SnT 2023
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
HOFBURG PALACE - Vienna and Online
19 TO 23 JUNE

Development and Validation of Coincidence Analysis/Quantification Software for Gamma-gamma Coincidence Counting

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Pacific Northwest NATIONAL LABORATORY

INTRODUCTION

- Multidimensional systems promising for IMS
- A Sophisticated γ-γ Coincidence Analysis/Quantification Software developed at Pacific Northwest National Laboratory, USA

METHODS/DATA

- Advanced python libraries and strategies implemented
- Experimental validation using underground γ-spectrometer
- Probabilities simulated using PNNL's Deception Supercomputer

START

RESULTS

- Experimentally tested up to 120 GB experimental data
- CTBT relevant radionuclides probabilities simulated
- Coincidence probabilities validated: <5% for 15 radionuclides

CONCLUSION

- Successful development and performance evaluation
- Execution tested for CTBT relevant radionuclides
- Experimental validation for 15 radionuclides

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BATTELLE

NNSA National Nuclear Security Administration

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PNNL-SA-186057

Abstract

Gamma-gamma coincidence techniques are known to improve the detection of particulate radionuclides relevant for Treaty monitoring purposes. To that end, Pacific Northwest National Laboratory (PNNL, USA) has developed a novel γ-γ coincidence analysis and radionuclide quantification software package. The software's execution has been tested for radionuclides relevant to Comprehensive Nuclear-Test-Ban Treaty (CTBT) and other radionuclides with complex decay schemes. This presentation discusses software's details, challenges encountered in its development, and its experimental validation. The validation was performed by experimentally measuring 15 radionuclides (including ^{140}Ba, ^{140}La, and ^{88}Y) using the Advanced Radionuclide Gamma-spectrOmeter (ARGO) located in the Shallow Underground Laboratory (SUL) at PNNL.

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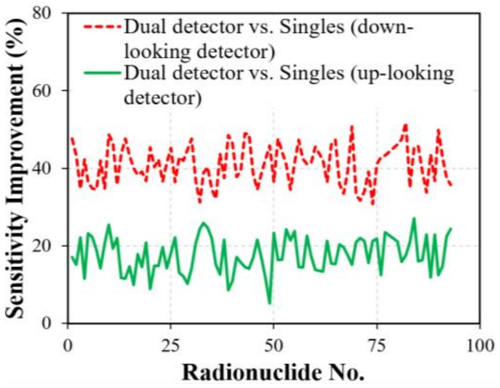
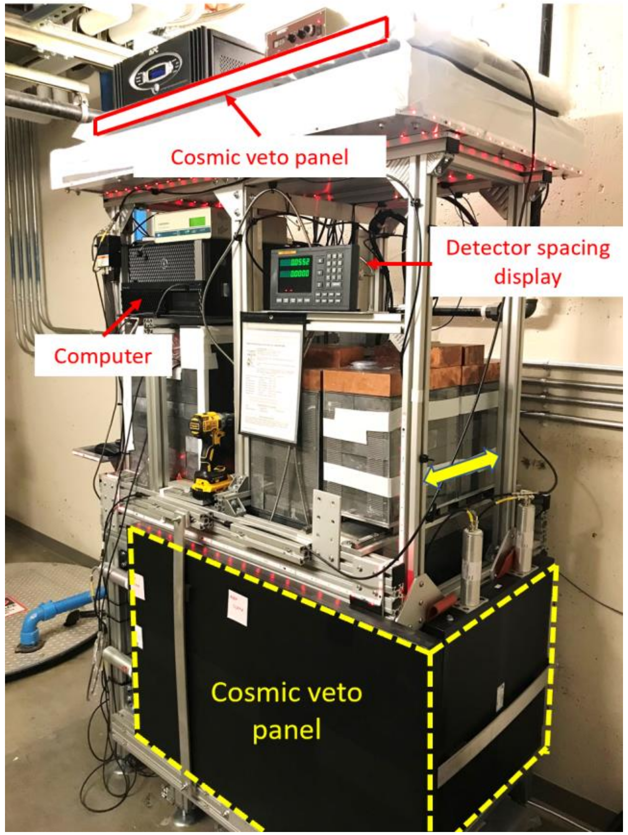
Introduction

- Radionuclide (RN) monitoring: one of four verification technologies of the IMS
- IMS: RN stations utilize high-resolution gamma spectrometry for particulate radionuclides
  - Such as: ^{140}La, ^{140}Ba, ^{134}Cs, ^{137}Cs, etc.



