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OSIRIS Validation & Verification Report

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Abstract

The On-Site Inspection RadioIsotopic Spectroscopy (OSIRIS) system is a gamma-ray spectroscopy instrument for on-site inspections conducted under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The OSIRIS software filters spectral analysis data, limiting displayed spectral information to only the 17 CTBT-relevant fission-product isotopes.

In this report, we review the CTBT requirements for on-site inspection radionuclide identifiers in Section 1. Additional requirements imposed by the design team are outlined in Section 2. OSIRIS software development is described in Section 3. Then a series of validation tests conducted during OSIRIS development are described in Section 4. The validation tests gauged if the nascent OSIRIS system would meet the CTBT and design-team requirements. One of those validation tests, a comparison of ORTEC GammaVision and OSIRIS gamma-ray spectral analyses, is presented in Appendix A.

The report concludes with a set of recommended verification tests to ensure that new OSIRIS systems also will meet the design requirements, and detailed instructions for OSIRIS verification tests are presented in Section 5.

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1. Introduction

The On-Site Inspection RadioIsotopic Spectroscopy (OSIRIS) system is a gamma-ray spectroscopy instrument for on-site inspections conducted under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). [1] OSIRIS identifies fission-product isotopes with a high-resolution gamma-ray spectrometer. The spectrometer is controlled by a ruggedized notebook computer running data acquisition and data analysis software customized for field use in areas containing potentially sensitive information such as proliferation-sensitive radionuclide information that might be encountered during CTBT on-site inspections. The OSIRIS spectrometer and computer are shown in Figure 1.

The spectrometer can be used to identify radioisotopes in samples collected from the soil or, in the "*in-situ*" counting geometry, it can directly measure radioisotopes deposited on the ground. In either geometry, the spectrometer measures the energy-intensity pattern or "spectrum" of gamma rays striking the spectrometer germanium crystal. From the energies of the gamma-ray peaks in the spectrum, the emitting radioisotopes are determined, and from the intensities, the quantities of each radioisotope can be learned. A fission-product gamma-ray energy spectrum is shown in Figure 2.

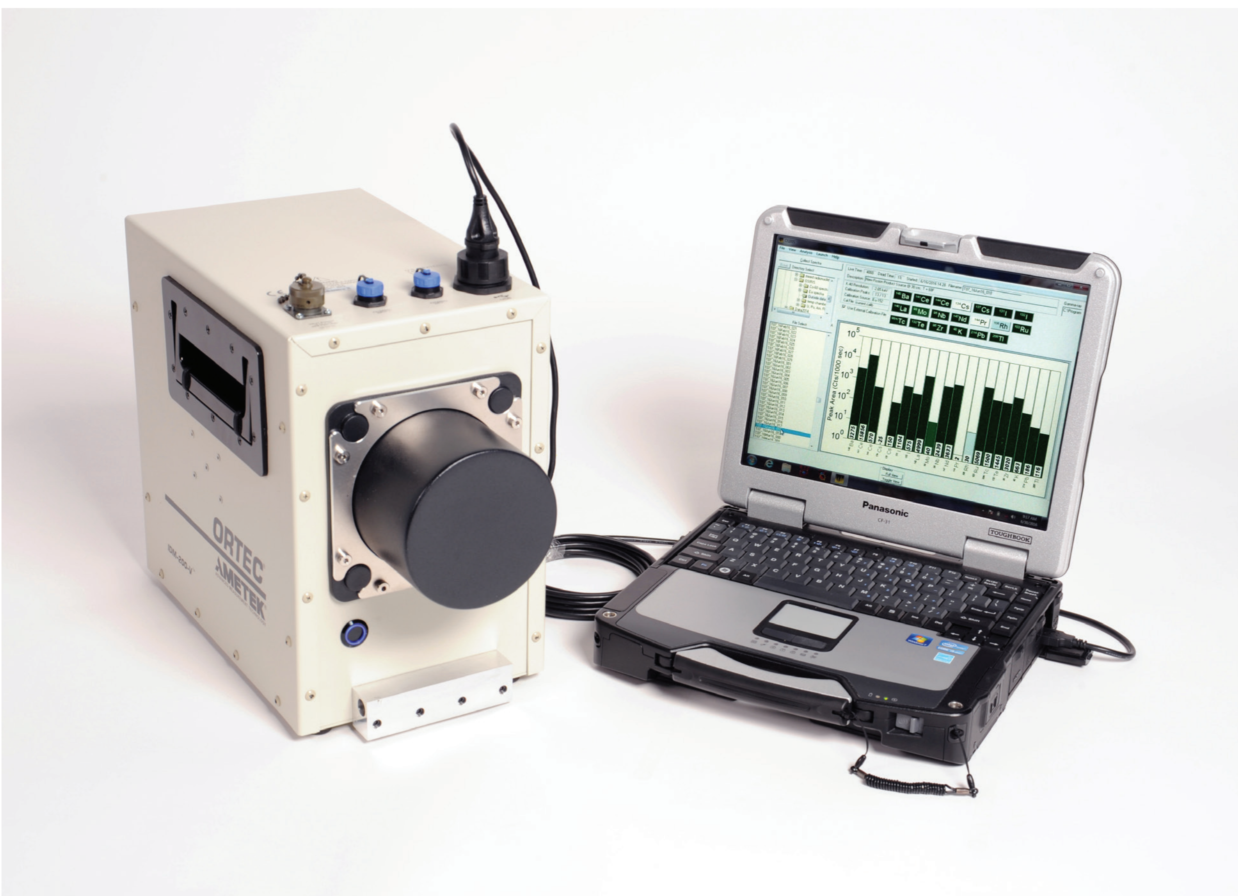

Figure 1: *OSIRIS spectrometer and computer.*

1.1 CTBT On-Site Inspection Requirements

Each State Party under the CTBT has the right to request an on-site inspection in accordance with the provisions of the CTBT. The treaty and its Protocol allow the use of gamma-ray spectroscopy during the conduct of an on-site inspection, and they also allow for measurement restrictions as a managed access tool by the Inspected State Party. [2]

If an underground nuclear test leaks to the surface ("vents"), radioisotopes produced by the explosion may be deposited on the ground as particulate matter, and these isotopes are best identified by an HPGe gamma-ray spectroscopy system like OSIRIS.

Paragraph 89(b) of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) Protocol limits the radiation measurements to those isotopes and energies relevant to the determination that a nuclear explosion has occurred so as not to disclose irrelevant and potentially sensitive information. [3] To minimize the intrusiveness of gamma-ray spectral measurements during on-site inspections, the CTBT Organization Preparatory Commission (CTBTO PrepCom) Working Group B has agreed to restrict gamma-ray spectral measurements during a CTBT on-site inspection to these seventeen activation and fission products: Ba-140, Ce-141, Ce-144, Cs-134, Cs-137, I-131, I-132, La-140, Mo-99, N-95, Nd-147, Pr-144, Rh-106, Ru-103, Tc-99m, Te-132, Zr-95. [4]

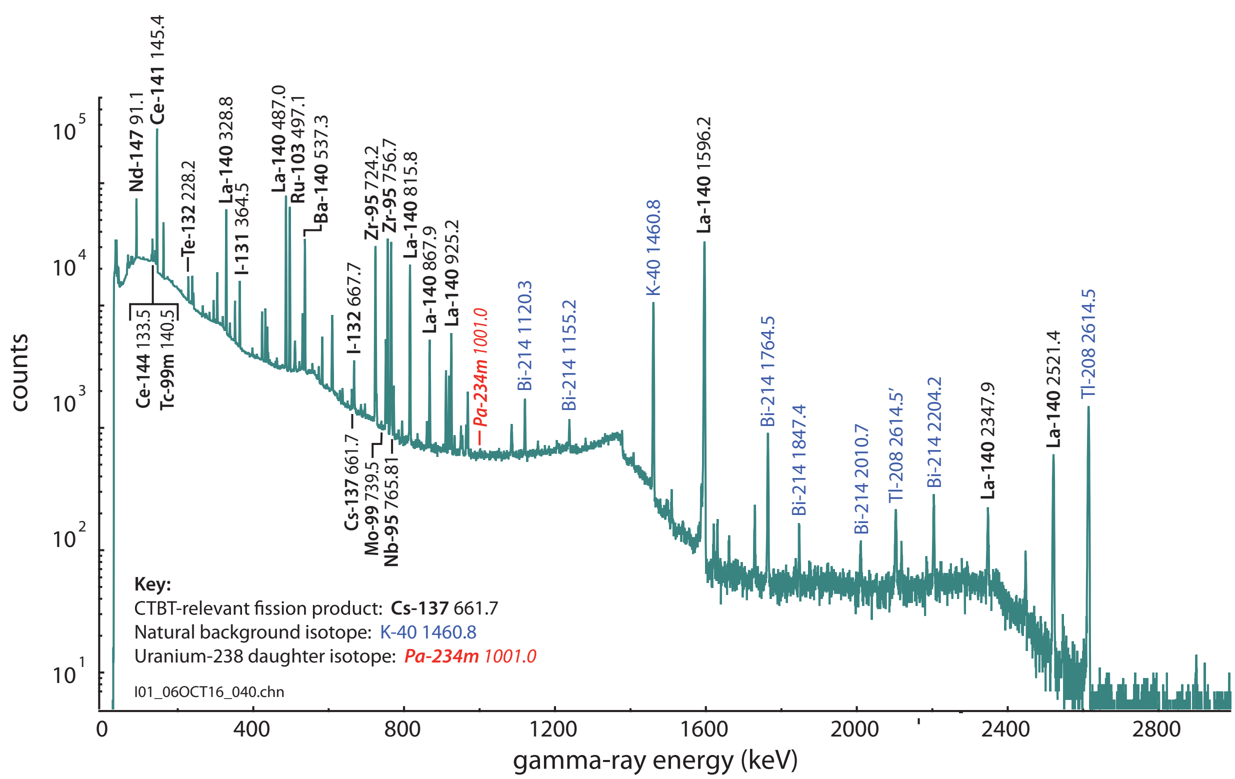

Figure 2: *Fission-product gamma-ray spectrum.*

1.2 Data Filter

The OSIRIS software filters spectral information measured during an on-site inspection. Only the radioisotopic information needed to conduct the inspection (the "CTBT- relevant radionuclides") is revealed to the user, not the entire gamma-ray spectrum.

A notional spectroscopic measurement data filter, termed by others an "information barrier" [5], is depicted in Figure 3. The data filter hardware and software hide full spectral information from users, revealing only treaty-relevant information on its display device.

1.3 Filtered Data Display

The OSIRIS software does not display raw gamma-ray spectra like that shown in Figure 2 to the operator; instead, the information display is limited to radioisotopes relevant to CTBT on-site inspections, as shown in Figure 4.

1.4 Validation and Verification

In this report, we introduce the principal features of the OSIRIS system, review the essential functionality of on-site inspection systems for the CTBT, trace the development of OSIRIS software, describe the validation tests performed during OSIRIS system development, and recommend a set of verifications for newly-manufactured OSIRIS instruments, per IEEE Standard 1012-2016. [6]

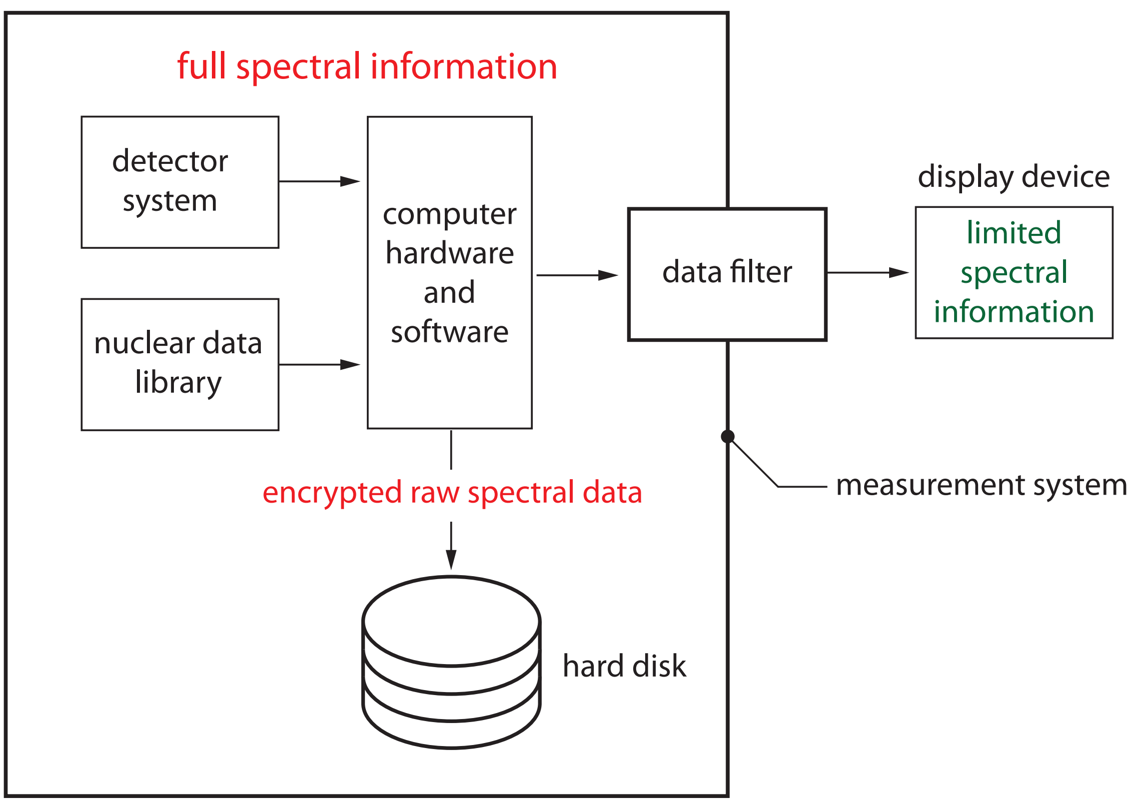

Figure 3: *Information barrier concept.*

2. Essential OSIRIS Functionality

OSIRIS is a gamma-ray spectroscopy system, customized for on-site inspections under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The required OSIRIS functionality is as follows.

2.1 OSIRIS System

As a system, OSIRIS must detect, identify by isotope, and quantify fission-product radioactivity produced by an underground nuclear test and released to the surface.

OSIRIS must not reveal to its operators radioisotopes other than the 17 CTBT-relevant fission products. In particular, OSIRIS gamma-ray spectra may not be displayed to users, and they must be stored as encrypted data files.

2.2 Hardware

Fission-product gamma-ray spectra can be complex, as shown in Figure 2 above, and hence they must be measured with an HPGe spectrometer. The OSIRIS system will be used in remote locations, and it should be ruggedized to protect against rough handling in the field, mechanically-cooled, to eliminate the need for liquid nitrogen, and operable by both battery and AC-line power.

A ruggedized notebook computer controls the spectrometer, analyzes spectral data, displays spectral analysis results, and stores encrypted spectral data files.

The histogram memory in the OSIRIS spectrometer stores a copy of the current spectrum. Normally, this spectrum is retained even when the spectrometer is powered down. To prevent copying a spectrum from the spectrometer, the spectrometer histogram memory is erased whenever the spectrometer data acquisition computer USB cable is disconnected.

2.3 Software

2.3.1 Gamma-Ray Spectrometer Control

The OSIRIS software must emulate standard gamma-ray spectrometer functions, for example:

- spectrometer initialization
  - – high voltage ON/OFF
  - – gain adjustment
  - – pole-zero cancellation
- data acquisition
  - – start, for a preset live time interval
  - – stop, manually or at the end of a preset interval
  - – store spectral data
  - – clear
- spectrometer shutdown

2.3.2 Energy Calibration

The energy calibration procedure must not display the actual spectrum to the user, as radioisotopes outside the list of CTBT-relevant fission products may be present at the measurement site. The energy calibration software should display display the calibration peaks, the energy vs. channel least-squares fit, and the fit residuals.

2.3.3 Data Analysis and Display

The spectral analysis software should operate in parallel with data acquisition, and it should display filtered spectrum analysis results to users in real time, updating every 10 seconds. The results for all 17 CBTB-relevant fission products are shown by a "thermometer bar" display, like in Figure 4. More detailed analysis results for each isotope are obtained by clicking a button for the desired isotope above the thermometer bars. The information window for Zr-95 is shown in Figure 5.

