The Berkeley Atlas: A database of absolute cross sections for inelastic gamma-ray production with 14 MeV neutrons

Workshop for Applied Nuclear Data Activities (WANDA 2025)

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The Berkeley Atlas Team

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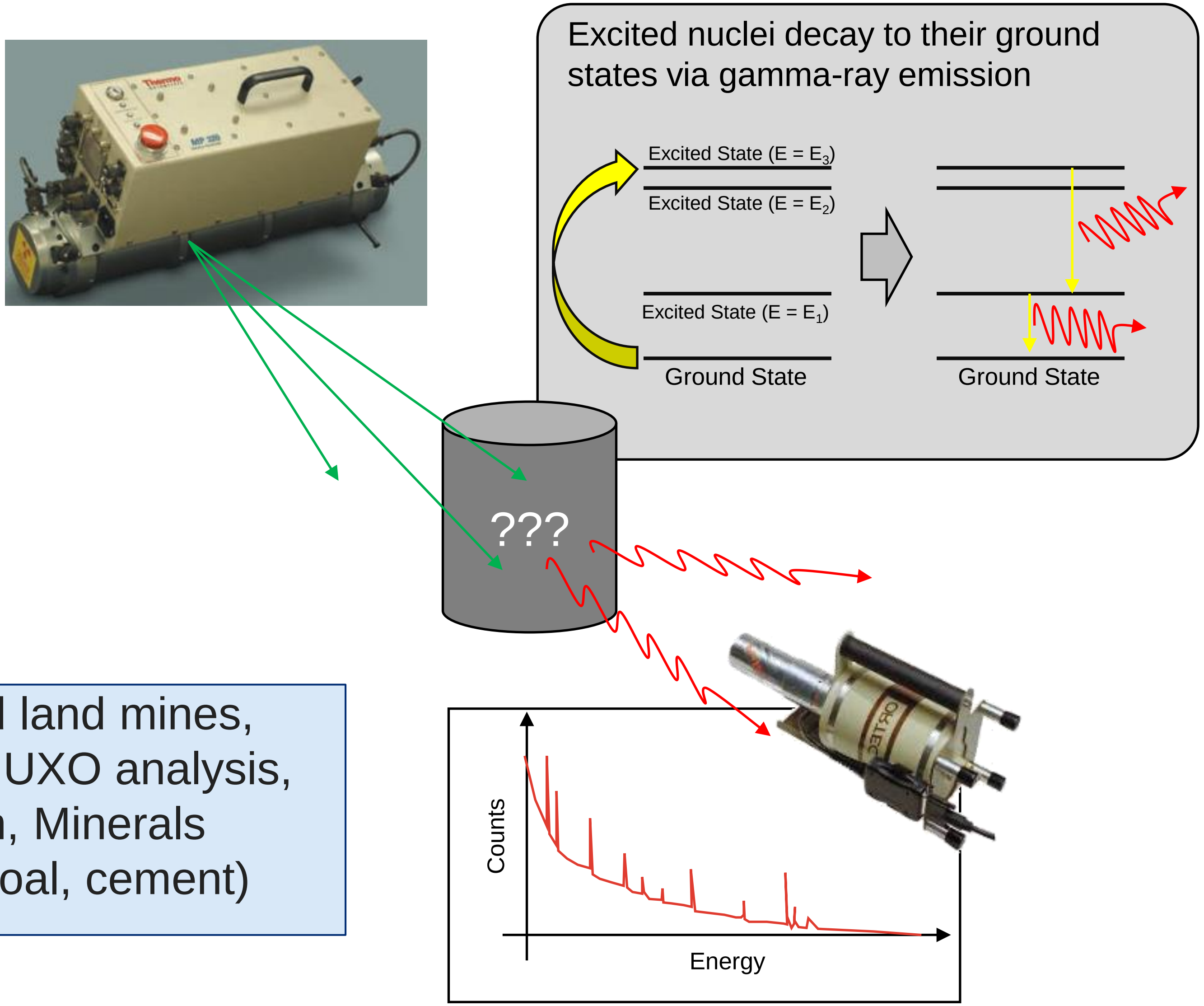
The Berkeley Atlas Team

