CVT Workshop

October 31 – November 1, 2018

Stilbene Cell for Radioxenon Detection

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Introduction and Motivation

- Comprehensive Nuclear-Test Ban Treaty bans nuclear testing worldwide

- Established a verification regime consisting of 4 continuously monitoring technologies:
  - Seismic
  - Infrasound
  - Hydro acoustic
  - **Radionuclide**

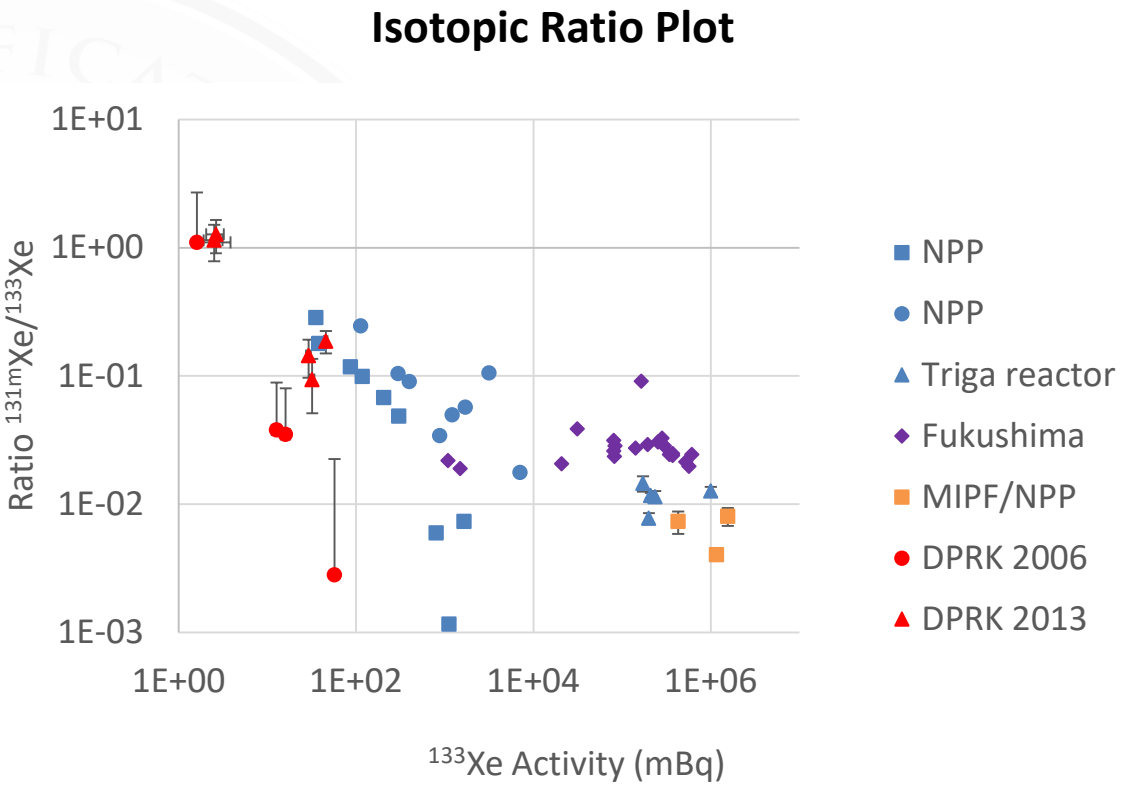
International Monitoring System: Radionuclide Stations

Ctbto.org

67 radionuclide stations worldwide (red)
80 total radionuclide stations planed (grey)
25 radioxenon stations (R+)

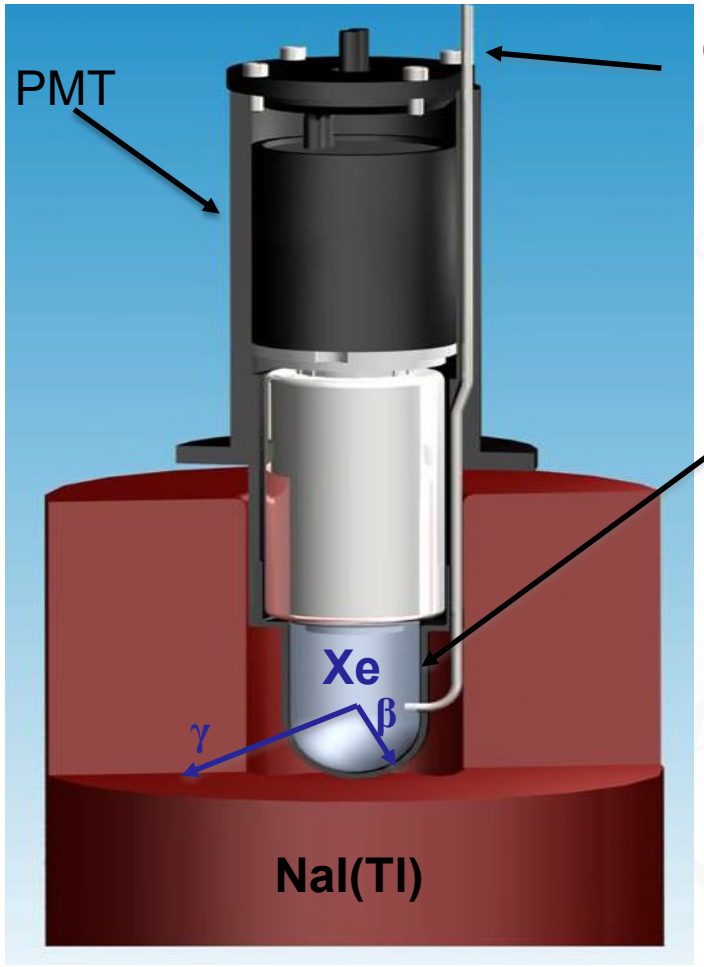
Radioxenon for Nuclear Explosion Monitoring