- Multidetector systems promising for IMS:
  - Superior detection efficiency
  - γ-γ Coincidence signatures
  - Operationally resilient



M. Sharma et al., SnT-2021

- Additional detectors bring complexity
  - **Data processing, analysis, and quantification** ⇒ sophisticated software
  - Mathematical operations, Nuclear Structure, Characterized source-detector geometry

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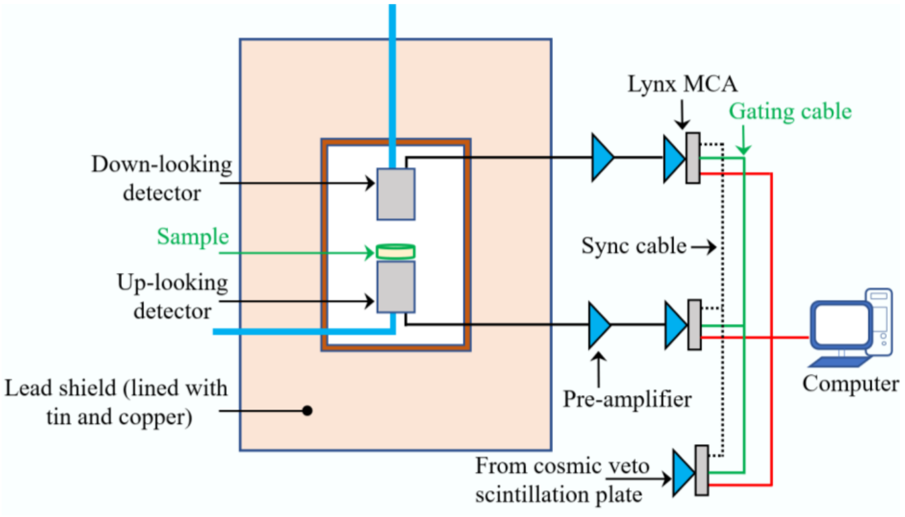
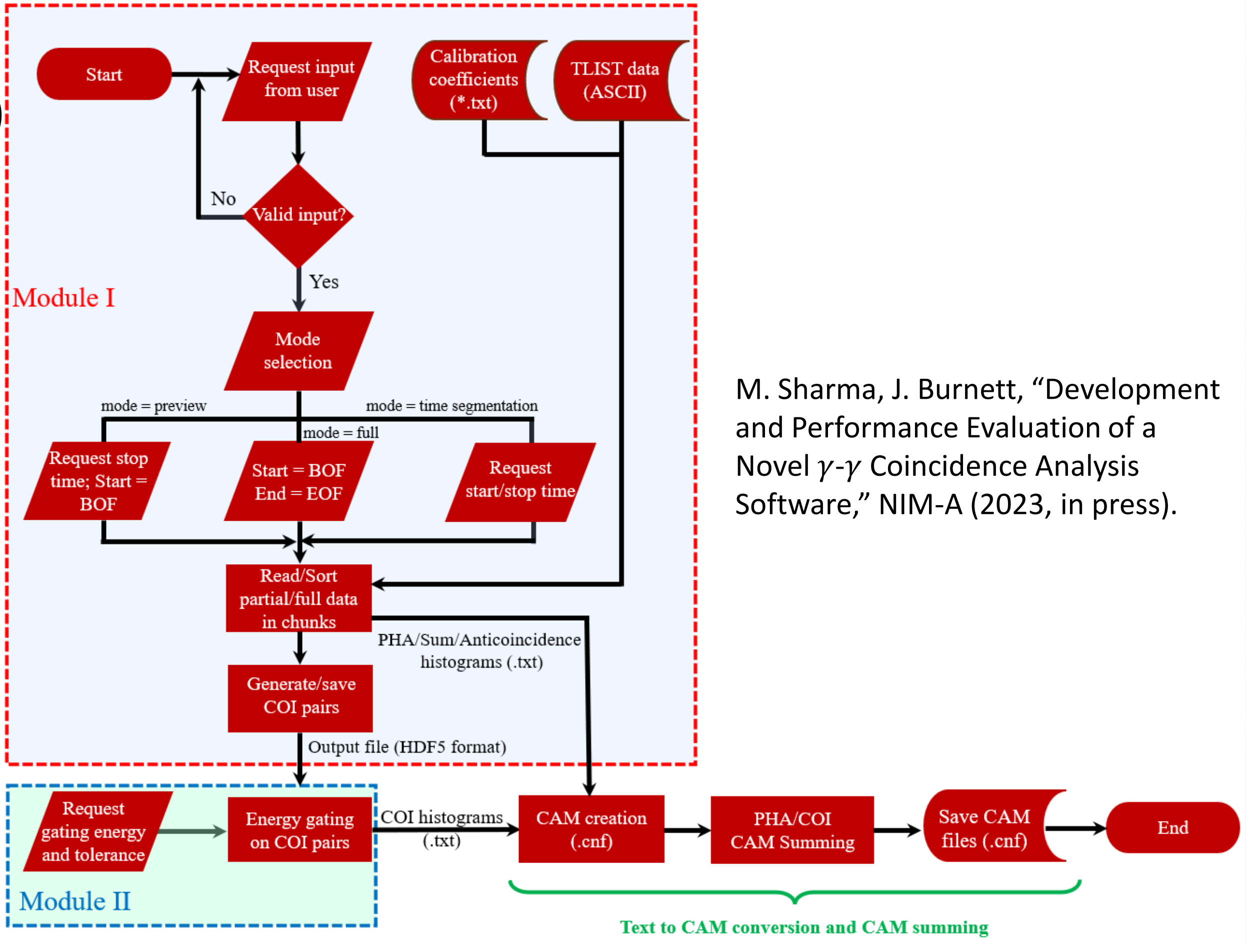
Software-I: Coincidence Analysis