Institution	Team Members	Expertise					
		Measurements	Compilations	Evaluations	Processing	Validation	Applications
Johns Hopkins Applied Physics Laboratory (APL)	Patrick Peplowski (Project PI) Jack Wilson (Co-I)	✓				✓	✓
Lawrence Berkeley National Laboratory	Arun Persaud (Institutional PI) Mauricio Ayllon-Unzueta (Institutional PI)	✓					✓
University of California, Berkeley	Lee Bernstein (Collaborator) Charles (Joe) Henderson (Graduate Student)	✓				✓	✓
Brookhaven National Laboratory / National Nuclear Data Center	Emanuel Chimanski (Institutional PI) David Brown (Co-I)		✓	✓			
SLB, Inc.	Marie-Laure Mauborgne (Collaborator)	✓				✓	✓

The nuclear data pipeline, from *Kolos et al.* (2022), **Current nuclear data needs for applications**, Phys. Rev. Res. 4.

Applications of Neutron Inelastic Scattering

- Neutron interrogation of an unknown material
  - Gamma-ray energies are isotope-diagnostic
  - Gamma-ray intensities provide material abundances, if:
    - Gamma-ray branching ratios and
    - Gamma-ray production cross sections are known.



Applications: Explosive detection, Buried land mines, **Planetary Science,** Chemical weapons, UXO analysis, Drug detection, In-Vivo body composition, Minerals mining and exploration, Bulk materials (coal, cement)

Motivation – Nuclear Data Deficiencies

- Experimental work has revealed that nuclear data is not sufficient for many elements of interest. Improved nuclear data is required.
- Prior efforts in this area have identified:
  - Spurious (not-real) gamma-ray peaks
    - Lim et al., (2017)
    - Mauborgne et al. (2020)
  - Unphysical gamma-ray emission energy distributions (peak shapes):
    - Prettyman et al. (2006)
    - Peplowski (2020)
  - Inaccurate gamma-ray production rates
    - Yamashita et al. (2003)
    - Bruckner et al. (2011)
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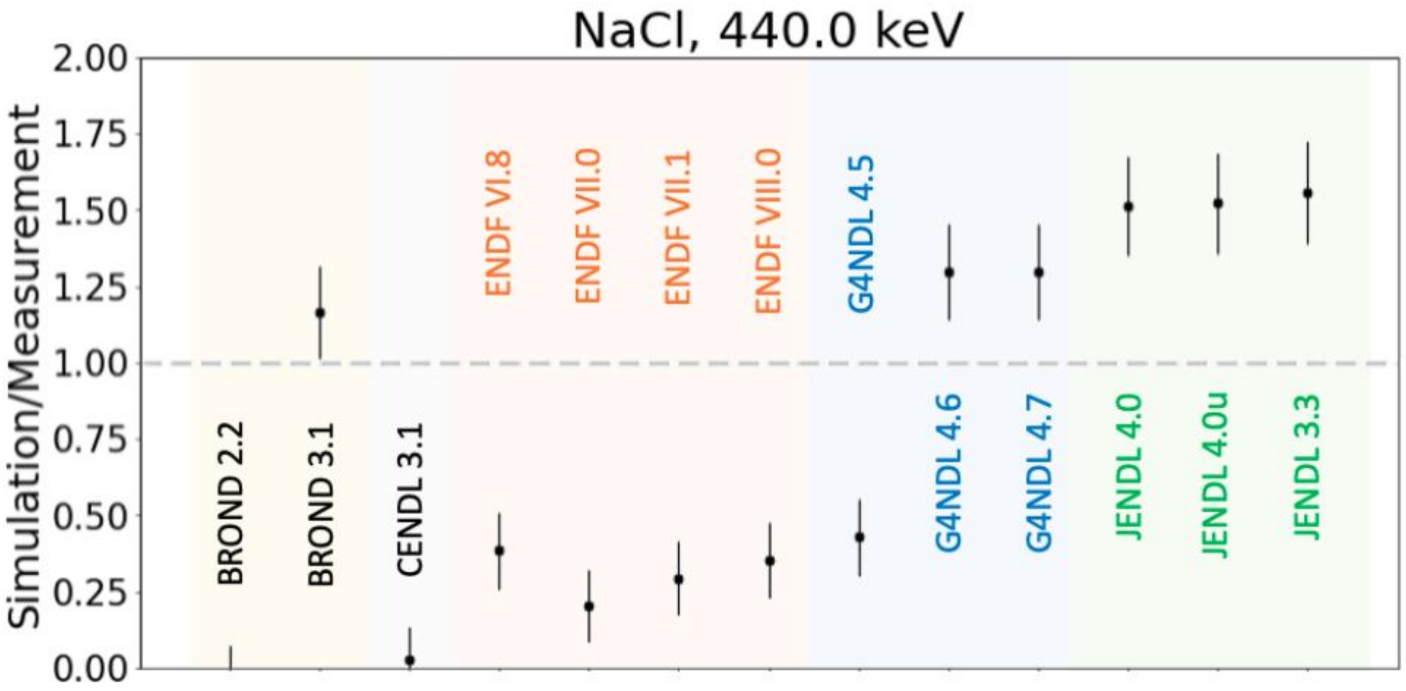

