Expert System SHAMAN and Comparison of its Coincidence Correction to KORSUM

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Outline

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Background

SHAMAN

- Expert system for radionuclide identification that uses conservative inference rules and a comprehensive nuclide library
- Designed to replace the human expert in gamma-ray spectrum interpretation
- Aims to find the most probable nuclide composition explaining all spectrum peaks
- Development was started in 1987 at Helsinki University of Technology (TKK, now Aalto), tens of person-years have been invested

(Demo can be arranged.)

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Essential Features

- Expert system with an inference engine and a set of selection rules
- Radionuclide data extracted from ENSDF and NUDAT databases into a comprehensive library of 3600 nuclides and 80,000 gamma-ray and X-ray lines
- Decay scheme data for 120 important nuclides utilized in coincidence summing correction
- Features background subtraction, coincidence summing correction and self-absorption correction methods
- Can estimate sizes of true coincidence sum peaks, random sum peaks, annihilation escape peaks, and X-ray escape peaks
- Fully tailorable reports, scripting capability
- Supports SQL database called LINSSI

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Selected Publications

1. P.A. Aarnio, T.T. Hakulinen, "Developing a Personal Computer Based Expert System for Radionuclide Identification". Article in book New Computing Techniques in Physics Research. Proceedings of the First International Workshop on Software Engineering, Artificial Intelligence and Expert Systems in High Energy and Nuclear Physics. March 19-24, 1990, Lyon Villeurbanne, France. Editions du Centre National de la Recherche Scientifique. Paris 1990.
2. P.A. Aarnio et al., "Expert System for Nuclide Identification and Interpretation of Gamma Spectrum Analysis". JRNC 160 (1992) 245-252.
3. P.A. Aarnio et al.,"Application of the Nuclide Identification System Shaman in Monitoring the Comprehensive Test Ban Treaty". JRNC 235 (1998) 95.
4. P.A. Aarnio et al., "The Nuclide Identification System Shaman in the Verification of the Comprehensive Nuclear-Test-Ban Treaty". JRNC 248 (2001) 587.
5. P.A. Aarnio et al., "Analysis Pipeline for Air Filter Gamma-Ray Spectra from the CTBT Verification Network". JRNC 263 (2005) 251.
6. P.A. Aarnio et al., "Performance of UniSampo-Shaman with Gamma-Ray Spectra Containing Known Traces of Fission Products". JRNC 276 (2008) 455.
7. J.J Ala-Heikkilä, "Analysis Methods for Airborne Radioactivity". Doctoral Dissertation, Helsinki University of Technology, TKK Dissertations 129, Espoo 2008; available at `http://lib.tkk.fi/Diss/2008/isbn9789512294404/`

(JRNC = Journal of Radioanalytical and Nuclear Chemistry)

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Basic References

Implementation in SHAMAN

The CC-method implemented in SHAMAN is based on the classical references:

1. D.S. Andreev et al., Instruments and Experimental Techniques 25 (1972) 1358–1360.
2. G.J. McCallum, G.E. Coote, Nuclear Instruments and Methods 130 (1975) 189–197.
3. R.J. Gehrke et al., Nuclear Instruments and Methods 147 (1977) 405–423.
4. K. Debertin, U. Schötzig, Nuclear Instruments and Methods 158 (1979) 471–477.
5. K. Sinkko, H. Aaltonen, Report STUK-B-VALO 40, Helsinki 1985.

Implementation in KORSUM

KORSUM is a stand-alone program for coincidence correction calculation by K. Debertin et al. (Ref. 4). Its results were kindly provided to us by Weihua Zhang (Radiation Protection Bureau, Health Canada).

Mathematical Formulas

$$
\begin{aligned}
C_{ik} &= S^*_{ik}/S_{ik} = L_i a_{ik}/(N_i A_{ik} M_k) \\
L_i &= N^*_i + \sum_{n=i+1}^{m} L_n x_{ni} \\
a_{ik} &= \frac{x_{ik}\epsilon_{p,ik}}{1+\alpha_{ik}} \\
A_{ik} &= a_{ik} + \sum_{j=k+1}^{i-1} a_{ij} A_{jk} \\
M_k &= \sum_{j=0}^{k-1} b_{kj} M_j\,, \;\; M_0 = 1 \\
N_i &= N^*_i + \sum_{n=i+1}^{m} N_n b_{ni} \\
b_{ik} &= x_{ik}\left(1 - \frac{\epsilon_{t,ik}}{1+\alpha_{ik}}\right)
\end{aligned}
$$

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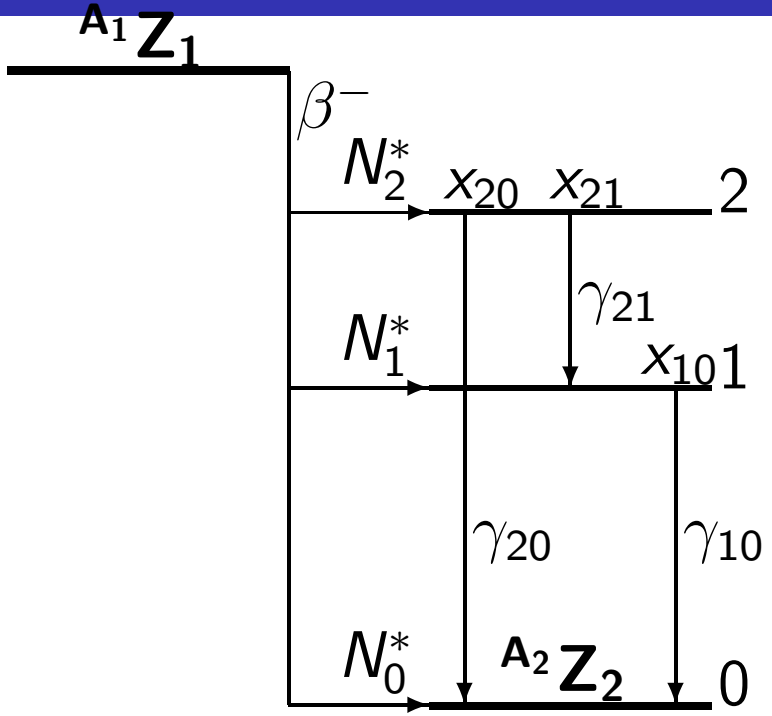
Example: Simple Decay Scheme



