

## For Enrichment Analysis of Uranium Spectra from CZT Detectors

- Determines  $^{235}\text{U}$  enrichment from Cadmium Zinc Telluride (CZT) detector spectra
- Integrated data collection and analysis
- Rapid operation
- Visual display of spectra and results
- Operates in the region of 50 to 200 keV
- No calibration standards necessary to correct for matrix or container effects
- ORTEC CONNECTIONS-32 compliant
- Operates with any ORTEC MCB
- Easy-to-use Windows®-based Graphical User Interface
- Results shown on the spot as well as stored in Access® database

## Introduction

In the CZTU<sup>1</sup> program from ORTEC,<sup>2</sup> the power of multi-group analysis for the analysis of uranium samples with room-temperature CZT detectors has been coupled with the most advanced user interface for data collection.

CZTU V1.0 represents the newest member of a set of programs for isotopic analysis that have been in use worldwide since 1990 for a range of measurements related to nuclear materials control and accountancy. A full member of the CONNECTIONS-32 family, CZTU displays the acquiring data during acquisition, then rapidly analyzes and reports results, all in a single, easy-to-use program.

The program, operating under Windows 2000/XP, is fully integrated into the ORTEC CONNECTIONS-32 platform. All ORTEC multichannel buffer hardware is supported whether networked or standalone. Other portable MCA types such as the Los Alamos designed M<sup>3</sup>CA and the GBS/Rosendorf MiniMCA166 are also supported. (Check with ORTEC for latest additions.)

Lab systems based on ORTEC MCBs such as the DSPEC family, 900-series NIM MCBs, and TRUMP™ MCA plug-in cards are all supported by CZTU, as well as non-ORTEC hardware systems using the MatchMaker™ Acquisition Interface Module. Contact ORTEC for hardware system details for CZT detectors.

The easy-to-understand operator interface is shown in Figure 1. The current status of the detector is shown on the right. A special count-rate meter mode shows the instantaneous count rate of a selected region. The spectrum can be displayed while the data are being collected.

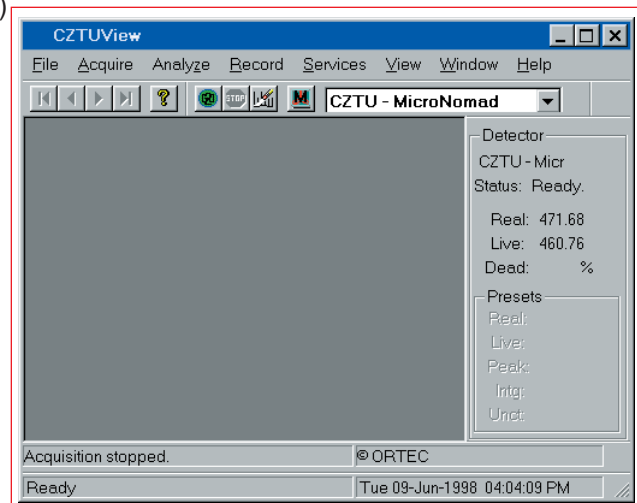


Figure 1

The Start/Save/Report feature (Figure 2) gives one-button collection and analysis — via keyboard or mouse — making it easy for operators even when having to wear protective suits in active areas.

Reanalysis of spectra on disk or in the MCB is easy — just click and select (Figure 3). All the spectra collected by CZTU are stored in the ORTEC standard spectrum (SPC) format, which can be read by many programs. This format includes all of the CZTU analysis parameters, as well as the hardware description records — everything you need to verify the results. In addition, 10 other popular formats are supported, so that other spectra can be analyzed with this modern version of CZTU analysis.

Analysis parameters are specified in clear easy-to-understand dialog boxes (Figures 4–8). The modeled detector peak shape can be refined by the peak definition part of the program. Analysis parameters can be saved to disk for use on other samples and recalled as required.