GEANT4 fails to reproduced 440-keV gamma-ray production from Na, as measured during a benchmarking experiment detailed by Peplowski (2020).

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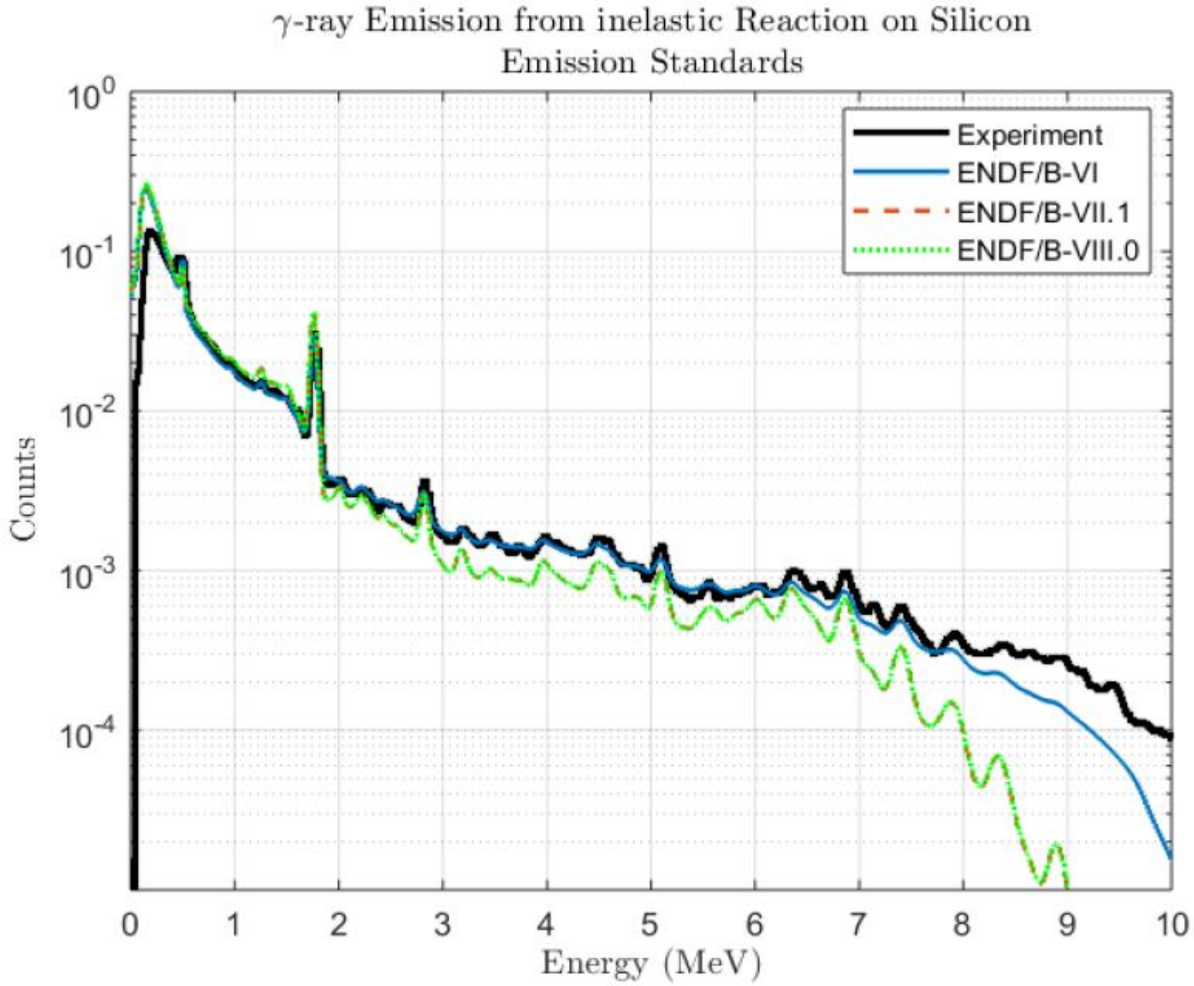


