SOLEX: a tunable monochromatic X-ray source tool for X-ray detectors characterization

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Metrological context

The LNE-LNHB is the French metrology institute for ionizing radiation: One of its missions is to provide accurate radionuclide decay data to the users by:

- accurately measuring photon emission intensities,
- evaluating radionuclide decay data,
- publishing recommended data (Nucleide).

X-ray emission intensities of radionuclides \( (P_K \omega_K) \) [1]

Energy-dispersive (ED) detector efficiency characterization

Need of detector calibration independent from radionuclide decay data

Available atomic data and associated uncertainties

Fluorescence yields: \( \omega \)

Most of the available experimental data are older than 30 years [2] and measured with less accurate setup than nowadays capabilities:

- \( \omega_K \) uncertainties are larger than 3% for most elements with \( Z < 30 \)
- \( \omega_L \) uncertainties are larger than 15% for all elements [3,4]

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1. SOLEX : The monochromatic & tunable X-ray source
   1.1 The source setup
   1.2 The source technical properties
   1.3 Reference detector

2. Energy-dispersive X-ray spectrometer (EDS) characterization
   2.1 Surface Map
   2.2 EDS response function
   2.3 EDS efficiency calibration

3. Other capabilities of SOLEX
   3.1 Total mass attenuation coefficients measurements
   3.2 Fluorescence yields
1.1 SOLEX, a tunable monochromatic X-ray source: principles

- X-ray tube
- Dispersive crystal
- Johann geometry [6]
- Fixed output: X-ray tube & crystal are moving
- LabVIEW™ interfaced

1.2 SOLEX: a tunable monochromatic X-ray source [7]

**Output 1**: X-ray Detector (HPGe, Si(Li), SDD...)

**Vacuum chamber (10^{-7} hPa)**

**X-ray tube**
- Windowless, water-cooled
- Several anodes materials: (Cu, Au, Ag Hastelloy...)
- HV up to 50 kV
- Controllable intensity up to 100 mA
- Intensity fluctuations <1%

**Dispersive Crystal: Bragg law**
- Emitted X-rays: FWHM ~ some eVs
- Different Crystals (InSb, Beryl, LiF, Quartz...)
- 0.6 keV ≤ E ≤ 28 keV

**Options**
- Removable filter holder
- Proportional counter for absolute flux measurements

1.2 SOLEX: characteristics

- Good energy resolution & reproducible energy-calibration
- Worse spectral resolution

$\Delta E/E \sim 0.1\%$
1.3 Gazeous Proportional Counter as reference detector

- Mounted on the 2\textsuperscript{nd} output
- Two beryllium windows
- Full transmission/absorption characterization
- Dedicated to full-energy peak efficiency calibration
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2.1 EDS characterization: surface map

- 2D scan (40 x 40 mm)
- Beam size about 0.5 x 0.5 mm
- Spectrum acquisition and automated treatment

1830 eV

2984 eV
2.2 EDS characterization: response function

Si(Li) EDS
Monochromatic photons
Energy = 3 keV

Total Spectrum
Full-energy peak (total absorption)
Escape peak
Photoelectrons escape
Auger electrons escape
Interaction of Auger electrons of the electrode
Interaction of photoelectrons of the electrode
L- fluorescence peak of the electrode
K- fluorescence peak of aluminum
2.3 EDS full-energy peak efficiency calibration

Full-energy peak efficiency of a Si(Li) detector

\[ \eta_{\text{det}} = \frac{N_{\text{det}}}{N_{\text{PC}} \times t_{\text{det}} / t_{\text{PC}}} \]

Comparison with the PC:

Si K-edge \( \rightarrow \) dead layer

X-ray counting system based on YAG scintillator and a PM [8]

DUVEX: association of a YAG and a PM

2.3 EDS full-energy peak efficiency calibration [9]

- Measurement of screen thicknesses: (scanning around the binding energy)
- Germanium partial active layer: peak shape analysis

Be window 10\(\mu\)m
Collimator
Al infra-red screen 0.113 (18) \(\mu\)m
Ni electrode 51 (20) nm
Ge dead layer 11.6 (61) nm
Ge partial active layer: 1.27(4) \(\mu\)m
Ge crystal: 4 mm

3. Other capabilities of SOLEX

Mass attenuation coefficients measurements / Filter transmission

NIST XCOM database [10]

CXRO database [11]

Filter Transmission

- Choose from a list of common materials:
  - Enter Formula
  - Chemical Formula: SiO2
- Density: 2.6 g/cm³ (enter negative number to use tabulated values)
- Thickness: 2 mm
- Photon Energy (eV) Range from 10 to 10000 and Wavelengths in the range of 0.14 nm to 124 nm

To request a graph, select Linear or Plot, then press this button: Submit Request

To reset to default values, press this button: Reset


3.1 Total mass attenuation coefficients (example of Cu)

\[
\frac{\mu}{\rho} = \frac{\tau_{K,L,M\ldots}}{\rho} + \frac{\tau_{cs}}{\rho} + \frac{\tau_{ics}}{\rho}
\]

\[
\frac{\mu}{\rho} = -\frac{A}{M} \times \ln \left( \frac{I_t}{I_{ref}} \right)
\]
3.2 Fluorescence yields

Only one solid angle to measure
Simultaneous measurement of the input beam and the fluorescence lines
Low input rate

<table>
<thead>
<tr>
<th>Z</th>
<th>element</th>
<th>$\omega_{K\alpha}$</th>
<th>$\omega_{K\beta}$</th>
<th>$\omega_K$</th>
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<tr>
<td>22</td>
<td>Ti</td>
<td>0.206(23)</td>
<td>0.0233(55)</td>
<td>0.230(28)</td>
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<td>23</td>
<td>V</td>
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<td>0.0269(32)</td>
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<td>Fe</td>
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<td>0.0452(24)</td>
<td>0.369(18)</td>
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<tr>
<td>27</td>
<td>Co</td>
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<td>0.0427(38)</td>
<td>0.375(33)</td>
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<tr>
<td>29</td>
<td>Cu</td>
<td>0.384(16)</td>
<td>0.0535(30)</td>
<td>0.437(19)</td>
</tr>
<tr>
<td>30</td>
<td>Zn</td>
<td>0.427(19)</td>
<td>0.0682(33)</td>
<td>0.495(22)</td>
</tr>
</tbody>
</table>

Conclusion

- **SOLEX**
  - Laboratory tool: permanent access
  - Flexible
  - Easier than synchrotron, however with less flux

- **Tool for accurate characterization of detectors in the 1-20 keV energy range**
  - Detector response homogeneity (mapping)
  - Detector response function
  - Efficiency calibration (independent of radionuclides decay data)

- **Tool for accurate characterization of materials**
  - Improved facility (monochromatic photons, EDS, tuneability)
  - Transmission (filters, sample)
  - Attenuation coefficients
  - Fluorescence yields
  - Etc.