Time delay AnaLysis using binAry SearcH (TALASH)

- TALASH development constraints:
  - Implementation: Windows, Python, TLIST (Canberra)
  - Output: Genie-2000
- Large data problem (high count rate/time)



Schematic of a 'dual-detector' system



M. Sharma, J. Burnett, "Development and Performance Evaluation of a Novel γ-γ Coincidence Analysis Software," NIM-A (2023, in press).

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SOFTWARE (I)
SOFTWARE (II)
VALIDATION RESULTS
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Software-I: Coincidence Analysis

Performance Optimization

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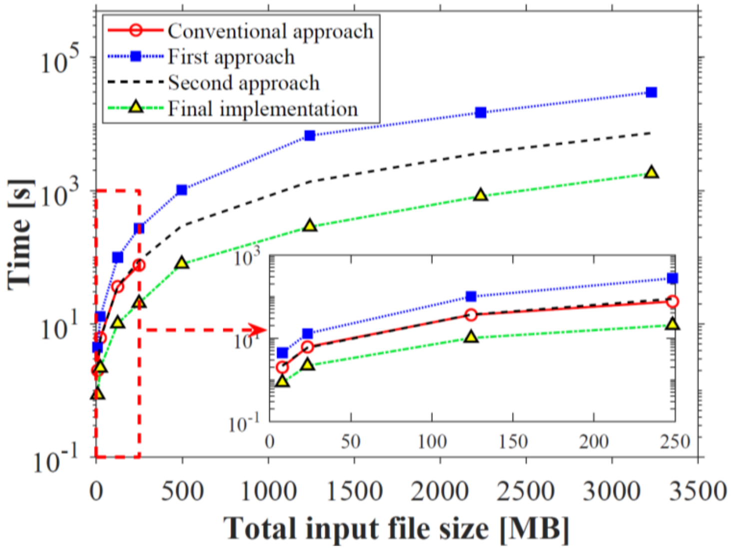
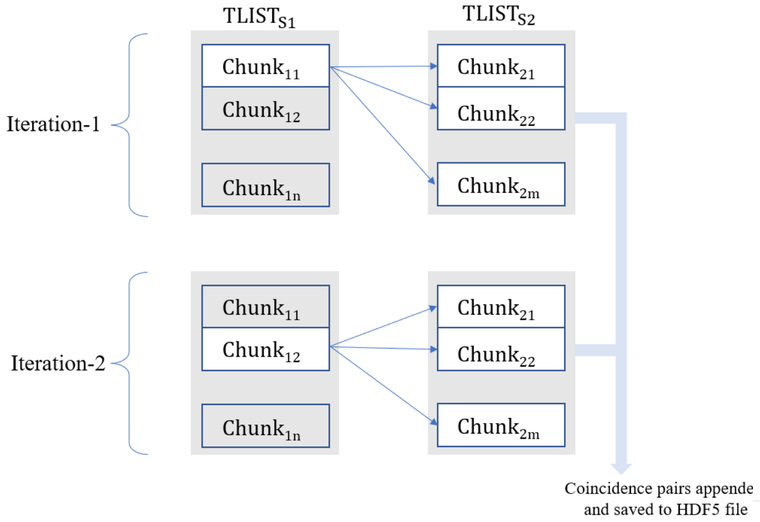
Performance Optimization with Synthetic Data

