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Title: FRAM v.6.1's Improvements

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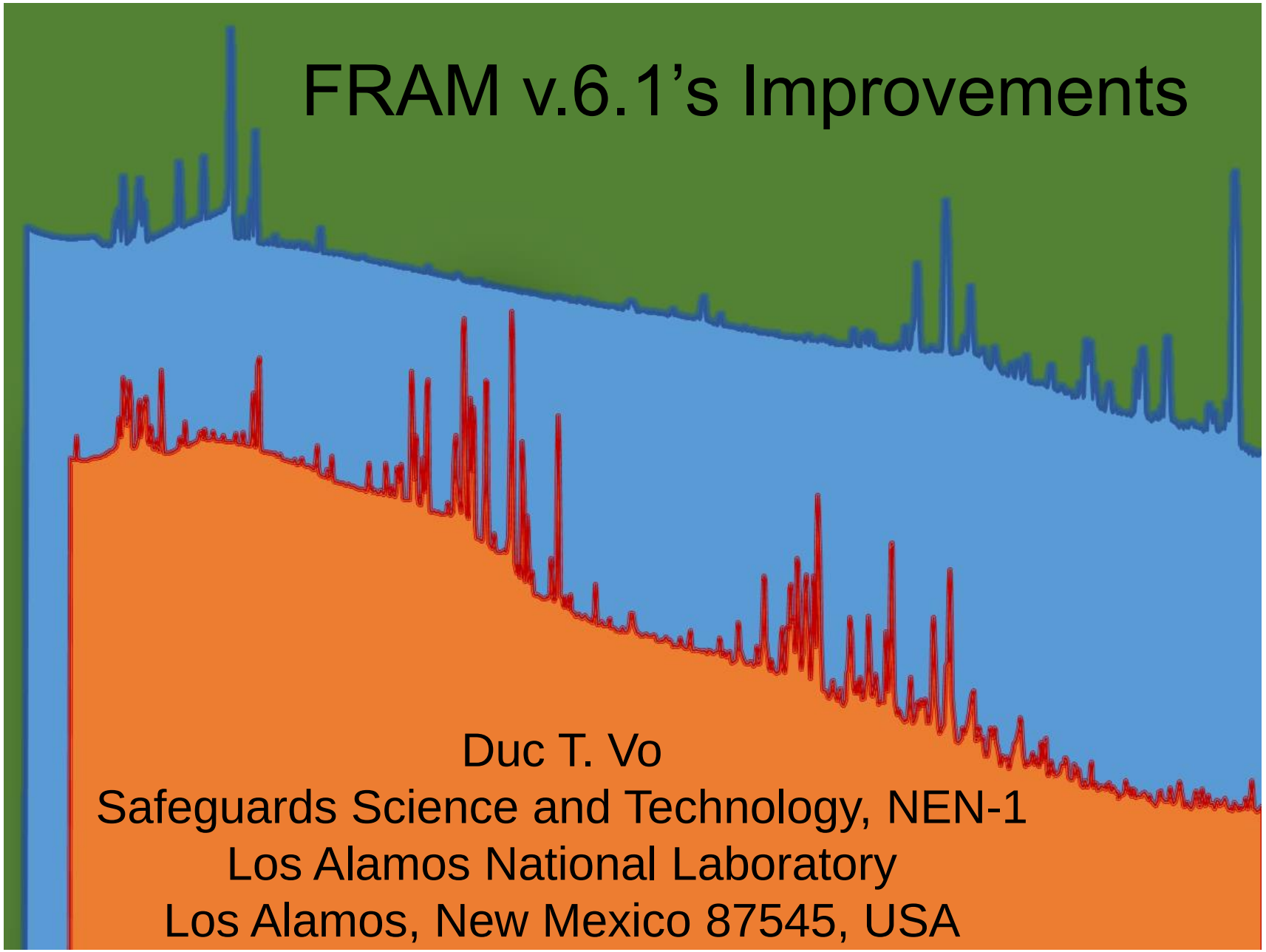
FRAM v.6.1's Improvements



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What is FRAM?

- FRAM is an isotopic analysis code nominally designed for plutonium and uranium.
- Fixed-energy Response-function Analysis with Multiple efficiencies.
- Self-calibration using several gamma-ray peaks.
- User-editable analysis parameters.
- Analyze gamma ray data from 30keV to >1MeV of HPGe, CdTe, CZT, and LaBr3 detector.

Development of FRAM

- FRAM was first developed in the mid-1980s to analyze plutonium spectra. It ran on a MicroVAX computer with the VMS operating system.
- The first version of the FRAM code running on PC/Windows 3.1, called PC/FRAM, was released in 1994.
- FRAM v.2 was released in 1997 with additional capability to analyze uranium spectra. It ran on Windows 3.1 and 95 and was licensed to Ortec.
- FRAM v.3 was released in 1999 as a 32-bit code, running on Windows 95, 98, and NT. It was licensed to Ortec and Canberra.

Development of FRAM cont.

- FRAM v.4 was released in 2001/2002. It had the capability to analyze the 100-keV X-ray region of both plutonium and uranium spectra. It ran on Windows 95, 98, NT, 2000, and XP. It was licensed to Ortec and Canberra.
- FRAM v.5.1 was released in 2011 with a completely different user interface and the capability to run in the command line mode. It ran on all 32-bit and 64-bit Windows versions from Windows 95 to Windows 10. It was licensed to Ortec and Canberra.
- FRAM v.5.2 was released in 2013 with some minor upgrades from v.5.1 and was licensed to Ortec and Canberra.
- FRAM v.6.1 was released in March 2020 with many upgrades from v.5.2.

FRAM Analysis steps

i. Determine energy calibration.

ii. Determine full width at half-maximum (FWHM) calibration.

iii. Determine peak shape (tail) calibration.

iv. Fit the regions to obtain peak areas.

v. Determine relative efficiency curve.

vi. Calculate the relative activities of the isotopes.

vii. Adjust the background of the analysis regions.

viii. **HPGe:** Repeat steps iv to vii several times (default: five iterations).