- Noble gases can reach the surface even in underground explosions making clandestine testing difficult
- Radioxenon has the highest cumulative fission yield of the noble gases produced
- Radioxenon has been measured from a variety of sources such as Chernobyl, Fukushima, and DPRK nuclear tests



C. B. Sivels, A. M. Prinke, J. I. McIntyre, S. D. Clarkei, S. A. Pozzi, "Anticoincidence analysis for radioxenon detection," Journal of Radioanalytical and Nuclear Chemistry, vol. 318, 1, pp. 561-567, 2018.

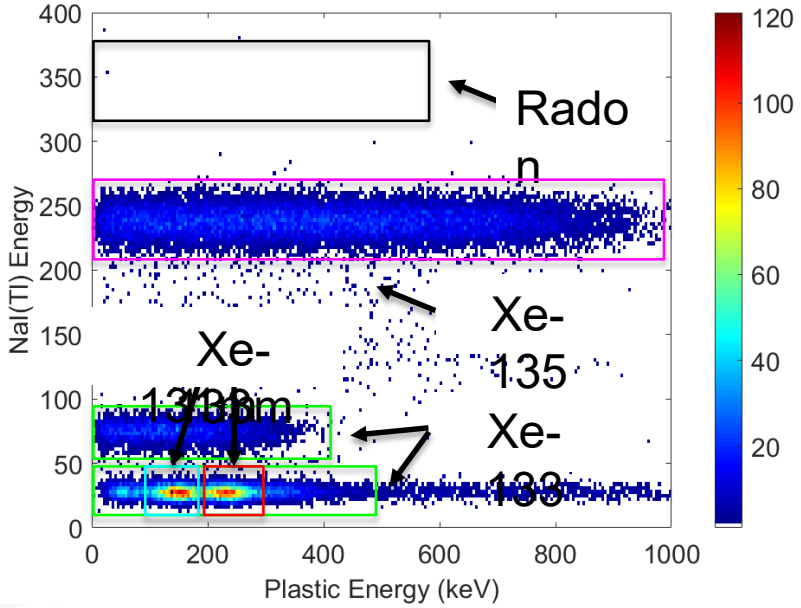
Current Method to Measure Radioxenon



Cooper M.W. et al. NIM A (2007) 579:426-430 doi: 10.1016/j.nima.2007.04.092

Isotope	Electron Energy (keV)	Photon Energy (keV)	Half-life
^{131m}Xe	129	~30	11.84 d
^{133m}Xe	198	~30	2.198 d
^{133}Xe	346 (endpoint)	~30 and 80	5.248 d
^{135}Xe	950 (endpoint)	250	9.14 h

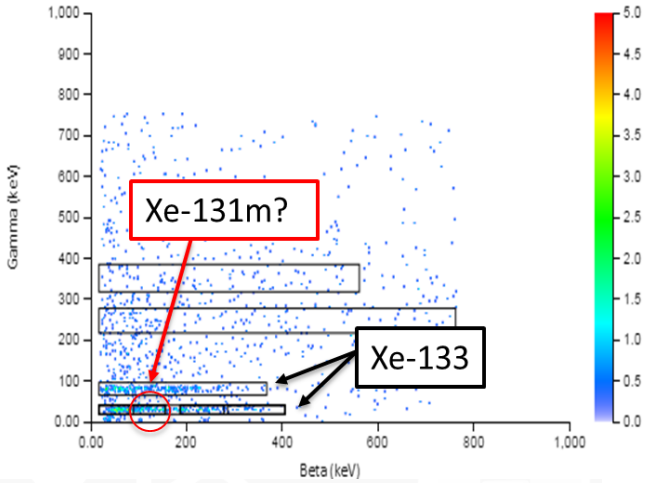
Simulation of the 4 radioxenon isotopes of interest



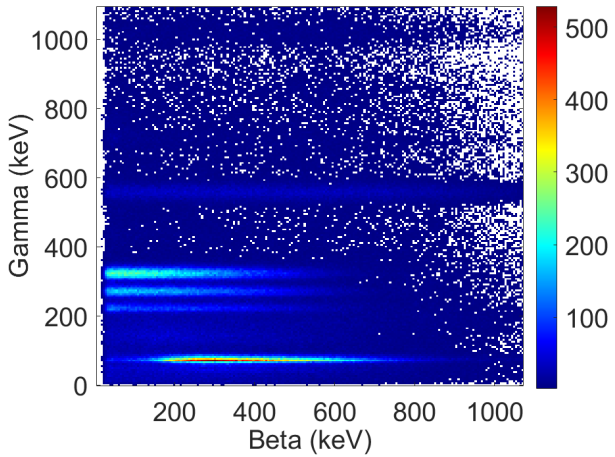
Current Limitations to Radioxenon Detection

