SAND2011-3773C

Office of Nonproliferation and Verification Research & Development

SNM Movement Detection / Radiation Sensors and Advanced Materials Portfolio Review

RadSensing2011

^{6}Li with alkali halides and PSD for thermal neutron detection

Erik Brubaker

Sandia National Labs, Livermore, CA

9 June, 2011

^{6}Li in alkali halides with PSD

One talk, two projects

- **"A He-3 Replacement Detector: Inorganic Scintillators with Li-6 Conversion Layers and PSD"**
  - **SNM Movement portfolio**
  - **$275k, 1 year feasibility study**
  - **Erik Brubaker (PI), Dean Dibble, both SNL.**

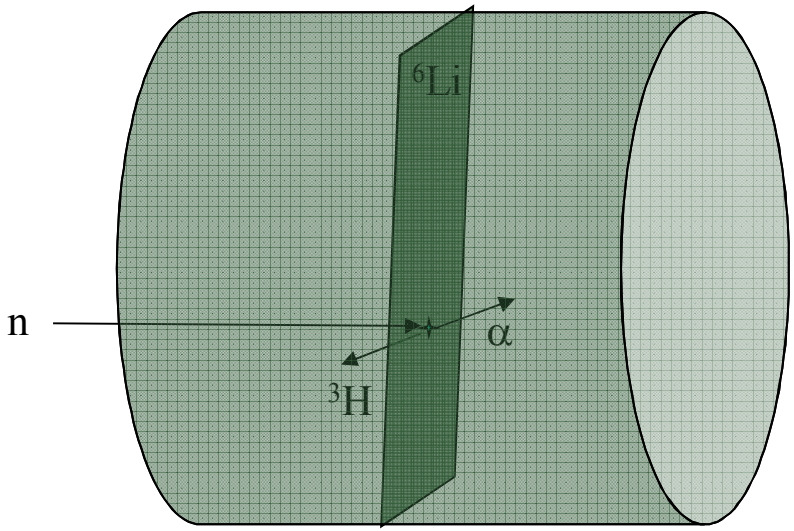
- **"A He-3 Replacement Detector: ^{6}Li-doped Inorganic Scintillators with PSD"**
  - **Advanced Materials portfolio**
  - **$200k, 1 year feasibility study**
  - **Erik Brubaker (PI), Dean Dibble, Pin Yang, all SNL.**

^{6}Li in alkali halides with PSD

Overview

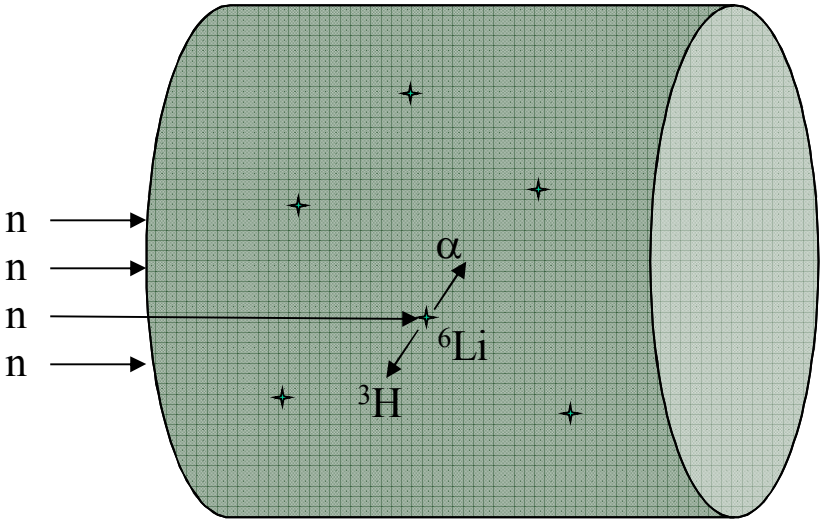
- We will use NaI(Tl) or CsI(Tl) with Li-6 as thermal neutron capture agent.
- ^{6}Li(n,α)^{3}H reaction yields 2.0 MeV alpha, 2.7 MeV ^{3}H → detected in scintillator.
- PSD discriminates heavier alpha, triton recoils from gamma events.

^{6}Li foil



➢ **Efficiency of a single converter foil limited by α/t range of 20-100 μm.**

^{6}Li as dopant



➢ **Efficiency depends on dopant concentration achievable without degrading too much the scintillation.**

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^{6}Li in alkali halides with PSD

Goals

National Nuclear Security Administration
Defense Nuclear Nonproliferation

- **Foil: The goal of our investigation is to observe the anticipated effect and characterize our thermal neutron detection efficiency as a function of gamma background rejection. Feasibility as a helium-3 replacement concept would be indicated by the demonstration of a single-foil detection efficiency of ~1% with gamma sensitivity of ~10^{-4}; or a well-motivated extrapolation to such performance based on experimental results.**
- **Dopant: The goal of our investigation is to observe the anticipated effect and characterize our thermal neutron detection efficiency as a function of gamma background rejection. Feasibility as a helium-3 replacement concept would be indicated by the demonstration of a detection efficiency of ~5% in a two inch crystal with gamma sensitivity of ~10^{-4}; or a well-motivated extrapolation to such performance based on experimental results.**