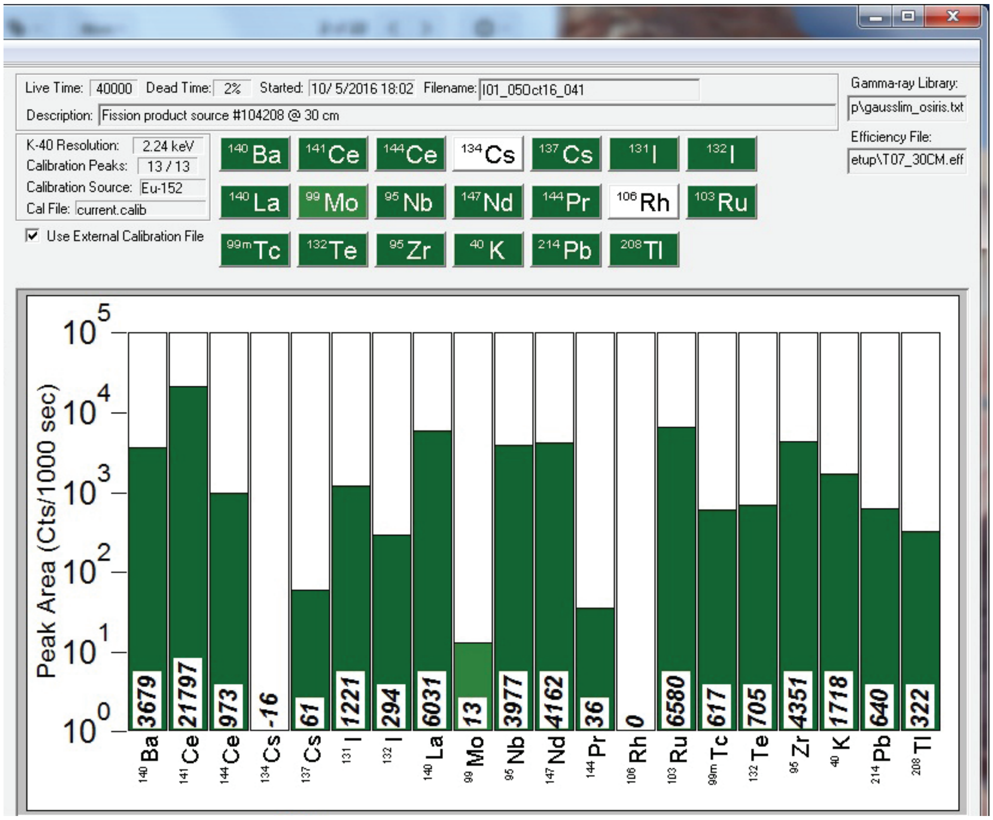

Figure 4: *OSIRIS "thermometer bar" display of CTBT-relevant isotopes.*

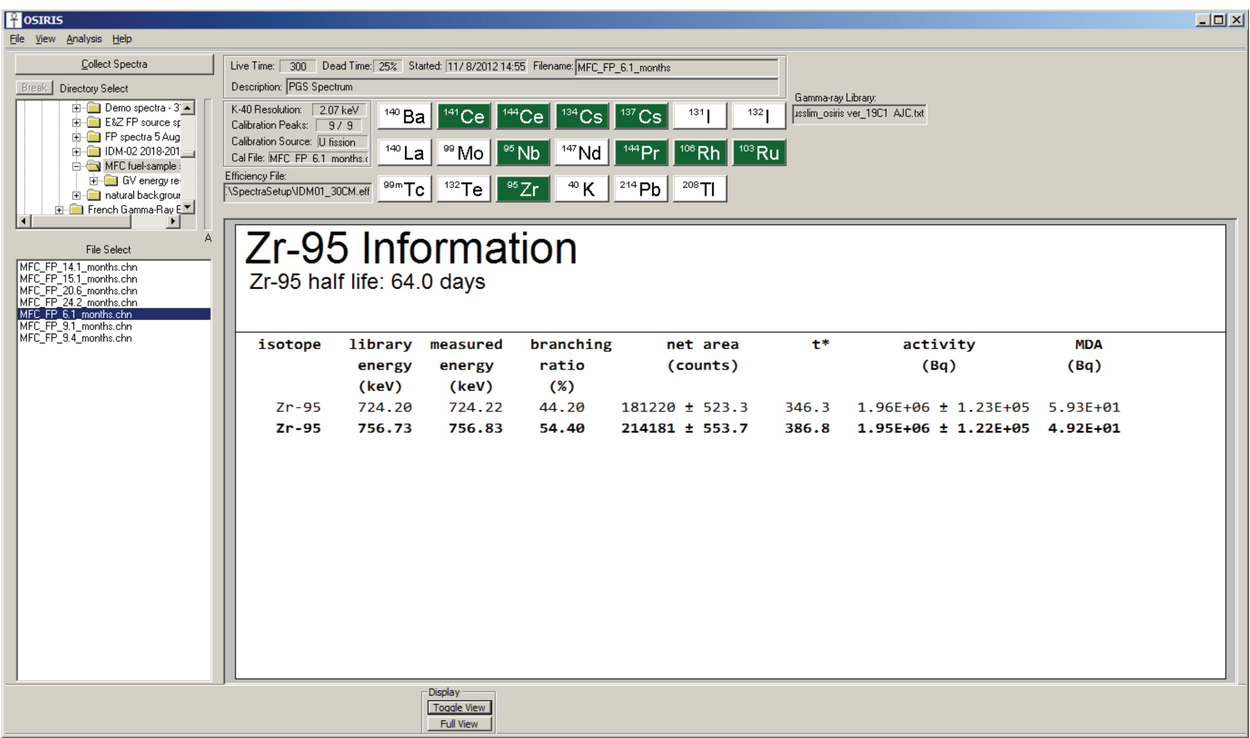

Figure 5: *Zr-95 isotopic information window.*

3. OSIRIS Software Development History

The OSIRIS software controls data acquisition, performs analyses of the acquired spectral data, filters the analysis results for display, and encrypts the spectral data prior to hard-disk storage.

3.1 Data Acquisition Software

The OSIRIS data acquisition code is written in C++. The ORTEC IDM-200V gamma-ray spectrometer is controlled using ORTEC MCB CONNECTIONS-32 software. The measured spectral data is moved from the spectrometer to the control computer using selected dynamic-linked libraries (DLLs) from the ORTEC Analysis Results Programmer's Toolkit, A12-32.

The data acquisition code used in OSIRIS is nearly identical to the proven PINS data acquisition software used to operate ORTEC SMART HPGe detectors with DigiDART multichannel analyzers and Transpec-100 HPGe gamma-ray spectrometers.

3.2 Spectral Data Analysis Software

The OSIRIS spectral analysis software supervisory logic is shown in Figure 6. Following initialization and energy calibration, a gamma-ray spectrum is acquired. Next a peak search is performed using the zero-area square-wave correlation method of Black. [7] Based on the detected and required peaks, the peak-fitting regions are determined with the GAUSS-VII gamma-ray spectrum analysis algorithms of Helmer and McCullagh. [8] Peak fits are then conducted region-by-region, and the radioisotopes evident in the spectrum are identified using a look-up table of peak centroid energies. [9] For peak detection, OSIRIS currently requires the peak area to exceed the peak background uncertainty by a factor of 3 or more. Finally, information on the treaty-relevant fission products is pushed across the data filter for display to the user. The spectrum is re-analyzed every 10 seconds, and the display is updated after each re-analysis.

3.2.1 The GAUSS Spectral Analysis Engine

Our late colleague Dick Helmer designed four successive versions of the GAUSS spectral analysis codes from 1965 through 1983. GAUSS-I was used for analysis of sodium-iodide spectra; GAUSS-III, GAUSS-V, and GAUSS-VII are designed for use with Ge spectra. During its development, GAUSS-VII was extensively tested on fission-product spectra.

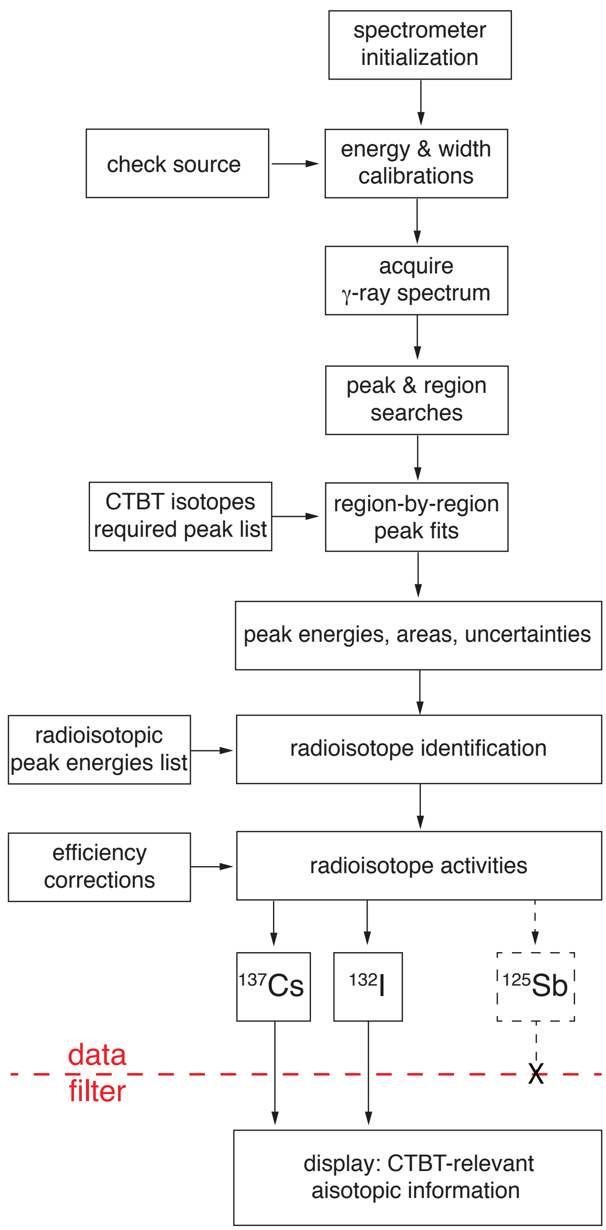

Figure 6: *OSIRIS spectral analysis software supervisory logic.*

Our colleague Ann Egger has developed an interactive version, GAUSS-XI, based on GAUSS-VII. [10]

OSIRIS peak region determination and peak fits are carried out with GAUSS-VII algorithms. GAUSS peak analyses use nonlinear least-squares fits to spectral peaks and the underlying Compton background. Figure 7 displays a GAUSS fit of overlapping peaks in the 650- to 680-keV region of a nuclear reactor fuel-sample spectrum. Note that GAUSS determines both net peak areas, as indicated by the blue shading of the Cs-137 peak, and the centroid energies, as the arrow in the I-132 peak demonstrates. Also note that GAUSS can correctly analyze the overlapping I-132 and Sb-125 peaks.

3.2.2 PINS Implementation

INL's PINS nondestructive analysis system for military munitions was first developed using summing methods of gamma-ray spectral peak analysis. But PINS capture gamma-ray spectra are often complex, and summing methods proved to be somewhat inaccurate, especially for doublet peaks. In 2000, GAUSS-VII was adopted for PINS spectral analysis. The spectral peak analysis results are fed into a chemical-identification decision tree to identify chemical warfare agents like GB nerve agent ("sarin"), explosives like TNT, smoke-producing chemicals like white phosphorus, and practice-munition fills like plaster-of-Paris.

PINS has subsequently analyzed the contents of thousands of suspect chemical munitions for the U.S. Army. During user training, we noted that energy calibration proved difficult for the soldiers, and in 2003, just before PINS was deployed to Iraq, an automatic energy calibration routine was added to the software. Auto energy calibration reduced PINS training time by a factor of two.

3.2.3 OSIRIS Implementation

For OSIRIS, the PINS chemical-identification decision tree was removed from the software, since the GAUSS peak analysis directly identifies radioisotopes, net peak areas, and the related

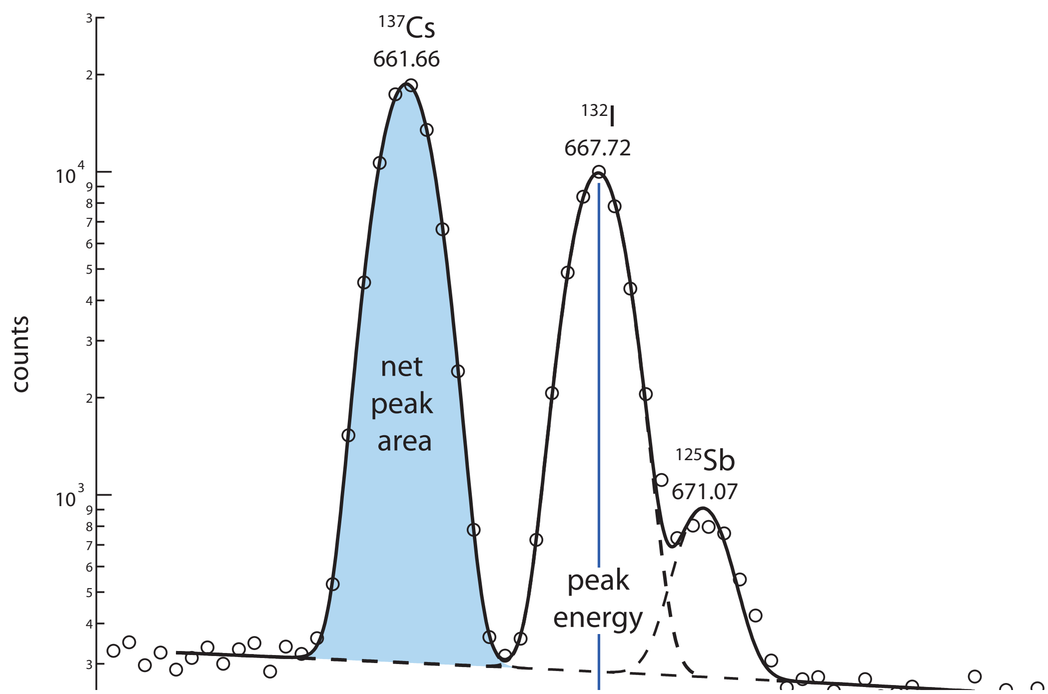

Figure 7: *GAUSS fit of fission-product gamma-ray peaks.*

uncertainties. The activity of a given radioisotope is directly proportional to its gamma-ray net peak areas. The PINS thermometer-bar display indicating the intensities of gamma rays produced by selected chemical elements has been recycled to display the intensities of gamma rays produced by the seventeen CTBT-relevant fission products.

OSIRIS also displays information on three common natural-background isotopes, K-40, Pb-214, Th-228, to assure users that the spectrometer is operating correctly in the absence of fission-product gamma rays.

3.2.4 OSIRIS Energy Calibration

PINS systems are energy calibrated from neutron-induced gamma-ray peaks found in most every PINS spectrum, including peaks from aluminum, germanium, hydrogen, iron, and silicon.

The PINS software that performed a linear least-squares fit of gamma-ray peak energies to peak centroid channels was carried over to OSIRIS. But instead a list of neutron-capture gamma-ray energies, tables of Eu-152, Th-228, and natural background gamma rays are used by OSIRIS. Using a 1 to 5 microcurie Eu-152 source, OSIRIS can be accurately energy calibrated in 100 seconds. Absent a Eu-152 or Th-228 check source, OSIRIS can be energy calibrated using natural background gamma rays, but an accurate calibration requires a longer counting time, typically 1,000 seconds.

As sensitive isotopes might be revealed during an energy-calibration spectral measurement, OSIRIS does not display the actual raw calibration spectrum. It displays the measured intensities of the expected peaks of the calibration source instead, as shown in Figure 8.

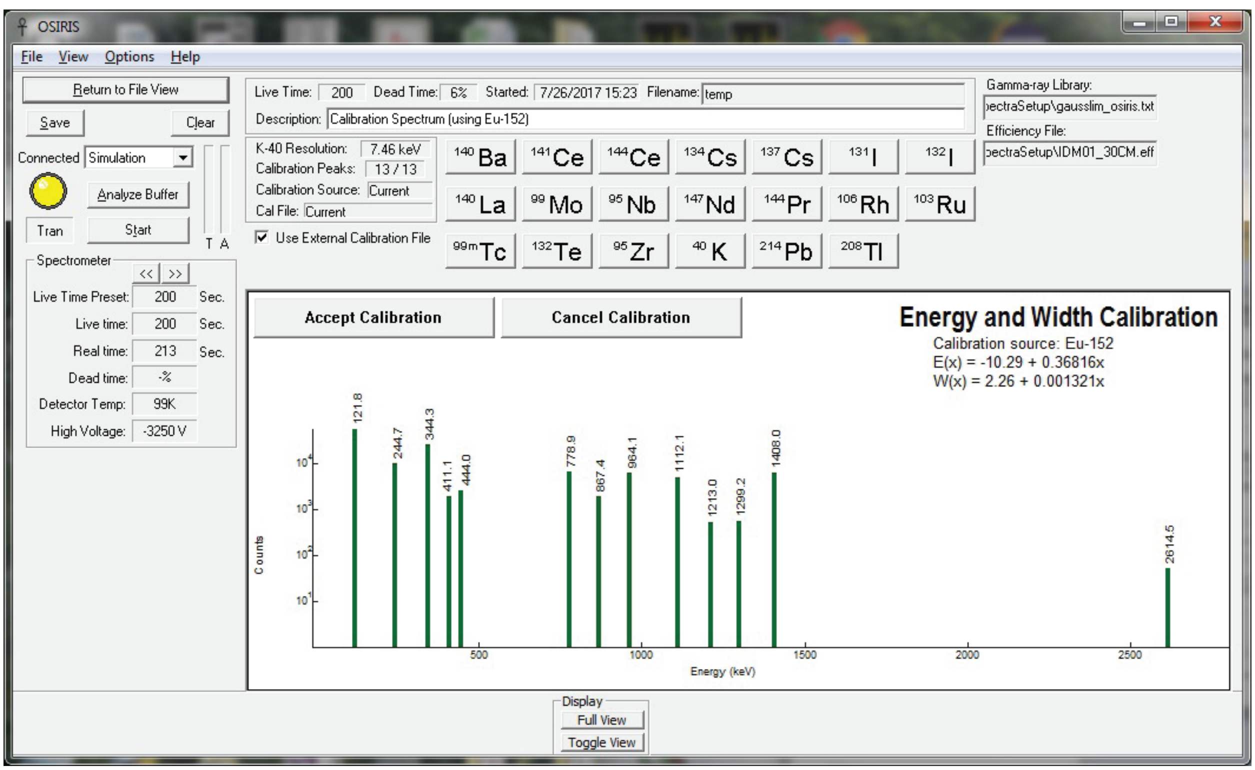

Figure 8: *OSIRIS energy calibration spectrum window.*

3.3 Graphic User Interface and Filtered Data Display Software

The main OSIRIS user screen is shown above in Figure 4. Besides the isotopic thermometer bars, the display includes buttons for starting and stopping data acquisition, presetting the counting live time, and viewing additional information on each of the seventeen CTBT-relevant isotopes. For example, clicking the Cs-134 or Cs-137 button brings up the isotope information box shown in Figure 9. The Cs-134/Cs-137 activity ratio is important in distinguishing a nuclear weapon test fission product spectrum from a reactor-accident spectrum. In the former, the radiocesium ratio is 0, as essentially no Cs-134 is produced in a nuclear explosion; while in a reactor accident, the ratio is usually non-zero. For the Chernobyl accident, the radiocesium ratio was 0.50 ± 0.05. [11]

3.4 Data Encryption Software

Prior to data storage, OSIRIS spectral files are encrypted, using the 128-bit implementation of the Advanced Encryption Standard. [12] During encryption, a "hash" digital signature is computed, and it is saved for comparison on decryption, to ensure the spectra data are unchanged. The hash calculation is performed using the Secure Hash Algorithm-256 (SHA-256, for short) developed by the National Security Agency. [13]

The OSIRIS encryption and decryption keys are protected using the RSA public/private key encryption method. [14]