- Xe-133 interferes with metastable isotopes complicating source characterization
- Radon interferes with all ROIs and its removal is a major system component
- Memory Effect: Radioxenon diffuses into plastic raising the background of subsequent measurements and decreasing detector sensitivity

DPRK Nuclear Test – February 2016



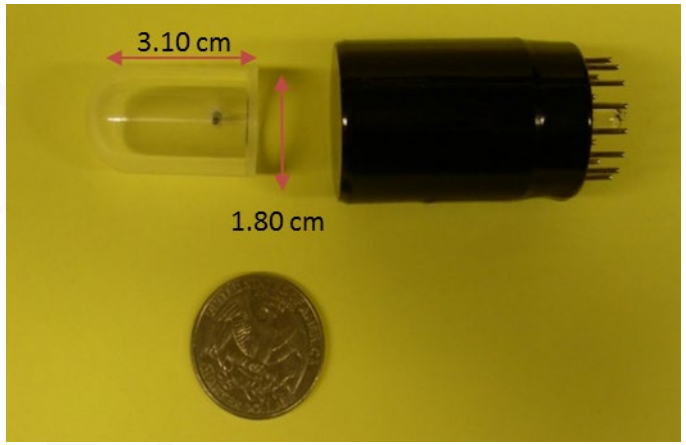
Radon Measurement



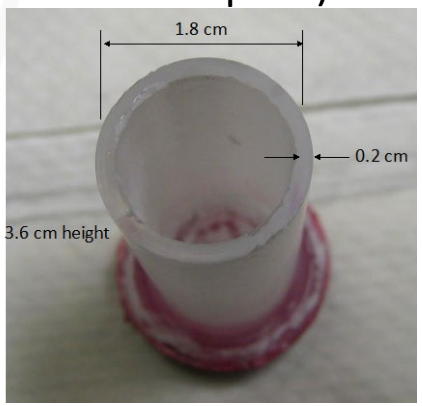
Advantages of Stilbene

- Improved energy resolution
  - Decreases ROI bounds leading to increased sensitivity
- Pulse Shape Discrimination
  - Discrimination of radon alphas and xenon betas
- Decreased memory effect
  - Improves detector sensitivity and extends measurement time
- Alternative scintillator
  - Maintains geometry and efficiency

PNNL plastic beta cell



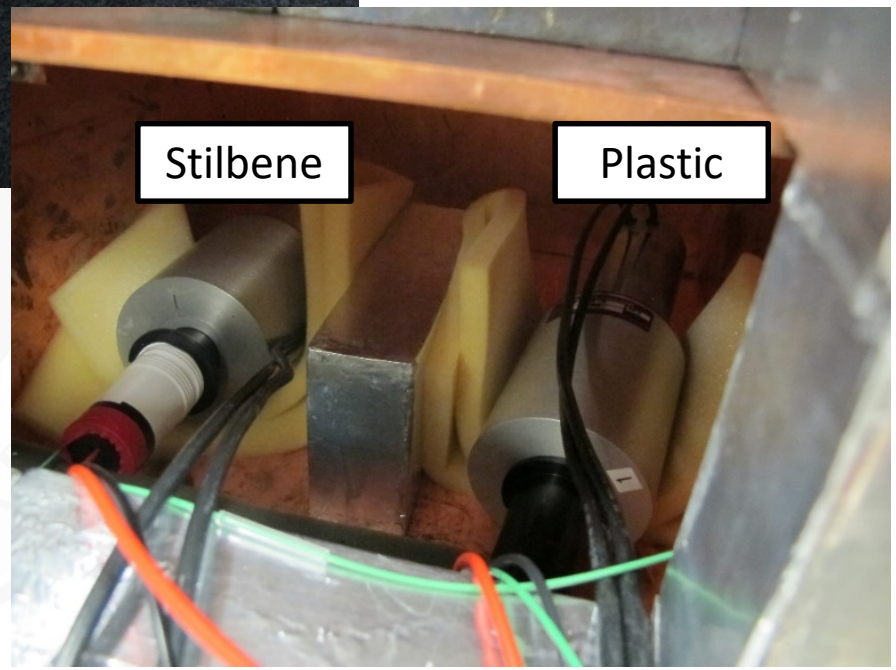
Stilbene Prototype (Manufactured by Inrad Optics)



