, coincidence measurements (doubles) are required to determine the curium mass because the vitrification process results in a significant (alpha,n) neutron production rate which is treated as an unknown. In the case of leached hulls measurements, there is no significant (alpha,n) production and one can obtain the mass of Pu and U from singles measurements.

Verification measurements - truncated multiplicity

The truncated multiplicity method is used for the measurement of very small Pu items when the cosmic ray background interferes with the measurement. Truncated multiplicity analysis uses only the first three multiplicity values (the zeros, ones, and twos) in the multiplicity distributions and thus ignores the higher multiplicities that are produced primarily by cosmic rays; this improves the precision of the assay mass. Truncated multiplicity analysis is an example of gate multiplicity analysis and is described in Ref. 17.

Verification measurements - active calibration curve

This is the same as verification by passive calibration curve, except that the calibration mass is ^{235}U rather than ^{240}Pu and the doubles rate is corrected for the decay of the AmLi sources.

Verification measurements - collar

The verification is based on the algorithms in Ref. 12 for thermal-mode and fast-mode active measurements of LWR fuel. The error analysis is essentially that described in Ref. 13.

Verification measurements - active multiplicity

In its present state of development, the active multiplicity technique does not verify the ^{235}U mass of an item; it is only able to determine the neutron multiplication of the item. The multiplication is determined from the triples and doubles rates using the active multiplicity equations; the doubles and triples rates in the active multiplicity equations are the same as those in the passive multiplicity equations [7] except that the spontaneous fission moments are replaced by the thermal neutron induced fission moments of ^{235}U , the induced fission moments are replaced by the 2-MeV induced fission moments of ^{235}U , and the spontaneous fission rate is replaced by the rate of ^{235}U fissions induced by AmLi neutrons. The calculation requires the first, second, and third factorial moments of the thermal neutron induced fission of ^{235}U (default values: 2.414, 4.638, and 6.818, respectively [9]) and of the 2-MeV induced fission of ^{235}U (default values: 2.637, 5.623, and 9.476, respectively [9]).

Verification measurements - active/passive

Active/passive verification is used for active verification (except UNCL verification) when the item has a significant passive neutron yield. The item is measured with and without the americium-lithium (AmLi) interrogation sources. The net doubles rate is used for the verification exactly as for verification by active calibration curve.

Holdup measurements

The holdup measurement option performs multiple measurements of a glovebox at different positions, and then averages the count rate data from each position into a single value for use in calculating the ^{240}Pu effective mass in a glovebox. The multiple measurements are obtained from scanning the glovebox with neutron slab detectors. The INCC software controls the data collection so that all the measurements for a single glovebox are stored in one data file.

Calibration

Calibration measurements are the same as verification measurements, except that the verification masses are not calculated.

Command Line Flags

INCC has limited command line flag features.

/IMPORT

The **IMPORT** flag has one purpose, as described in the chapter “Import Operator Declarations from Operator Review and Measurements from Radiation Review”, p. 24.

The import task may be started manually, by invoking INCC from a command line with the **/IMPORT** flag, e.g. `C:\incc>incc /import`

/INITIALIZE

The **Initialize** flag causes INCC to import specified transfer files and initial data files into a new or existing database. The files may be identified singly by name, or collectively by folder name, or by zip archive. The target database is configured with the content of the specified files. The processing is logged. Subsequent import processing of measurement data files may immediately follow the database preparation steps of **/initialize**.

/Initialize \path\to\an\transfer\file (1)

/Initialize \path\to\an\initial data cal file (2)

/Initialize \path\to\an\initial data detector file (3)

/Initialize \path\to\an\folder -- (4) the folder is searched for all transfer and initial data files. Those found are used to initialize the target database. The initialize processing order is based on the file names. For transfer files, this means oldest first, usually followed by initial data files, in a simple alphabetical order.

/Initialize \path\to\an\zipfile.zip -- (5) the zip file is extracted to a temporary folder, and then processed as above, see (4)

Supporting flags used with **/Initialize** and **/Import** operations.