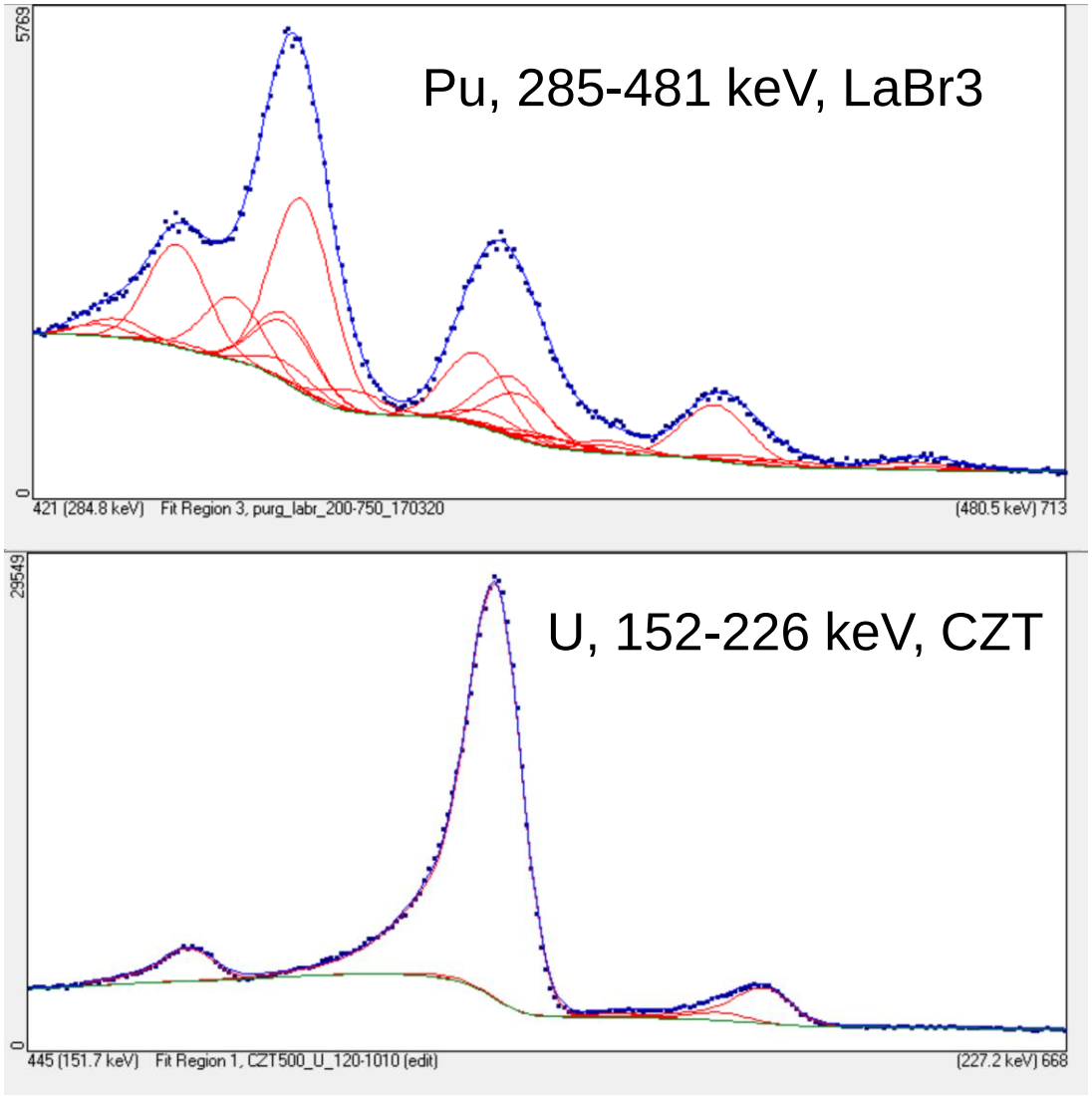
viii. **LaBr3 & CZT:** Repeat steps i to vii several times.

ix. Estimate ^{242}Pu or ^{236}U by correlation if needed.

x. Calculate the final isotopic fractions of the isotopes.

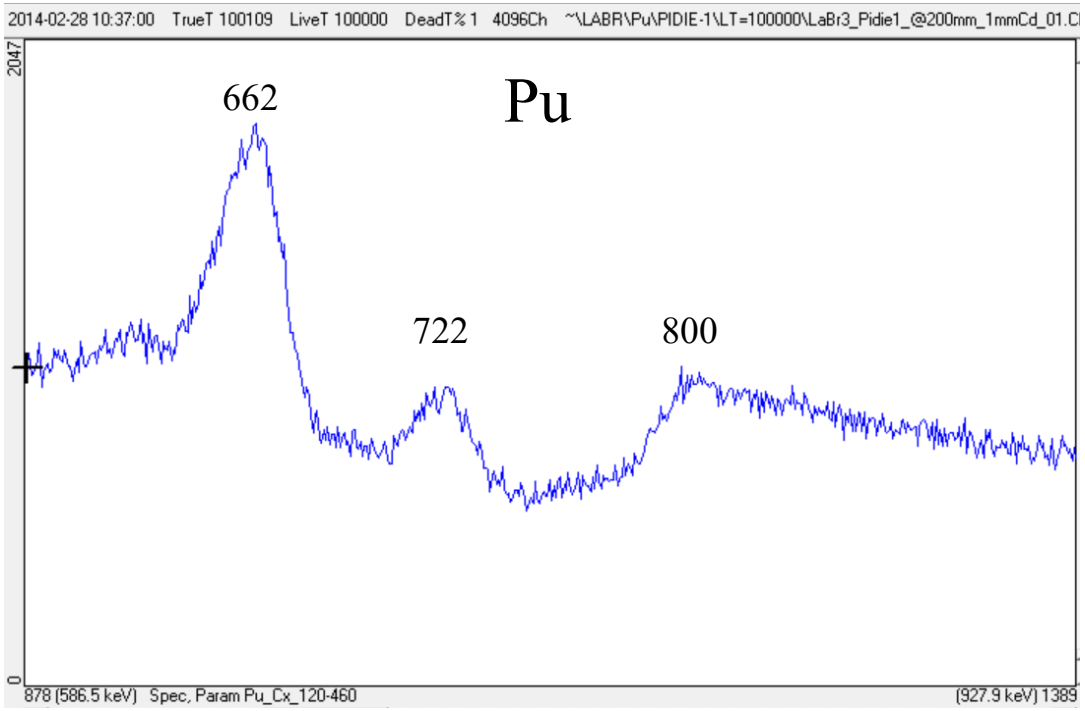
Peak fitting

- FRAM uses linear least squares to fit the peaks of the HPGe spectra.
- FRAM uses a nonlinear least squares fit technique, combining the Powell's minimization method with the linear least squares fit to fit the peaks of the LaBr3 and CZT spectra.