SLB, Inc. uses measured gamma spectra from experiments to interpret data due to shortcomings in neutron cross section libraries (see example from Mauborgne et al., 2020)

Berkeley Atlas Project

- Produce an Atlas of cross sections, measured at 14 MeV neutron energy, to improve neutron cross section libraries.
- We have a new technique for making high-precision measurements of gamma-ray production cross sections using a DT neutron generator, paired with associated particle imaging (API).
- Upgrades to existing API system
- Perform identical measurements on a range of target material of interest for applied nuclear sciences.
- Provide cross-section measurements to the NNDC for evaluation and incorporation into future neutron cross section libraries releases.

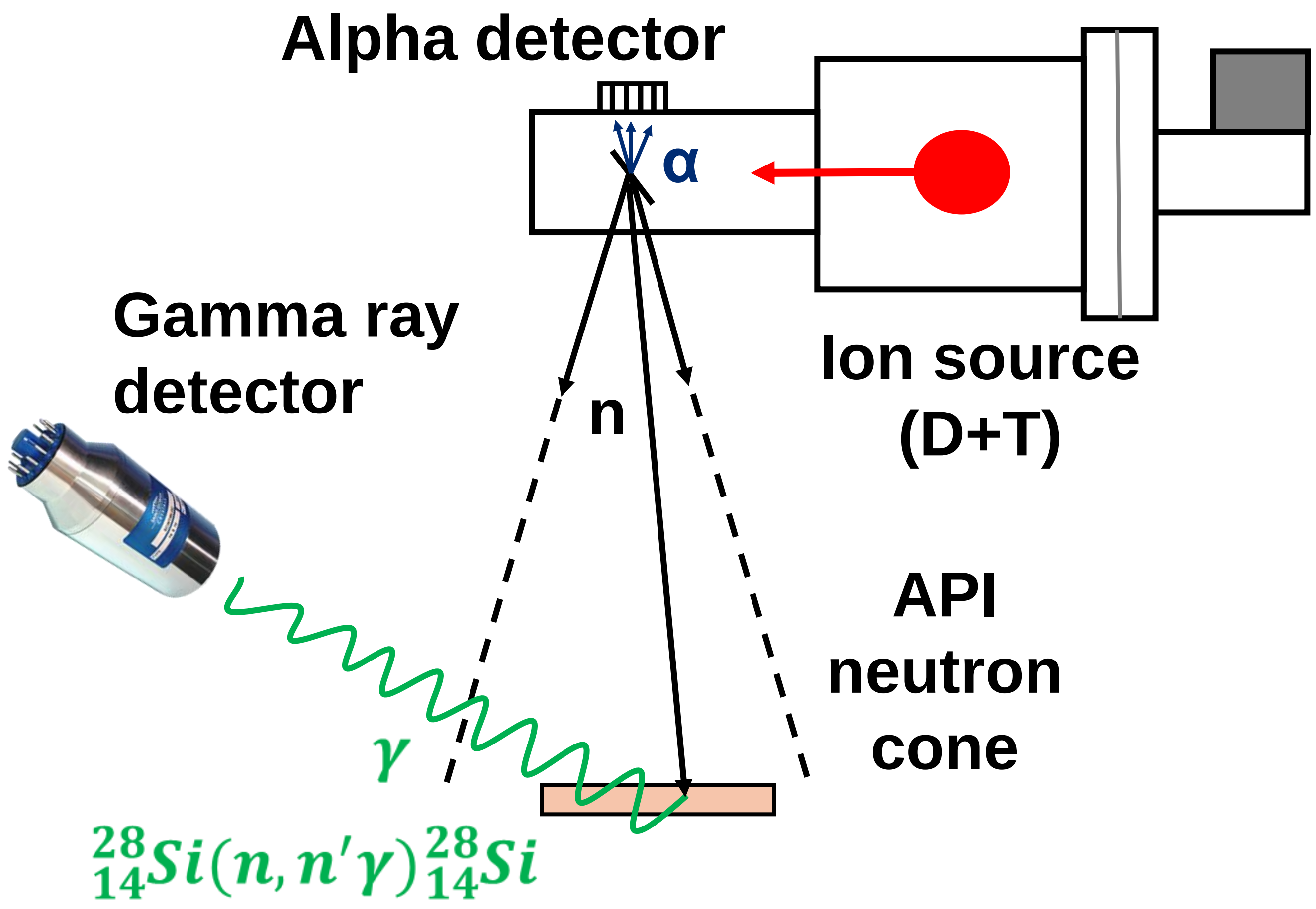
Table 2. Preliminary list of target isotopes and gamma-rays for this study