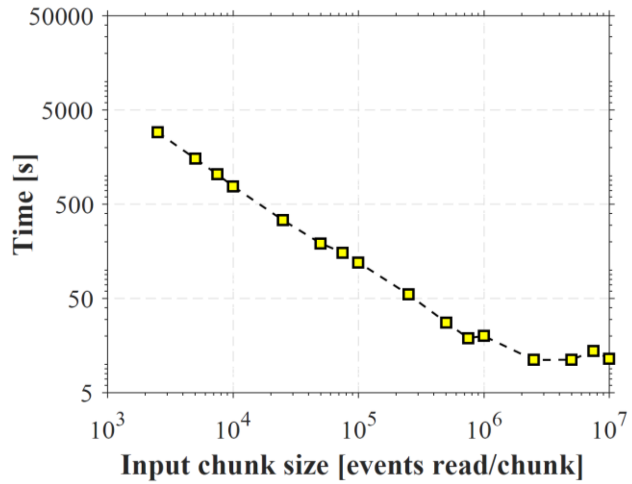


PyTables NumPy Pandas

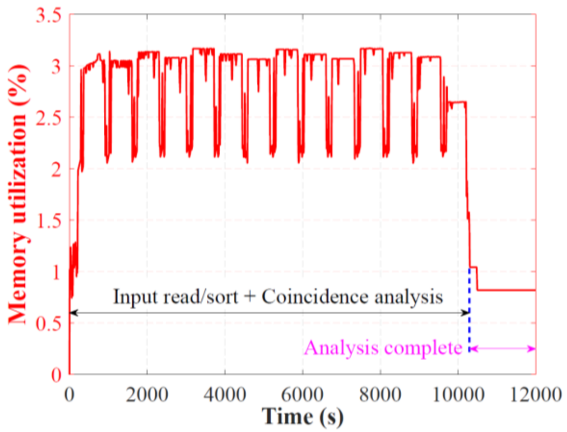
Sophisticated Strategies



Large Data Chunking - optimization



Memory Utilization during Coincidence Search



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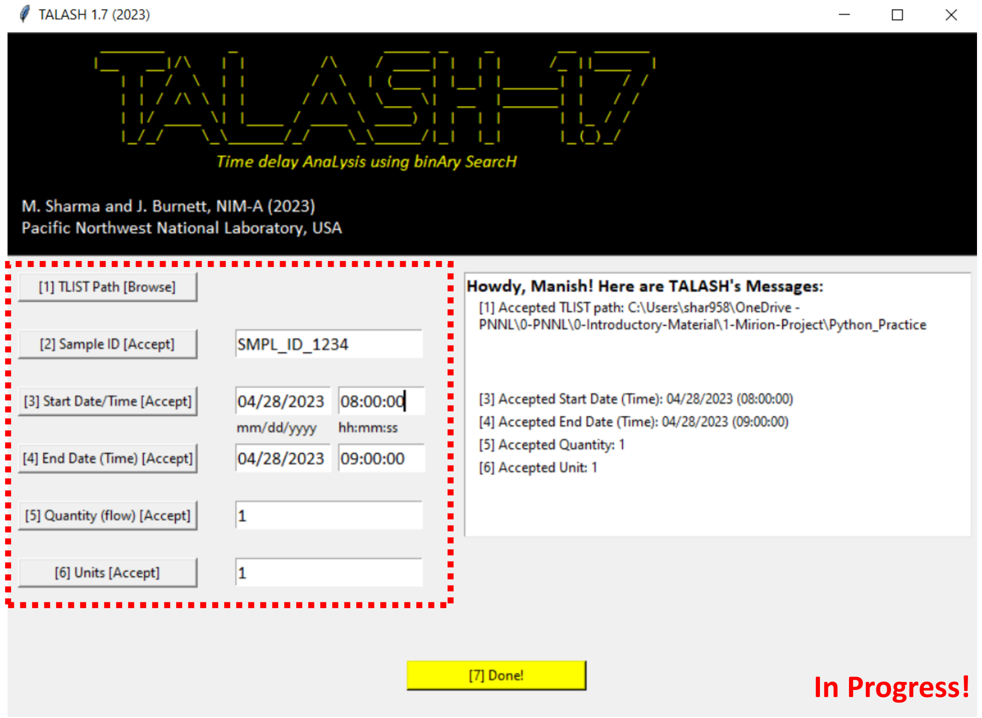
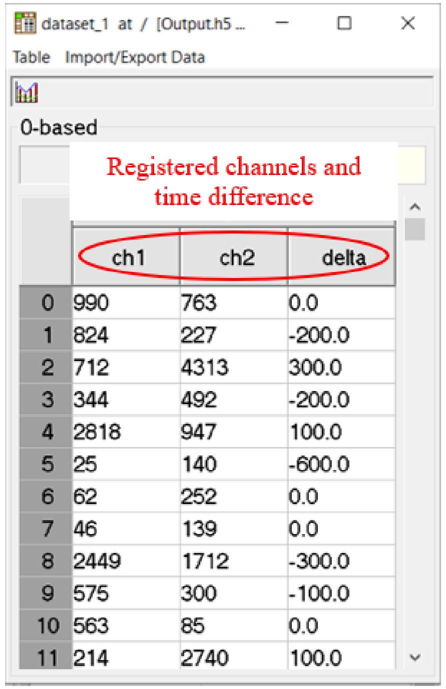