^{238}Pu and ^{234}U correlation

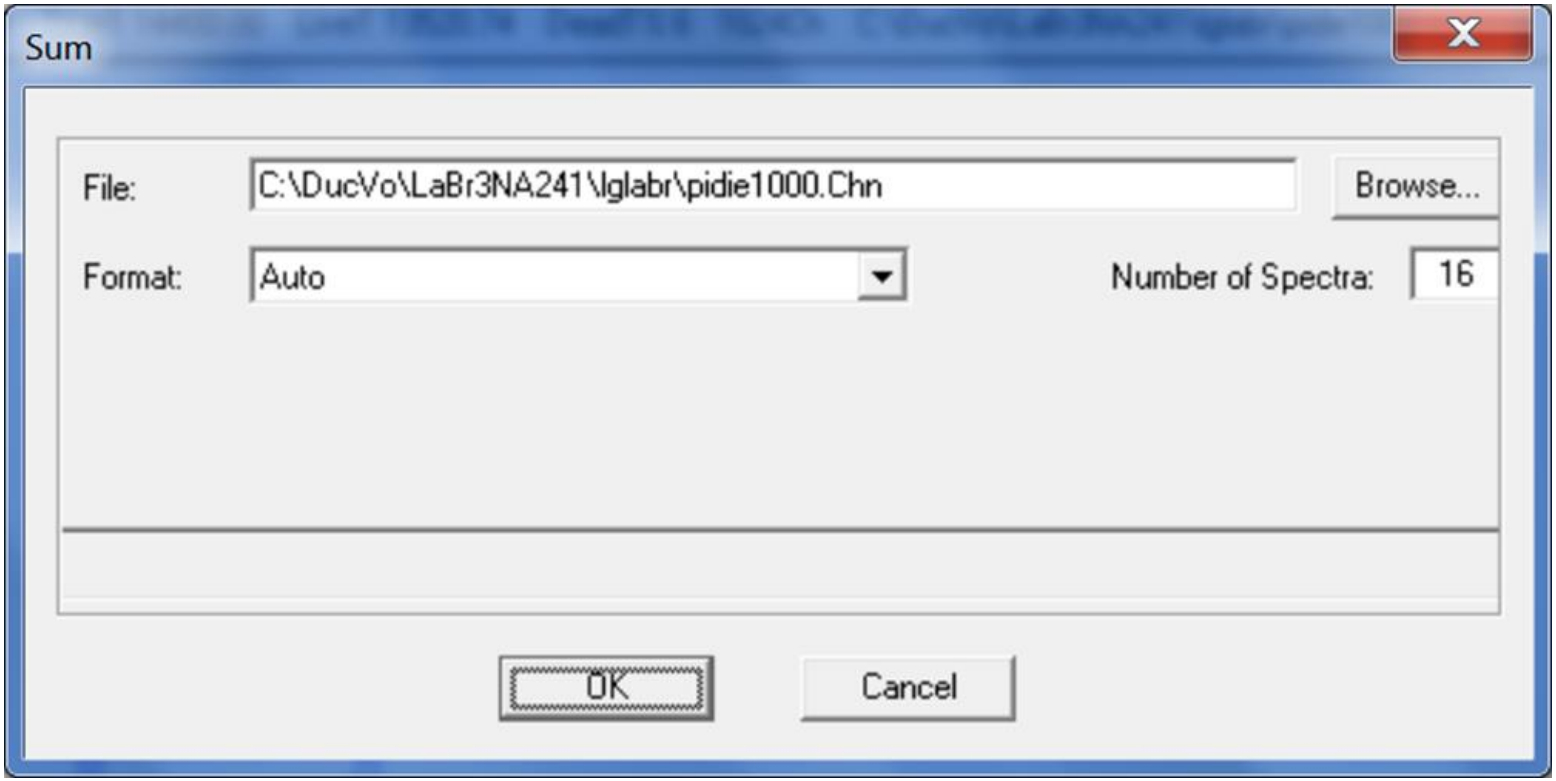
- Pu-238 has the only peak for activity at 766 keV
- The LaBr3 spectra have peaks from radioactive lanthanum in the detector itself at about 800 keV.
- This leads to bad ^{238}Pu 766-keV peak area.



- $\frac{^{238}\mathrm{Pu}}{^{239}\mathrm{Pu}} = c\left(\frac{^{240}\mathrm{Pu}}{^{239}\mathrm{Pu}}\right)^{d}$

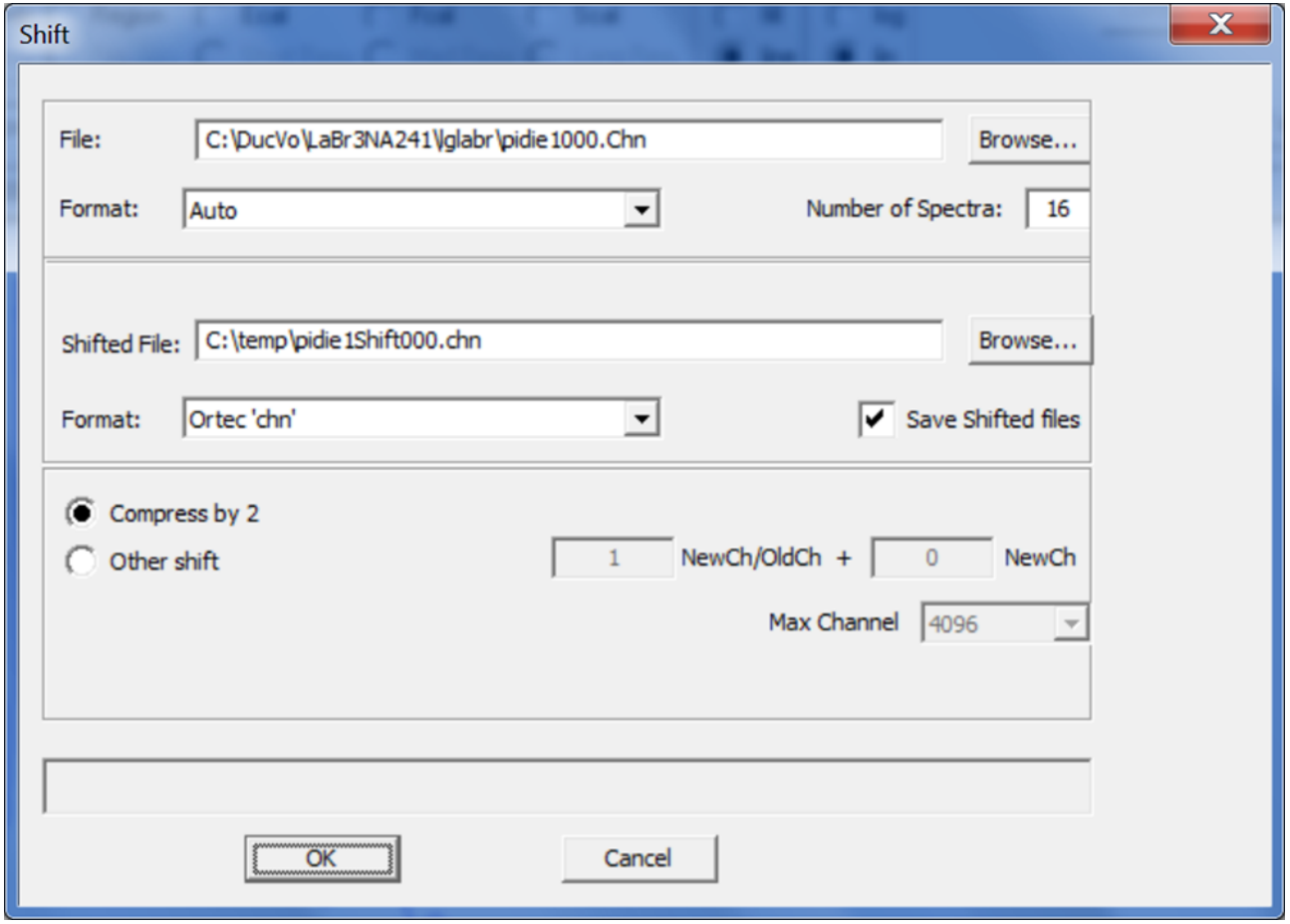
- The ^{234}U 121-keV peak is weak
- $\frac{^{234}\mathrm{U}}{^{235}\mathrm{U}} = a\frac{^{235}\mathrm{U}}{^{238}\mathrm{U}} + b$