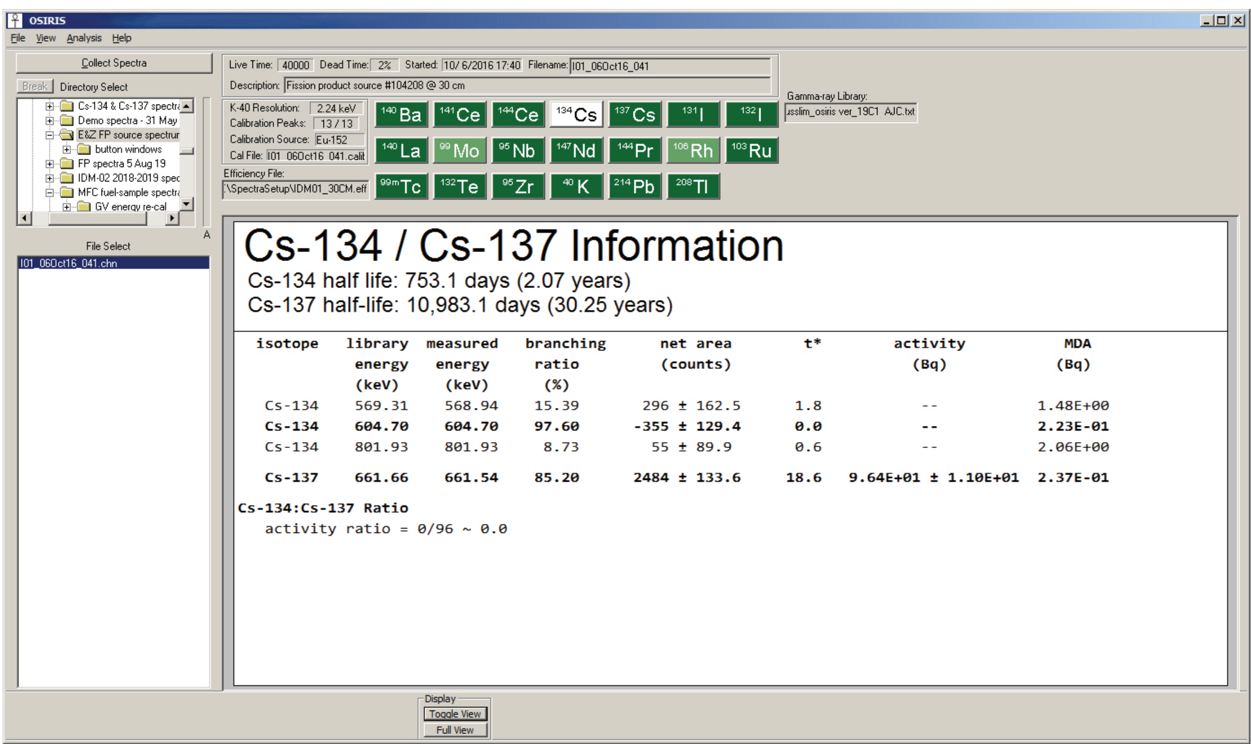

Figure 9: *Cs-134/Cs-137 information window. These data were measured from a fission-product source containing no Cs-134, and hence the Cs-134/Cs-137 activity ratio is zero.*

4. OSIRIS Validation Tests

OSIRIS system performance has been validated in a series of hardware, software, and system tests. The first tests of the Transpec-100 spectrometer occurred during development of the PINS-3 CF system, before OSIRIS development had started. Next, OSIRIS software was tested independently from the hardware, using both measured and synthetic gamma-ray spectra. Starting in 2016, OSIRIS was exercised as a complete hardware-software system in the final series of validation tests.

4.1 Hardware Validation Tests

An n-type ORTEC Transpec-100 gamma-ray spectrometer is a key component of the PINS-3 CF instrument, and, as such, it was extensively tested by INL from 2006 to 2011. PINS-3 CF development included tests at military installations with actual chemical warfare agents.

Given INL experience with the Transpec-100 as a PINS system component, it was natural to select the p-type Transpec-100 for the OSIRIS project. The key Transpec-100 features include its 40% relative efficiency, 2.3-keV energy resolution at 1332 keV, freedom from liquid nitrogen logistics, AC-line and battery-powered operation, and proven compatibility with INL data acquistion and data-analysis software.

After brief tests in early 2014 at INL, the OSIRIS Transpec-100 was sent to the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) in Vienna, Austria, to participate in the International Field Exercise (IFE14) on-site inspection exercise held in Jordan in October-November 2014. [15] At IFE14, the spectrometer was mounted on a tripod and operated in the *in-situ* mode, as shown in Figure 10, and it is said to have performed well. [16]

Figure 10: *A tripod-mounted OSIRIS spectrometer is set up at the IFE14 exercise in Jordan.*

4.2 Initial Software Validation Tests

OSIRIS software has been validated in tests from 2012 to 2019, as enumerated in Table 1. The testing included actual fission-product gamma-ray spectra from uranium samples irradiated at INL, commercial fission-product sources, and legacy radiation at the Nevada National Security Site, formerly the Nevada Test Site. As discussed in section 4.2.2, the OSIRIS spectral analysis software has also been tested with a set of synthetic fission-product spectra produced by our LLNL and PNNL colleagues. Apprendix B reports a recent comparision of OSIRIS and ORTEC GammaVision analyses of the synthetic spectra.

4.2.1 Uranium Fuel-Sample Tests

The first tests of OSIRIS software were performed with gamma-ray spectra measured from seven uranium fuel samples irradiated in the Advanced Test Reactor at INL. After irradiation, the samples had cooled prior to measurement for six to twenty-four months, providing an assortment of fission-product gamma rays for spectral analysis, depending on the cooling time and fission-product half-lives.

4.2.2 Synthetic Spectral Tests

Ge detectors had not been invented when the United States and most other countries stopped atmospheric testing in 1963, and hence, to our knowledge, there are not high-resolution gamma-ray spectra available from nuclear tests. Accordingly, for testing OSIRIS, a set of 100 fission-product gamma-ray spectra was synthesized by Lawrence Livermore National Laboratory and Pacific Northwest National Laboratory, using the MCNP and SYNTH codes. [17] The spectra were designed from the following nine on-site inspection scenarios:

Table 1: OSIRIS Software Development Tasks

Description	Completion Date	OSIRIS Version
Remove PINS chemical identification code	April 2013	1.0
Reset GAUSS spectrum-analysis engine to ID radioisotopes	August 2013	1.0
Modify thermometer-bar display	October 2013	1.1
Add isotope information windows to GUI	December 2013	1.1
Test OSIRIS on MFC irradiated reactor-fuel spectra	February 2014	1.1
Modify auto e-cal software for use with Eu-152 sources	April 2014	1.1.3
Test OSIRIS on LLNL/PNNL synthetic spectra	June 2014	1.1.8
Modify OSIRIS for use with multiple gamma-ray libraries	March 2015	1.2
Test OSIRIS auto e-cal software	June 2015	1.4
Steve Schubert program review	July 2015	1.4
INL OSIRIS system tests	July 2016	1.6.1
PNNL OSIRIS system tests	September 2016	1.6.1
Nevada OSIRIS system tests	March 2017	1.6.1
Add point-source and *in-situ* geometry efficiencies	November 2017	1.7.1
Encryption & decryption software development and testing	January 2018	1.7.2
New analysis and calibration report formats	February 2018	1.7.3
Minimum detectable activity (MDA) calculation	August 2018	1.7.5
Ratio tests for Cs-134 and Cs-137	February 2019	1.7.6
Updated gamma-ray library version 19C	June 2019	1.7.8
Isotope information window upgrades	July 2019	1.7.9
GammaVision - OSIRIS spectral analysis comparison	August 2019	1.7.9

1. Nuclear explosion – strong underground release including particulates, assayed weeks after explosion
2. Nuclear explosion – weak activity with limited particulate release, assayed 1-2 weeks after explosion
3. Nuclear explosion – weak activity with limited particulate release assayed 1-2 years after explosion
4. Nuclear explosion – Gas-only release with subsequent decay-daughter particulate deposition, assayed weeks after explosion
5. Legacy testing debris assayed decades after explosion, "Nevada Test Site" aboveground surface/shallowly buried or similar
6. Reactor accident – Predominantly volatile release, "Fukushima"
7. Reactor accident – Core release with refractories & volatiles, "Chernobyl"
8. Spent-fuel reprocessing waste site
9. Industrial/medical isotope production waste site

Of these, the first four scenarios are not compliant with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) while the latter five are treaty-compliant.

The synthetic spectra were based on actual measured spectra, to the extent possible, but often computer simulations were necessary to combine the fission-product signal with a natural background gamma-ray spectrum.

The synthetic spectra were analyzed twice. The baseline analysis was performed visually by an experienced spectroscopist using the INL interactive program GAUSS XI. The spectra were also analyzed "blind" (automatically) by OSIRIS. The expert and OSIRIS analyses agreed well, with OSIRIS identifying CTBT-relevant fission products correctly at the 95% level or better, as discussed in detail in a 2014 *Nuclear Instruments and Methods in Physics Research* paper. [18]

4.2.3 Automatic Energy Calibration

The spectrum analysis algorithms rely on accurate calibration of the spectrometer energy scale. OSIRIS energy calibrations must be sufficiently accurate to correctly identify the CTBT-relevant radioisotopes in complex spectra. For example, the fission product Cs-137 is identified by a peak at 661.66 keV. If the spectrometer energy calibration is just 0.9% hight, this peak would be mistakenly identified as the 667.73-keV I-132 fission-product gamma ray.

With care, it is routine to calibrate high-resolution gamma-ray spectrometer spectral energies to 0.1%. In 2015 tests of the OSIRIS automatic energy calibration routine, it was possible to calibrate the spectrometer energy scale to 0.012% in 100 seconds, using a microcurie-strength Eu-152 check source. The automatic energy calibration algorithm is explained in a 2015 OSIRIS report. [19]

4.3 System Integration Tests

In addition to restricting spectral information to the seventeen CTBT-relevant isotopes, the following metrics were used to evaluate OSIRIS performance in the system integration tests:

- Detection of the CTBT-relevant fission-product isotopes actually present in a spectrum.
- Non-detection of the CTBT-relevant fission-product isotopes not present.
- Correct net peak areas for CTBT-relevant gamma-ray peaks.
- Accurate spectrometer energy calibrations.
- Stable spectrometer electronic gain between energy calibrations.

4.3.1 Hardware Modifications

To address several data-security concerns presented by the Transpec-100, in 2016 it was replaced by a modified ORTEC Independent Detector Module mechanically-cooled HPGe spectrometer, model IDM-200-V. This model is now designated IDM-200-R.

A standard IDM spectrometer retains spectra in its internal histogram memory, even when powered off. OSIRIS IDM spectrometers are factory-modified to erase histogram memory whenever the USB cable is disconnected from the control computer.

4.3.2 Energy Calibration Stability

Since OSIRIS identifies radioisotopes from gamma-ray peak energies, an accurate and stable spectrometer energy calibration is critical for proper operation of the instrument. The accuracy of the automatic energy-calibration routine was discussed above at the end of section 4.2. While we believe the spectrometer will be recalibrated daily in field use, we have studied energy calibration stability as a function of time over month-long periods, and also as a function of temperature.

As a baseline the OSIRIS energy calibration stability was measured over five days in an air-conditioned laboratory, it was found to be stable within 0.031 keV.

Next, we monitored the energy calibration stability during month-long outdoor tests in winter at INL, as shown in Figure 11, and in summer at PNNL. The test results are presented graphically in Figure 12. In both tests, the energy calibration remained stable within 0.113 keV.

We also tested system stability in an environmental chamber between +10 °F (-12 °C) and 122 °F (50 °C). The Eu-152 121-keV and 1408-keV gamma-ray peak centroids moved less than 0.21 keV in this test, as can be seen in Figure 13.

4.3.3 Radiation Background Test

Two OSIRIS systems were operated in the *in-situ* mode at two locations on the Nevada National Security Site, formerly the Nevada Test Site. One measurement location had relatively low, but measureable radiation background, a legacy of atmospheric nuclear weapons testing in the 1950s and early 1960s. The background at the second location was a factor of 15 higher. At both locations,

Figure 11: *Winter test of OSIRIS at INL.*

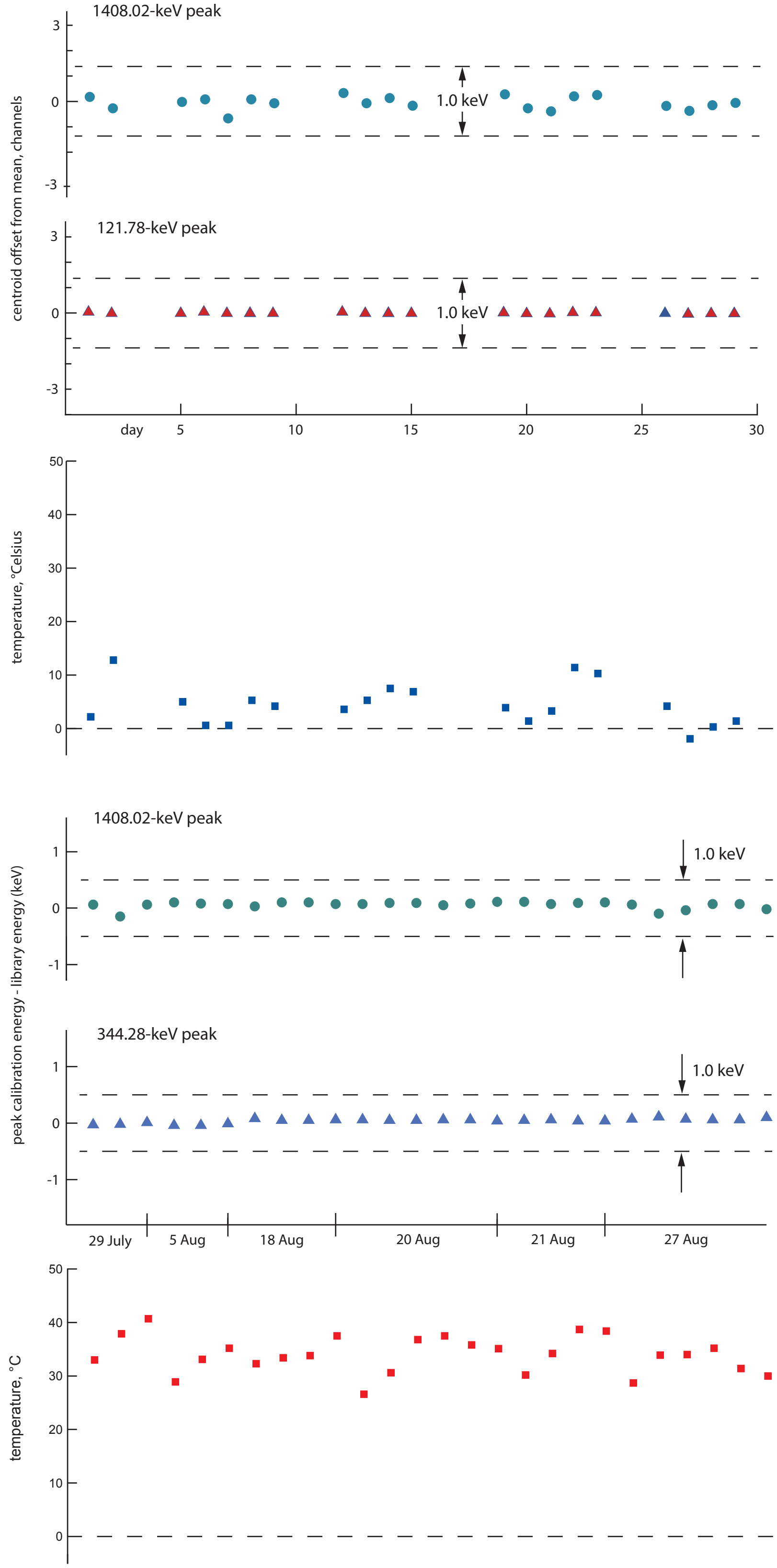

Figure 12: *Winter and summer spectrometer energy-calibration stability test results.*

the OSIRIS systems detected two CTBT-relevant fission products 65-day Zr-95 and its 35-day daughter Nb-95 from a microcurie source placed beneath the spectrometers, as shown in Figure 14.

On the last day of testing in Nevada, a storm developed suddenly, and gale-force winds tossed the shipping container where the control computer was sheltered from the rain. The USB cable connecting the control computer to the spectrometer pulled over the tripod, causing the spectrometer to fall to the ground. INL sent the spectrometer to ORTEC for evaluation, and it was found to meet its original specifications. In short, it survived an unscheduled one-meter drop test unscathed.

4.3.4 Fission-Product Decay Curves

For almost a year in 2015-16, a commercial fission-product source was counted with an OSIRIS system at INL as a long-term test of measurement accuracy. The test evaluation criterion is simple: do the measured gamma-peak areas match the theoretical decay curves for each fission-product?

