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System Tests of OSIRIS

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A spectrum-blind gamma-ray spectrometer for on-site inspections under the Comprehensive Nuclear-Test-Ban Treaty

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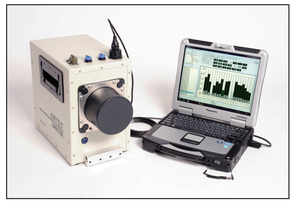

Figure A: *The OSIRIS HPGe gamma-ray spectrometer and control computer.*

Figure B: *Winter OSIRIS testing at Idaho National Laboratory.*

Figure C: *Field test of OSIRIS at the Nevada National Security Site. Note the red/yellow fission-product source container below the instrument.*

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1. Introduction

The On-Site Inspection RadioIsotopic Spectroscopy (OSIRIS) system is a spectrum-blind instrument for the acquisition and analysis of high-resolution gamma-ray (γ-ray) spectra during on-site inspections under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). [1]

Unlike most spectrometers, the OSIRIS system does not display actual γ-ray spectra, and its software filter limits the display of spectral information to just seventeen CTBT-relevant fission-product isotopes. [2] As an example, a complex fission-product γ-ray spectrum is presented in Figure 2, and the filtered OSIRIS data display of that spectrum is shown in Figure 3. Note the OSIRIS display makes no mention of the weak 1001-keV ^{238}U daughter peak in Figure 2. The OSIRIS data filter is depicted schematically in Figure 4.

Details of the OSIRIS software and its initial testing have been described at the SnT2015 Conference and in *Nuclear Instruments and Methods in Physics Research* A. [3]

At SnT2017, we report our 2015-2017 tests of OSIRIS as a hardware-software system.

2. OSIRIS Energy Calibration

OSIRIS does not display raw γ-ray spectra, and its energy calibration cannot be checked visually. Instead, OSIRIS calibrates the spectral energy scale automatically, using ^{152}Eu, ^{228}Th, or natural background γ-radiation sources. [4]

Since γ-ray spectrometers identify radioisotopes by their associated spectral peak energies, accurate and stable energy calibration is essential for correct isotopic identifications. During an on-site inspection, it is likely OSIRIS will be used outdoors, not in an air-conditioned lab; and hence, we have tested OSIRIS energy-calibration stability versus both temperature and time.

2.1. OSIRIS spectrometer

It is also likely OSIRIS will be used in a remote location, where liquid nitrogen and electrical power may not be readily available. For these reasons, we have chosen a modified ORTEC IDM-200V mechanically-cooled, battery-operable HPGe γ-ray spectrometer for OSIRIS. The spectrometer and its control computer are shown in Figure A. The IDM-200V uses the same electronics as the ORTEC Transpec-100 spectrometer used in the CTBTO Integrated Field Exercise 2014. [5]

2.2 OSIRIS system energy-calibration stability versus temperature

The OSIRIS spectrometer energy-calibration stability versus temperature was tested repeatedly in an environmental chamber from −12 °C (+10 °F) to 50 °C (122 °F). The variations of the ^{152}Eu 121-keV and 1408-keV peak-centroid positions vs. temperature, typically less than ± 0.23 keV, are shown in Figure 5.

2.3 OSIRIS energy-calibration stability over time

If a spectrometer is energy-calibrated daily, its calibration must remain stable for at least 24 hours. As a baseline, we first monitored the spectrometer energy-calibration stability indoors, and found it remained stable over 5 days within 0.031 keV (1 σ). Next, we conducted month-long tests of the spectrometer outdoors at both Idaho National Laboratory (INL) and Pacific Northwest National Laboratory (PNNL). Testing at INL took place during winter conditions, as shown in Figure B. The INL energy-calibration stability test results are displayed in Figure 6, and the PNNL summer test results are shown in Figure 7. The calibration remained constant ± 0.113 keV in both tests.

3. OSIRIS fission-product identification

OSIRIS is designed to measure fission-product isotopes during an on-site inspection under the CTBT. To evaluate OSIRIS measurement accuracy, we recorded γ-ray spectra from a fission-product radioactive source as it decayed. Our evaluation criterion is simple: do the OSIRIS spectroscopic data points match the known decay curves of fission-product isotopes?