Sum spectra



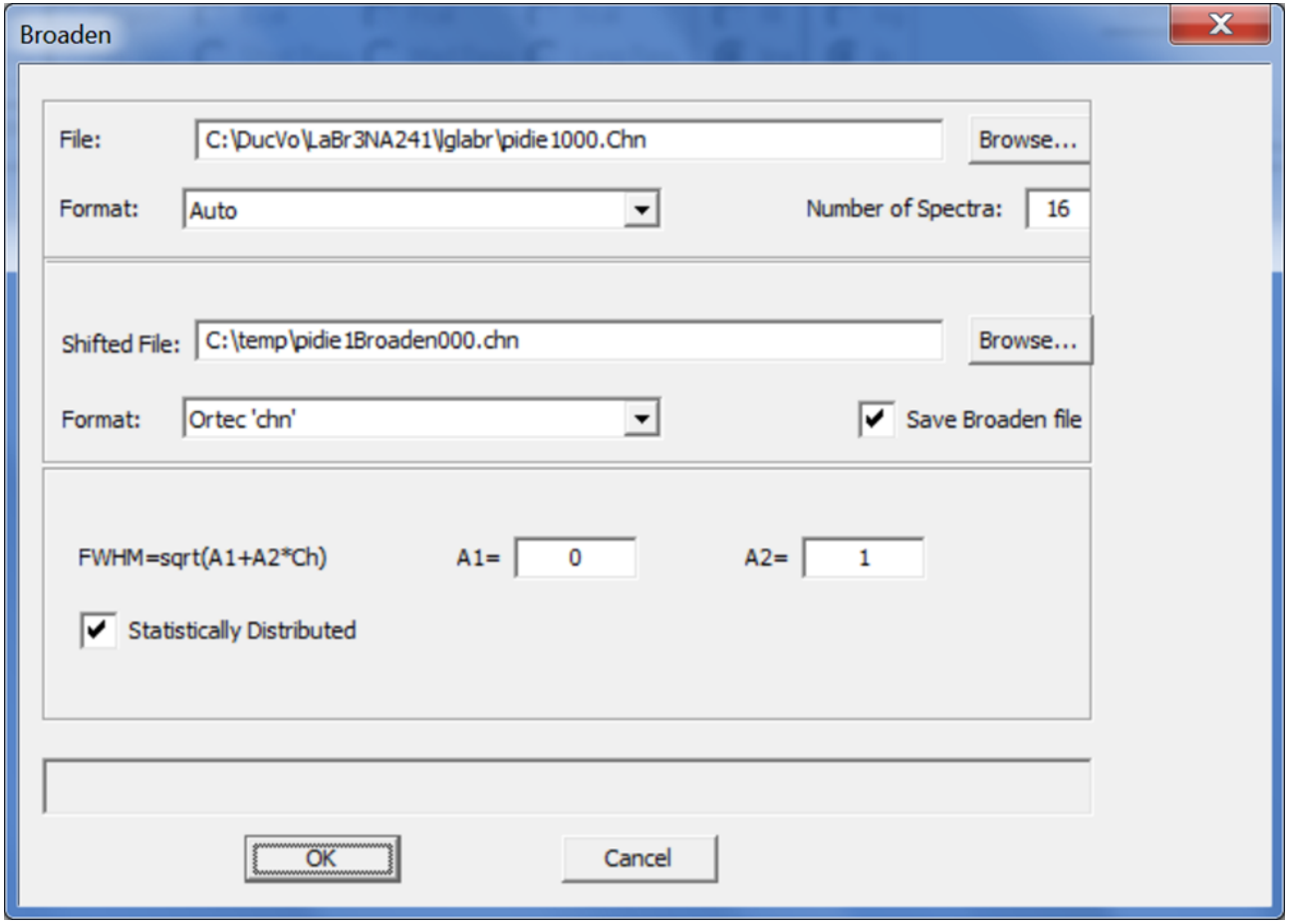
- The Measure | Sum option opens the Sum dialog to allow the user to enter information about the spectra to be summed.

Shift spectrum



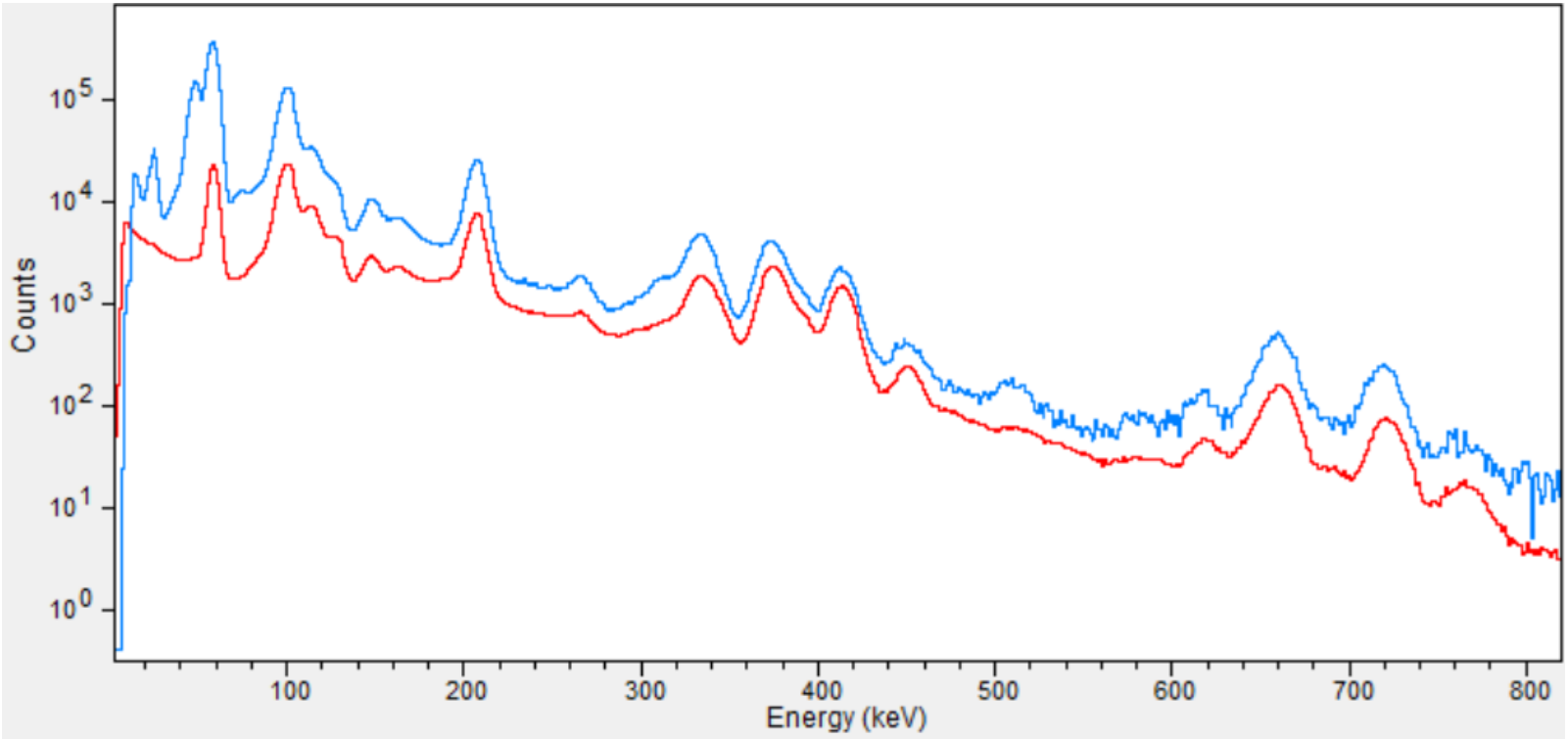
- FRAM fits a peak best when its FWHM is 8–10 channels.
- Many spectra are acquired with FWHM from about 20 to 100 channels wide.
- The Measure | Shift option opens the Shift dialog to allow the user to enter information about the spectra to be shifted.