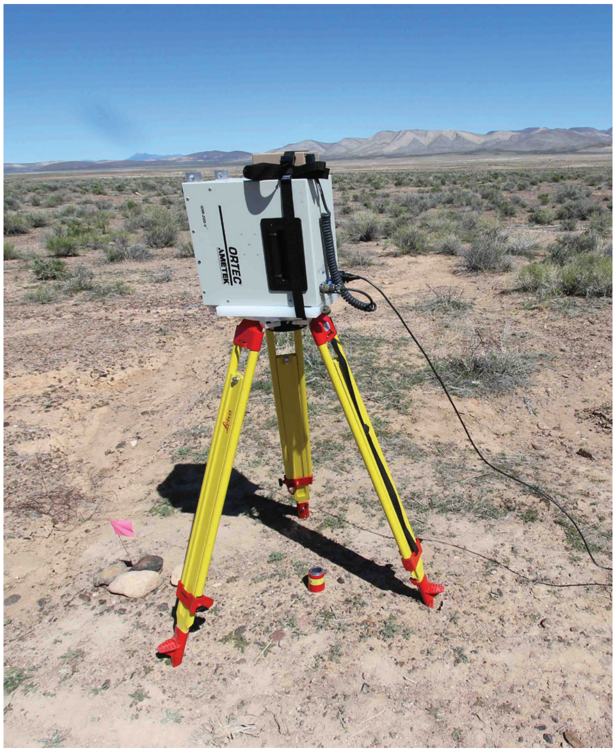

Figure 14: *OSIRIS system test at the Nevada National Security Site.*

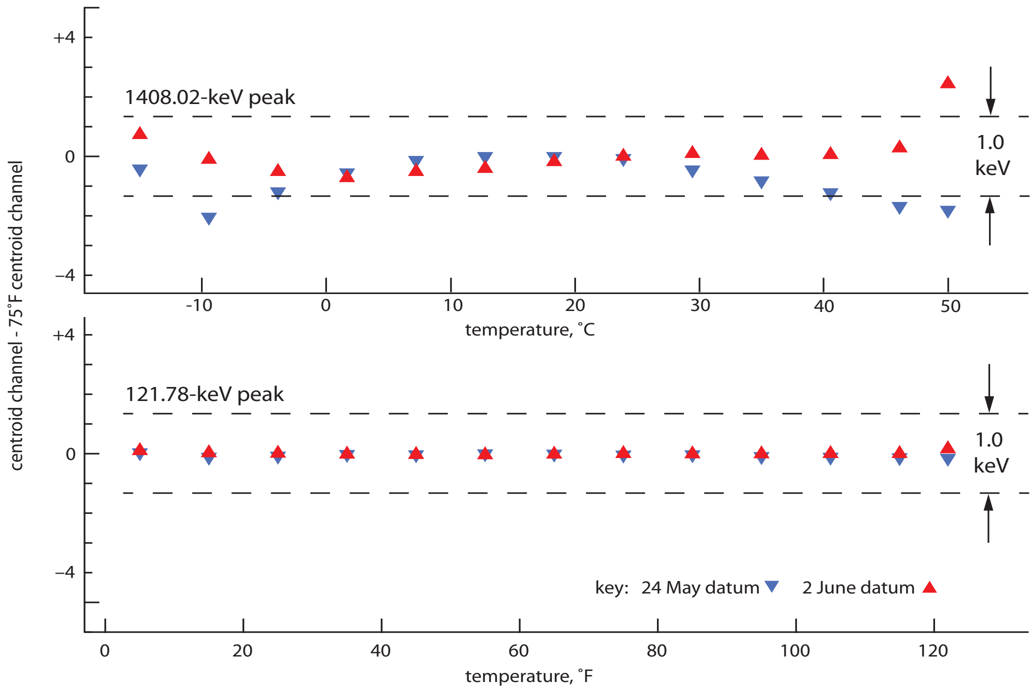

Figure 13: *Environmental chamber temperature energy-calibration stability test results.*

The results are shown in Figure 15. In this figure, the decay curves and measurement data for six representative CTBT-relevant fission products are shown. The black decay curves are calculated from fission-product half-lives, and the measurements are indicated by small colored circles. The measured points and theoretical decay curves are in excellent agreement.

4.3.5 Encryption and Decryption Testing

An encryption function using the Advanced Encryption Standard-128 is included in the OSIRIS code, and raw gamma-ray spectra are automatically encrypted when stored on the control-computer hard disk. Encrypted OSIRIS files are denoted with the ".echn" file extension. Before a spectral file is encrypted, a hash digital signature is calculated and stored with the encrypted file, for later verification. The OSIRIS encryption and decryption keys are passed using the RSA public/private key-encryption method. The public key must be present on the control computer to encrypt spectral files. The private key is required for decryption, and it is not to be copied to the instrument-control computer. The decryption program, OSIRIS Decryptor, and the associated encryption key program, OSIRIS Key Generator, should be kept on a supervisory computer that does not travel to the field with the OSIRIS instrument.

The key generation, encryption, and decryption for OSIRIS spectra were first validated in a series of hardware, software, and system tests in January 2018. During these tests, the key generator program was used to create a set of "public" and "private" encryption keys saved to a selected folder on a supervisory computer. Only the public encryption key was transferred to via USB thumb drive to the OSIRIS instrument-control computer. The private key was not moved from its saved file folder on the supervisory computer.

Spectra from microcurie-strength check sources (^{137}Cs, ^{60}Co, ^{152}Eu) were collected using the OSIRIS system. During the collection, the system

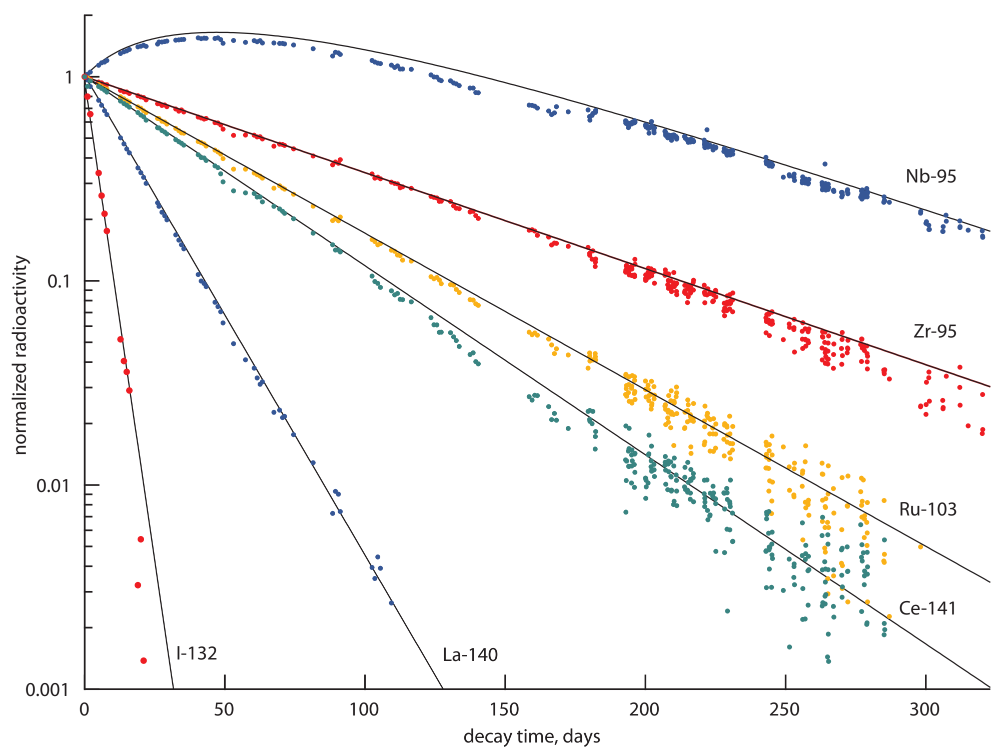

Figure 15: *OSIRIS measurements of activity vs. time for six CTBT-relevant fission-product isotopes. The solid black decay curves are calculated from fission-product half-lives, and the colored circles are experimental data points.*

software saved the data in an encrypted format using this "public" key, along with an encrypted "hash" digital signature file.

Attempts were made to open the .echn files with various spectral analysis programs, including GammaVision, Maestro, and PINS+. In all cases, these programs could not read the encrypted spectral files. Next, the .echn file extension was re-named to a file extension type the spectral analysis programs were designed to read, e.g., .chn, .txt, .doc, and .spc, but the re-named encrypted files were still unreadable by the spectral analysis programs.

After verifying that the encrypted files couldn't be read by analysis programs, the spectral files (.echn and .hash files) were transferred via USB thumb drive to the supervisory computer containing the OSIRIS Decryptor programs. The spectra were decrypted using the OSIRIS Decryptor program and the private key. After decryption, the spectral data, now formatted as a ".chn" file, could be cleanly read by OSIRIS and Maestro, displaying the gamma-ray peaks associated with the various check sources used in these tests.

4.3.6 Revalidation Tests

ORTEC has requested that INL revalidate OSIRIS software by repeating some of the tests conducted with earlier versions of the code. To date, five early tests of OSIRIS have been revalidated.

4.3.6.1 Analysis of MFC Fission-Product Spectra

The first test of OSIRIS data analysis was performed in 2014 on a set of seven gamma-ray spectra measured from experimental uranium reactor fuel samples irradiated at the INL Advanced Test Reactor. After 6 to 24 months of cooling, the fuel samples were counted in a hot cell at the INL Materials and Fuels Complex (MFC), using a tightly-collimated HPGe detector.

The MFC spectra were re-analyzed in December 2018, and compared to analyses with the ORTEC GammaVision spectral analysis program and the INL GAUSS XI interactive spectral analysis program. As shown in Table 2, the mean OSIRIS/GammaVision net-peak-area ratio is 0.995 for this set of spectra, and the mean OSIRIS net-peak-area ratio is 1.001.

4.3.6.2 Analysis of Spectra From a Commercial Fission-Product Source

In January 2019, the OSIRIS and GammaVision analyses of a spectrum from a new commercial fission-product source were compared. The new source contained 15 of the 17 CTBT-relevant fission-product isotopes. The CTBT isotopes Cs-134 and Rh-106 are missing, presumably due to radiochemical processing during source manufacture. Supplementing the commercial-source spectrum with an MFC spectrum that includes the two missing CTBT isotopes, the mean OSIRIS/GammaVision peak area ratio is 1.003, as shown in Table 3.

Table 2: Comparison of OSIRIS and GammaVision Analyses of MFC Fission-Product Spectra.

	peak area comparison means	
spectrum	OSIRIS/GammaVision	OSIRIS/GAUSS XI
MFC_FP_6.1_months.chn	1.013	0.998
MFC_FP_9.1_months.chn	0.984	1.003
MFC_FP_9.4_months.chn	0.979	0.999
MFC_FP_14.1_months.chn	0.984	1.007
MFC_FP_15.1_months.chn	1.014	1.001
MFC_FP_20.2_months.chn	0.991	1.000
MFC_FP_24.2_months.chn	1.002	1.001
overall means	**0.995**	**1.001**

Table 3: Osiris, GammaVision, and GAUSS XI Fission-Product Analysis Comparisons

			OSIRIS		GammaVision (GV)		GAUSS XI		OSIRIS/GV	OSIRIS/ GAUSS XI
Spectrum file	isotope	Library Egamma (keV)	area (counts)	sig area (gounts)	area (counts)	sig area (counts)	area (counts)	sig area (counts)	peak area ratios	
I06Oct16_041.chn	Ba-140	537.31	139505	420.6	141037	479.5	138432	421.8	0.989	1.008
I06Oct16_041.chn	Ce-141	145.44	866288	1027.5	870653	1131.8	865371	1052.0	0.995	1.001
I06Oct16_041.chn	Ce-144	133.54	38677	514.0	38592	721.7	39331	551.1	1.002	0.983
MFC_FP_24-2.chn	Cs-134	604.69	5323644	2360.00	5193514	2596.8	5316159	2356.6	1.025	1.001
I06Oct16_041.chn	Cs-137	661.66	2785	126.2	2679	209.5	2657	130.6	1.040	1.048
I06Oct16_041.chn	I-131	364.48	44799	286.3	44571	490.3	44762	312.4	1.005	1.001
I06Oct16_041.chn	I-132	667.73	9902	151.1	9602	227.6	9707	175.2	1.031	1.020
I06Oct16_041.chn	La-140	487.02	330743	612.7	329510	724.9	328878	615.4	1.004	1.006
I06Oct16_041.chn	Mo-99	(see Tc-99m below)								
I06Oct16_041.chn	Nb-95	765.81	161721	420.7	164720	444.7	160811	423.5	0.982	1.006
I06Oct16_041.chn	Nd-147	531.02	24282	244.2	24248	322.5	23859	231.3	1.001	1.018
I06Oct16_041.chn	Pr-144	696.51	1552	112.6	1618	245.8	1533	146.9	0.959	1.013
MFC_FP_24-2.chn	Rh-106	621.8	594311	876.7	582557	932.1	593875	872.0	1.020	1.001
I06Oct16_041.chn	Ru-103	497.08	258696	548.0	257721	670.1	257095	548.5	1.004	1.006
I06Oct16_041.chn	Tc-99m	140.51	18795	462.8	20976	694.3	19687	591.0	0.896	0.955
I06Oct16_041.chn	Te-132	228.16	23568	320.1	21110	532.0	23258	361.7	1.116	1.013
I06Oct16_041.chn	Zr-95	756.73	172164	450.5	175323	455.8	171421	440.3	0.982	1.004
								Mean	**1.0032**	**1.005**

These comparison results were summarized in a poster presented at a Department of Energy Nuclear Explosion Monitoring program review in March 2019. This poster was also displayed at the Comprehensive Nuclear-Test-Ban Organization Science and Technology Conference (SnT19) held in Vienna, Austria, in June 2019.

4.3.6.3 Analysis of the LLNL-PNNL Set of Synthetic Fission-Product Spectra

In 2014, INL compared OSIRIS automated analyses of a set of fission-product spectra with hand analyses performed using the INL GAUSS XI program for visual spectral analysis. One hundred spectra were synthesized by our colleagues at Lawrence Livermore National Laboratory (LLNL) and Pacific Northwest National Laboratory (PNNL), simulating spectra produced by both treaty-compliant and non-treaty compliant scenarios. The results of this comparison were included in a 2015 *Nuclear Instruments and Methods in Physics Research* paper on the design of OSIRIS.

In July 2016, the synthetic spectra were re-analyzed by OSIRIS and analyzed for the first time by GammaVision. The analysis results are compared in detail in Appendix A. The mean OSIRIS/GammaVision net peak area ratio for the fission products detected in the 100 synthetic spectra is 0.969 ± 0.077.

4.3.6.4 Analysis of Nevada spectra

Two fission products, Nb-95 and Zr-95 were detected in spectra from a fission-product source measured at the Nevada Nuclear Security Site in a March 2017 test. The source was about six months old, and its shorter-lived isotopes had decayed away. The Nevada spectra were re-analyzed in August 2019, and the same two fission-product isotopes were detected.

4.3.6.5 Energy and Peak-Width Calibration

An IDM spectrometer is energy- and peak-width-calibrated daily at INL, using OSIRIS software, as part of a continuing year-long count of a fission-product source. The OSIRIS energy and peak-width calibrations continue to appear to be quite accurate. As an example, OSIRIS analysis of a spectrum measured on 5 August 2019 for 10,000 live seconds detected gamma-ray peaks for the fission products Ce-144, Cs-137, Nb-95, and Zr-95, plus the natural background isotopes K-40, Pb-214, and Tl-208. The mean difference between the library energy and measured energy for these peaks is 0.004 ± 0.15.

4.3.6.6 Gamma-Ray Point-Source Detection Efficiency

OSIRIS computes the radioactivity in becquerels (Bq) for each treaty-relevant isotope it detects. The activity A is computed from gamma-ray spectral data using the expression

$A = N/(LT \cdot EP \cdot \eta)$,

where N is the net area in counts of the gamma-ray peak of interest; LT is the counting live time, EP is the emission probability, also known as the branching ratio, for the peak of interest; and η is the detection efficiency. The uncertainty in the net peak area is about 3% for peaks containing 1,000 counts, and 1% for peaks containing 10,000 counts. The live-time uncertainty is 0.02% or less for counts of 100 second duration or longer. The emission probabilities for strong gamma rays emitted by the CTBT-relevant isotopes are known to a part in 10^4. The greatest uncertainty in determining the activity is that of the detection efficiency.

The detection efficiency η is a function of both gamma-ray energy and source-detector distance. For both INL OSIRIS spectrometers, the detection efficiency has been measured with a mixed-radioisotope source emitting gamma rays over energies from 59 to 1836 keV. A curve of efficiency vs. energy was produced by cubic-spline interpolation between the ten discrete gamma-ray energies emitted by the source. Mixed-source measurements were performed at 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 cm from the detector end cap, and the corresponding efficiency curves are supplied with OSIRIS software

To gauge the accuracy of the OSIRIS detection efficiency curves, we measured a 23.09 kilobecquerel (0.624 microcurie) Cs-137 source at 10 cm source-detector increments for both IDM spectrometers. The results are presented in Table 4. For spectrometer IDM-01, the mean OSIRIS -calculated activity agrees to the calibrated source activity within 1%. For IDM-01, the mean calculated activity agrees to the source activity within 3%. Currently, the OSIRIS activity uncertainty is stated as 5% – 4% due to mixed-source activity uncertainty, and an 1% for source-position uncertainty.

Table 4: OSIRIS Source Activity Calculations

	spectrometer IDM-01		spectrometer IDM-02	
distance (cm)	OSIRIS activity (kBq)	uncert. (kBq)	OSIRIS activity (kBq)	uncert. (kBq)
10	23.0	1.26	23.9	1.30
20	23.1	1.34	23.8	1.38
30	23.6	1.38	24.2	1.41
40	22.9	1.35	23.9	1.44
50	22.6	1.35	23.9	1.42
60	23.3	1.38	24.0	1.43
70	22.8	1.36	23.5	1.41
80	22.9	1.39	23.5	1.40
90	22.0	1.33	23.5	1.43
100	22.7	1.34	23.9	1.42
mean	22.89		23.81	
std. dev.	0.43		0.24	
source	23.09		23.09	
mean/ source	**0.991**		**1.031**	

5. OSIRIS Verification

This section explains the steps necessary to verify a new OSIRIS system is ready for use. In the verification of an OSIRIS system, two Windows computers are required. One, the instrument control computer, is the ruggedized laptop that will travel to the field with the IDM spectrometer. The second, termed here the supervisory computer, will host the software for encryption-key generation and spectrum-file decryption. For data security, the encryption-key and decryption software should never be installed on a control computer.

It may be helpful to have a copy of the OSIRIS User's Manual on hand for reference during verification testing.

5.1 Hardware Verification

The day before the planned verification tests, plug the spectrometer into AC line power, and switch-on the spectrometer. Do not try to cool the spectrometer on battery power. While the spectrometer is cooling, its pushbutton power switch will blink its blue color on and off. When it has cooled to operating temperature, about 120 Kelvin, the switch glows a steady blue.

5.1.1 Spectrometer Energy Resolution and Relative Efficiency Measurements

- ❑ Connect a computer loaded with a data acquisition program, e.g. GammaVision or Maestro, to the IDM spectrometer. Either the supervisory or control computer could be used for these measurements, or another computer entirely.
- ❑ Test the HPGe spectrometer energy resolution at 1332 keV.
- ❑ Test the HPGe spectrometer relative efficiency, again at 1332 keV.
- ❑ Note whether the spectrometer meets the OSIRIS specifications:
- ❑ Energy resolution: 2.3 keV FWHM or less for the 1332-keV Co-60 peak.
- ❑ Relative efficiency of 50 ± 3% at 1332-keV.

5.1.2 Spectrometer Histogram Memory Security Feature

Disconnecting the USB cable erases spectrometer histogram memory.