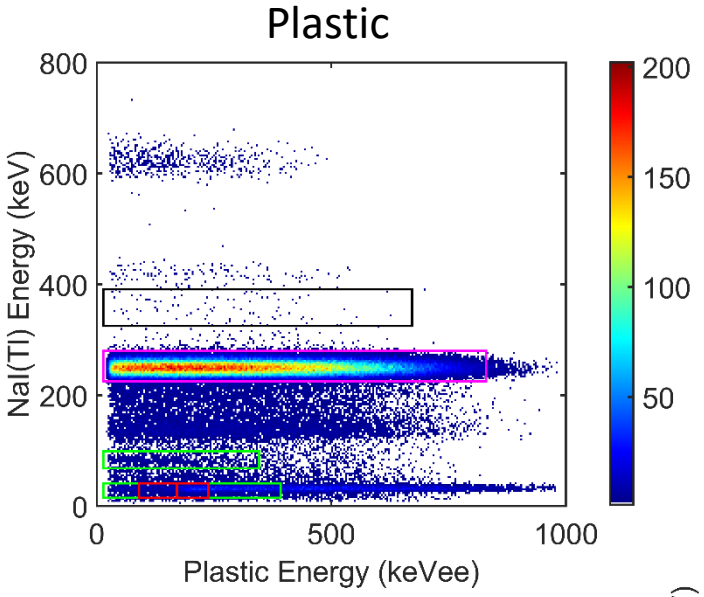
W.K. Warburton, "Stilbene Research to Support a Portable β/γ Scintillation Detector with Improved Radioxenon MDC's" RMR 2014

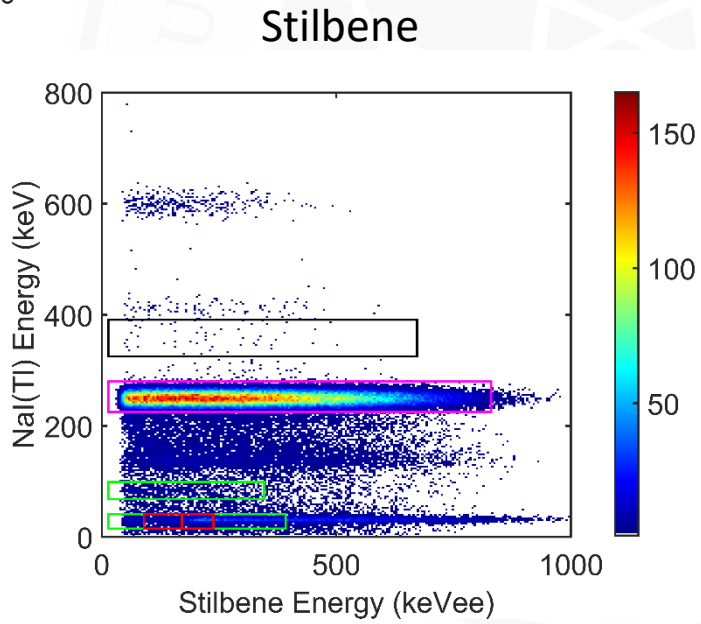
Overview of PNNL Experimental Campaigns

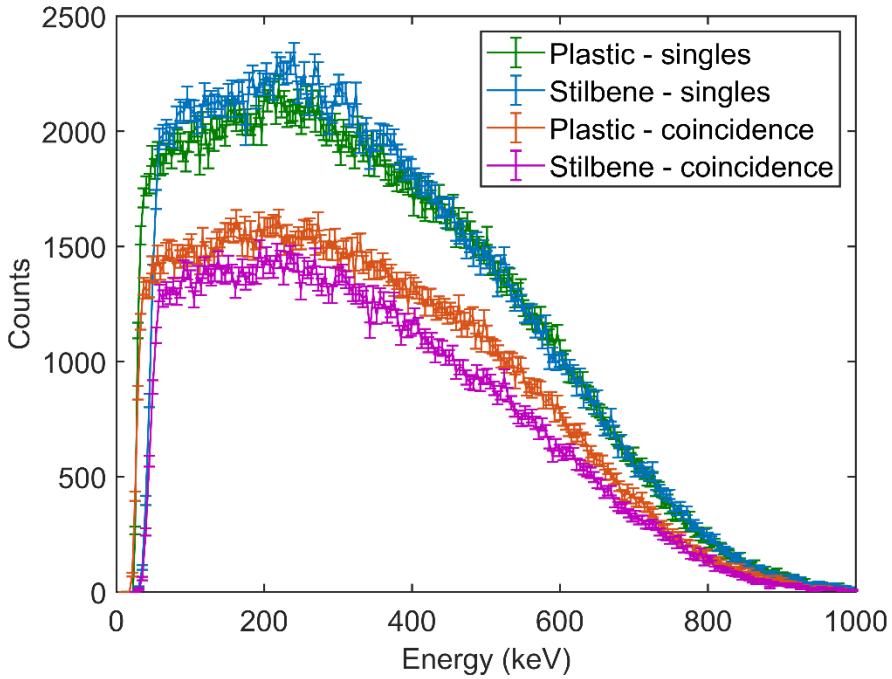
- Side by side plastic and stilbene experiments
  - Gas line connected to both detectors
  - Stilbene cell volume is 20% larger
  - Solid angle difference
- Experimental Campaign 1
  - Tested vacuum stability of cell
- Experimental Campaign 2
  - Full characterization campaign