At the end of each analysis, the results are automatically stored in the Access format database, as well as printed or displayed for the operator. The three database tables (see for example, Figure 9) can be viewed by CZTU or by Access. This powerful data storage method makes summary reports, exception reports, and many other useful outputs easy and simple to create.

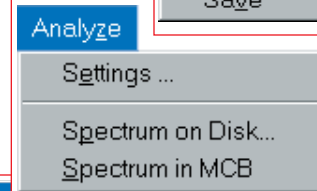
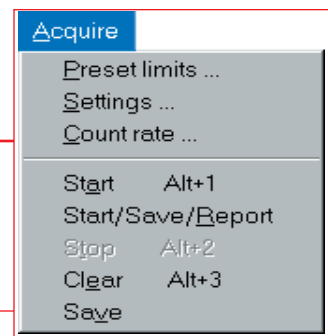


Figure 2

Figure 3

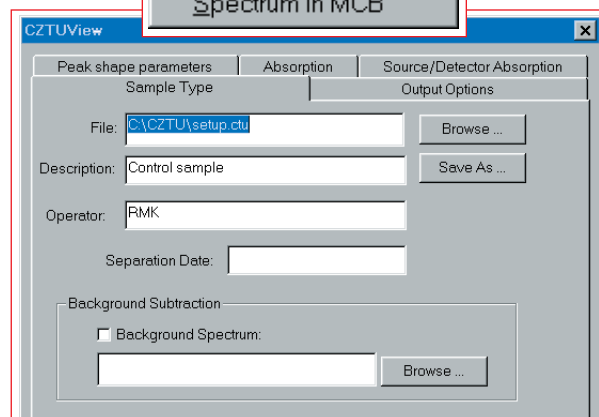


Figure 4

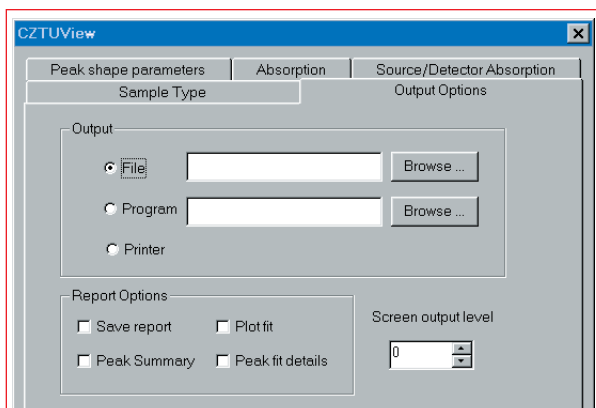


Figure 5

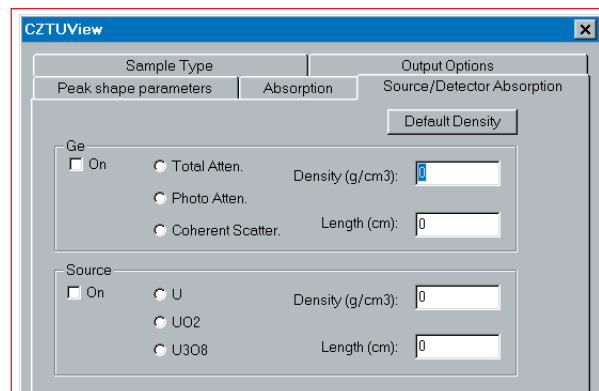


Figure 6

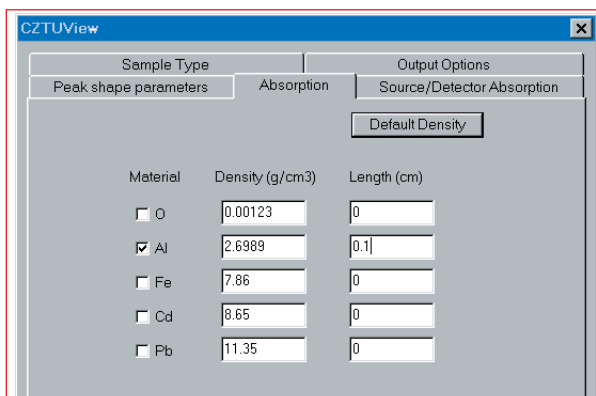


Figure 7

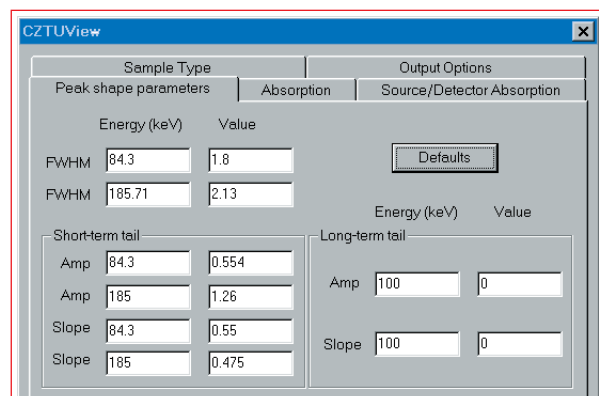


Figure 8

Figure 9

### Analysis Principles of CZTU

Most radioactive isotopes emit gamma- or x-rays whose energies and intensities are characteristic of the isotope. In a radioactive sample spectrum the amount of an isotope present is proportional to the observed size of the full energy gamma- or x-ray peak of that isotope. Accurately measuring the peak intensities from different isotopes allows the sample's isotopic composition to be determined.

For accurate peak intensity determination, there are several requirements:

- Separation of the full-energy absorption peaks from the background (Compton continuum);
- A mathematical description of the peak shapes, as a function of energy, for gamma- and x-rays;
- A fitting algorithm which varies the peak shape parameters to get the best fit, (defined as the minimum least-squares deviation between the data points and their calculated values);
- A data set of theoretical relative intensities and energy of each gamma- or x-ray in a region-of-interest for each isotope or x-ray source;
- A way to correct the data set for instrumental efficiencies and photon transmission to the detector peculiar to each data set collected.

[Because of the typical poor statistics in a CZT spectra a universal "best" fit correction was found to give the best results.]