Isotope	Gamma-Ray Lines (keV)	Isotope	Gamma-Ray Lines (keV)	Isotope	Gamma-Ray Lines (keV)
^{12}C	**4438**	^{35}Cl	1763	^{59}Co	1099, 1190, 1292, 1459, 1481
^{14}N	**2313**	^{39}K	1454	**^{58}Ni**	**1454**
^{16}O	**6129**	^{40}Ca	3736	**^{60}Ni**	**1332**
^{23}Na	**440, 1634**	^{48}Ti	983	^{63}Cu	670, 962
^{24}Mg	**1369**	^{52}Cr	1434	^{65}Cu	771
^{26}Mg	**1809**	^{54}Cr	834	^{64}Zn	992
^{27}Al	**843, 1014, 2211**	^{55}Mn	858	^{66}Zn	1039, 1873
^{28}Si	**1779**	**^{54}Fe**	**1408**	^{90}Zr	1761
^{32}S	2232	**^{56}Fe**	**846, 1238, 1811**	^{208}Pb	2616

The Atlas will include gamma-ray production cross sections for 27 different isotopes (38 different gamma-ray emissions) for materials of interest to the wide variety of applied nuclear fields listed previously.

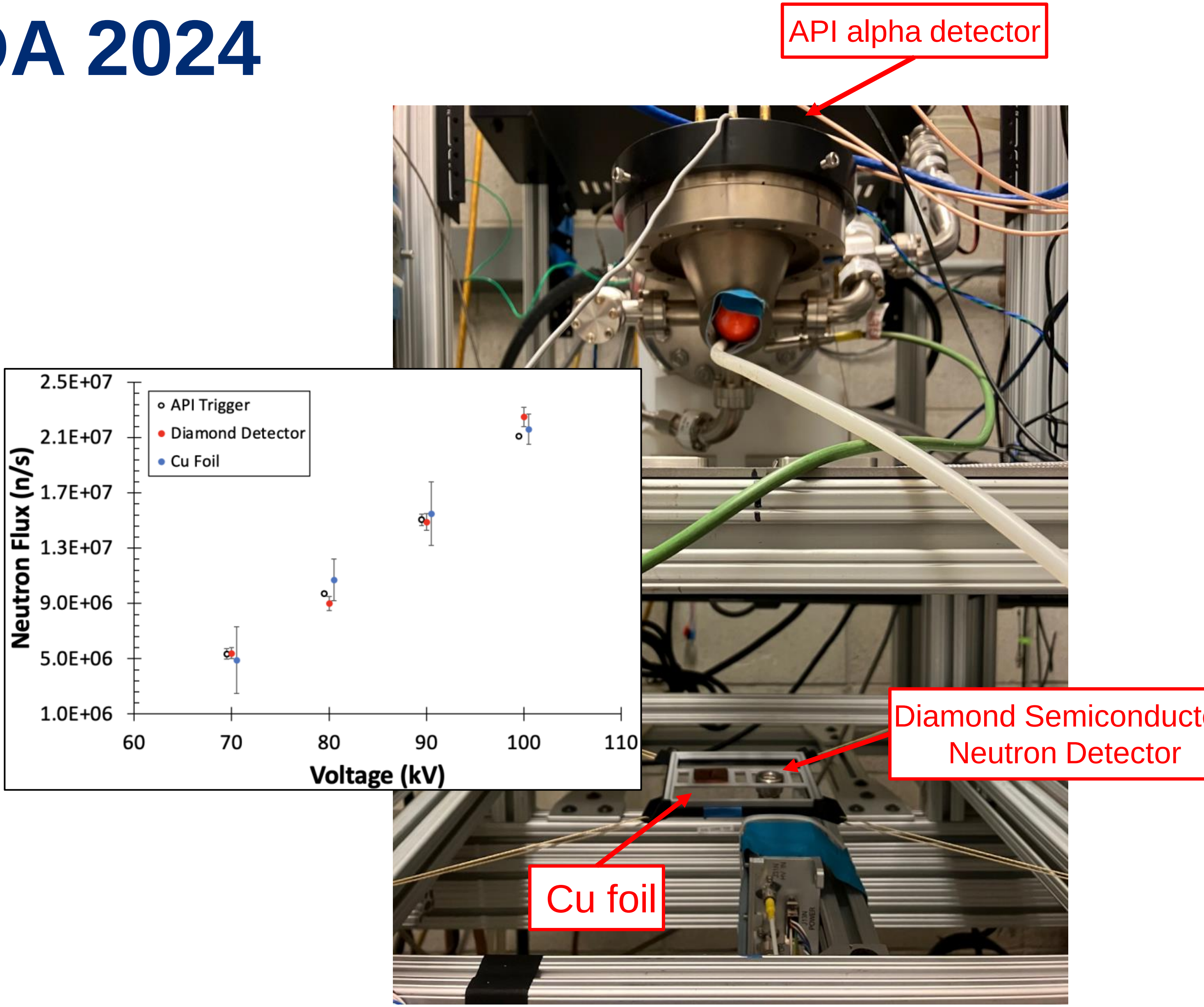
Associated Particle Imaging (API)

- **Direct neutron flux measurements** with low uncertainties due to alpha-tagging.
- **Only prompt reactions** within coincident window (10's of ns).
- **Quasi-monoenergetic** 14.1 MeV neutrons.
- Strong **background suppression**.
- Compact, low-cost.



Progress since WANDA 2024

- Validated ability to make precise measurements of neutron flux on target.
- Replaced scintillator-based gamma-ray detectors ($CeBr_3$, $LaBr_3$, NaI) with HPGe.
  - 2.4 keV @ 661.7 keV
  - 30-ns timing resolution
- Validated measurement approach and data analysis process via trial measurements with titanium targets.



