FRAM V5.2
Plutonium and Uranium Isotopic Analysis Software
Advanced Isotopic Ratio Analysis Software for HPGe Gamma-Ray Spectra

- Analyzes Pu, and a wide variety of heterogeneous samples containing Pu, Am, U, and other nuclides including $^{242}$Pu.
- Operates with a single HPGe detector, including ORTEC Detective and trans-SPEC families.
- No calibration standards necessary.
- Works with shielded samples.
- Select from a large number of supplied sample/geometry conditions or add more types.
- Auto-analysis function for samples of unknown characteristics.
- Command-line mode of operation allows easy incorporation into other applications.
- Windows 64-bit and 32-bit compatible.
- Significant enhancements over previous versions.

The FRAM code\(^1\) has been under evolutionary development at Los Alamos National Laboratory since the mid 1980s. It analyzes the gamma-ray spectrum taken with a germanium detector, of items containing plutonium or uranium, or both and quantifies the distribution of plutonium or uranium isotopes. $^{241}$Am and other transuranic isotopes (including uranium in mixed uranium-plutonium oxides) that contribute measurable gamma rays to the spectrum can also be quantified relative to plutonium.

It also analyzes spectra from items containing only uranium, and can quantify the uranium isotopic distribution. These measurements can be performed on samples of any size, geometry, and physical and chemical composition.

Easy-to-Use Windows User Interface

ORTEC FRAM is a member of the ORTEC CONNECTIONS family of products. It operates within the ORTEC CONNECTIONS network spectroscopy architecture, giving greater flexibility in choice of MCA hardware, including the latest DSPEC 50 and DSPEC 502 digital spectrometers, and fully integrated spectrometers such as the Detective, trans-SPEC and IDM series.

The highly graphical FRAM user interface complies with the latest Windows conventions and is easy to use. Version 5.1 has a new look that, for simplicity, provides a single interface for all data displays. A single dialog bar controls all aspects of spectrum and results display, making it easy for the user to verify the quality of the data or analysis without leaving the FRAM main window.

FRAM provides acquisition control of all MCA hardware supported by ORTEC CONNECTIONS. The ORTEC MAESTRO® MCA software program is used for hardware system setup prior to use, and can be removed from the PC to secure the MCB from changes.

\(^1\)FRAM: Fixed-energy Response function Analysis with Multi-
ple efficiency. FRAM is also a word of Scandinavian origin meaning “forward” or “onward”, being the name of the ship used by the polar explorers Nansen, Sverdrup, and
FRAM Analysis Capabilities

Sample Type
The versatility of FRAM and its ability to analyze a wide variety of samples stems from its reliance upon generic analysis algorithms. Specific information needed to guide the analysis is encoded into a set of parameters and stored in a database. This information includes the regions and peaks to be examined, the isotopes to be used in the analysis, and special information for performing a number of diagnostic tests on the spectrum. For analysis of well characterized “routine” samples, a single analysis parameter set may be easily constructed; for less well known samples, an automatic mode is provided in which the optimum sample parameter set is determined iteratively in an automated fashion.

Analysis Methods
FRAM analyzes photopeaks from the spectrum of plutonium or uranium gamma rays. The spectrum contains peaks from the plutonium isotopes $^{238}$Pu to $^{241}$Pu, $^{241}$Am, and often other isotopes such as $^{239}$U or $^{237}$Np. FRAM combines this information to produce isotopic ratios independent of sample size, shape, physical and chemical composition, measurement geometry, and container characteristics. The results are obtained using only the spectral data and known fundamental nuclear constants. Calibration with standards is NOT necessary.

Peak Area Determination
FRAM uses response function methods to determine all peak areas, fitting a Gaussian with a single exponential on the low-energy side to model the gamma-ray peak shapes and uses a Lorentzian to model x-ray peaks.

Material Categories Analyzed:
- $2–95\%$ $^{240}$Pu
- $0.01–50\%$ $^{241}$Am
- Interferences from $^{243}$Am–$^{239}$Np, $^{237}$Np, and $^{244}$Cm
- $80\%$ $^{238}$Pu
- Shielded samples ($>13\text{mm Pb for Pu, \ >16\text{mm Steel for U}}$)
- Heterogeneous Am/Pu
- Nonequilibrium $^{241}$Pu–$^{237}$U
- MOX: $^{233}$U/Pu from 0.005–35
- Pu with $80–95\%$ $^{240}$Pu
- $^{235}$U/$^{241}$U in pure $\text{U (no Pu)}$
- $^{231}$U; $^{241}$Am: Pu = 24:1:1

Fitting in the 640 keV region from the spectrum of a 1 kg PuO$_2$ sample with 16% $^{240}$Pu.
Relative Efficiency
FRAM uses a separate efficiency curve for each isotope. This allows it to measure the specific power of pyrochemical residues with biases that are reduced by as much as a factor of ten from analyses that do not use multiple efficiency curves.

The multiple efficiency feature of FRAM may also be used for other heterogeneous samples. The physical and chemical characteristics of the sample may not be uniform or even well known. Items may contain mixtures of solids and powders with no ill effect so long as the plutonium is isotopically uniform. Both physical and empirical efficiency models are provided.

Analysis for Isotopic Ratios
The approach used is that of finding a least squares solution to a set of linear equations involving peak areas, relative efficiency, and isotope ratios as unknowns. The method allows use of multiple peaks in the analysis with resulting improved measurement precision.

Analysis Parameters Database
The analysis parameters database is important in the power and flexibility of FRAM. These parameter sets are grouped into five categories: peak fitting parameters, gamma-ray peaks to be searched for, energy regions to be searched, isotopes to be used, and special application constants. Multiple parameter sets can be easily accommodated.