- ❑ Acquire a gamma-ray spectrum for a few hundred seconds. Natural background will suffice.
- ❑ Close the data acquisition program. This will erase the spectrum in local memory.
- ❑ Restart the data acquisition program. Verify the spectrum re-appears. If so, it was retained in the spectrometer's histogram memory.
- ❑ Disconnect the USB cable from the control computer.
- ❑ Reconnect the cable.
- ❑ Verify that the spectrum was cleared.

5.1.3 Battery Operation

- ❑ Disconnect the AC power cable from the outlet.
- ❑ Verify the spectrometer continues to operate on its internal battery.

5.1.4 Software Removal

- ❑ If the control computer was used for the measurements and tests described above in section 5.1, remove the data acquisition program, that is, GammaVision or Maestro. It is not a secure practice to have any data acquisition program on the control computer except OSIRIS when the system ships from the factory or is deployed to the field.

5.2. Software Verification

5.2.1 OSIRIS Software Installation

The InstallShield program installs the OSIRIS software for data acquisition, data analysis, and data encryption. In addition, a set of spectral files for testing OSIRIS software operation will be written to the control computer hard drive. InstallShield indicates when installation is complete.

- ❑ Install the OSIRIS software from a compact disk onto a spectrometer control computer using the InstallShield program.

5.2.2 Encryption Software Installation

- ❑ Install the encryption-key generation and decryption software on the master computer, typically an office desktop, using InstallShield.
- ❑ Start the OSIRIS key-generator program by clicking the key icon shown in Figure 16. A new window will open, as shown in Figure 17.
- ❑ Click the Make New Key Pair button. A new dialog box appears.
- ❑ Enter a file name for the keys.
- ❑ Browse to the storage folder for the key files and click the Open button.
- ❑ Verify the keys have been created in the key generator window.
- ❑ Click the Exit Program button.
- ❑ Copy the public key only to a USB thumb drive.

5.2.3 Fission-Product Identification

To verify OSIRIS software fission-product identification, operate OSIRIS in File View mode, and browse to the example fission-product spectra directory.

5.2.3.1 Thermometer Bar Display

- ❑ Click on spectrum I01_06Oct16_041.chn
- ❑ Verify the OSIRIS thermometer bars identify 15 of the 17 CTBT-relevant fission products, all save Cs-134 and Rh-10, as shown in Figure 18.
- ❑ Click spectrum MFC_FP_24.2.chn
- ❑ Verify the OSIRIS display thermometer bars identify the CTBT isotopes Ce-144, Cs-134, Cs-137, Nb-95, Pr-144, Rh-106, and Zr-95, as shown in Figure 19.

5.2.3.2 Cs-134 Isotope Information Window

Figure 16: *Encryption-key generator program launch icon.*

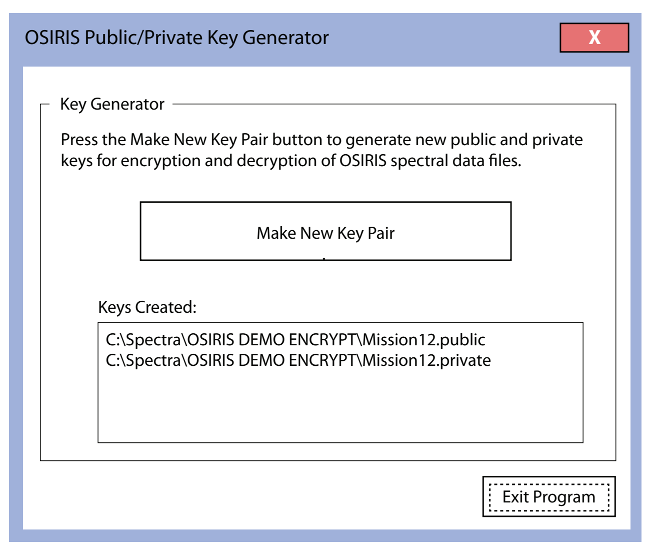

Figure 17: *OSIRIS key generator window.*

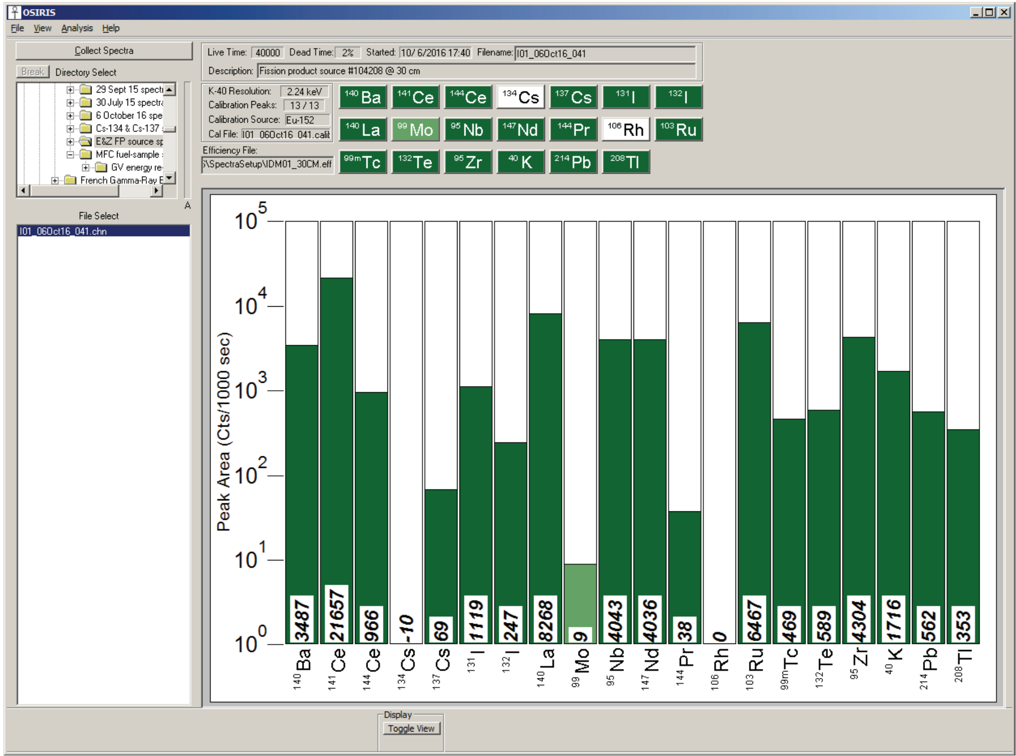

Figure 18: *Thermometer bar display for spectrum I01_06Oct16_041.chn.*

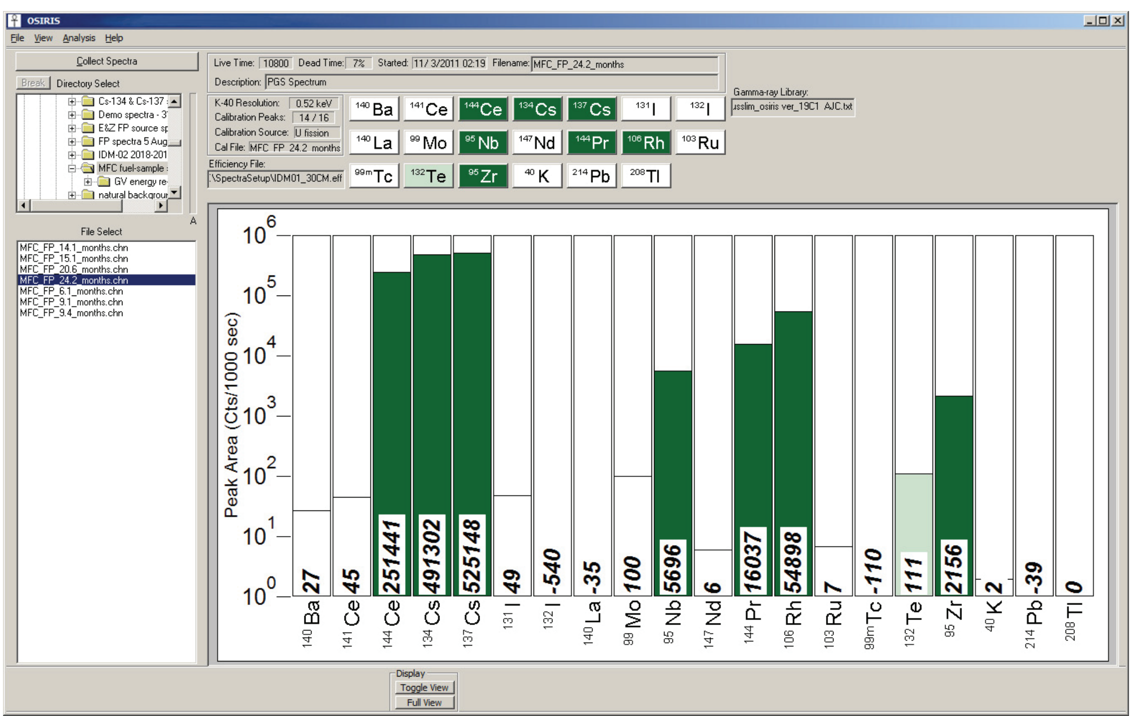

Figure 19*. Thermometer-bar display for spectrum MFC_FP_24.2.chn.*

- ❑ Click the Cs-134 button atop the thermometer bar display. The thermometer bars will be replaced by the Cs-134/Cs-137 information window shown in Figure 20. Clicking the Cs-137 button opens the same window. Both Cs-134 and Cs-137 are CTBT-relevant isotopes.

5.2.3.3 Radiocesium (Cs-134/Cs137) Ratio

- ❑ Verify the radiocesium ratio displayed in the Cs-134/Cs-137 information window is about 0.75 ± 0.1.

5.2.3.4 Other Isotope Information Windows

- ❑ Click the other isotope buttons.
- ❑ Verify detection of the CTBT isotopes Ce-144, Nb-95, Pr-144, Rh-106, and Zr-95.

Note that only those isotopes with buttons colored green like Cs-137 were detected by OSIRIS. The white buttons, like Ba-140, indicate radioisotopes that were not detected at the 3-sigma level above background.

5.3 OSIRIS System Verification

To verify the complete OSIRIS system is operating correctly, test that it measures and correctly analyzes a gamma-ray spectrum that includes at least one CTBT-relevant fission product. Alas, many of the CTBT fission products have relatively short half-lives. Hence, the CTBT fission product of choice for this test is Cs-137, an isotope with a half-life of 30.1 years, and widely available as a commercial gamma-ray check source. Most "mixed" radioisotope sources used for detector efficiency calibration include Cs-137, and that type of source would work fine for this system verification test.

A microcurie-strength Eu-152 check source is also need to energy-calibrate the spectrometer.

5.3.1 Control Computer Settings

5.3.1.1 Spectrum Directory

- ❑ Create a directory on the control computer to store measured gamma-ray spectra, energy-calibration information, data analysis summaries, and the public encryption key.

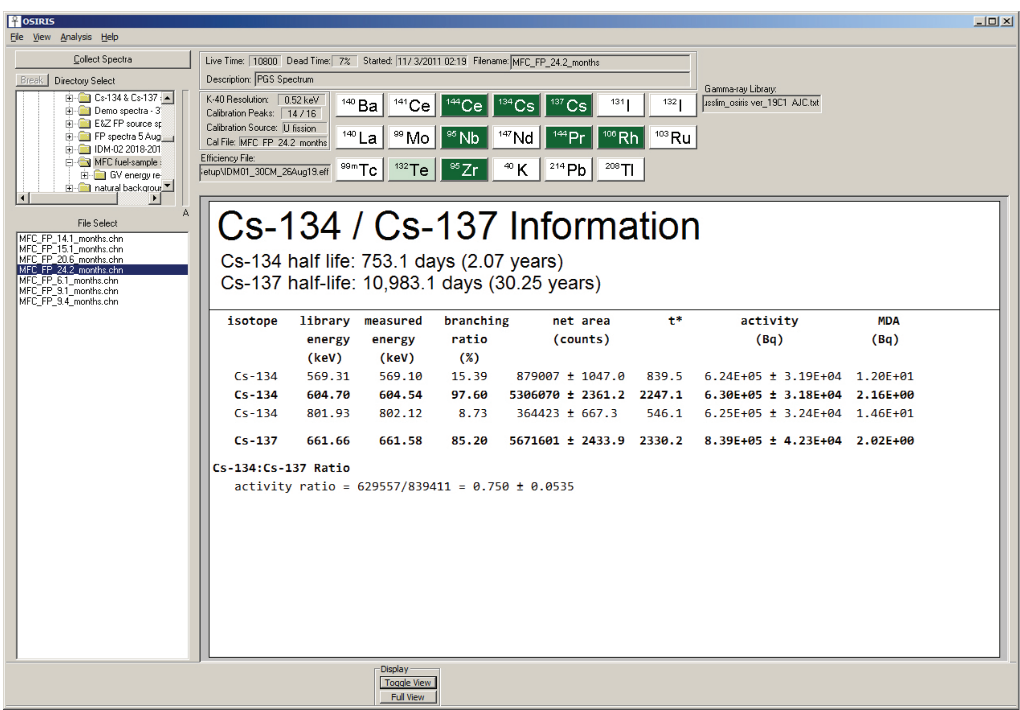

Figure 20: *Cs-134/Cs-137 information window for spectrum MFC_FP_24.2.chn.*

5.3.1.2 Encryption Key

- ❑ Copy the public encryption key that was created on the master computer to the control computer and place it in the spectrum directory just created.

5.3.1.3 Detection Efficiency File

- ❑ Choose the Set Efficiency File… item in the OSIRIS Analysis menu. A file-browser window opens.
- ❑ Select the 30-centimeter point-source efficiency file "IDM01_30CM.eff"

The selected efficiency file name appears to the right of the isotope buttons at the top of the display.

5.3.2 Spectrometer Data Connection

Connect the control computer to the spectrometer by USB cable.

5.3.3 System Startup

- ❑ Ensure the spectrometer power button is glowing a steady blue.

If not, wait until the power button stops flashing, indicating the spectrometer HPGe crystal has reached operating temperature.

- ❑ On the control computer click the OSIRIS icon shown in Figure 21. The main display screen appears.

Figure 21: *OSIRIS program lauanch icon.*

- ❑ Click the Collect Spectra button at the top-left of the OSIRIS display.
- ❑ Choose Startup Checklist from the Options menu. This two-page checklist is shown in Figure 22.
- ❑ A microcurie-strength Eu-152 source is used for the auto gain adjustment, and it should be placed on the detector centerline, about 30 cm (12 inches) from the black plastic end cap of the detector.
- ❑ Follow the Startup Checklist instructions.

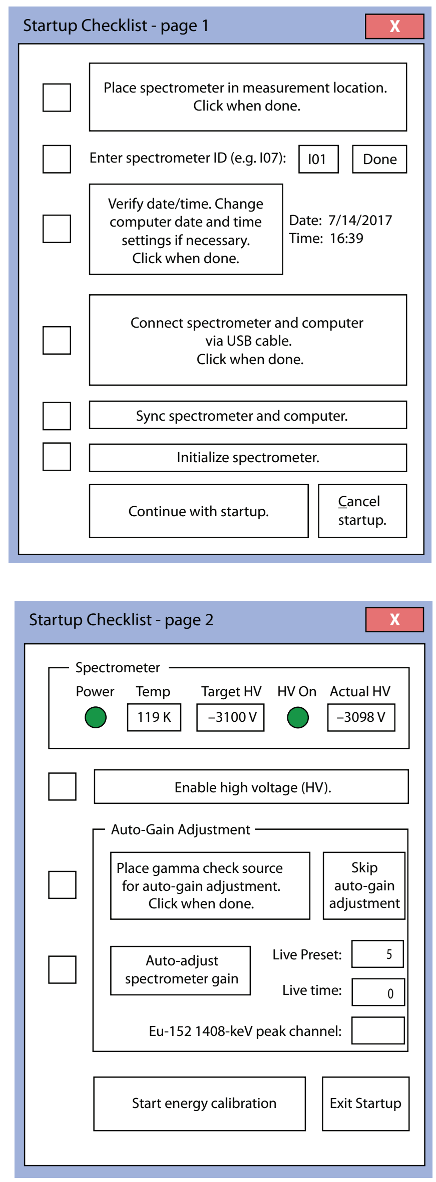

Figure 22: *Startup checklists.*

5.3.4 Energy Calibration

Keep the Eu-152 source on the detector centerline, and start the energy calibration per the instructions below. Check the dead time fraction when energy calibration begins. If it exceeds 10%, move the source away from the detector until it falls to below tht value.