Software-I: Coincidence Analysis

TALASH: Output (GUI)

TALASH - GUI

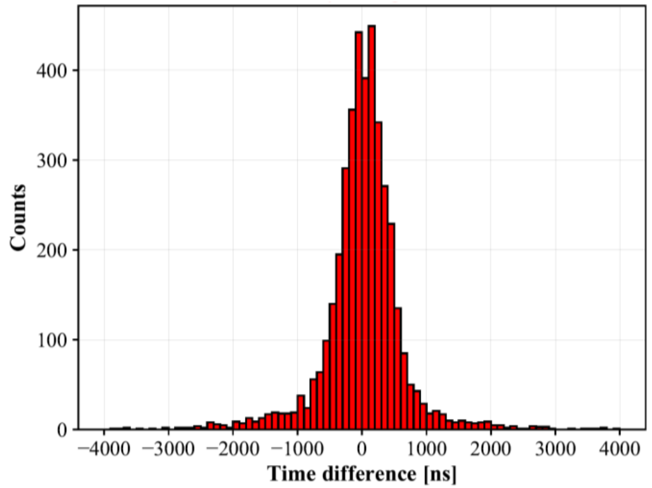


TALASH – Output (HDF5)



	ch1	ch2	delta
0	990	763	0.0
1	824	227	-200.0
2	712	4313	300.0
3	344	492	-200.0
4	2818	947	100.0
5	25	140	-600.0
6	62	252	0.0
7	46	139	0.0
8	2449	1712	-300.0
9	575	300	-100.0
10	563	85	0.0
11	214	2740	100.0