Results: Xe-135 Measurement



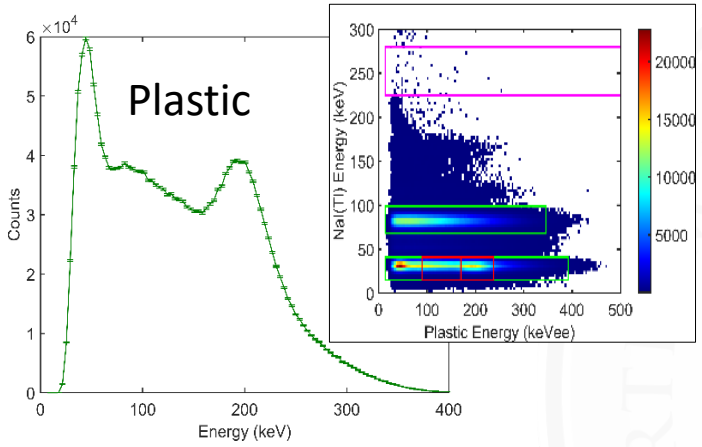


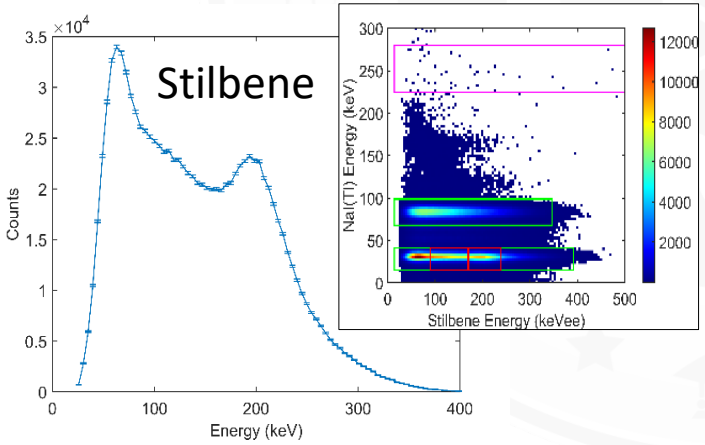


- Ratio of coincidence to singles counts is less for stilbene compared to plastic suggesting gamma efficiency drop