Broaden spectrum



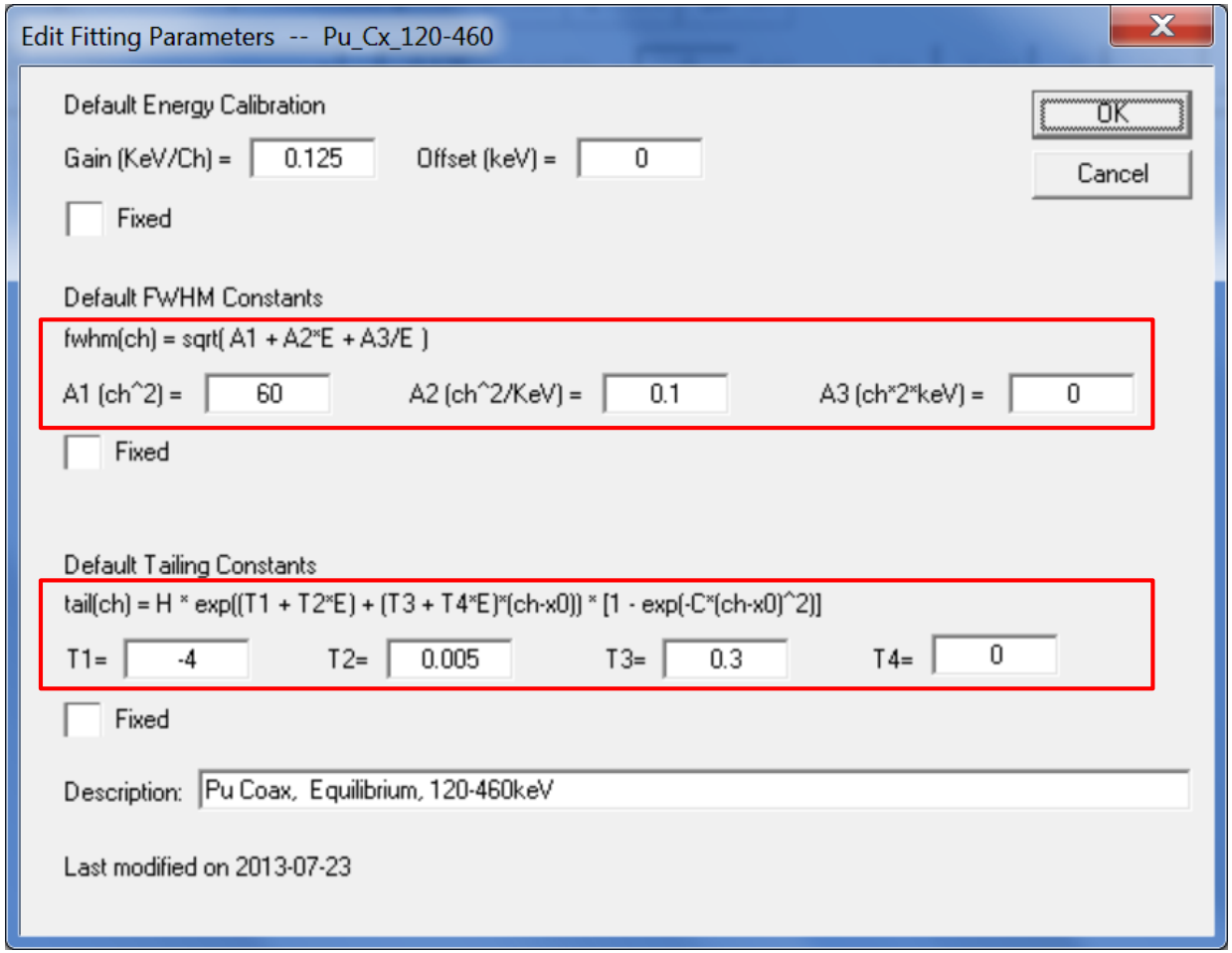
The Measure | Broaden option opens the Broaden dialog box to allow the user to enter information about the spectra to be broadened.