TALASH – Sample Delay Histogram



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TALASH Output

- Coincidence pairs
- Singles/Summed spectra
- Coincidence spectra

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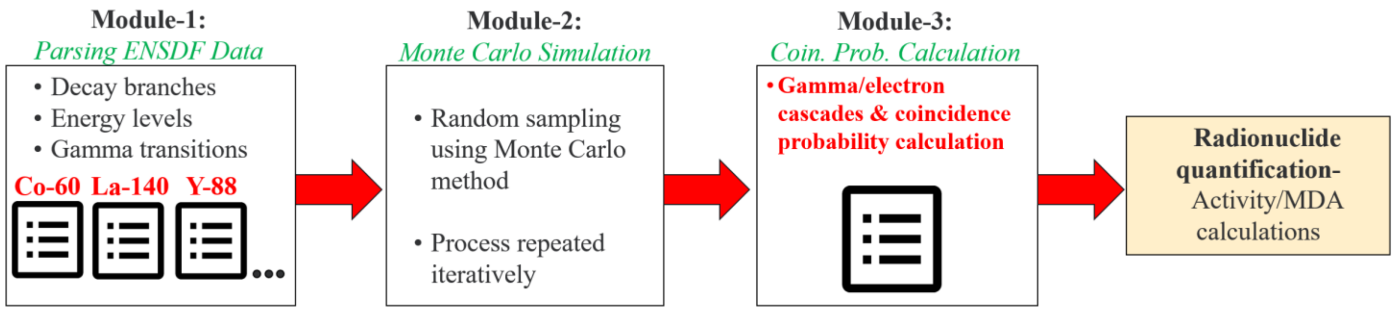
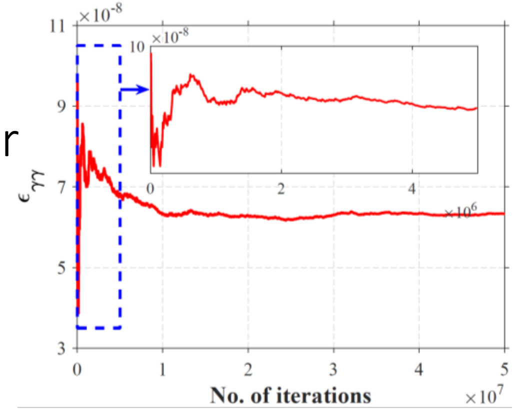
Software-2: Radionuclide Quantification using γ-γ Signatures

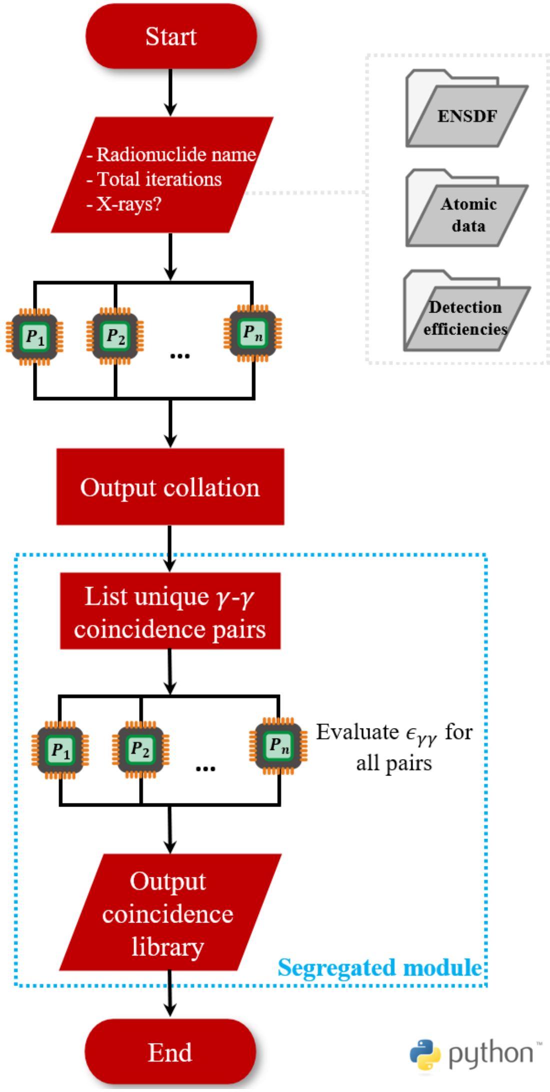
Overview and Modules



- Strategies:
  - Python, multiprocessing implementation
  - Modular structure to reduce computational burden

- Archived γ-e^- cascades for CTBT-relevant radionuclides - PNNL's Deception Supercomputer