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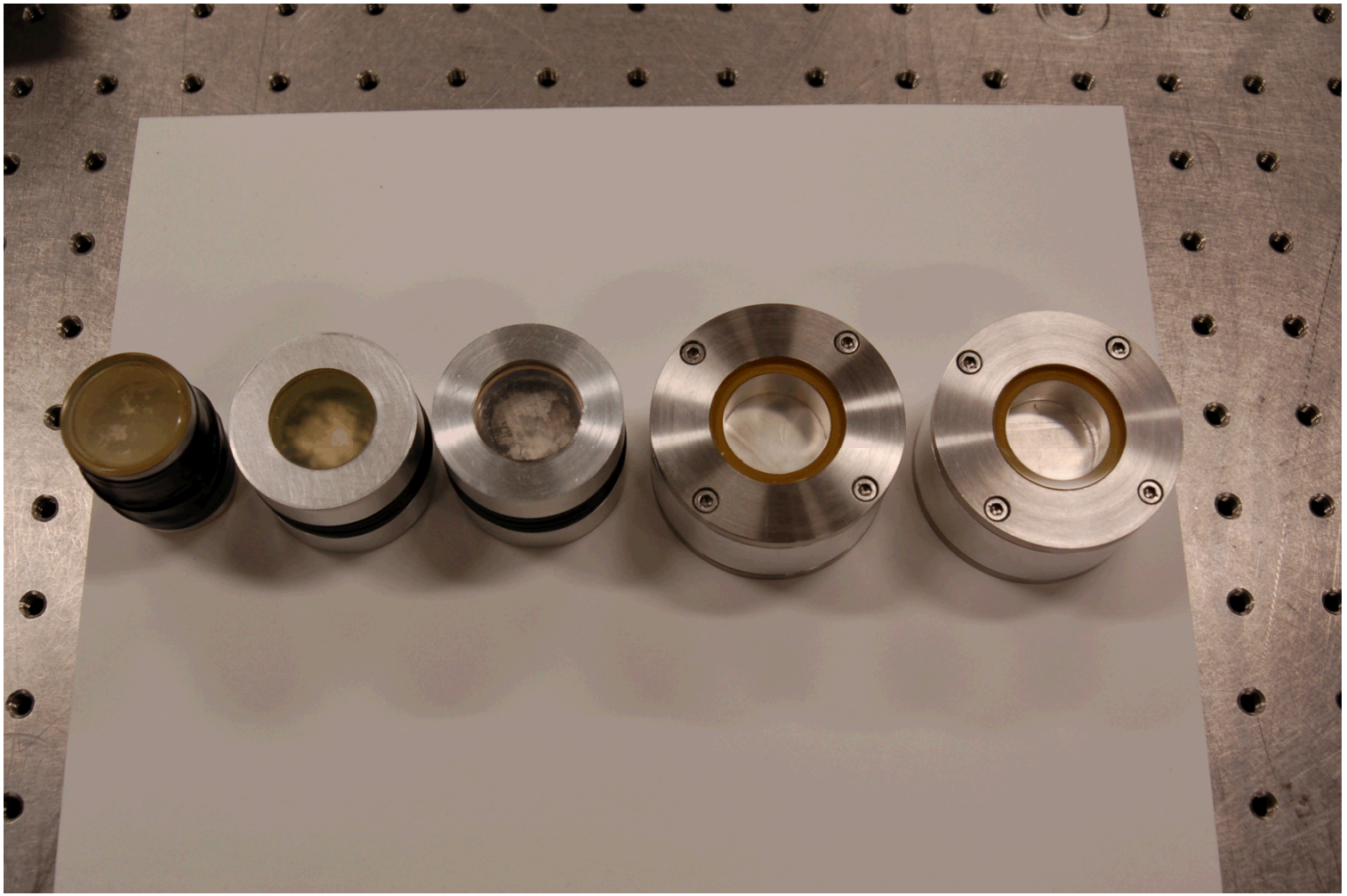
^{6}Li in alkali halides with PSD