/Target \path\to\existing db\or\location\for\new db\
-- required

/DBSource \optional\path\to\an\zipped\inccdb.zip\used as
an\initial\db
-- otherwise an empty db is used

/DataSource \optional\path\to\the\shared\RAD\location\for\files\
ncc+nop+cop+ncc
-- use with **/import**, default is existing values in incc.ini

/Preserve

-- default INCC behavior is “reckless”, overwriting an existing **/target** database with new material. Using **/preserve** prevents the overwrite

/ExportLocation

\optional\path\to\the\shared\RAD\location\and\name\for\the\tab-delimited\file\used\by “IR”

-- use with **/import**, default is existing value in incc.ini

/LogLocation \path\to\folder\with\optional\file.name

-- Specify the folder to place the log file. When no name is given, an auto-generated file name is created, and all log messages generated during a clock-hour are directed to the log file. If the file name is used, that file becomes the unified log file for the duration of the incc operation.

/quiet

-- default behavior is the database setting for ‘Maintain>Some Settings...>Allow or Suppress all dialogs and pop-ups during IMPORT’. In an empty database the database setting is ‘Allow’, and user interaction may cause dialogs and acknowledgement pop-ups to appear during runtime. Such interaction is unwelcome in batch processing use. Use the **/quiet** flag to suppress user interaction no matter what the source or target database setting may be.

Other details:

- Flags are **not** case-sensitive.
- The flags **/initialize /DBSource /ExportLocation, /LogLocation** and **/DataSource**, when present, must each be followed by a path.
- **/import**, when used, must come first in the argument list.
- Parameters are parsed only by the presence of a ‘/’. A new command line flag starts when a ‘/’ is encountered by the command line parser. File paths and names with embedded white space need not be quoted. This is counter-intuitive to traditional command line and command shell parsing behavior, and is a legacy of the UI library used in INCC.
- When the log file is auto-created, a separate new file is created every hour. A new log file is created every hour to manage file size and clutter. All log messages within an hour are directed to the latest hourly file. Manually specifying a log file (**/LogLocation**) avoids the hourly log behavior.

Command line examples

Preparing a new database with calibration parameters

```
incc /initialize C:\INCC Test\incc delta /LogLocation \tmp\incc  
xfer.log /target \tmp\db
```

- 1: Start log file in \tmp\incc xfer.log
- 2: Create an empty database at \tmp\db if one is not found
- 3: Load all transfer and initial data files found in the “C:\INCC Test\incc delta” folder into the database at \tmp\db.

Preparing a new database with one set of calibration parameters from a transfer file, then analyzing one or more NCC files

```
incc /import /initialize C:\INCC Test\8C404735.RTS /loglocation \tmp  
/target \tmp\db /datasource C:\RRP\IPCAS\data /exportlocation  
C:\tmp\data
```

- 1: Start auto-named log file in \tmp, uses a time stamp and mnemonic cue in the file name
- 2: Create an empty database at \tmp\db if one is not found
- 3: Load the info in the rates-only transfer file C:\INCC Test\8C404735.RTS into the database
- 4: Start the IMPORT processing, using C:\RRP\IPCAS\data as the source of cop/nop/ncc files
- 5: Write the “IR” txt file in C:\tmp\data, using the default filename incc.txt

Importing NCC files into a new database, but using a specific pre-configured source database as the starting point

```
incc.exe /import /target \tmp\db /dbsource c:\ndar  
config\incccfg\inccdb.zip /datasource c:\rrp\ipcass\data  
/exportlocation C:\tmp\data
```

- 1: Start auto-named log file in <incc.exe install location>, uses a time stamp and mnemonic cue in the file name
- 2: Create a database using the /dbsource inccdb.zip at \tmp\db, overwriting any existing database
- 3: Start the IMPORT processing, using C:\RRP\IPCAS\data as the source of cop/nop/ncc files
- 4: Write the “IR” txt file in C:\tmp\data, using the default filename incc.txt

Preparing a new database with multiple sets of calibration parameters from initial data and transfer files, stored in a zip archive, then analyzing one or more NCC files

```
incc.exe /import /initialize C:\INCC Test\test some files.zip  
/loglocation \tmp\ziptest.txt /target \tmp\db /datasource  
C:\RRP\IPCAS\data /exportlocation C:\tmp\data
```

- 1: Start log file in \tmp\ziptest.txt
- 2: Create an empty database at \tmp\db if one is not found
- 3: Load all transfer and initial data files found in “C:\INCC Test\test some files.zip” into the database at \tmp\db.
- 4: Start the IMPORT processing, using C:\RRP\IPCAS\data as the source of cop/nop/ncc files
- 5: Write the “IR” txt file in C:\tmp\data, using the default filename incc.txt