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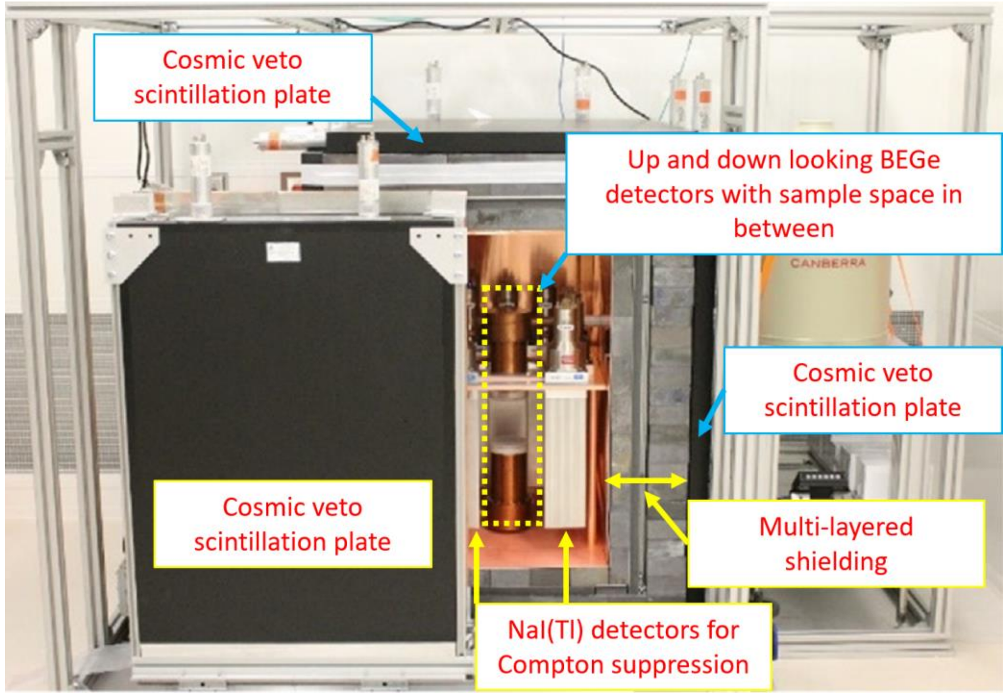
Validation Results

PNNL's Advanced Radionuclide Gamma spectrOmeter-I



Validation of Detection Probabilities (Experiment vs Software)

Radionuclide	Coincidence Energy (keV)		$\epsilon_{\gamma\gamma}$		Δ (%)
	Gated	Observed	Experiment	Simulated	
^{60}Co	1173.2	1332.5	6.5E-4	6.3E-4	2.6
^{88}Y	1836.1	898.0	5.6E-4	5.6E-4	0.3
^{99}Mo	181.1	739.5	3.7E-4	3.7E-4	0.8
^{132}Te	228.2	49.7	3.3E-3	3.2E-3	1.2
^{140}Ba	162.7	304.8	4.9E-4	4.9E-4	0.5
^{140}La	1596.0	328.0	2.6E-4	2.6E-4	0.3
^{103}Ru	53.3	557.1	2.7E-5	2.8E-5	3.2
^{143}Ce	57.4	293.3	1.1E-3	1.1E-3	1.2
^{140}La	1596.0	328.0	2.6E-4	2.6E-4	0.2
^{42}K	1524.6	312.6	6.8E-6	6.5E-6	4.2
^{97}Zr	254.2	1148.0	1.7E-5	1.7E-5	0.0
^{132}I	522.7	772.6	2.2E-4	2.2E-4	0.2
^{133}I	706.6	529.9	3.4E-5	3.3E-5	0.8
^{131}I	80.2	284.0	4.8E-4	4.9E-4	1.0
^{153}Sm	103.2	69.7	7.0E-4	7.0E-4	0.4

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Conclusions

- Development of sophisticated coincidence analysis/quantification software at PNNL
  - Performance evaluation and optimization

- Software's execution tested for CTBT relevant radionuclides (and complex decay radionuclides, ^{233}U)
  - Validated with experimental measurement of 15 radionuclides (using calibration standards and irradiated samples)

- What's not discussed, but has been done:
  - Comparison with existing software (AWE's RIMMER)
  - Impact of interferences (own/other emissions)
  - Convergence behavior for 15 radionuclides
  - Further details on experimental probability calculation and comparison

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Thank You!

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