Broaden spectrum example



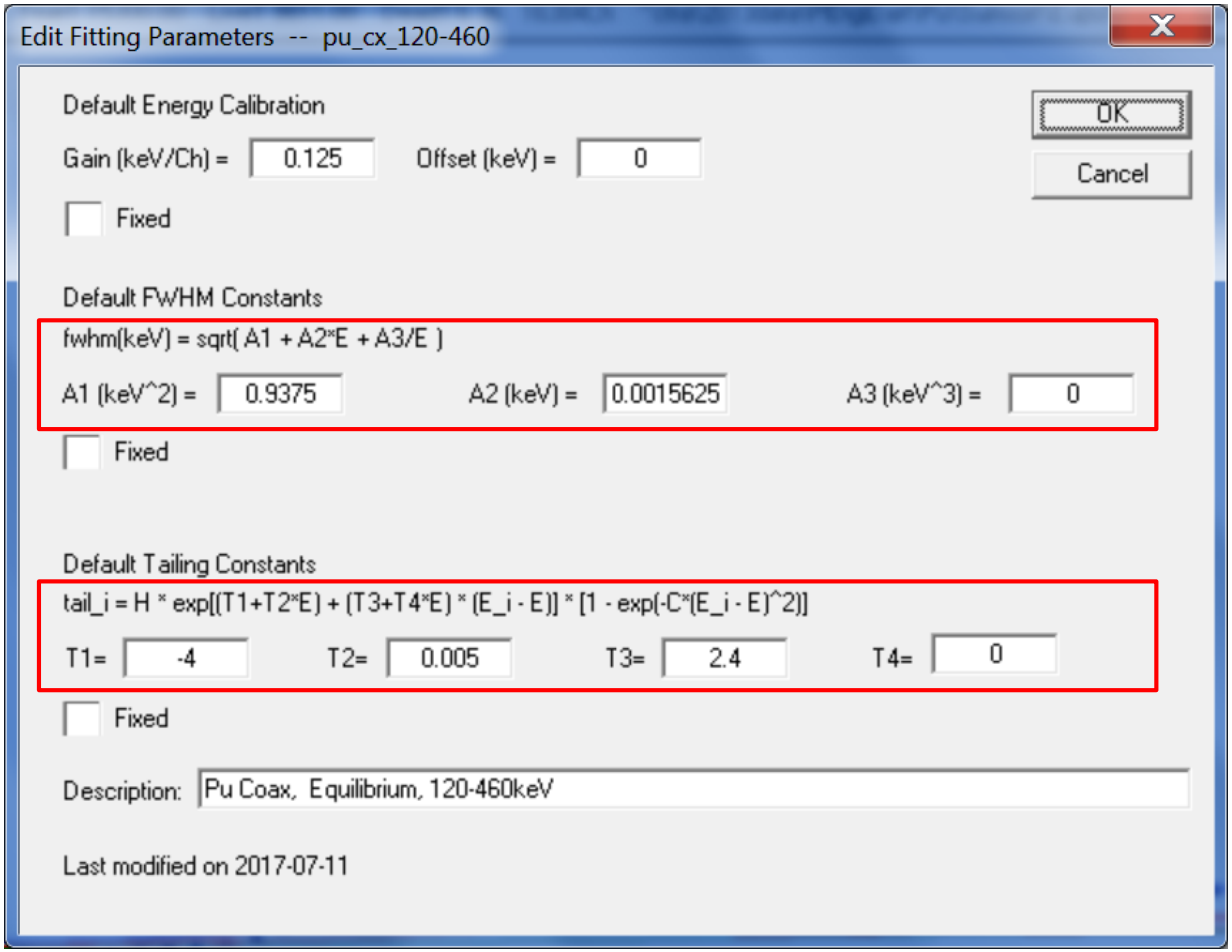
- The blue spectrum is from a 2” diameter and 0.5” length LaBr3
- The red spectrum is a broaden spectrum of a 2” diameter and 2” length (~25% relative efficiency) coaxial HPGe.

Fitting parameters (v.5.2)



- The FWHM and Tail parameters depend on the channels.
- When the energy calibration is changed then the FWHM and Tail parameters need to change.

Fitting parameters (v.6.1)



- The FWHM and Tail parameters depend on the energy.
- These parameters depend on the detector but are independent of the energy calibration.

True heterogeneous model

- FRAM v.5.2 heterogeneous efficiency

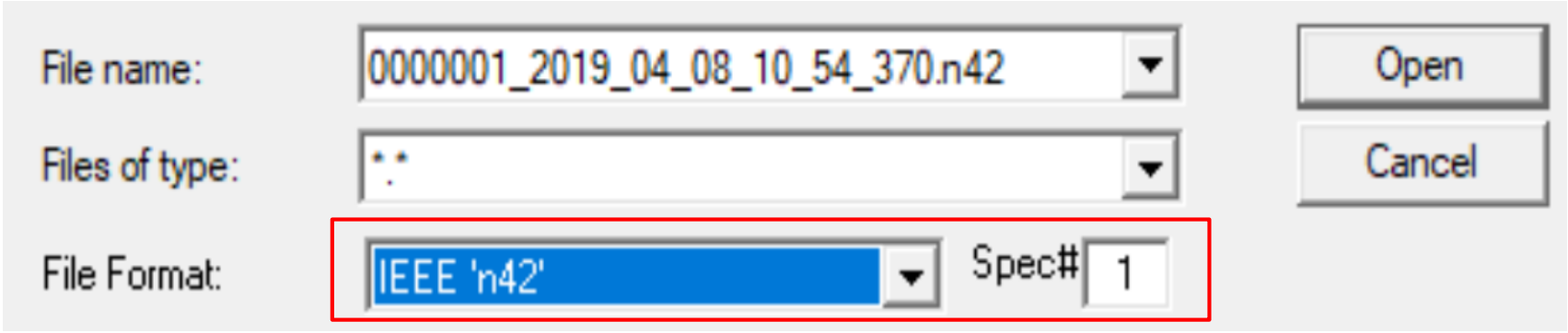
$$RE = \left[\frac{\left(1-\exp(-\mu_0 x_0)\right)}{(\mu_0 x_0)}\right] * [\exp(-\mu_1 x_1) * \exp(-\mu_2 x_2) * \exp(-\mu_3 x_3)] * [A_i]$$
$$* \left[\exp\left(\frac{C_j}{E}\right)\right] * [Detector\ Efficiency] * [Correction\ Factor]$$

- FRAM v.6.1 adds true heterogeneous efficiency

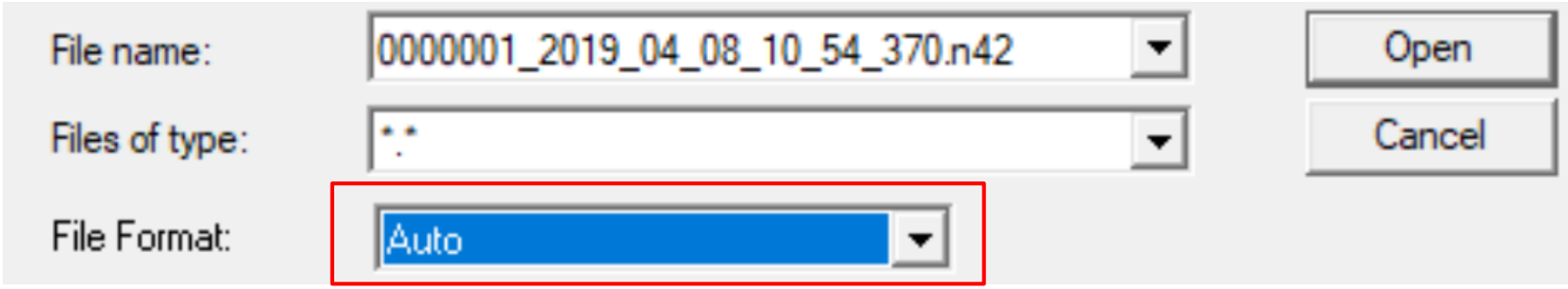
$$RE = \left[\frac{\left(1-\exp(-\mu_0 x_j)\right)}{(\mu_0 x_j)}\right] * [\exp(-\mu_1 x_1) * \exp(-\mu_2 x_2) * \exp(-\mu_3 x_3)] * [A_i]$$
$$* [Detector\ Efficiency] * [Correction\ Factor]$$