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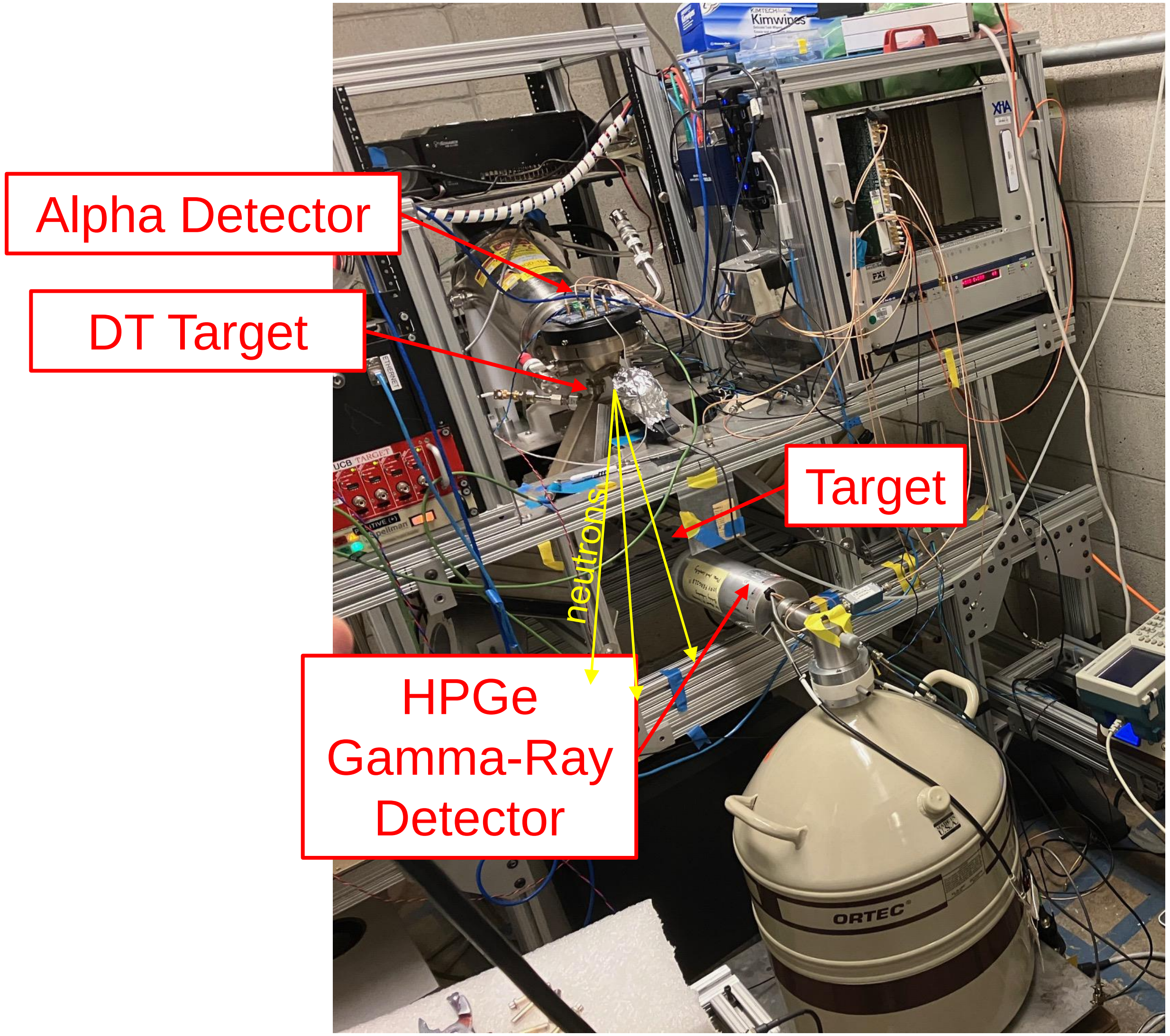