Preparing a new database with multiple calibration parameters from initial data and transfer files, stored in a folder, then analyzing one or more NCC files

```
incc.exe /import /initialize C:\INCC Test\test dir /loglocation  
\tmp\foldertest.txt /target \tmp\db /datasource C:\RRP\IPCAS\data  
/exportlocation C:\tmp\data
```

- 1: Start log file in \tmp\ foldertest.txt
- 2: Create an empty database at \tmp\db if one is not found
- 3: Load all transfer and initial data files found in the folder “C:\INCC Test\test dir” into the database at \tmp\db.
- 4: Start the IMPORT processing, using C:\RRP\IPCAS\data as the source of cop/nop/ncc files
- 5: Write the “IR” txt file in C:\tmp\data, using the default filename incc.txt

References

- [1] N. Ensslin, "Principles of Neutron Coincidence Counting," in *Passive Nondestructive Assay of Nuclear Materials*, D. Reilly, et al., eds., US Nuclear Regulatory Commission, NUREG/CR-5550 (1991).
- [2] H. O. Menlove and J. E. Swansen, "A High-Performance Neutron Time Correlation Counter," *Nuclear Technology*, Vol. 71, pp. 497-505 (1985).
- [3] N. Dytlewski et al., "Measurement Variances in Thermal Neutron Coincidence Counting," *Nuclear Instr. Methods*, A327, pp. 469-479 (1993).
- [4] J. E. Stewart et al., "Defining an Effective Plutonium Mass for Induced Fission (IF)," in "Safeguards and Security Progress Report," compiled by D. B. Smith and G. R. Jaramillo, Los Alamos National Laboratory report LA-11356-PR, pp.18-21 (1987).
- [5] T. E. Sampson, "Plutonium Isotopic Composition by Gamma-Ray Spectroscopy," in *Passive Nondestructive Assay of Nuclear Materials*, D. Reilly, et al., eds., US Nuclear Regulatory Commission, NUREG/CR-5550 (1991).
- [6] "American National Standard Guide to Calibrating Nondestructive Assay Systems," American National Standards Institute, ANSI N15.20-1975 (1975).
- [7] D. M. Cifarelli and W. Hage, "Models for a Three-Parameter Analysis of Neutron Signal Correlation Measurements for Fissile Material Assay," *Nuclear Instr. Methods*, A251, pp. 550-563 (1986).
- [8] N. E. Holden and M. S. Zucker, "A Re-Evaluation of the Average Prompt Neutron Emission Multiplicity (NuBar) Values from Fission of Uranium and Transuranium Nuclides," *IAEA Advisory Group, Meeting on Nuclear Standard Reference Data*, Geel, Belgium, Nov. 1984, IAEA-TECDOC-335, p. 248, BNL 35513.
- [9] M. S. Zucker and N. E. Holden, "Energy Dependence of the Neutron Multiplicity P_v in Fast Neutron Induced Fission of $^{235,238}\text{U}$ and ^{239}Pu ," *Proceedings, International Symposium on Nuclear Material Safeguards*, Vienna, Nov. 1986, Vol. 2, pp. 329-347 (1987), BNL 38665.
- [10] N. Ensslin, "The Origin of Neutron Radiation" in *Passive Nondestructive Assay of Nuclear Materials*, D. Reilly, et al., eds., US Nuclear Regulatory Commission, NUREG/CR-5550 (1991).
- [11] H. O. Menlove et al., "WDAS Operation Manual Including the Add-A-Source Function," Los Alamos National Laboratory report LA-12292-M (1992).