Results: Xe-133m and Xe-131m Measurements

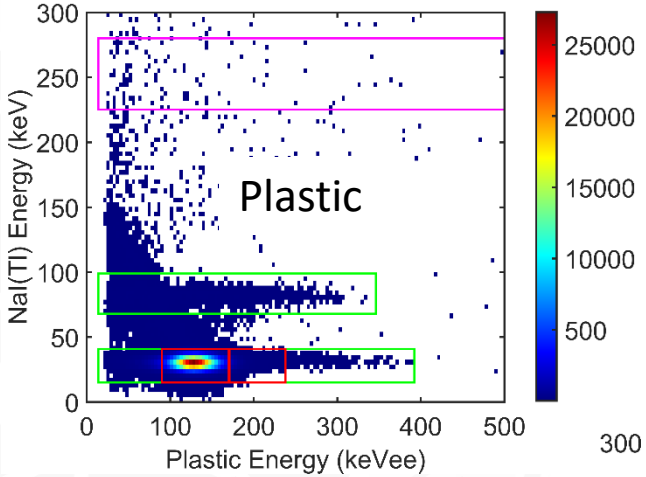
Xe-133m

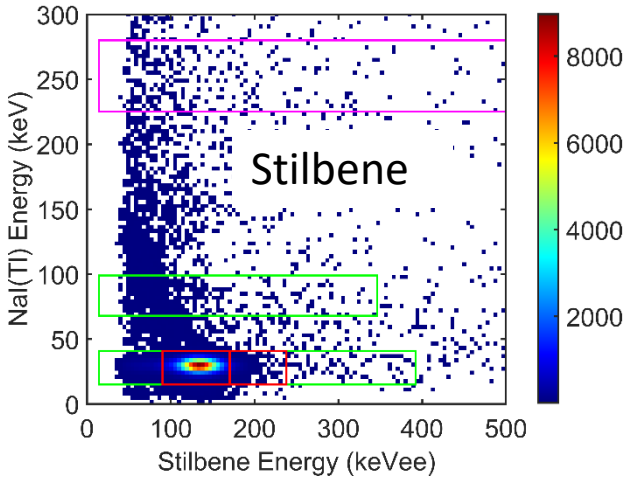




- Beta spectra gated on 30-keV
- 45-keV broadened for stilbene

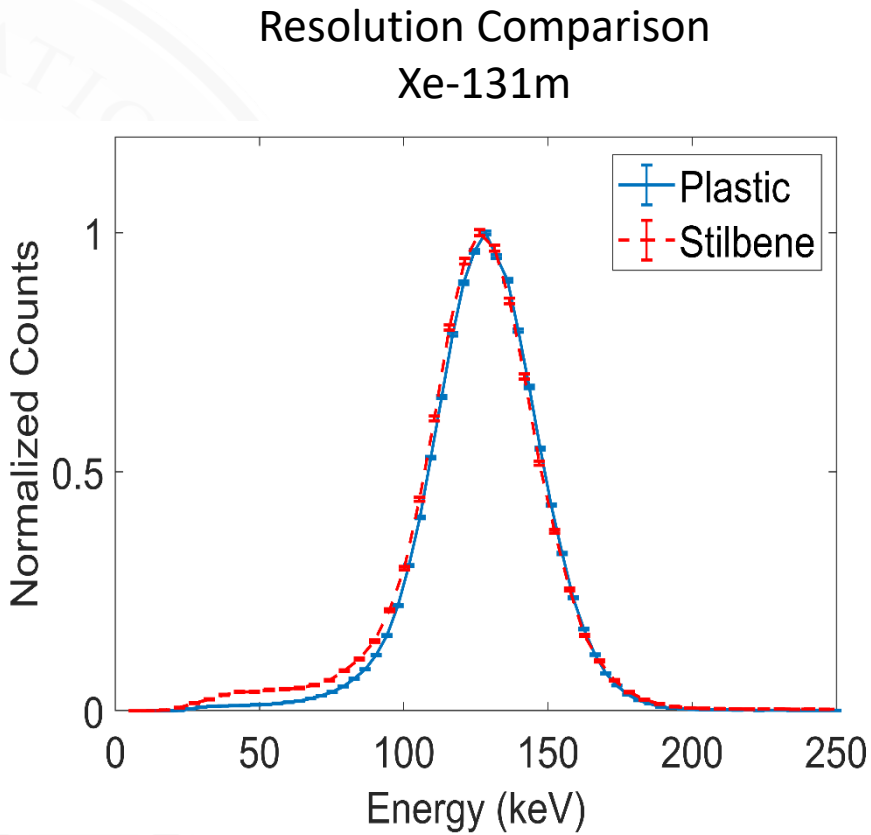
Xe-131m





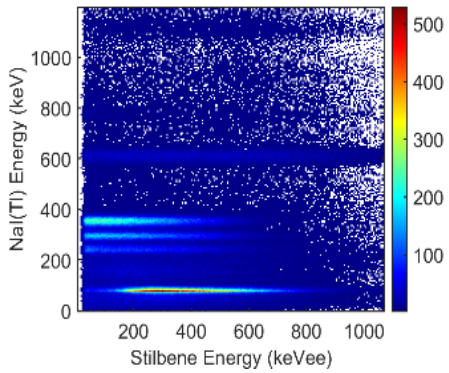
Results: Detector Characterization

- Stilbene resolution slightly improved
  - 2.2 keV FWHM decrease
- Stilbene efficiency decreased
  - Average 15% decrease
- Efficiency decrease for stilbene cell leads to increased minimum detectable concentration
  - Average 0.1 mBq/m^3 increase

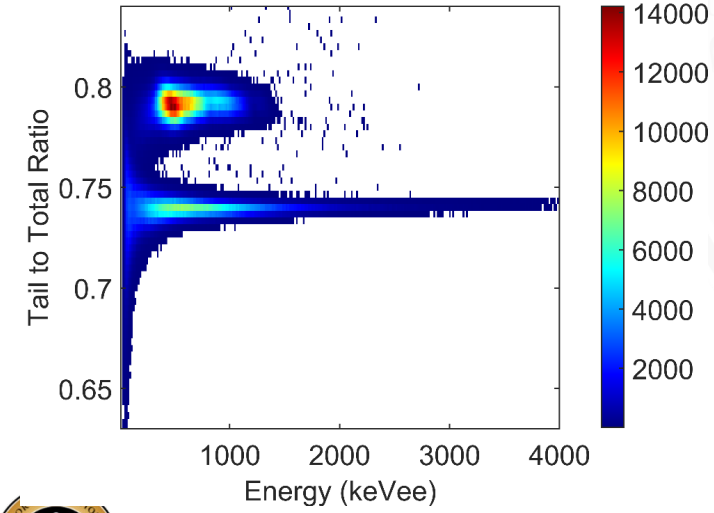


Results: Radon Pulse Shape Discrimination

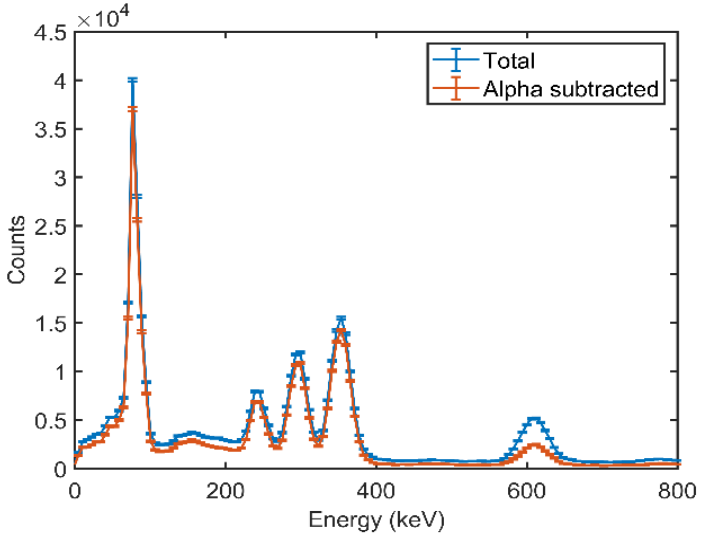
- The use of stilbene allows for the identification of alpha particles emitted by radon which can be used to mitigate interference
- Results in 1% decrease in MDC for Xe-135 and can be used for environmental monitoring applications