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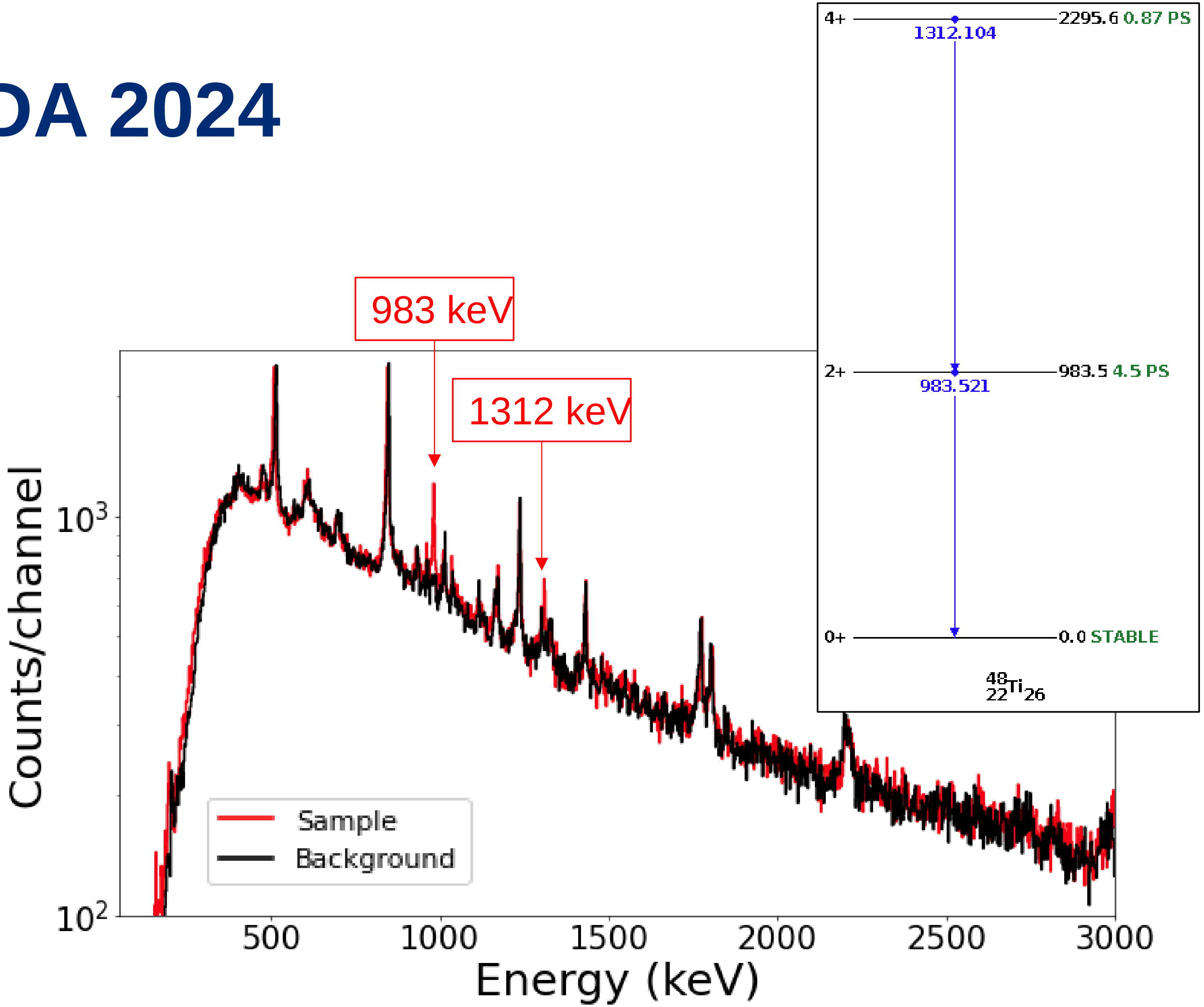

2.4 keV FWHM @ 661.7 keV

Schedule

- 24-28 March 2024: Commissioning experiment with Fe target
  - Validate our experimental technique using a well-known cross section
  - Plan to write a technique paper detailing cross section measurements with DT-API & HPGe detectors
- May 2025: All thin-target measurements (27 isotopes, 38 separate gamma-ray emissions)
  - Publish the Berkeley Atlas
- Summer 2025: Thick-target measurements
- Early 2026: Incorporate measurements into ENDF evaluations & perform EMPIRE modeling.