- ❑ The Energy Calibration Checklist, shown in Figure 23, appears when the Startup Checklist has been completed. The same Eu-152 source is used for energy calibration.
- ❑ Enter "Eu-152" as the type of gamma-ray source.
- ❑ Preset the energy calibration live time to 300 seconds (five minutes).
- ❑ Click the Start Energy Calibration button. The Energy Calibration Checklist window will close.
- ❑ The Energy Calibration display window, displayed in Figure 24, opens, and the

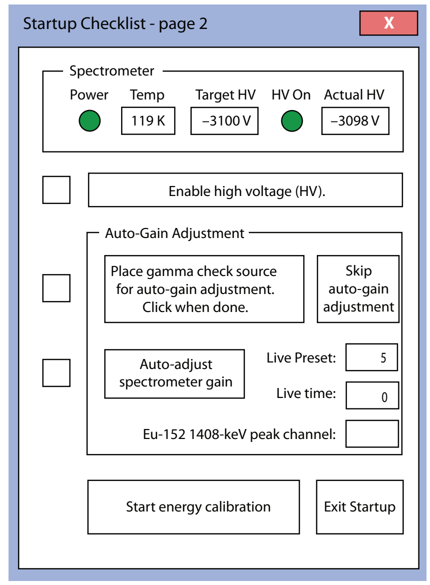

Figure 23: *Energy Calibration Checklist.*

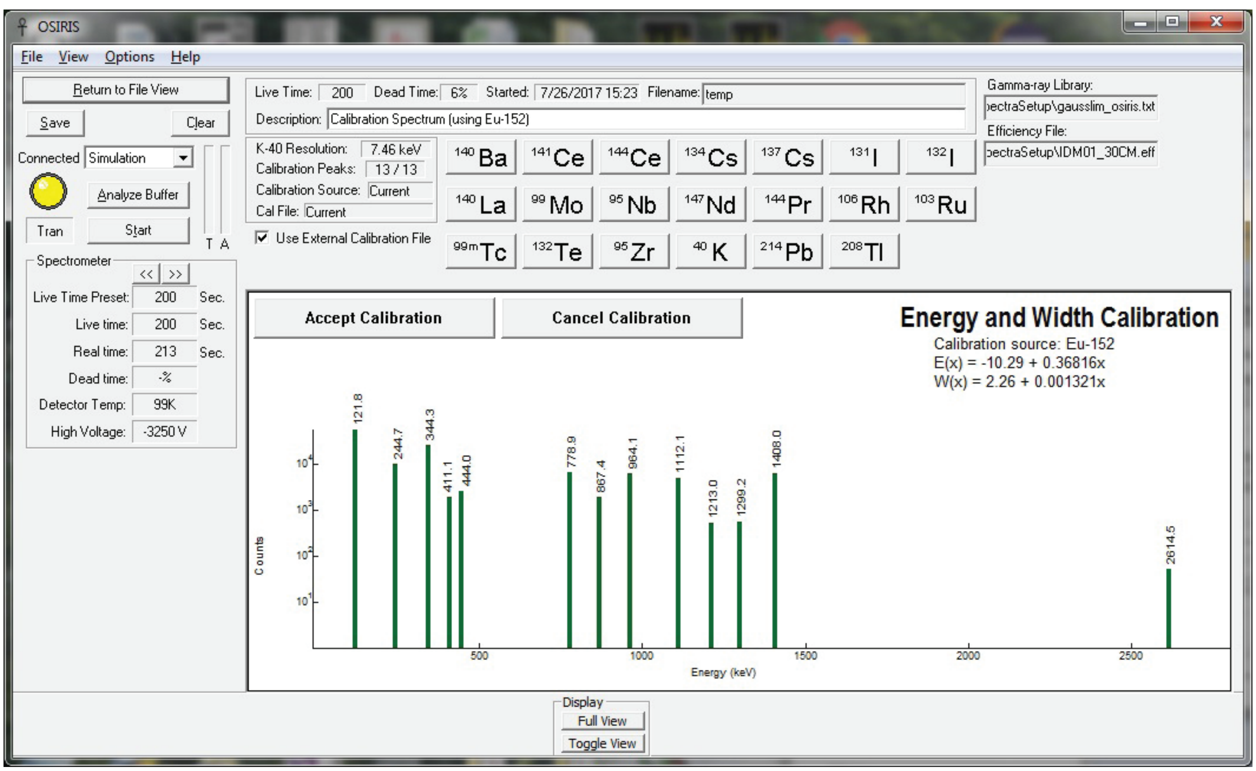

Figure 24: *Energy-calibration display window.*

spectrometer begins counting the calibration gamma-ray source. The spectrometer status light at the top left of the display will turn green, and the counting live time will increment.

- ❑ When the preset live time is reached, counting stops and the status light turns yellow.
- ❑ Using the Toggle View button at the bottom center of Energy Calibration display window, examine the least-square fit plot, shown in Figure 25.
- ❑ If the energy calibration appears correct, click the Accept Calibration button in the Energy Calibration display window.
- ❑ If the energy calibration appears to be incorrect, click the Cancel Calibration button in the Energy Calibration display window. Try again by clicking the Calibrate item in the Options menu. Choosing a longer counting interval will likely improve the calibration results. If possible, count long enough to acquire 1,000 counts or more in most of the energy calibration peaks.

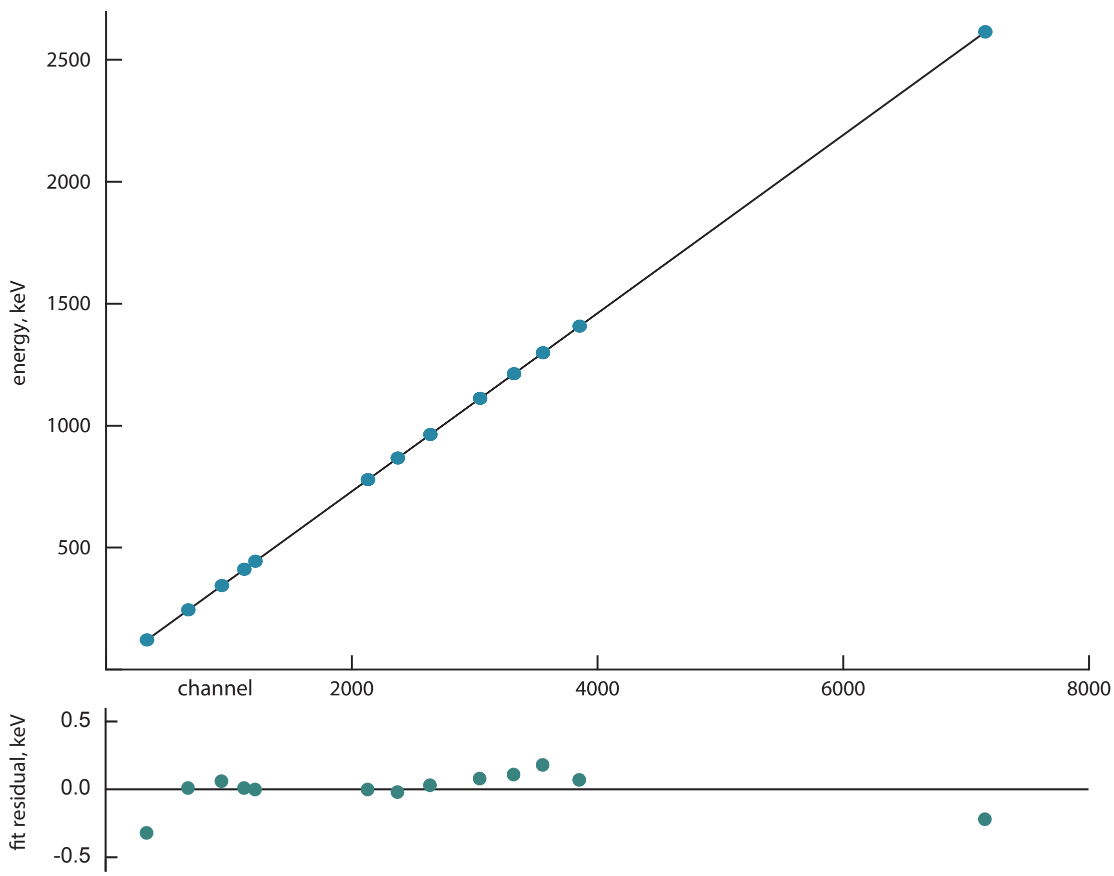

Figure 25: *Energy calibration least-squares fit plot.*

5.3.5 Spectral Measurement

- ❑ Place a radioactive point source containing one or more CTBT-relevant fission products on the detector centerline 30 cm (11.8 inches) from the front face of the black plastic detector end cap. As noted above, Cs-137 is a good choice.
- ❑ Check that the display is in Collect Spectra mode, not File View mode. If the yellow status light is not visible at the top left of the screen, click the Collect Spectra button immediately below the menu names. The file browser will disappear, replaced by the status light and the data acquisition controls.
- ❑ Preset the live time, by either or two methods:
- ❑ Choose the Spectrometer Properties… item from the Options menu. Then choose the Presets item of the submenu. Enter the desired live time in seconds and click the Close button.
- ❑ Click the left and right Double-Arrowhead buttons just below the Start/Stop button in the spectrometer controls increases or decreases the preset live time in 500-second increments.
- ❑ The preset livetime is displayed just below the Double-Arrowhead buttons.
- ❑ Clear the spectrometer memory by clicking the Clear button above and to the right of the status light.
- ❑ Click the Start button to begin the count. The status light color will change from yellow to green, and the live time display will now increment. Note that the Start button label toggles to Stop when counting begins.
- ❑ Data acquisition can be halted at any time by clicking the Stop button. Acquisition stops automatically when the live time reaches the preset live time, and the status light changes from green to yellow.
- ❑ The thermometer bar display indicates the number of counts in the strongest peak for each fission-product isotope.
- ❑ If possible, count the source until it produces 5,000 to 10,000 counts in one of the fission product peaks.

5.3.6 Fission-Product Identification

The thermometer bar display will indicate the fission products it has detected from the source and the source peak area per 1,000 live seconds. Detection confidence is indicated by green shading: the darker color indicates increased confidence. The thermometer-bar display for a Cs-137 source is shown in Figure 26.

By pushing the related button for an isotope, more detailed spectral information is provided in a window that replaces the thermometer bars. The thermometer bar view can be restored by clicking the Toggle View button at the bottom of the display.

- ❑ Click the Cs-137 button above the thermometer bars. Note the area and uncertainty of the 661.66-keV Cs-137 peak. The Cs-14/Cs-137 information box opens, as shown in Figure 27. Also note the Cs-134/Cs-137 ratio. This ratio will be zero when counting a Cs-137 source.

5.3.7 Saving a Spectral File

The Save commend writes an encrypted version of the spectrum to the control computer hard disk. The first time a spectrum is saved, the public encryption key must be identified. Encrypted spectral files have the extension ".ecn"

An open (non-encrypted) spectrum-analysis summary file with the extension ".PRanalysis", is also produced for each spectral measurement.

- ❑ Click the Save button immediately above the status light. The Save dialog window opens.
- ❑ Save dialog window will propose a name for the spectral file; the name can be either accepted or changed.

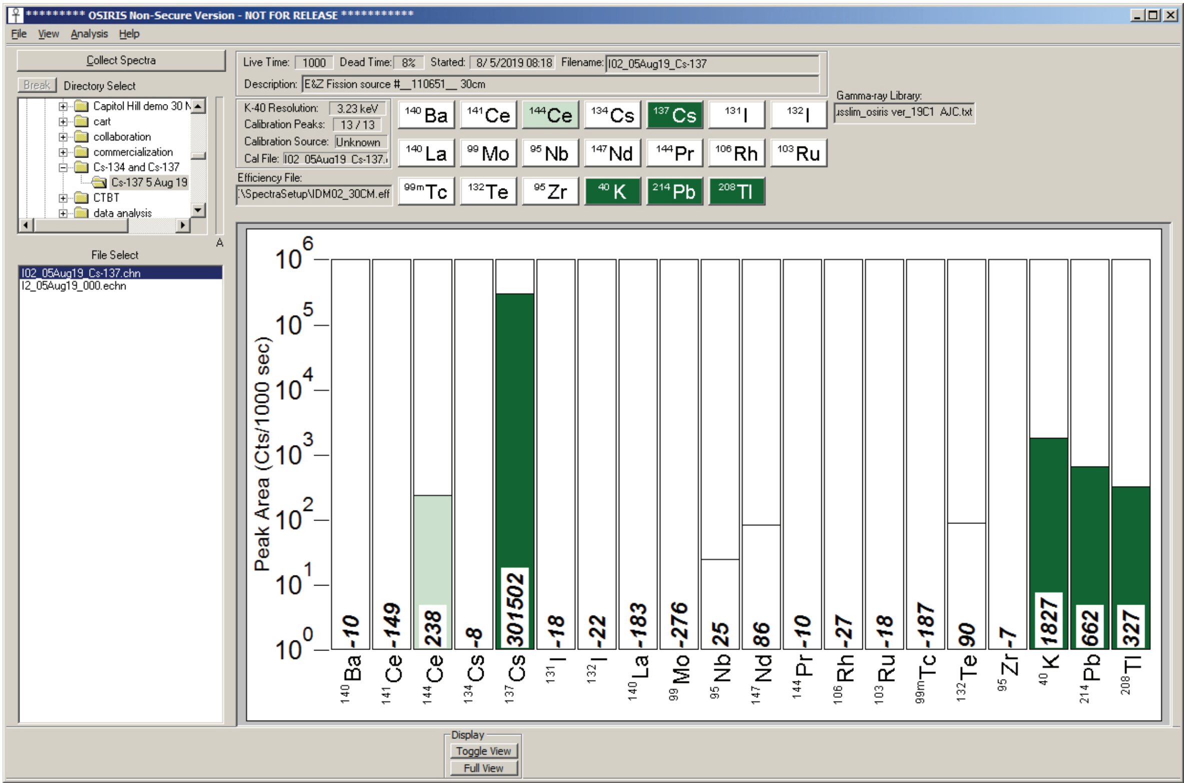

Figure 26: *OSIRIS thermometer-bar display for a Cs-137 source.*

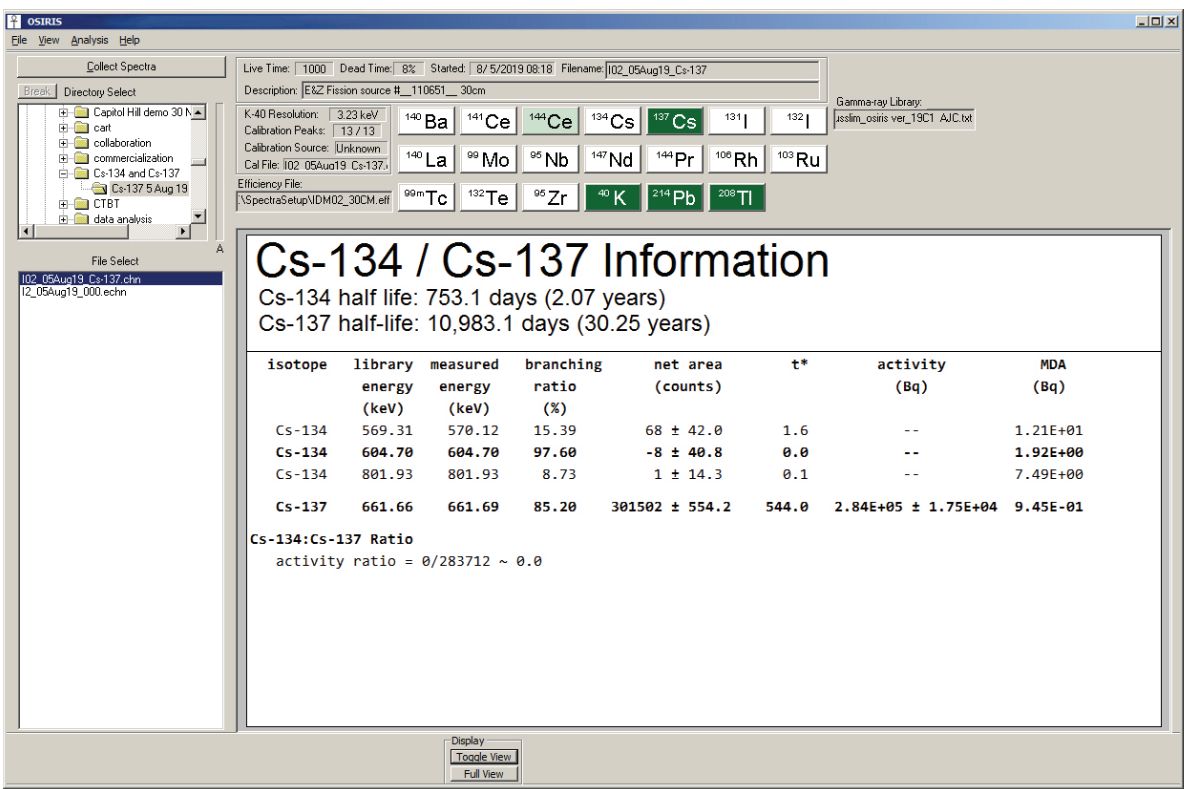

Figure 27: *Cs-137 information window.*

- ❑ A public key is needed to encrypt the file before saving it to disk. Click the Choose Public Key button to browse to the location of the public key loaded on the control computer in step 5.3.1.2 above.
- ❑ When spectral name and the public key have been chosen, click the OK button in the Save dialog window.
- ❑ Verify the encrypted spectral file appears in the directory chosen earlier in step 5.3.1.1.

5.3.8 System Shutdown

Just as at startup, a checklist prompts the user during system shutdown.

- ❑ Choose the Shutdown Checklist… item from the Options menu. The Shutdown Checklist, shown in Figure 28, will appear.

5.3.9 Decrypting a Spectral File.

- ❑ Copy the encrypted file you created plus the related hash file (*.hash) to a jump drive, and move them to the supervisory computer.
- ❑ Click the decryption program icon shown in Figure 29. The decryption window opens, as displayed in Figure 30.
- ❑ Browse to select the file to be decrypted and the private encryption key created earlier.
- ❑ Click the Decrypt button. The window below the button will display the name of the decrypted spectral file.

Figure 29: *OSIRIS decryption program icon.*

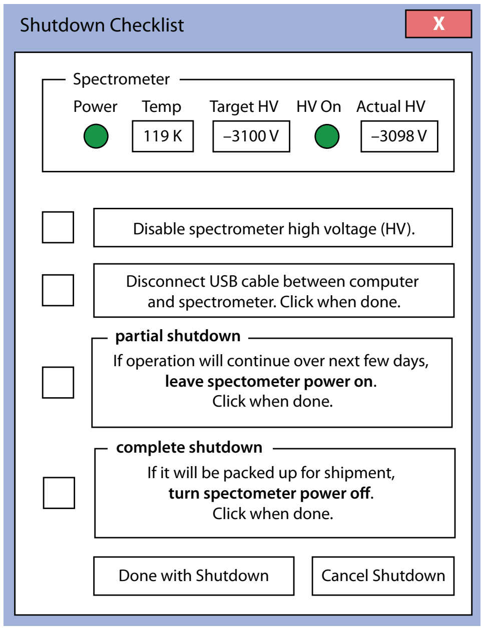

Figure 28: *Shutdown checklist.*

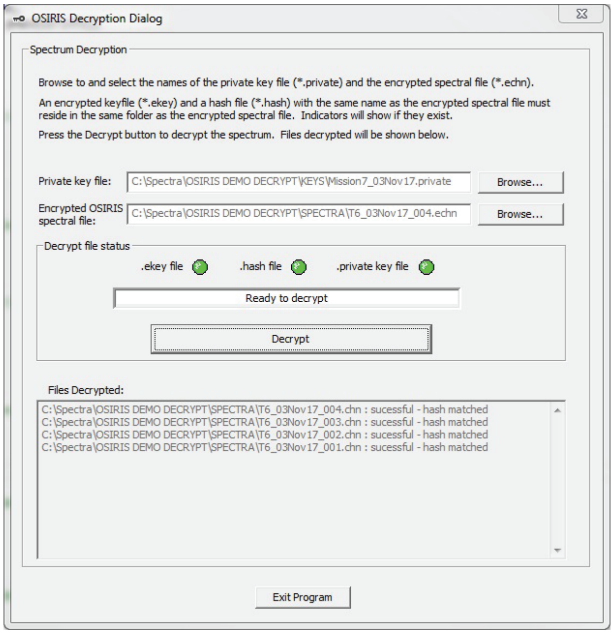

Figure 30: *OSIRIS Decryption window*

5.3.10 Viewing a Decrypted Spectral File

The decrypted file will have an extension of ".chn", and it can be viewed using standard spectral display programs like Maestro and GammaVision.