Auto-Analysis Feature
The auto analysis feature in FRAM allows automatic reanalysis of the spectrum, with changed parameters, based upon the current results. Auto analysis can start with any parameter set and works with both plutonium and uranium in all the energy ranges. The user has the freedom to program the analysis (by means of the Application Constants in the parameter set) to determine the properties of the material such as: shielded, MOX, plutonium burnup, uranium enrichment, interference isotope, or heterogeneous. For example, after an analysis of the mid energy region (120–500 keV) of a plutonium spectrum, it can check both the lower energy (~100 keV) and higher energy (~700 keV) regions to see if those regions are more favorable.
Plutonium or Uranium Analysis
A parameter set can be set up for uranium (only) spectra. In this case, different isotopic ratios are calculated and the summary is formatted differently.

Estimation of $^{242}\text{Pu}$
The estimation of $^{242}\text{Pu}$ is done via a correlation model using an industry standard formula with user specified parameters. Their values may be stored in any one of the parameter sets used for analysis. This model accommodates most of the commonly proposed correlations for $^{242}\text{Pu}$.

Decay Correction of Isotopic Fractions
For samples which are at least 5 years old, the 14.35-year half life of $^{241}\text{Pu}$ can lead to a significant change in the $^{242}\text{Pu}$ fraction, which, if unaccounted for, can lead to (relative) errors on the order of 4% in the $^{239}\text{Pu}$ fraction.
FRAM can decay correct the isotopic fractions of Pu and Am.

New Command Options in Application Constants
Many of the new changes in FRAM can be turned on or off with the built-in commands in the Application Constants section of the parameter set.
- Correction for peaks in the 100-keV region,
- Systematic uncertainties,
- Sum peak correction option,
- Improved $^{236}\text{U}$ correlation option,
- Number of iterations.

New Command-Line Mode of Operation
The Command-Line Operation mode is intended for users who want to incorporate FRAM into their own applications. This mode allows the user to make a very simple interface to the FRAM analysis engine.

New Measure-Compare Option
This new option allows the user to directly compare the results of an analysis with a decay-corrected declared value. The differences between the measured and declared values are expressed in terms of the standard deviations of the measured and declared values.
Analysis Improvements.

Version 5.1 and 5.2 of FRAM incorporates many analysis improvements:

- Pu 100-keV region analysis,
- U 100-keV region analysis,
- Provision for inclusion of systematic uncertainties in output results,
- Maximum channel range extended to 32k channels,
- Maximum energy range for physical model efficiency extended to ~10 MeV,
- Improved energy calibration peak search,
- Improved $^{238}\text{U}$ correlation,
- Error bars and error band for relative efficiency points and fit,
- Interactive, real-time parameter editing,
- Improved compatibility with commercial formats for multiple spectra,
- Excel-compatible results file for multiple spectra analysis and comparison,
- Improved parameter set version control,
- Fill and line spectrum display modes.
- Extensive auto-analysis.

- V5.2 only:
  - Improved parameter sets.
  - Improved uncertainty calculation.
  - Improved handling of multiple efficiency curves.
  - Improvements to command line mode operation.

Germanium Detector Requirements

FRAM can perform a complete isotopic analysis using either a single planar or a single coaxial detector. The benefits of being able to operate with a single HPGe detector are obvious: cost, space, convenience, ease of use, and reliability. When used with the “traditional” single planar detector, it is used often (but not always) to collect and analyze data in the 120–420 keV range.

The most common energy range used in conjunction with a coaxial detector is 0–1024 keV. Various analysis modes can be used in this wide data range. If the 120–200 keV range is available, FRAM will work best analyzing in the range of 120–450 keV. If this is not possible (for example, if the sample is shielded or in a thick-walled container), FRAM can still obtain a complete analysis using only those gamma rays above 200 keV from a single coaxial detector.

The optimum choice of detector depends on the applications expected to be encountered. A planar detector is usually the detector of choice if all measured items are unshielded or are in “thin-walled” containers. If shielded containers, thick-walled containers, or a mixture of all container types are encountered, a single coaxial detector is optimum. The ORTEC Safeguards Series HPGe detectors are highly recommended.

In many applications the ORTEC Detective and trans-SPEC portable spectrometers have proven highly effective. FRAM software includes starting analysis parameter sets for the ORTEC Detective.
Password Protection and Security
An access control system within FRAM stores a list of users, their passwords, and access rights granted to them. Three of the items listed in the Edit menu are protected by this mechanism: the Parameters option, the General Defaults option, and the User List. When all these options are in operation, the user will be asked to supply a name and a password. If the security check fails, control returns to the main menu.

Output Display and Listings
Three levels of output display (Short Result, Med Result, and Long Result) may be selected in the FRAM dialog bar and displayed in the FRAM window for all analysis results. A screen copy of the Short Result is automatically sent to the monitor after each analysis.

Prerequisites
As a CONNECTIONS family member, FRAM-BW will operate correctly on any system supporting CONNECTIONS compatible hardware. The software operates under all currently supported Windows operating systems. Windows 7 64-bit hardware compatibility is available for all ORTEC instruments that use USB and TCP/IP connectivity. These instruments, as well as other legacy hardware, are also supported with Windows 7 and XP 32-bit operating systems.

Ordering Information

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>FRAM-BW</td>
<td>FRAM-BW Version 5.2 Gamma-Ray Isotopic Analysis Software. Includes MAESTRO MCA Emulation software.</td>
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<tr>
<td>FRAM-GW</td>
<td>Documentation for FRAM-BW</td>
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<tr>
<td>FRAM-UW</td>
<td>Update for FRAM-BW</td>
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