New file formats

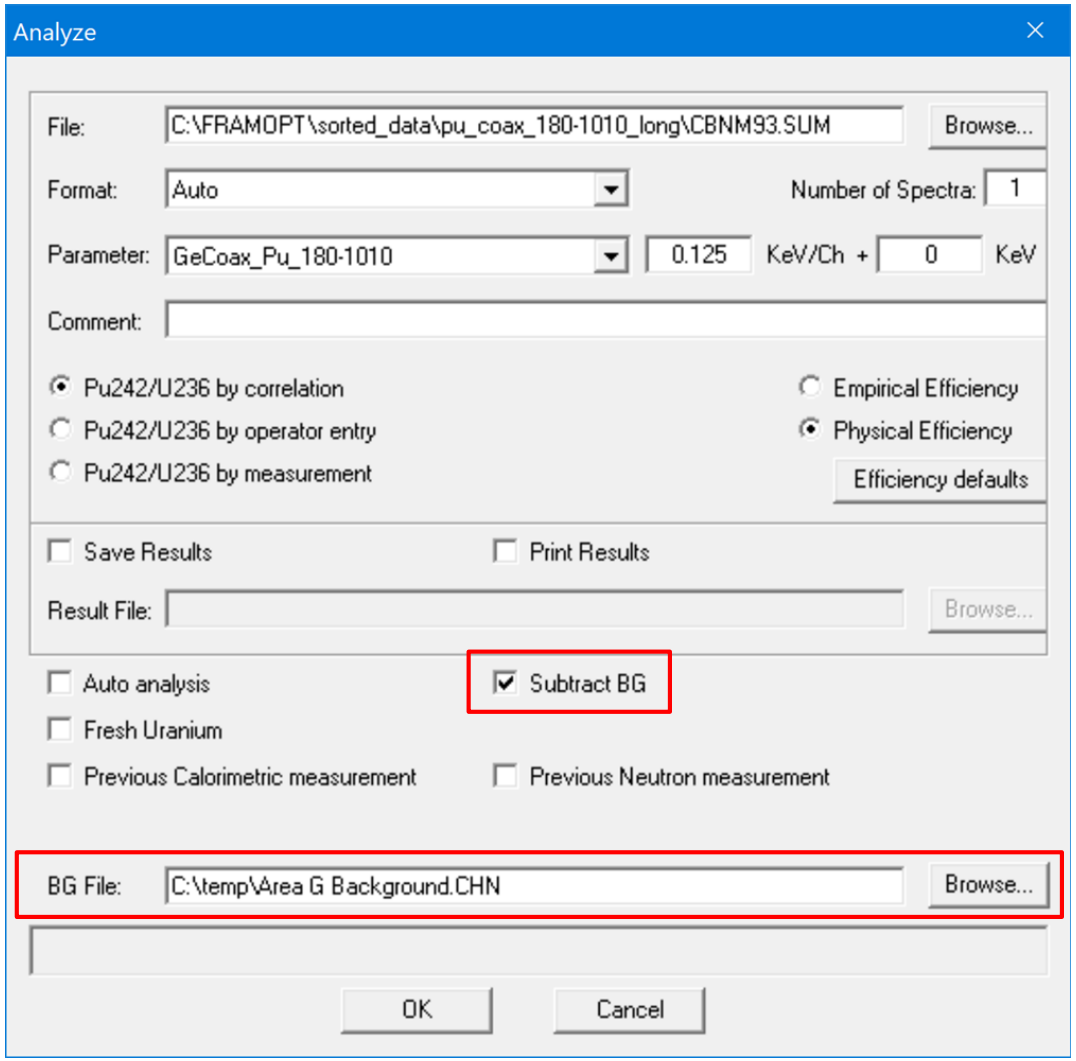
- N42 file format



- Auto format: can automatically read the files that are saved with one of the following formats: Ortec ‘chn’, Ortec ‘spc’, Canberra ‘mca’, Canberra ‘cnf’, IAEA ‘spe’, ASCII ‘txt’, and IEEE ‘n42’.