- ❑ Start GammaVision or Maestro on the supervisory computer.
- ❑ Recall the decrypted spectrum.
- ❑ The Cs-137 gamma-ray peak will be seen at 661.66 keV. Natural background peaks will also appear in the spectrum, including the 351.93-keV Pb-214 peak, 911.16-keV Ac-228 peak, the 1460.83-keV K-40 peak, and the 2614.53-keV Tl-208 peak. An example Cs-137 spectrum measured with an IDM spectrometer at INL is displayed in Figure 31.
- ❑ Verify the presence of the Cs-137 and K-40 gamma-ray peaks.
- ❑ Measure the net area of the Cs-137 peak, and compare it the net area provided by OSIRIS in step 5.3.6 above. The peak areas should agree within 10%.

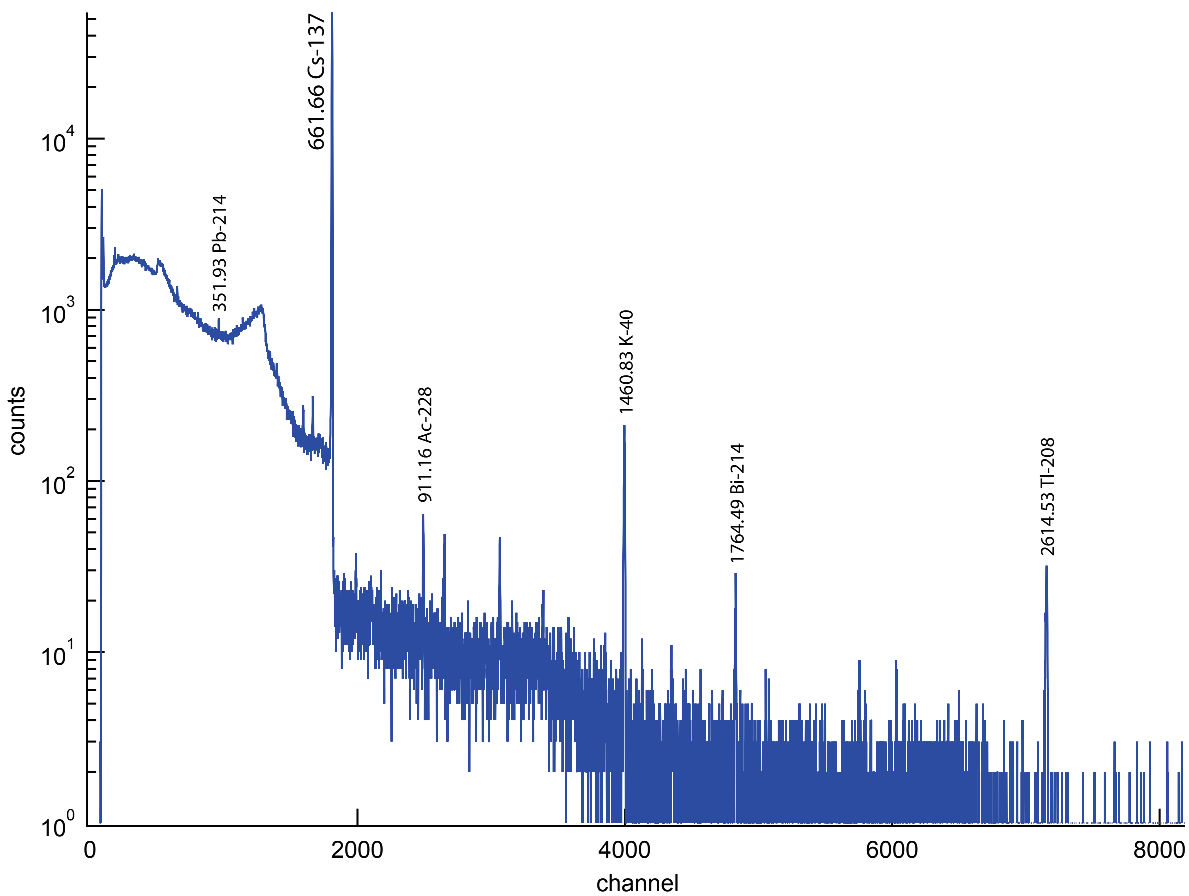

Figure 31: *Gamma-ray spectrum produced by a Cs-137 source.*

Appendix A: Comparison of OSIRIS and GammaVision Spectral Analyses

In 2014, INL compared OSIRIS automated analyses of a set of fission-product spectra with hand analyses performed using the INL GAUSS XI program for visual spectral analysis. In 2015, an OSIRIS project review committee chaired by Steve Schubert of Pacific Northwest National Laboratory (PNNL) suggested repeating the comparison using a commercial spectral analysis code like ORTEC's GammaVision. In 2019, ORTEC made the same request, as part of OSIRIS validation testing.

1. Comparison Spectra

One hundred gamma-ray spectra for testing OSIRIS were synthesized in 2013-14 at Lawrence Livermore National Laboratory (LLNL) and PNNL, using the MCNP and SYNTH codes. The treaty-compliant scenarios, for example reactor-accident and spent-fuel reprocessing, and treaty-non-compliant scenarios, e.g. nuclear explosions, used to create these spectra are described above in section 4.2.2.

The synthetic spectra each contain gamma-ray peaks from 0 to 15 fission products, and the most-common isotope is Cs-137. All 17 CTBT-relevant fission products appear in the synthetic spectra set. In addition, all of the spectra contain peaks from natural background gamma radiation. K-40 and Pb-214 peaks were present in every spectrum, and the 2614.53-keV Tl-208 peak was present in 47 of the spectra.

Interpretation of these spectra requires good energy calibrations prior to analysis for both OSIRIS and GammaVision, plus a peak-width calibration for OSIRIS, and alas, these calibrations were not provided by our LLNL and PNNL colleagues. Energy and width calibrations for these spectra were performed for OSIRIS testing in 2014, and saved in text files with the same name as the corresponding gamma-ray spectrum, with the extension ".calib". We were unable to copy the OSIRIS energy calibration equation into GammaVision.

2. Spectral Analysis Methods

The synthetic spectra were analyzed using GammaVision version 8.00.03 and OSIRIS version 1.7.8. Both codes used gamma-ray libraries listing the strongest peaks of the seventeen CTBT-relevant fission products, plus five common natural background radioisotopes: Ac-228, Bi-212, Bi-24, K-40, Pb-212, Pb-214, and Tl-208.

All spectra were analyzed in "automatic" mode; unlike GammaVision, OSIRIS does not have a manual spectral analysis mode. While GammaVision can perform energy calibrations automatically, this feature did not always work correctly on low-statistics spectra. Hence, a manual GammaVision energy calibration was performed for every spectrum. The GammaVision and OSIRIS energy calibrations agreed well, to a fraction of a keV in most instances. The detection threshold for both codes was set to 3-sigma above background. For OSIRIS, the significance level is indicated by the t* variable listed at the right of other OSIRIS information.

Spectrum 23, a simulation of a Chernobyl-like nuclear reactor accident, is shown in Figure A-1, and it will be used as an example in this section.

The OSIRIS analysis results for spectrum 23 are shown in Table A-1. Note that OSIRIS only reports information on the 17 CTBT-relevant fission products, plus a few common natural background isotopes. OSIRIS always reports analysis information for all 17 fission products, even if no peaks were detected at a significant level.

The corresponding GammaVision analysis of spectrum 23 is shown in Table A-2. GammaVision only reports gamma-ray peaks that have exceeded a pre-set significance level.

The OSIRIS analysis results are reported in a text file with the extension ".PRanalysis".

GammaVision spectral analyses are presented in text files with the extension ".rpt"

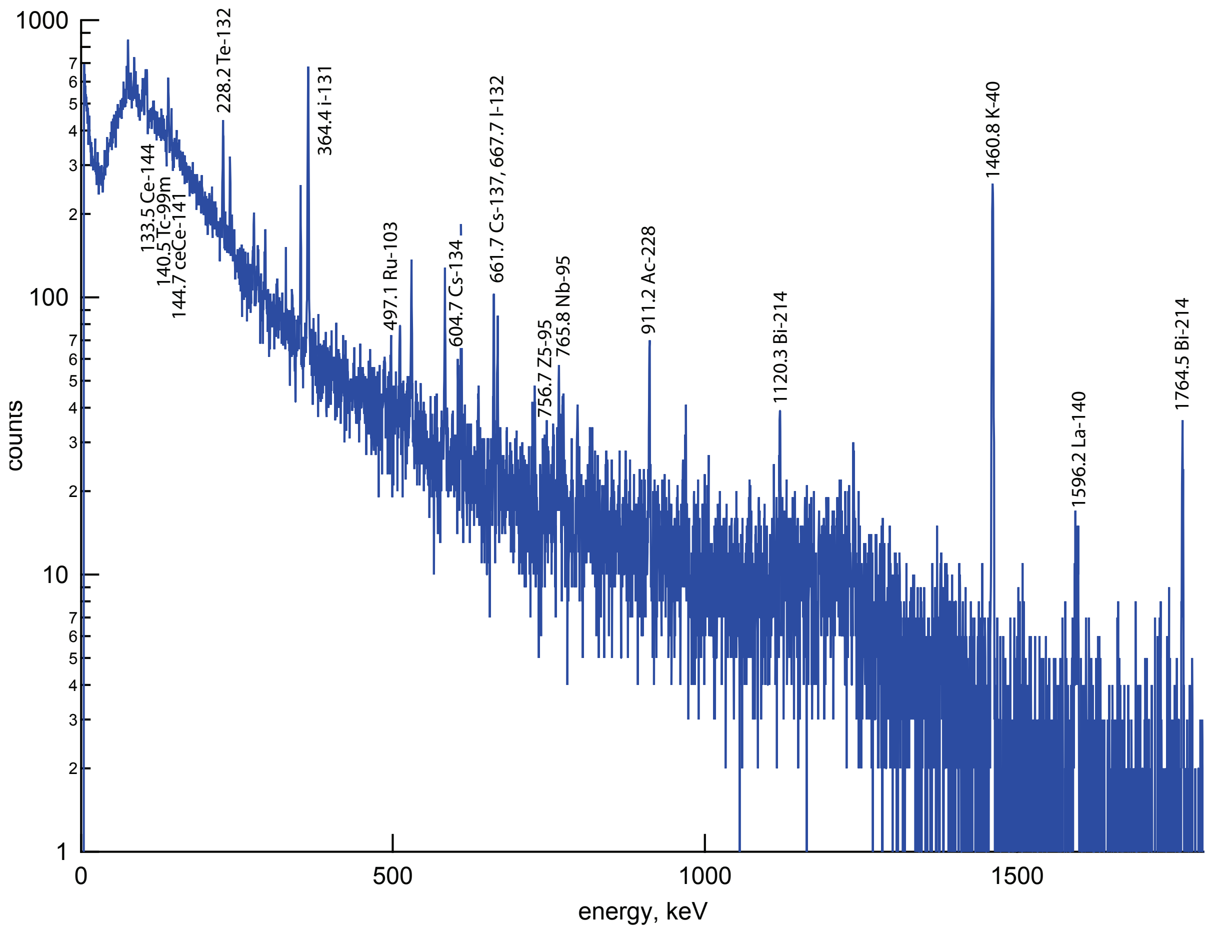

Figure A-1: *Spectrum 23, synthesized from a nuclear-reactor accident scenario*

Table A-1 OSIRIS spectrum analysis report for spectrum 23

Isotope	Detected?	Library Egamma (keV)	Branching Ratio (%)	Net Area (counts)	t*
Ba-140	Yes	162.66	6.2	-61.1 ± 50.1	0.0
Ba-140	Yes	304.85	4.3	10.7 ± 25.5	0.4
Ba-140	Yes	537.20	24.4	70.2 ± 18.5	3.8
Ce-141	Yes	145.77	48.2	412.3 ± 58.2	7.1
Ce-144	Yes	133.51	11.0	175.2 ± 53.4	3.3
Cs-134	Yes	569.52	15.4	13.2 ± 14.5	0.9
Cs-134	Yes	604.98	97.6	175.4 ± 19.9	8.8
Cs-134	Yes	801.93	8.7	18.8 ± 13.6	1.4
Cs-137	Yes	661.93	85.2	333.6 ± 26.7	12.5
I-131	Yes	284.40	6.1	152.2 ± 35.4	4.3
I-131	Yes	364.64	81.6	2698.8 ± 58.4	46.2
I-131	Yes	636.04	7.2	57.4 ± 18.5	3.1
I-132	Yes	522.55	16.1	18.0 ± 18.5	1.0
I-132	Yes	667.97	98.7	227.8 ± 22.0	10.4
I-132	Yes	772.56	76.2	152.6 ± 17.1	8.9
I-132	Yes	954.62	18.1	16.1 ± 13.0	1.2
La-140	Yes	329.00	20.7	183.5 ± 30.7	6.0
La-140	Yes	487.25	45.9	98.2 ± 20.1	4.9
La-140	Yes	815.95	23.6	52.9 ± 13.9	3.80
La-140	Yes	1597.15	95.4	70.2 ± 10.2	6.9
Mo-99	No	180.34	6.1	19.4 ± 43.8	0.4
Mo-99	No	740.68	12.1	43.5 ± 16.8	2.6
Nb-95	Yes	766.11	99.8	162.6 ± 18.4	8.8
Nd-147	No	319.41	2.0	64.7 ± 26.0	2.5
Nd-147	No	531.02	13.1	11.5 ± 25.8	0.4
Pr-144	No	696.51	1.3	20.8 ± 14.9	1.41
Rh-106	No	621.80	10.0	29.1 ± 22.5	1.3
Rh-106	No	1051.26	1.5	8.5 ± 9.9	0.9
Ru-103	Yes	497.31	91.0	167.4 ± 21.3	7.9
Tc-99m	Yes	140.77	89.0	940.5 ± 64.9	14.5
Te-132	Yes	228.92	88.2	851.2 ± 47.1	18.1
Zr-95	Yes	724.55	44.2	84.5 ± 15.5	5.5
Zr-95	Yes	757.31	54.4	73.5 ± 15.3	4.8
K-40	Yes	949.83	15.0	0.6 ± 11.8	0.1
K-40	Yes	1460.90	10.7	1576.6 ± 40.3	39.1
Pb-214	Yes	241.98	18.5	128.1 ± 42.1	3.0
Pb-214	Yes	295.91	18.2	313.9 ± 35.3	8.9
Pb-214	Yes	352.59	35.8	591.8 ± 34.7	17.1
Tl-208	No	1593.37	8.2	35.9 ± 8.9	4.0
Tl-208	No	2103.53	13.9	0.0 ± 1.1	0
Tl-208	No	2614.53	99.8	0.0 ± 1.2	0

Table A-2 GammaVision analysis report for spectrum 23

Nuclide	Peak Centroid (channel)	Peak Energy (keV)	Background (counts)	Net Area (counts)	Intensity (counts/sec)	Uncert. (%)	FWHM (keV)
TC-99M	385.42	140.51	4709.	1077.	0.299	9.51	1.452D
CE-141	398.86	145.44	4407.	503.	0.139	19.20	1.450D
TE-132	623.87	227.95	2526.	1223.	0.339	7.10	1.600
Pb-212	654.17	239.06	1748.	481.	0.133	13.39	1.106
Pb-214	807.89	295.42	1449.	357.	0.099	17.67	1.978s
Pb-214	962.85	352.23	1075.	594.	0.165	9.80	1.109
J-131	995.93	364.36	1388.	2900.	0.804	2.93	1.572s
RU-103	1357.17	496.78	473.	160.	0.044	22.52	1.614
CS-134	1651.57	604.69	266.	169.	0.047	15.71	1.418D
Bi-214	1664.17	609.31	295.	633.	0.175	5.52	1.419D
J-131	1738.73	636.63	308.	125.	0.035	23.52	2.701s
CS-137	1807.01	661.66	276.	322.	0.089	9.18	1.428D
J-132	1822.40	667.30	286.	208.	0.058	13.41	1.429D
Bi-212	1986.23	727.34	197.	84.	0.023	26.52	1.130
J-132	2109.95	772.68	254.	134.	0.037	18.89	1.457D
Bi-214	3058.34	1120.16	169.	167.	0.046	15.17	2.141s
K-40	3988.03	1460.66	81.	1645.	0.456	2.68	2.101s
Bi-214	4817.87	1764.49	11.	190.	0.053	7.87	2.062

3. Analysis Comparison Methods

For each spectrum, the OSIRIS analysis data were copied into a Microsoft Excel spreadsheet in alphabetical isotopic order. GammaVision lists detected gamma-ray peaks in increasing energy order, not alphabetically by isotope name. The GammaVision data for a given spectrum were copied into the spreadsheet next to the OSIRIS information, placed in alphabetical order by isotope using the Excel Sort function, and matched by peak energy to the OSIRIS data.

If both codes detected a given fission product, the ratio of the net areas of its strongest peak were then calculated, as shown for spectrum 23 in the right-most column of Table A-3.

The natural background results were entered in another spreadsheet location, as shown in Table A-4, and for the thirteen spectra where no fission products were detected, the natural background peaks provide the only basis for comparison. Peak area ratios were also calculated for the natural background peaks of K-40, Pb-214, and/or Tl-208, when those isotopes were detected by both codes.