### The Analysis Process

The net peak in a given region is calculated by determining and then subtracting a background function from the raw data. The background function in a CZT spectrum is harder to accurately determine than in a germanium detector spectrum. CZT detectors are typically very small and consequently very inefficient with typically poor statistics data. In addition, CZT peaks have relatively long, low-energy tails that make finding the "correct" background more difficult. Both of these

## Typical CZT Spectrum of Uranium

CZTU was developed to determine the enrichment of  $^{235}\text{U}$  in uranium samples. The program, requiring no special calibration sources, uses information obtainable from the sample spectra themselves to determine the isotopic ratios. A spectrum is shown in Figure 10.

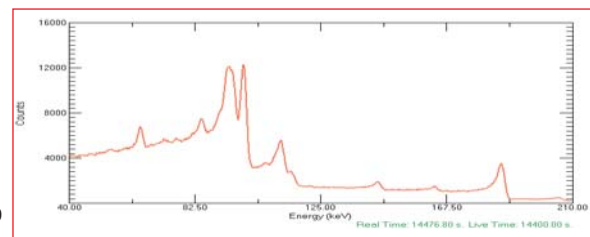


Figure 10

complications were addressed in the CZTU program by choosing as "good" a background as possible and then iterating other background choices around this initial value to see which background gives the minimum reduced Chi-squared fit to the data.

CZT gamma peak shapes are described very well by a Gaussian peak and a low-energy exponential tail. X-ray peak shapes are described very well by a so-called Voigt profile<sup>3</sup> — a convolution of the detector response (a Gaussian and low-energy exponential tail) with the intrinsic x-ray energy distribution (a Lorentzian).

To fit the data, the energy and intensity of each gamma- or x-ray from the decay of a given isotope are needed. To this are added the fluorescent x-rays created by gammas/ x-rays interacting in the source or collimator material. For example, in the 87–102 keV range, gamma- and x-rays arise from three different sources: the decay of  $^{235}\text{U}$ ,  $^{238}\text{U}$ , and three fluorescent U x-rays. The theoretical intensities have to be corrected for detector efficiencies and transmissions vs. energy.