- [12] H. O. Menlove, et al., "Neutron Collar Calibration and Evaluation for Assay of LWR Fuel Assemblies Containing Burnable Neutron Absorbers," Los Alamos National Laboratory report LA-11965-MS (1990).
- [13] P. De Ridder, "Neutron Collar Error Propagation Model," International Atomic Energy Agency report IOM-PSA-144/91 (1991).
- [14] Menlove, H.O., Beddingfield, D.H., Rinard, P.M., and Wenz, T.R., "The Curium Tagging Approach for Enhanced Safeguards for Spent Fuel Handling and Reprocessing," International Atomic Energy Agency Symposium on International Safeguards, Vienna, Austria, Oct. 13-17, 1997.
- [15] Rinard, P.M., and Menlove, H.O., "Applications of Curium Measurements for Safeguarding at Reprocessing Plants," Los Alamos National Laboratory report, LA-UR-95-2788, 1995.
- [16] Menlove, H.O., and Miura, N., "The Use of Curium Neutrons to verify Plutonium in Spent Fuel and Reprocessing Wastes," Los Alamos National Laboratory report, LA-12774-MS, 1994.
- [17] M. S. Krick, "Thermal Neutron Multiplicity Counting of Samples with Very Low Fission Rates," 38th Annual Meeting, Institute of Nuclear Materials Management, Phoenix, AZ, USA, July 1997.
- [18] M. S. Krick, D. G. Langner, and J. E. Stewart, "Energy-Dependent Bias in Plutonium Verification Measurements Using Thermal Neutron Multiplicity Counters," Symposium on International Safeguards, International Atomic Energy Agency, Vienna, Austria, Oct. 1997.
- [19] N. Ensslin et al., "Application Guide to Neutron Multiplicity Counting," Los Alamos National Laboratory report LA-13422-M (1998).
- [20] D. Reilly et al., eds., *Passive Nondestructive Assay of Nuclear Materials*, Los Alamos National Laboratory report LA-UR-90-732 (1990).
- [21] N. Dytlewski, "Dead-time corrections for multiplicity counters," Nucl. Instr. Meth. A305, pp. 492-494 (1991).
- [22] H. O. Menlove, "Multiplicity Dead Time Corrections," Los Alamos National Laboratory memo N-1-92-742 (1992) (unpublished).
- [23] P. R. Bevington, *Data Reduction and Error Analysis for the Physical Sciences*, McGraw-Hill (1969).

- [24] P. Griffiths and I. D. Hill, eds., *Applied Statistics Algorithms*, Ellis Horwood Limited (1985).
- [25] R. B. Firestone, *Table of Isotopes, Eighth Edition*, John Wiley & Sons (1996).
- [26] “Nuclear Materials — Plutonium-Bearing Solids — Calibration Techniques for Calorimetric Assay,” American National Standards Institute, ANSI N15.22-1987.
- [27] R. S. Burington, *Handbook of Mathematical Tables and Formulas*, Handbook Publishers (1956).
- [28] “The 1986 CODATA Recommended Values of the Fundamental Physical Constants,” Journal of Research of the National Bureau of Standards, 92, pp. 85-95 (1987).
- [29] F. Rasetti, *Elements of Nuclear Physics*, Prentice-Hall (1936).
- [30] N. Ensslin et al., “Analysis of Initial In-Plant Active Neutron Multiplicity Measurements,” *Nucl. Mater. Manag.* 22 (Proc. Issue), 465-470 (1993).
- [31] H. O. Menlove, et al., “Neutron Collar Calibration and Evaluation for Assay of LWR Fuel Assemblies Containing Burnable Neutron Absorbers,” Los Alamos National Laboratory report LA-11965-MS (1990).
- [32] M. S. Krick, W. H. Geist, D. R. Mayo and J. M. Burward-Hoy, *Achieving Accurate Neutron-Multiplicity Analysis of Metals and Oxides with Weighted Point Model Equations*, Los Alamos National Laboratory report LA-UR-04-4357 (2004).
- [33] M. S. Krick, W. H. Geist, D. R. Mayo, *A Weighted Point Model for the Thermal Neutron Multiplicity Assay of High-Mass Plutonium Samples*, Los Alamos National Laboratory report LA-14157 (Oct. 2005).
- [34] J. Longo, *Integrated Review Software, INCC COM Interface Specification*, Los Alamos National Laboratory report LA-UR-05-3723 (Aug. 26, 2007).
- [35] R. Ottmar, P. van Belle, S. Croft, P. M. J. Chard, L. C-A Bourva, U. Blohm-Hieber, *An Empirical Measurement of the Specific ^{240}Pu -Effective Mass of ^{238}Pu and ^{242}Pu* , Proceedings of the 21st ESARDA Symposium on Safeguards and Nuclear Materials Management, ESARDA (1999).