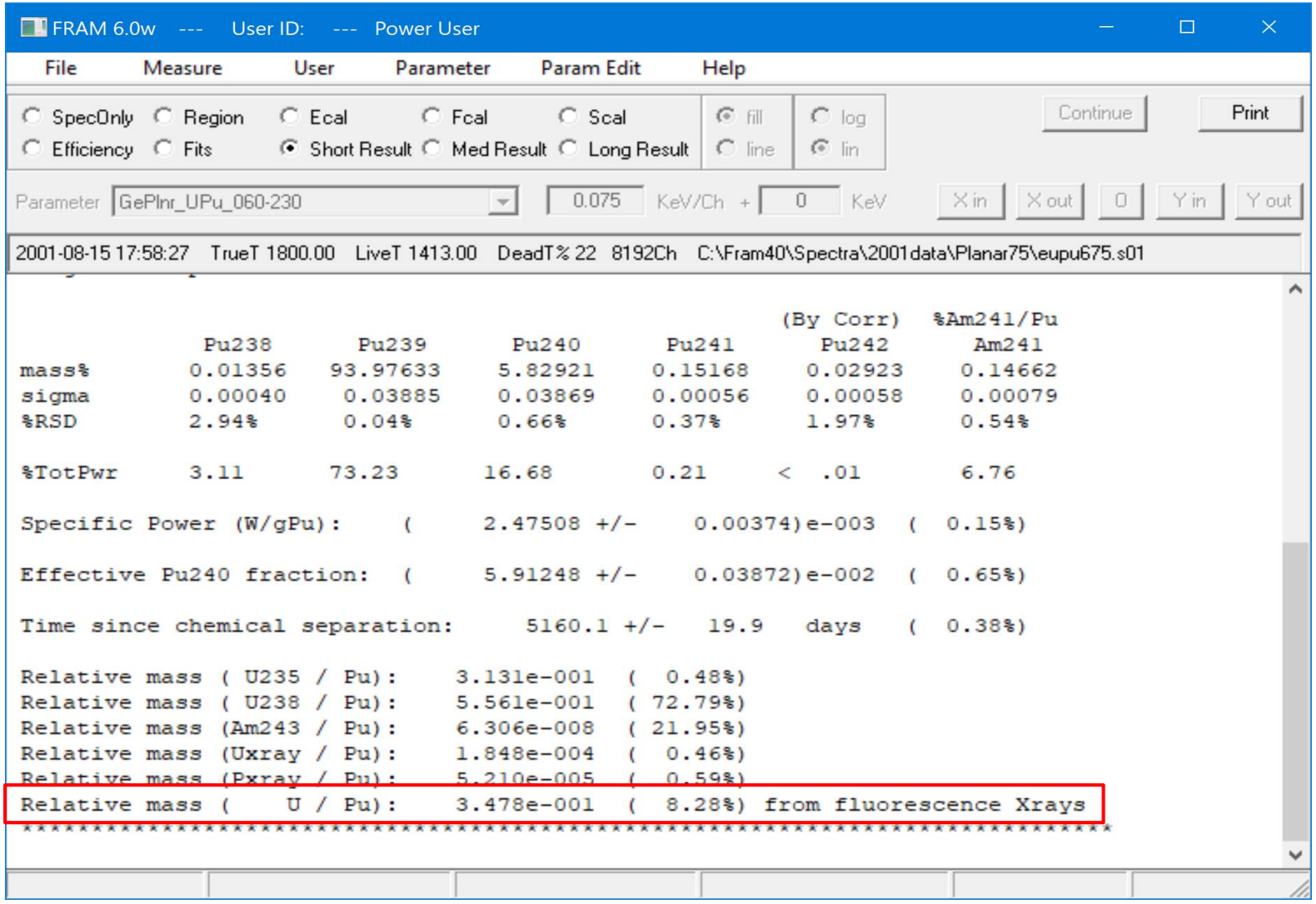


Background file subtraction



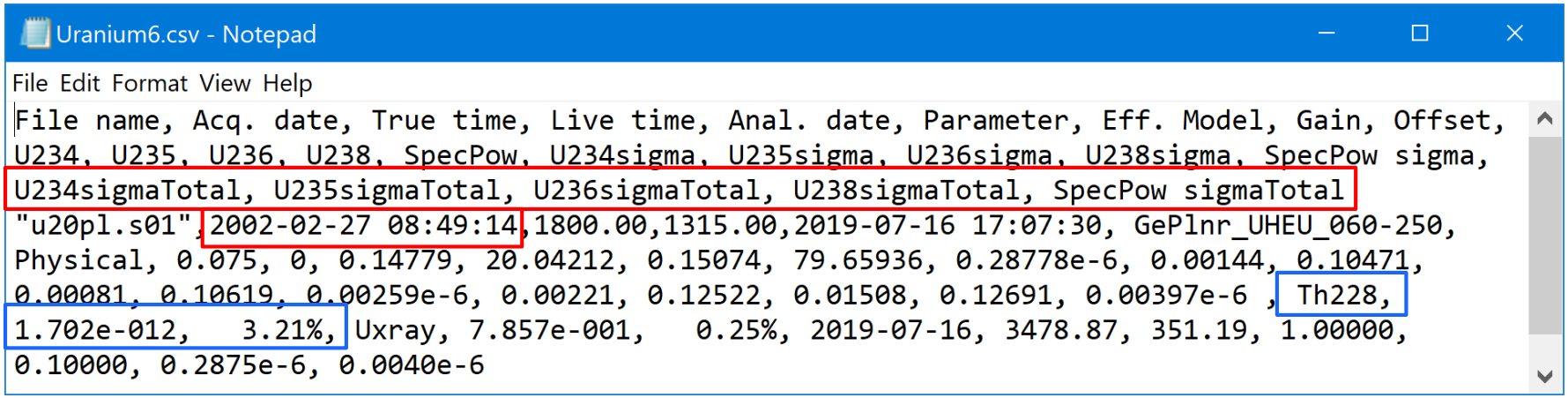
- FRAM will at first calculate the energy, FWHM, and peak shape calibrations of the main spectrum.
- Fit the BG spectrum with the calibrations of the main spectrum.
- Fit the main spectrum. The BG peak areas are subtracted from the measured peak areas.

U/Pu ratio from fluorescence X-rays



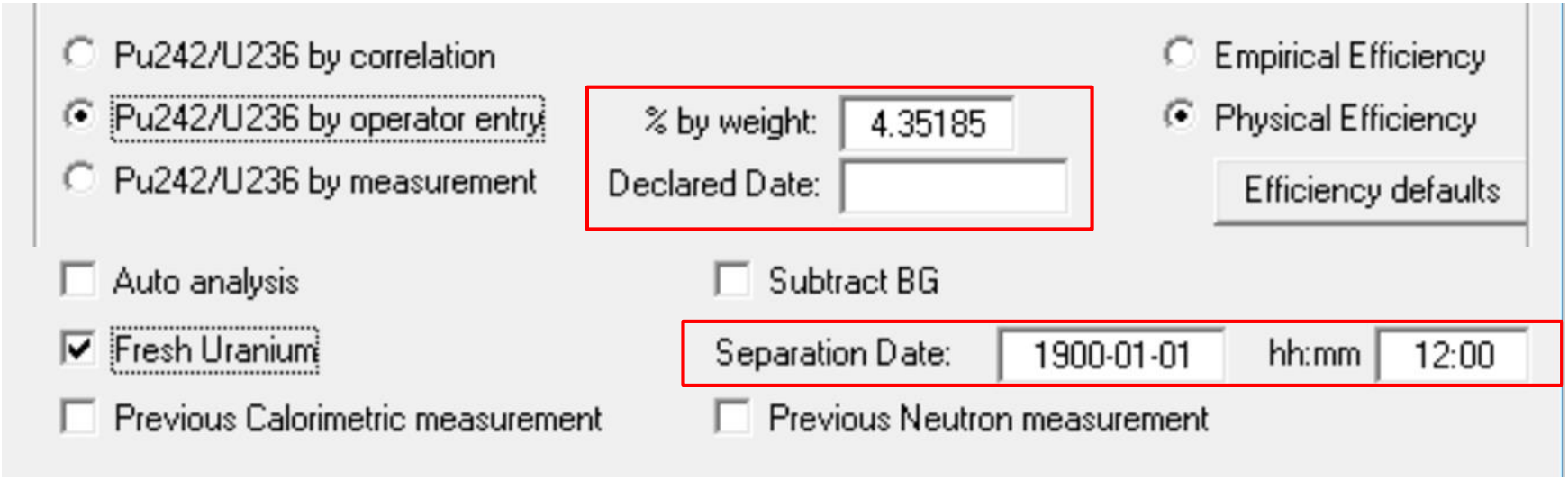
CSV and log file

- After an analysis, FRAM writes one-line results to the plutonium.csv or uranium.csv file, depending on the type of analysis. It writes one-line results to the FRAMcmd.log for the command line mode analysis.



Other features

- Instantaneous simulation
- U summed peak correction
- List file in command line mode
- Real true time and live time
- Drag and drop
- Expanded low-energy tail
- Spectrum display option
- Maximum FWHM rule
- Efficiency curve fit warning
- Quadratic step background
- Constrained efficiency curve shape
- Declared date and time



Remarks

- The good: FRAM v.5.2 code, created using Microsoft Visual C++ 6, can run on all Windows platforms, from Windows 95 to Windows 10.
- The bad: Microsoft Visual C++ 6 runs on Windows XP but not Windows 7 or later Windows.
- The weird: FRAM v.6.1 was written using Microsoft Visual C++ 2012 installed on a Windows 10 computer.
- The ugly: The FRAM v.6.1 code created by Microsoft Visual C++ 2012 can run on Windows 7, Windows 10, and most Windows XP systems.
- This work was supported by the U.S. Department of Energy, Office of International Nuclear Safeguards (NA-241), Office of Nuclear Verification (NA-243), and the United States Support Program (USSP).