The goal in the calculation process is to find the set of peak shape parameters and intensities that most closely approximate the measured net signal. This "best" fit gives a minimum reduced Chi-square difference between the calculated signal and the measured data. To find the "best" fit, the equations describing the various peaks are approximated by using first-order Taylor's series expansions about the trial values of the free parameters. The parameters are adjusted to minimize the difference between the equations and the data. These adjustments are found by performing non-linear least squares iterations on these equations. [This procedure is also known as the Gauss-Seidel or Newton-Raphson method.] For rapid convergence the closer the initial choices are to the "real" values, the quicker the fitting process converges. One of the outputs of the fitting process is the "best" amplitude of each isotope peak. These can be used to find the "best" measurement of the isotopic composition of the source.

## CZTU Performance

CZTU uses an 'MGA-style' analysis — making use of experience gained from the U235 code, part of the MGA++ series of codes developed by LLNL. CZTU determines enrichment results for <sup>235,238</sup>U to <10% uncertainty over a wide range of enrichments. At both high (>75%) and ultra-low enrichments, the uncertainty is greater because of the relatively small <sup>238</sup>U and <sup>235</sup>U peaks.

Isotope	Range (wt %)	Absolute Accuracy (%)
<sup>238</sup> U	5–30	15
	30–99	10
<sup>235</sup> U	0.1–1.0	15
	1.0–70	10
	70–95	15
<sup>234</sup> U	0.01–1.0	10–30

## Measurement Parameters

### Sample Matrix

Uranium can be measured either as metal, oxide, hexafluoride, or in solution. Sample shielding that significantly attenuates 100-keV photons will negatively impact the analysis.

### Detector Resolution

Detector	Resolution@122 keV		
	Optimum	Nominal	Acceptable
CdZnTe	2.0 keV	2.2 keV	2.5 keV

### Interferences

*The Problem:* Pb x-rays in the analysis region may compromise the analysis.

*The Answer:* Avoid Pb absorbers and shielding. Alternatively, cover Pb surfaces with graded Z materials to minimize the number of Pb x-rays.

### Statistics

Sample strength, shielding, uncertainty requirements, and enrichment will determine the counting time required. Many samples, however, can be adequately analyzed in under 30 minutes.

### Sample Age

CZTU assumes samples are in decay equilibrium. Fresh samples can be analyzed two weeks after their known separation date.

### Prerequisites

CZTU will operate correctly on any system supporting ORTEC multichannel buffer hardware under Windows 2000/XP. MAESTRO-32 and WINPLOTS are included with CZTU for any other spectrum viewing and plotting.

### Order Information

To order, specify:

Model	Description
<b>CZTU-B32</b>	CZTU Isotopic Analysis software V1.0
<b>CZTU-U32</b>	Update to CZTU-B32
<b>CZTU-G32</b>	Documentation for CZTU-B32
<b>CZTU-N32</b>	CZTU additional network copies

<sup>1</sup>LLNL License TL-1346-96.

<sup>2</sup>ORTEC Signs CZTU Licensing and Development Agreement with LLNL

ORTEC and Lawrence Livermore National Laboratory have entered into licensing and development agreements for specialized software for nuclear safeguards applications. The license covers the CZTU suite of codes, which analyze CZT detector gamma-ray spectra from a wide variety of nuclear safeguards samples in order to determine uranium enrichment. The development agreement (CRADA) relates to further improvements to the code and an improved "seamless" integration within the ORTEC CONNECTIONS Windows 95/Windows NT spectroscopy environment for ease of use and reliability.

<sup>3</sup>K. Debertin and R.G. Helmer, *Gamma- and X-Ray Spectrometry with Semiconductor Detectors*, p. 185, Elsevier Science Publishers B.V., The Netherlands, 1988.