On-Site Inspection Radiol isotopic Spectroscopy (OSIRIS)
A Spectrum-Blind $\gamma$-Ray Spectroscopy System for On-Site Inspections under the Comprehensive Nuclear-Test-Ban Treaty

A. Caffrey, A. Egger, K. Krebs, J. Wharton
Idaho National Laboratory

T. Bowyer, B. Milbrath, G. Warren
Pacific Northwest National Laboratory

S. Kreek, S. Padgett, N. Wimer
Lawrence Livermore National Laboratory

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OSIRIS Development Path

**Software**

Data Acquisition & Analysis

Software Modifications and Test Spectra Generation

2013-2014

Software Testing

2014-2015

**Hardware**

γ-Ray Spectrometer

Transpec-100 Use in IFE 2014

2014

Software-Hardware Integration

2015

System Field Testing

2016-2017

**Notebook PC**
Osiris Design Requirements

1. Calibrate spectrometer energy scale with $\gamma$-ray check source
   - For example, $^{60}$Co, $^{152}$Eu, $^{228}$Th

2. Measure $\gamma$-ray spectra during CTBT on-site inspections
   - Spectral complexity requires high resolution (HPGe) spectrometer
   - Inspections will likely be in remote locations
     - Liquid nitrogen logistics will be problematic
     - Instruments probably may have to operate from battery power

3. Analyze measured $\gamma$-ray spectra in near-real time
   - The CTBT-relevant fission products and activation products
     - $^{140}$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
   - Natural background radioisotopes like $^{40}$K, $^{208}$Tl
   - Other radioisotopes, e.g., other fission products
4. Filter spectral analysis information to be displayed
   - Only CTBT-relevant radioisotope information will be displayed
   - Hide information on other radioisotopes irrelevant to the CTBT
   - Raw spectra will not be visible to operators

Treaty-related measurement-restriction precedent
   - Chemical Weapons Convention
     • Portable Isotopic Neutron Spectroscopy (PINS)
INL Irradiated Reactor Fuel Spectrum

Complex fission-product spectrum hidden from operator

AGR Fuel Sample
Cooling time: 24.2 months
OSIRIS Filtered Data Display

OSIRIS operators view this clear summary instead of a complex spectrum.
OSIRIS $^{134}$Cs/$^{137}$Cs Information Window

This window opens when the $^{134}$Cs button or the $^{137}$Cs button is clicked in the OSIRIS graphical user interface.

<table>
<thead>
<tr>
<th>isotope</th>
<th>library energy</th>
<th>measured energy</th>
<th>net area</th>
<th>$t^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs-134</td>
<td>569.31</td>
<td>569.18</td>
<td>874692.8</td>
<td>839.7</td>
</tr>
<tr>
<td>Cs-134</td>
<td>604.70</td>
<td>604.64</td>
<td>5312730.7</td>
<td>2251.9</td>
</tr>
<tr>
<td>Cs-134</td>
<td>795.85</td>
<td>796.19</td>
<td>3651670.9</td>
<td>1740.4</td>
</tr>
<tr>
<td>Cs-134</td>
<td>801.93</td>
<td>802.28</td>
<td>363554.6</td>
<td>539.8</td>
</tr>
<tr>
<td>Cs-137</td>
<td>661.66</td>
<td>661.59</td>
<td>5664162.0</td>
<td>2330.1</td>
</tr>
</tbody>
</table>

**Cs-134/Cs-137 Ratio**

$$\text{ratio} = \frac{5312730.7}{5664162.0} \cdot \frac{0.851}{0.976} = 0.82$$
Gamma-Ray Spectral Peak Analysis
Identify radioisotopes and measure their activities
OSIRIS Performance Criteria

1. True positives
   - Correctly identify the CTBT-relevant radioisotopes in a spectrum

2. True negatives
   - Ignore CTBT-relevant radioisotopes not present in spectrum

3. Peak-area accuracy
   - For detected CTBT radioisotopes, estimate peak areas accurately

4. Energy calibration accuracy
   - Calibrate spectral energy scale with accuracy sufficient to correctly identify the CTBT-relevant radioisotopes

5. Energy calibration stability
   - The energy calibration must not change between calibration checks

Energy calibration accuracy and stability are critical in a spectrum-blind system like OSIRIS
Software Testing

• Test spectra
  – INL reactor fuel experiments (7 spectra)
  – LLNL and PNNL synthetic spectra (150 spectra)
    • Environmental measurements
    • GEANT, MCNP, and SUPERSYNTH calculations

• Spectral analyses
  – Visual, using INL GAUSS XI interactive program
  – Automatic, using OSIRIS