3.1 Fission-product measurements over time

We used a commercial 3-microcurie (0.12-megabecquerel) mixed-fission-product source containing all of the CTBT-relevant isotopes, save ^{134}Cs and ^{106}Rh. [6] When new, this source produced a γ-ray spectrum like Figure 2. OSIRIS counted the source almost every day, in order to follow fission-product decay for nearly one year at INL. Decay curves were calculated from fission-product half-lives, not from a least-squares fit to the experimental data. For ^{95}Nb, the daughter isotope of ^{95}Zr, the calculated curve includes parent-daughter effects. The decay curves for six CTBT-relevant isotopes (solid black lines) are compared to the measured spectral data (small colored circles) in Figure 1, and the agreement is good.

3.2. Fission-product identification amid legacy radioactivity

In March 2017, a field test of OSIRIS was conducted in two areas at the Nevada National Security Site, formerly the Nevada Test Site. As shown in Figure C, the instrument was operated in the *in-situ* (downward-looking) counting mode, and the radioactive background in one test area was a factor of 15 higher than in the other test area. A six-months-old fission-product source was placed 1 meter directly below the spectrometer during measurements, and it was removed during background runs. While many of the short-lived isotopes in the source had decayed away, OSIRIS detected two CTBT-relevant fission products: 64-day ^{95}Zr and its 35-day daughter, ^{95}Nb at both test areas.

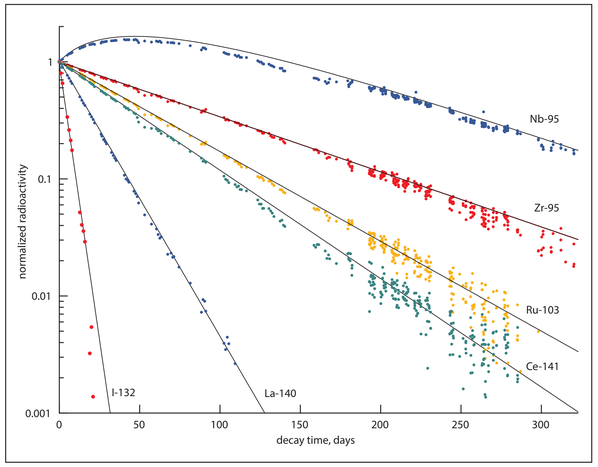

Figure 1: *OSIRIS measurements of activity vs time for six CTBT-relevant fission-product isotopes. The solid black decay curves are calculated from fission-product half-lives, and the colored circles are measured data points.*

4. Conclusions

We have conducted extensive system tests of the On-Site Inspection RadioIsotopic Spectroscopy (OSIRIS) system, a spectrum-blind instrument for the acquisition and analysis of high-resolution γ-ray spectra during CTBT on-site inspections.

A spectrum-blind instrument like OSIRIS must remain stable between energy calibrations, and hence we have tested the OSIRIS energy-calibration stability versus time and temperature. In temperature tests over a 62 °C (112 °F) range, the OSIRIS calibration remained stable within 0.23 keV. It is unlikely a spectrometer would encounter daily temperature changes this large during an on-site inspection. OSIRIS energy-calibration stability versus time was evaluated in month-long outdoor tests at both INL and PNNL, and in these tests, the calibration remained stable within 0.11 keV.

Recently, OSIRIS was field-tested at the Nevada National Security Site, and it identified two short-lived CTBT-relevant fission products amid legacy radioactive backgrounds.

To characterize OSIRIS identification of CTBT-relevant radioisotopes, we measured γ-ray spectra from a calibrated uranium fission-product source for almost one year. As the decay curves in Figure 1 attest, OSIRIS has correctly measured CTBT-relevant fission-product isotopes as their activities decayed by three orders of magnitude.

In summary, tests of the OSIRIS system have demonstrated good energy-calibration stability versus time and temperature, and accurate fission-product measurements, even in radioactive environments. OSIRIS is now an ORTEC commercial product. [7]

5. Acknowledgments

- OSIRIS research and development at INL, LLNL, and PNNL is sponsored by the Office of Nuclear Detonation Detection, NA-222, National Nuclear Security Administration, U.S. Department of Energy
- Gerry Schotik of the Nevada National Security Site provided valuable help during the March 1027 field test of OSIRIS.
- The ORTEC Division of Ametek, Inc. has provided key technical information about their instruments throughout the OSIRIS project.