$$C_{20} = \frac{1}{1+\frac{x_{21}\epsilon_{p21}x_{10}\epsilon_{p10}}{x_{20}\epsilon_{p20}}}$$

$$C_{21} = \frac{1}{x_{10}(1-\epsilon_{t10})}$$

$$C_{10} = \frac{1}{1-\frac{N_2^* x_{21}}{N_1^* + N_2^* x_{21}}\epsilon_{t21}}$$

Example case: Co-60

$x_{20} = N_1^* = N_0^* = 0,\ x_{21} = x_{10} = N_2^* = 1$

$\Rightarrow \quad S_{20} \propto \epsilon_{p21}\epsilon_{p10}\ ,\quad S_{21} \propto (1-\epsilon_{t10})\ ,\quad S_{10} \propto (1-\epsilon_{t21})\ .$

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Required Input

Input requirements for CC-calculation:

- Photopeak efficiency ϵ_p
- Total efficiency ϵ_t (empirical preferred, but SHAMAN can estimate ϵ_t from ϵ_p)
- Decay schemes for relevant nuclides: cascading information and transition data (energies, intensities, conversion coefficients etc.)

The CC-calculation is not sensitive to peak and total efficiencies. Normal accuracy (3 . . . 5 %) is sufficient.
Both KORSUM and SHAMAN have decay scheme data for ∼100 radionuclides. Both data files have been compiled manually from ENSDF data.

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Specifics of Shaman Implementation

The CC-calculation in SHAMAN:

- corrects for summing with 511 keV gammas (Na-22, Co-58)
- corrects for summing with X-rays from internal conversion
- corrects for summing with X-rays following EC
- requires manipulated decay schemes when metastable states are present
- calculates areas of coincidence sum peaks

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Comparison Procedure (1)

The coincidence correction factors (CCF) were compared on a gamma-by-gamma basis

- A set of 25 nuclides and their 291 gamma lines were used: Be-7, Na-22, Co-60, Y-88, Y-93, Zr-95, Nb-95, Mo-99, Tc-99M, Ru-103, Rh-106, Te-132, I-131, I-132, I-133, Cs-134, Ba-140, La-140, Ce-139, Ce-144, Pr-144, Nd-147, Eu-152, Eu-154, Eu-155.
- The peak and total efficiencies for this exercise were taken from a typical close geometry used for environmental samples: $\max(\epsilon_p) = 0.16$, $\max(\epsilon_t) = 0.37$.

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Comparison Procedure (2)

Differences in decay schemes produce significant differences

- The decay scheme file of KORSUM was converted to the format of SHAMAN in order to eliminate effects of different input.
- SHAMAN replaces the energies and emission probabilities in the decay scheme file with those in its library (because the library data are more reliable). A special version of SHAMAN was compiled where this feature was disabled.

  $\Rightarrow$ The inputs of both programs were as identical as possible.
- Test runs were also made with the default version of SHAMAN.

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Example Results: Y-88

E (keV)	I_0 (%)	C_K (abs)	C_S (abs)	diff (%)
850.60	0.036	1.4034	1.4064	+0.21
898.04	94.270	1.1592	1.1587	−0.05
1383.90	0.037	1.1591	1.1586	−0.04
1836.04	99.440	1.2018	1.2026	+0.07
2734.03	0.536	0.0784	0.0783	−0.08
3219.50	0.010	0.8297	0.8283	−0.17
		KORSUM	SHAMAN (modified)	

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Conclusions (1)

Overall statistics:

- The CCF-values calculated with KORSUM and SHAMAN were within 1 % of each other in 259/291 cases (89 %). All but 4 values were within 3 % of each other (99 %).

$\Rightarrow$ With identical input, the CC-calculation implementations in KORSUM and SHAMAN produce identical results.

- The CCF-values calculated with KORSUM and default-SHAMAN were within 1 % of each other in 219/291 cases (75 %). All but 27 values were within 3 % of each other (91 %).

$\Rightarrow$ The CC-calculation is sensitive to differences in decay schemes.

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Conclusions (2)

The four exceptional cases:

- 2.17 keV transition of Tc-99M: apparently the difference is due to extrapolation of efficiency curves to such a low energy.
- 443.8 and 556.9 keV lines of Ru-103: state Rh-103M prevents summing. The handling of metastabe states is different in KORSUM and SHAMAN, leading to a large discrepancy. (Using default SHAMAN, CCF's agree within 4 %.)
- 719.36 keV line of Eu-152: matched with an incorrect line in SHAMAN's library (two lines at the same energy).

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Summary

Coincidence correction is necessary in close measuring geometries

- The CC-calculation method of Andreev et al. has been implemented in SHAMAN. SHAMAN's CC-module additionally features calculation of sum peak areas.
- When given identical input, SHAMAN produces CCF's within 3 % of KORSUM's CCF's. No bias is seen in the results.
- The CC-calculation is sensitive to decay scheme details. ENSDF is the best source available.

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Thank you for your attention!

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