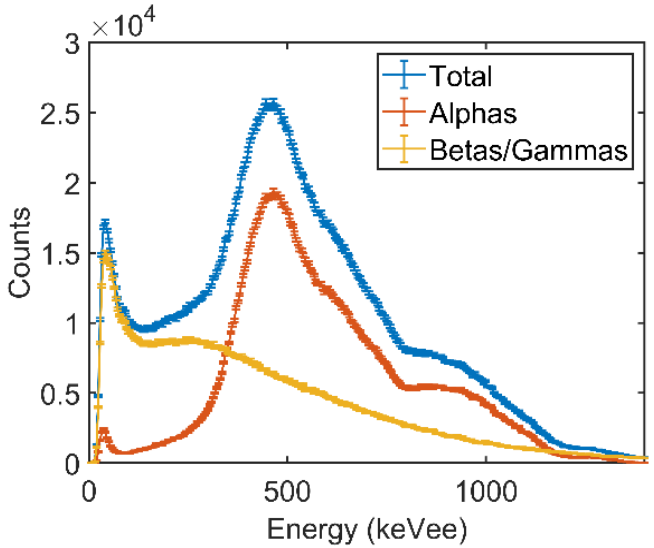
Radon Alpha/Beta Discrimination Experiment



NaI(Tl) Coincidence Spectrum



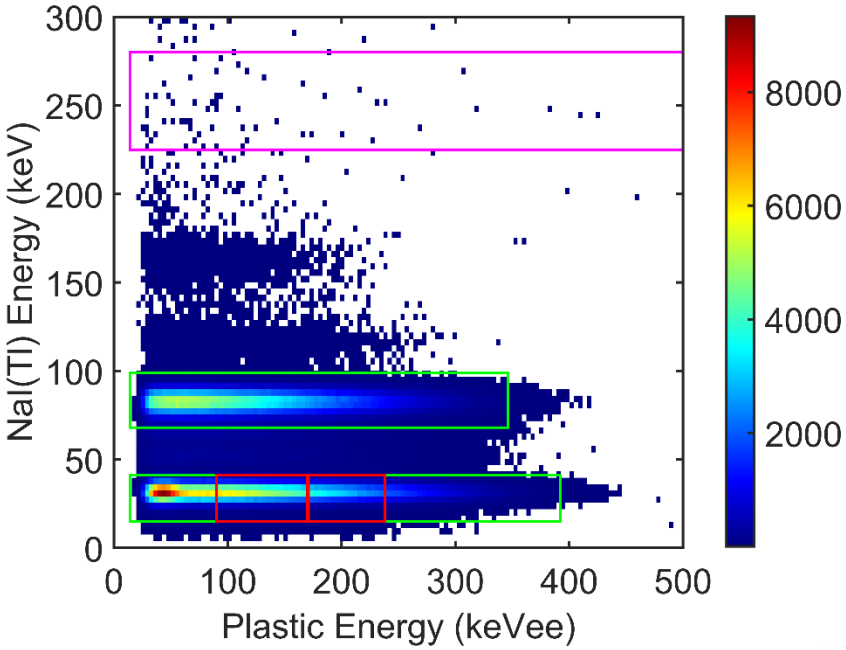
Stilbene Spectrum



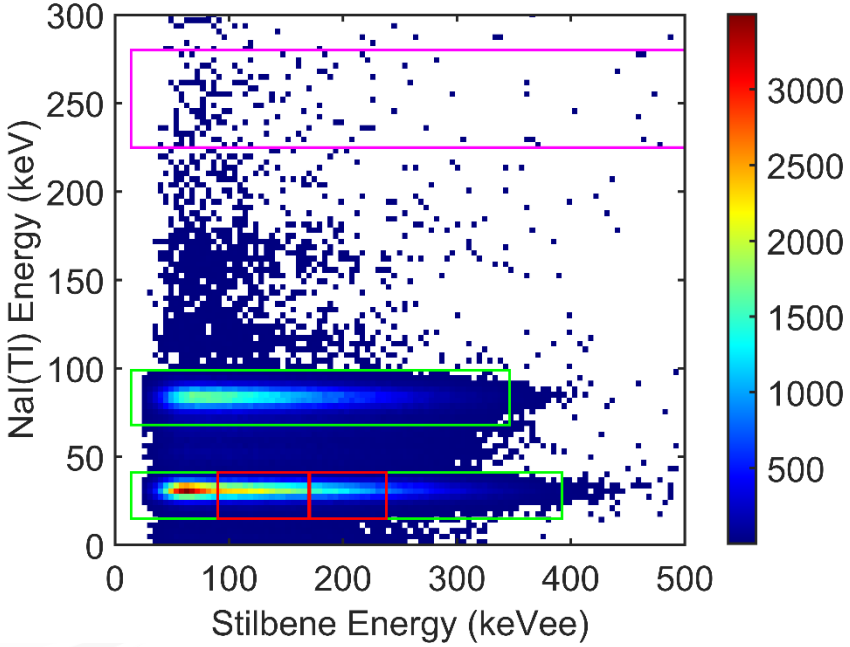
Memory Effect Experiment

- Testing for residual activity remaining in cells
- Xe-133 was measured for 3 days