References

1. The Comprehensive Nuclear-Test-Ban Treaty (CTBT) http://ctbto.org/the-treaty/
2. The seventeen fission-product isotopes are: ^{140}Ba, ^{141}Ce, ^{144}Ce, ^{134}Cs, ^{137}Cs, ^{131}I, ^{132}I, ^{140}La, ^{99}Mo, ^{95}Nb, ^{147}Nd, ^{144}Pr, ^{106}Rh, ^{103}Ru, ^{99m}Tc, ^{132}Te, ^{95}Zr, from the "Refined List of Radionuclides of Interest for OSI [On-Site Inspections]", Comprehensive Nuclear-Test- Ban Treaty Organization paper CTBT/WGB/TL-4/42 (January 2012).
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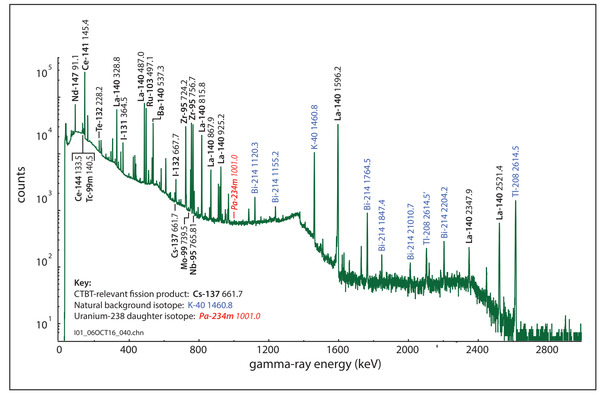

Figure 2: *Energy spectrum of a mixed fission-product gamma-ray source. [6]*

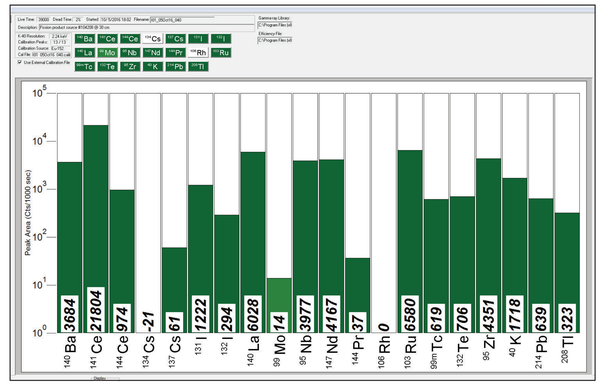

Figure 3: *OSIRIS computer display of the treaty-relevant isotopes detected in the spectrum of Figure 2.*

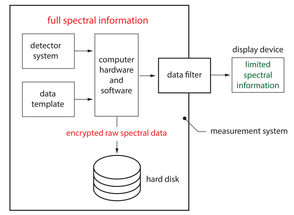

Figure 4: *Data filter concept.*

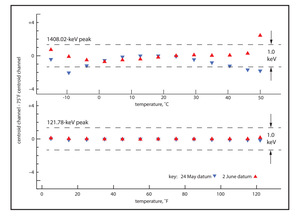

Figure 5: *OSIRIS energy-calibration stability vs. temperature.*

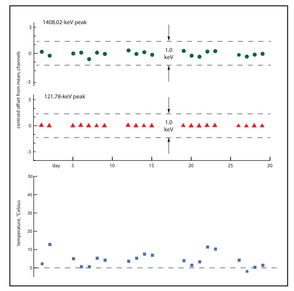

Figure 6: *Winter energy-calibration stability test of OSIRIS at Idaho National Laboratory.*

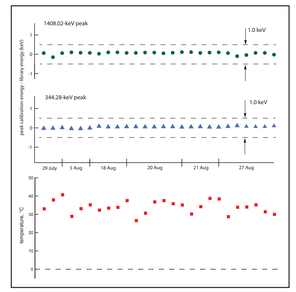

Figure 7: *Summer energy-calibration stability test of OSIRIS at Pacific Northwest National Laboratory.*