Table A-3: Fission-product analysis comparison for spectrum 23

			OSIRIS (0)				
Isotope	Detected ?	Library Energy	Measured Energy (keV)	branch (%)	Area (counts)	Uncert. (counts)	t*
Ba-140	No	162.66	162.66	6.2	-61.1	50.1	0
Ba-140	No	304.85	304.85	4.3	10.7	25.5	0.4
Ba-140	Yes	**537.26**	537.2	24.4	70.2	18.5	3.8
Ce-141	Yes	**144.75**	145.77	48.2	412.3	58.2	7.1
Ce-144	Yes	**133.51**	133.51	11	175.2	53.4	3.3
Cs-134	No	570.25	569.52	15.4	13.2	14.5	0.9
Cs-134	Yes	**604.69**	604.98	97.6	175.4	19.9	8.8
Cs-134	No	801.93	801.93	8.7	18.8	13.6	1.4
Cs-137	Yes	**661.66**	661.93	85.2	333.6	26.7	12.5
I-131	Yes	284.31	284.4	6.1	152.2	35.4	4.3
I-131	Yes	**364.49**	364.64	81.6	2698.8	58.4	46.2
I-131	Yes	636.99	636.04	7.2	57.4	18.5	3.1
I-132	No	522.68	522.55	16.1	18	18.5	1
I-132	Yes	667.72	667.97	98.7	227.8	22	10.4
I-132	No	772.68	772.56	76.2	152.6	17.1	8.9
I-132	No	954.62	954.62	18.1	16.1	13	1.2
La-140	Yes	328.76	329	20.7	183.5	30.7	6
La-140	Yes	**487.02**	487.25	45.9	98.2	20.1	4.9
La-140	Yes	815.77	815.95	23.6	52.9	13.9	3.8
La-140	Yes	1598.03	1597.15	95.4	70.2	10.2	6.9
Mo-99	No	**181.06**	180.34	6.1	19.4	43.8	0.4
Mo-99	No	738.75	740.68	12.1	43.5	16.8	2.6
Nb-95	Yes	**765.81**	766.11	99.8	162.6	18.4	8.8
Nd-147	No	319.41	319.41	2	64.7	26	2.5
Nd-147	No	**531.02**	531.02	13.1	11.5	25.8	0.4
Pr-144	No	**696.51**	696.51	1.3	20.8	14.9	1.4
Rh-106	No	**621.8**	621.8	10	29.1	22.5	1.3
Rh-106	No	1050.39	1051.26	1.5	8.5	9.9	0.9
Ru-103	Yes	**497.08**	497.31	91	167.4	21.3	7.9
Tc-99m	Yes	**140.51**	140.77	89	940.5	64.9	14.5
Te-132	Yes	**228.16**	228.92	88.2	851.2	47.1	18.1
Zr-95	Yes	724.2	724.55	44.2	84.5	15.5	5.5
Zr-95	Yes	**756.73**	757.31	54.4	73.5	15.3	4.8
CTBT fission products	**17**						
OSIRIS detected	**13**						

Table A-3: Fission-product analysis comparison for spectrum 23

GammaVision (GV)								O/GV
Nuclide	Peak Centroid (channels)	Measured Energy (keV)	Background (counts)	Net Area (counts)	Intensity (counts/sec)	Uncert. (%)	FWHM (keV)	peak area ratio
CE-141	398.86	145.44	4407.00	503.00	0.14	19.20	1.450D	0.820
CS-134	1651.57	604.69	266.00	169.00	0.05	15.71	1.418D	1.038
CS-137	1807.01	661.66	276.00	322.00	0.09	9.18	1.428D	1.036
I-131	995.93	364.36	1388.00	2900.00	0.80	2.93	1.572s	0.931
I-131	1738.73	636.63	308.00	125.00	0.04	23.52	2.701s	
I-132	1822.40	667.30	286.00	208.00	0.06	13.41	1.429D	1.095
I-132	2109.95	772.68	254.00	134.00	0.04	18.89	1.457D	
RU-103	1357.17	496.78	473.00	160.00	0.04	22.52	1.61	1.046
TC-99M	385.42	140.51	4709.00	1077.00	0.30	9.51	1.452D	0.873
TE-132	623.87	227.95	2526.00	1223.00	0.34	7.10	1.60	0.696
CTBT fission products 17							**mean**	**0.942**
GammaVision detected 8							**std. dev.**	**0.138**

Table A-4: Natural background isotopic analysis comparison for spectrum 23.

Osiris (0)							
Isotope	Detected ?	Library Energy (keV)	Measured Energy (keV)	Branch (%)	Area (counts)	Uncert. (counts)	t*
K-40	Yes	1460.83	1460.9	10.7	1576.6	40.3	39.1
Pb-214	Yes	295.21	295.91	18.2	313.9	35.3	8.9
Pb-214	Yes	351.93	352.59	35.8	591.8	34.7	17.1
Tl-208	No	2614.53	2614.53	99.8	0	1.20	0.0

Table A-4: Natural background isotopic analysis comparison for spectrum 23.

GammaVision (GV)								O/GV
Nuclide	Peak Centroid (channel)	Measured Energy (keV)	Background (counts)	Net Area (counts)	Intensity (counts/sec)	Uncert. (%)	FWHM (keV)	peak area ratio
Bi-212	1986.23	727.34	197.00	84.00	0.02	26.52	1.13	
Bi-214	1664.17	609.31	295.00	633.00	0.18	5.52	1.419D	
Bi-214	3058.34	1120.16	169.00	167.00	0.05	15.17	2.141s	
Bi-214	4817.87	1764.49	11.00	190.00	0.05	7.87	2.06	
K-40	3988.03	1460.66	81.00	1645.00	0.46	2.68	2.101s	0.958
Pb-212	654.17	239.06	1748.00	481.00	0.13	13.39	1.11	
Pb-214	807.89	295.42	1449.00	357.00	0.10	17.67	1.978s	
Pb-214	962.85	352.23	1075.00	594.00	0.17	9.80	1.11	0.996
							mean	**0.977**
							std. dev.	**0.027**

Table A-5: GammaVision and OSIRIS spectral analysis comparisons

spectrum	Fission Products Detected OSIRIS	Fission Products Detected GV	Detected Fission Products	Mean Peak Ratio (O/GV)	Area Ratio Uncert.
			Bold type *indicates an isotope detected by OSIRIS, but not detected by GammaVision.* *Underlined isotopes were detected by GammaVision, but not by OSIRIS.*		
1	0	0	None		
2	1	1	Cs-137	0.950	
3	10	8	**Ba-140**, Cs-134. Cs-137, I-131, I-132, **La-140, Nb-95**, Tc-99m, Te-132, **Zr-95**	0.976	0.105
4	1	1	Cs-137	0.888	
5	7	2	**Ce-144**, Cs-137, I-131, **I-132, La-140, Tc-99m, Te-132**	0.840	0.151
6	0	0	None		
7	0	0	None		
8	2	1	Cs-137, **Nd-147**	0.907	
9	3	3	Cs-134, Cs-137, Zr-95	0.796	0.094
10	0	0	None		
11	1	1	Cs-137	0.815	
12	14	14	Ba-140, Ce-141, Ce-144, Cs-134. Cs-137, I-131, I-132, La-140, Nb-95, Nd-147, Ru-103, Pr-144, Tc-99m, Te-132, Zr-95	0.979	0.102
13	0	0	None		
14	3	2	Cs-137, I-131, **Rh-106**	1.062	0.930
15	5	0	**Cs-137, I-131, La-140, Tc-99m, Te-132**		
16	5	0	None		
17	1	0	La-140		
18	5	5	Cs-134, Cs-137, I-131, I-132, Te-132	1.025	0.087
19	5	3	Cs-134, Cs-137, I-131, I-132, Te-132	1.093	0.262
20	1	1	Cs-137	0.902	
21	1	1	Cs-137	0.996	
22	0	0	None	1.070	
23	13	8	**Ba-140**, Ce-141, **Ce-144**, Cs-134. Cs-137, I-131, I-132, **La-140, Nb-95, Nd-147**, Ru-103, Tc-99m, Te-132	0.936	0.110
24	4	3	Cs-137, I-131, i-132, **La-140**	1.038	0.056
25	8	8	Cs-134, Cs-137, I-131, I-132, La-140, Pr-144, Rh-106, Te-132	1.020	0.056
26	7	6	Cs-134, Cs-137, I-131, I-132, La-140, **Pr-144**, Te-132	0.884	0.181
27	6	5	Cs-134, Cs-137, I-131, I-132, **La-140**, Te-132	0.972	0.071
28	4	3	Cs-134, Cs-137, **Te-132**, Zr-95	0.859	0.127
29	0	0	None		
30	8	8	Ce-141, Ce-144, Cs-137, Nb-95, Pr-144, Rh-106, Ru-103, Zr-95	1.036	0.050
31	1	1	Cs-137	1.001	
32	1	1	Cs-137	1.075	
33	3	3	Cs-134, Cs-137, Zr-95	0.943	0.198
34	6	3	**Ce-144**, Cs-134, **Cs-137**, Nb-95, **Ru-103**, Zr-95	0.991	0.054

Table A-5: GammaVision and OSIRIS spectral analysis comparisons

spectrum	Fission Products Detected		Detected Fission Products	Mean Peak Area Ratio	
	OSIRIS	GV		Ratio (O/GV)	Uncert.
35	14	12	Ba-140, Ce-141, **Ce-144**, Cs-134. Cs-137, I-131, I-132, La-140, **Mo-99**, Nb-95, **Nd-147**, Ru-103, Tc-99m, Te-132, Zr-95	0.961	0.100
36	1	2	Nb-95, Zr-95	0.984	
37	0	0	None		
38	6	2	**Ce-141, I-131**, La-140, **Nb-95**, Rh-106, Ru-103, **Zr-95**	0.986	0.045
39	13	13	Ba-140, Ce-141, Cs-134. Cs-137, I-131, I-132, La-140, Mo-99, Nb-95, Nd-147, Ru-103, Tc-99m, Te-132, Zr-95	0.992	0.110
40	3	3	Ce-144, Nb-95, Zr-95	0.817	0.373
41	5	4	Cs-134, Cs-137, Nb-95, **Rh-106**, Zr-95	0.979	0.181
42	7	6	Ba-140, Cs-137, I-131, I-132, La-140, **Nb-95**, Rh-106, Ru-103, Zr-95	1.009	0.025
43	1	1	Nb-95	1.191	
44	2	0	**Ce-144, Nb-95**		
45	1	1	Cs-137	0.869	
46	1	1	I-131	1.050	
47	1	1	Cs-137	0.993	
48	4	4	Cs-134, Cs-137, Nb-95, Zr-95	0.902	0.044
49	0	0	None		
50	1	0	**Cs-137**		
51	1	1	Cs-137	0.987	
52	5	3	**Cs-134**, Cs-137, I-131, **Mo-99**, Rh-106	0.984	0.190
53	2	2	Cs-137, I-131	1.025	0.110
54	1	1	Cs-137	0.771	
55	10	8	Ba-140, Ce-141, I-131, I-132, La-140, Nb-95, **Pr-144**, Ru-103, **Te-132**, Zr-95	1.005	0.047
56	1	1	I-131	0.858	
57	10	7	Cs-134, Cs-137, I-131, I-132, **La-140, Nb-95**, Pr-144, Rh-106, **Tc-99m**, Te-132	1.050	0.178
58	0	0	None		
59	6	6	Cs-137, I-131, I-132, La-140, Rh-106, Ru-103	1.005	0.053
60	13	12	Ba-140, Ce-141, Ce-144, I-131, I-132, La-140, Nb-95, Nd-147, **Pr-144**, Ru-103, Tc-99m, Te-132, Zr-95	0.995	0.096
61	0	0	None		
62	3	1	Cs-137	0.836	
63	8	8	Ce-141, Ce-144, Cs-137, Nb-95, Pr-144, Rh-106, Ru-103, Zr-95	1.046	0.147
64	3	3	Cs-137, Nb-95, Zr-95	0.971	0.138
65	1	1	Cs-137	1.001	
66	1	1	Cs-137	0.978	
67	2	1	Cs-137, **Ru-103**	0.984	
68	9	5	**Ce-141**, Cs-134, Cs-137, I-131, **I-132, La-140, Ru-103**, Tc-99m, Te-132	0.892	0.167
69	1	1	Cs-137	0.915	

Table A-5: GammaVision and OSIRIS spectral analysis comparisons

spectrum	Fission Products Detected		Detected Fission Products	Mean Peak Ratio	Area Ratio Uncert.
	OSIRIS	GV		(O/GV)	
70	0	0	None		
71	2	1	Cs-137, **La-140**	0.859	
72	3	3	Cs-137, I-131, I-132	0.991	0.017
73	6	5	Cs-134, Cs-137, I-131, I-132, **Tc-99m**, Te-132	0.975	0.051
74	8	8	Ce-141, Ce-144, Cs-137, Nb-95, Pr-144, Rh-106, Ru-103, Zr-95	1.034	0.102
75	2	0	**I-131, Te-132**		
76	3	3	Cs-137, I-131, I-132	0.956	0.044
77	1	1	Cs-137	0.995	
78	0	0			
79	0	0			
80	9	8	Ce-141, Ce-144, Cs-137, Nb-95, **Nd-147**, Pr-144, Rh-106, Ru-103, Zr-95	1.000	0.015
81	1	0	Cs-137		
82	6	5	Ce-144, Cs-137, Nb-95, Pr-144, Rh-106, **Ru-103**, Zr-95	1.034	0.112
83	15	14	Ba-140, Ce-141, Ce-144, Cs-134. Cs-137, I-131, I-132, La-140, Mo-99, Nb-95, **Pr-144**, Ru-103, Tc-99m, Te-132, Zr-95	0.983	0.068
84	5	6	Cs-137, Nb-95, Nd-147, <u>Rh-106</u>, Ru-103, Zr-95	1.006	0.056
85	0	0	None		
86	2	1	Cs-134, Cs-137	0.908	
87	5	5	Cs-134, Cs-137. Nb-95, Ru-103, Zr-95	0.914	0.227
88	8	7	Ba-140, Ce-141, I-131, La-140, Nb-95, **Nd-147**, Ru-103, Zr-95	0.997	0.089
89	3	3	Cs-134, Cs-137, Zr-95	1.002	0.086
90	1	0	Nb-95		
91	12	11	**Ba-140**, Ce-141, Cs-134, Cs-137, I-131, I-132, La-140, Nb-95, Nd-147, **Pr-144**, Ru-103, Tc-99m, Te-132, Zr-95	0.989	0.069
92	2	2	Cs-134, Cs-137	1.065	0.090
93	5	5	Cs-134, Cs-137, I-131, I-132, Te-132	0.991	0.128
94	1	1	Cs-137	0.998	
95	15	15	Ba-140, Ce-141, Ce-144, Cs-137, I-131, I-132, La-140, Mo-99, Nb-95, Nd-147, Pr-144, Ru-103, Tc-99m, Te-132, Zr-95	0.964	0.097
96	6	1	**Ce-144, Cs-137, I-131, I-132**, Te-132	0.791	
97	7	5	**Ce-144**, Cs-134, Cs-137, Nb-95, **Pr-144**, <u>Rh-106</u>, **Ru-103**, Zr-95	1.023	0.069
98	2	1	**Cs-134**, Cs-137	1.011	
99	2	2	Cs-137, I-131	1.024	0.315
100	0	0	None		
			mean	**0.969**	
			std. dev.	0.077	

4. Comparison Results

The comparison results for all 100 spectra are summarized in Table A-5. Of particular note are the detection of fission-product isotopes and the evaluation of their gamma-ray peaks.

Fission Products Detected

Gamma rays from a total of 394 fission-product isotope are evident in the synthetic spectra set. The individual fission products detected are listed for each spectrum in Table A-5 above. If an isotope was detected by OSIRIS but not by GammaVision, it is listed in bold type. If an isotope was missed by OSIRIS but detected by GammaVision, that is indicated by underlining the isotope name.

OSIRIS and GammaVision detected the same number of fission-product isotopes in 57 of the test spectra. In 12 spectra, OSIRIS identified one more isotope than GammaVision; two more in 10 spectra; three more in 9 spectra; 4 more in two spectra; and 5 more in five spectra. OSIRIS missed one isotope detected by GammaVision in five spectra, and in three of those five cases, the isotope missed by OSIRIS was Rh-106.

Fission Product Peak Areas

The mean net peak areas for fission products identified by both codes are listed for each spectrum in Table A-5. The mean over this set of spectra is 0.969 ± 0.077.

Natural Background Isotopes Detected

The natural background isotopes K-40 and Pb-214 were identified by OSIRIS in all 100 spectra. GammaVision missed the 351.9-keV Pb-214 peak in four of the spectra. The 2614.5-keV Tl-208 peak is present in 48, or about half of the spectra. When the Tl-208 peak was present, both codes detected it.

Natural Background Peak Areas

When detected by both codes, peak area ratios were calculated for the natural background isotopes K-40, Pb-214, and Tl-208. For the entire set of synthetic spectra, the mean natural background peak area ratio is 0.991.

5. Conclusions

OSIRIS and GammaVision both reliably detect CTBT-relevant fission-product gamma peaks, with OSIRIS holding a slight sensitivity advantage. In 57 of the spectra, both codes detected the same number of fission products. OSIRIS detected one more fission product than GammaVision in eleven spectra, two more fission products in another eleven spectra, and three to five more in nine other spectra. GammaVision detected a fission-product isotope that OSIRIS did not in six spectra.

For the fission-product isotopes detected by both codes, the OSIRIS to GammaVision net peak-area ratio mean is 0.969 ± 0.077. For natural background isotopes, the ratio mean is 0.991 ± 0.046. In short, the peak areas extracted by both codes are in excellent agreement.

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ORTEC is an instrument company that "thinks different," as the first author learned in graduate school. When he and his professor were having difficulty with the ORTEC 934 constant-fraction discriminator, ORTEC flew the electrical engineer who designed it, T.J. Paulus, to Baltimore to teach us how to adjust it for best performance.

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   "89. Pursuant to Article IV, paragraph 57 (b) and paragraph 88 (a) above, the inspected State Party shall have the right throughout the inspection area to take measures to protect sensitive installations and locations and to prevent disclosure of confidential information not related to the purpose of the inspection. Such measures may include, inter alia: (a) Shrouding of sensitive displays, stores, and equipment; (b) Restricting measurements of radionuclide activity and nuclear radiation to determining the presence or absence of those types and energies of radiation relevant to the purpose of the inspection; …"

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   "A set of interrelated or interacting activities that result in the development or assessment of system, software, or hardware products. Each activity consists of tasks. The life cycle processes may overlap one another. For verification and validation (V&V) purposes, no life cycle process is concluded until its development products are verified and validated according to the defined tasks in the verification and validation plan (VVP)."

   Validation

   "(A) The process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements."

   Verification

   "(B) The process of providing objective evidence that the system, software, or hardware and its associated products conform to requirements (e.g., for correctness, completeness, consistency, and accuracy) for all life cycle activities…"

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