• Spectrum analyses compared by computer
  – Compares visual and OSIRIS analyses for each gamma-ray peak
  – Computes scores by peak area and by isotope
Software Test Results

- Overall identification scores, in %:

<table>
<thead>
<tr>
<th>type</th>
<th>true positives</th>
<th>true negatives</th>
<th>false positives</th>
<th>false negatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treaty Fission Products</td>
<td>98.1</td>
<td>96.2</td>
<td>3.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Other Fission Products</td>
<td>86.5</td>
<td>94.9</td>
<td>5.1</td>
<td>13.5</td>
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<tr>
<td>Other Radioisotopes</td>
<td>95.0</td>
<td>96.8</td>
<td>3.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Natural Background</td>
<td>83.5</td>
<td>89.7</td>
<td>10.3</td>
<td>16.5</td>
</tr>
</tbody>
</table>

- All of the seventeen CTBT-relevant fission products identified
- Other fission products detected: $^{110m}$Ag, $^{136}$Cs, $^{154}$Eu, $^{125}$Sb, $^{91}$Y
- Natural background isotopes detected: $^{228}$Ac, $^{212}$Bi, $^{214}$Bi, $^{40}$K, $^{212}$Pb, $^{214}$Pb, $^{208}$Tl
- Software test results recently published
OSIRIS Hardware
Hardware Features

- **Spectrometer:** ORTEC Transpec-100
  - Mechanically-cooled
  - 40% relative efficiency
  - 2.1-keV energy resolution at 1.33 MeV
  - 12-hour battery life with external battery

- **Potential data security issues:**
  - Internal histogram memory with USB port
  - PDA-like computer atop spectrometer with display, SD card, separate USB port

- **Computer:** Panasonic Toughbook
  - Ruggedized, can be dropped from 2 meters
  - Screen readable in direct sunlight

- **Integrated Field Exercise 2014, Jordan**
  - *In-situ* gamma-ray spectrometer
System Integration, 2015

• Modify spectrometer for data security
  – Remove PDA and its USB port
  – Add switch for cooler
  – Modify histogram memory electronics

• Upgrade Toughbook data security
  – Encrypt OSIRIS spectral files

• Test OSIRIS as a system
  – Install OSIRIS software on the Panasonic Toughbook
  – Verify software interface between Toughbook and spectrometer
  – Conduct calibration stability tests in an environmental chamber
    • Re-create the temperature profiles from selected locations around the world
    • Spectrometer operating range: −15° C (+5 ° F) to 50 ° C (122° F)

• Begin commercialization
Field Testing, 2016-17

• INL Field Tests
  – Outdoors at the INL reactor site
  – January – June 2016
  – Fission-product measurements
  – Tests with $^{235}$U and $^{239}$Pu sources
  – Energy calibration stability checks

• PNNL Field Tests
  – Outdoors at the Hanford Site
  – July – September 2016

• Nevada Field Test
  – Nevada National Security Site (formerly, the Nevada Test Site)
  – Outdoors in November 2016
  – Fission-product measurements
    • Radiologically clean area
    • Contaminated area
Conclusions

- **OSIRIS $\gamma$-ray spectroscopy system for CTBT on-site inspections**
  - Mechanically-cooled HPGe spectrometer
  - Custom software with built-in data filter—”spectrum-blind”

- **Performance**
  - Five performance metrics have been defined
  - Software has been tested against 150 synthetic spectra
    - Test results published in *Nuclear Instruments and Methods in Physics Research A*
    - OSIRIS correctly identified treaty fission products > 95% of the time
  - Transpec-100 $\gamma$-ray spectrometer used successfully at IFE14

- **Future development**
  - Hardware-software system integration just beginning
  - Extensive field testing planned for 2016-2017
  - Technology being transferred to a commercial manufacturer

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.
OSIRIS software test results were announced at SORMA XV in June 2014


also available on-line: http://dx.doi.org/10.1016/j.nima.2014.10.066
Back-up Slides
OSIRIS Software Internals

- Auto energy calibration
- Peak search
  - “Zero-area square wave” cross-correlation algorithm
  - Similar to wavelet transform
- Directed fits
  - Peaks found by search are all fit.
  - If a required peak is not found by the search, a directed fit is performed.
- Peak fitting
  - Nonlinear least-squares Gaussian fits
  - GAUSS algorithms of Helmer, et al.
- Graphical user interface
  - Includes data filter

**OSIRIS supervisory logic**
OSIRIS Energy Calibration Window

Eu-152 check source
200 live seconds