Plastic

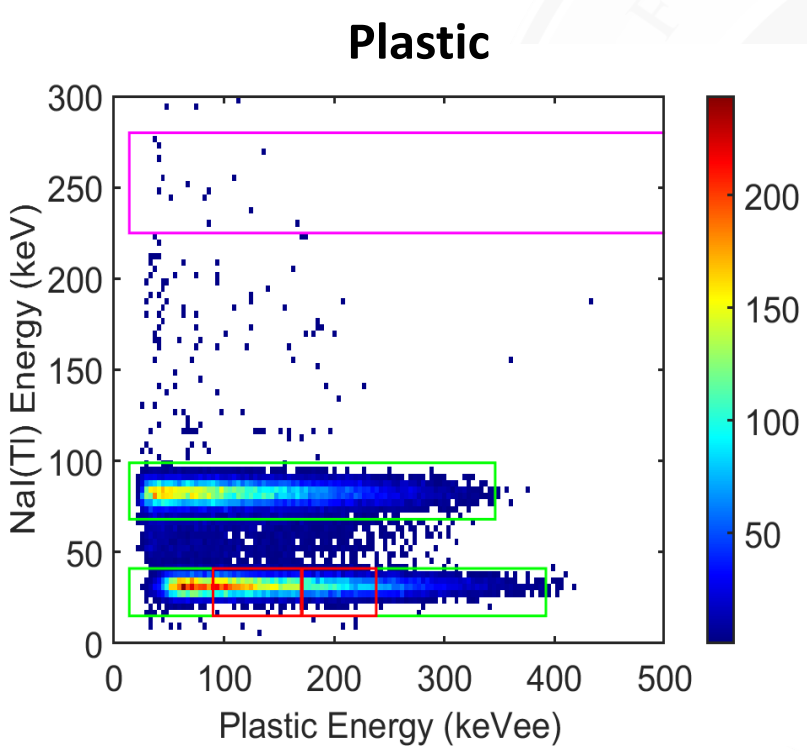


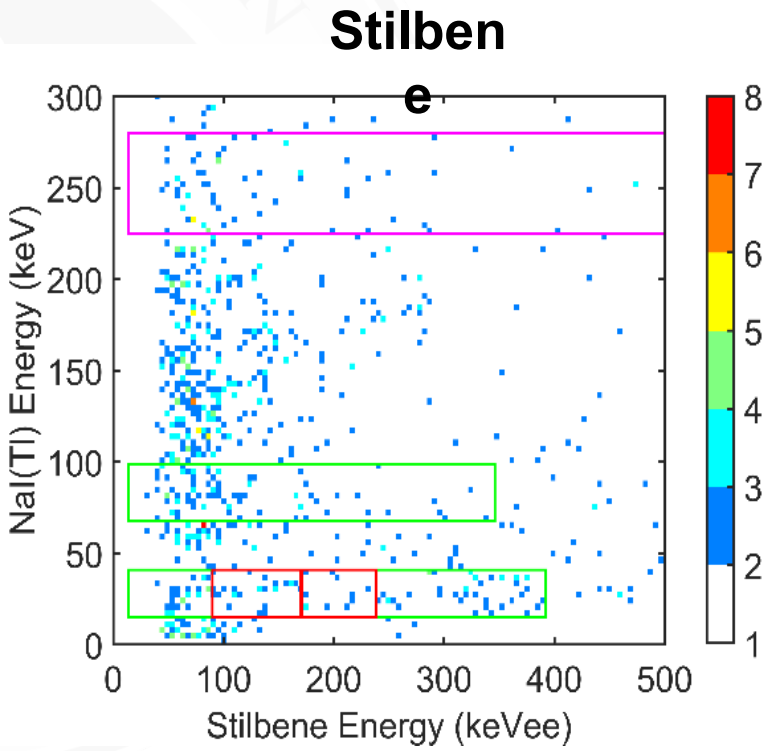
Stilbene



Results: Memory Effect Analysis

- Residual activity remaining: 4.5% plastic and 0.043% stilbene
- Memory effect is approximately 100-times smaller
- IMS stations would have extended time to measure atmospheric samples = **increased sensitivity**





CVT Impact

- Numerous internships and experimental campaigns at PNNL
- Participation in the 2017 CTBT Science and Technology conference in Vienna, Austria
- Presentation at the International Noble Gas Experiment Conference sparked interest from CTBT partners
- Research resulted in National Laboratory Impact Award

Conclusion

- The almost negligible memory effect of the stilbene cell can improve the overall sensitivity of the verification regime
- A balance between light collection and ruggedness is needed for in-field use of the stilbene cell to maximize performance
- Future work includes field measurements with the stilbene cell

Acknowledgements

The Consortium for Verification Technology (CVT) would like to thank the NNSA and DOE for the continued support of these research activities.

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