Foil samples produced/tested

NNSA National Nuclear Security Administration
Defense Nuclear Nonproliferation



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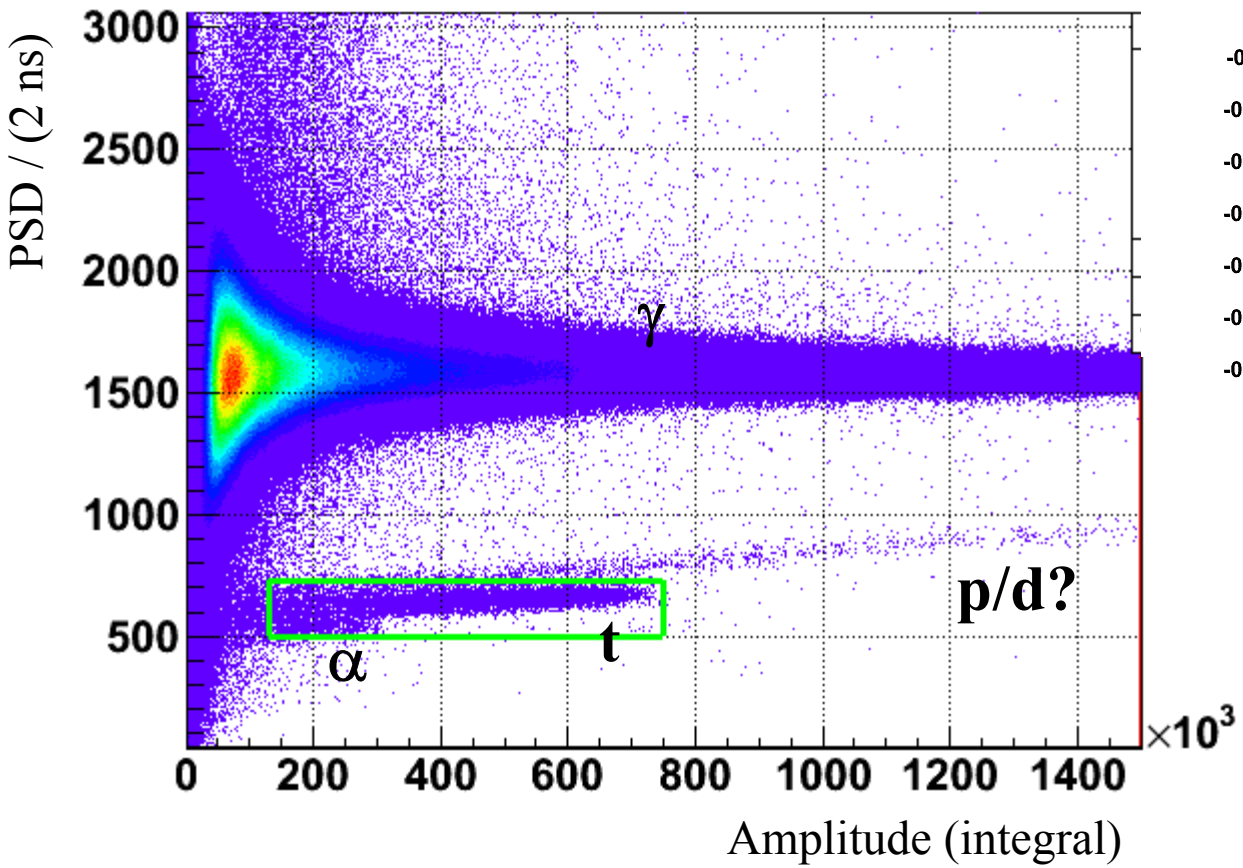
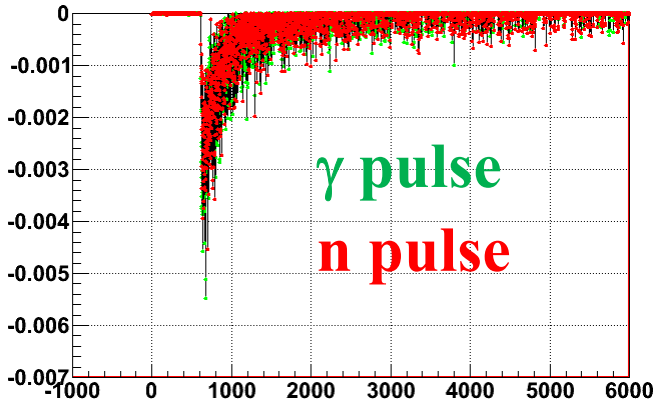
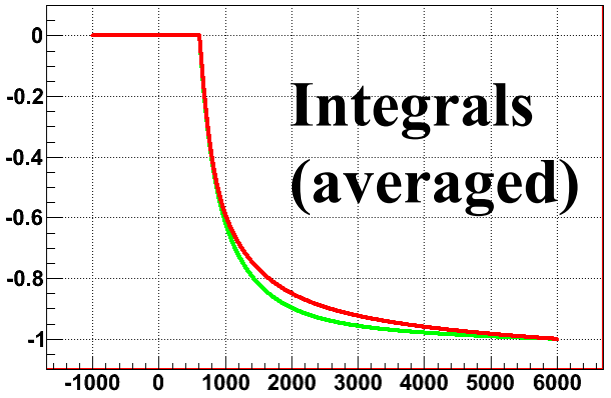
^{6}Li in alkali halides with PSD

Sample PSD vs Amplitude plot







CsI(Tl) PSD FOM: ~3

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^{6}Li in alkali halides with PSD

Doped samples produced/tested

National Nuclear Security Administration
Defense Nuclear Nonproliferation

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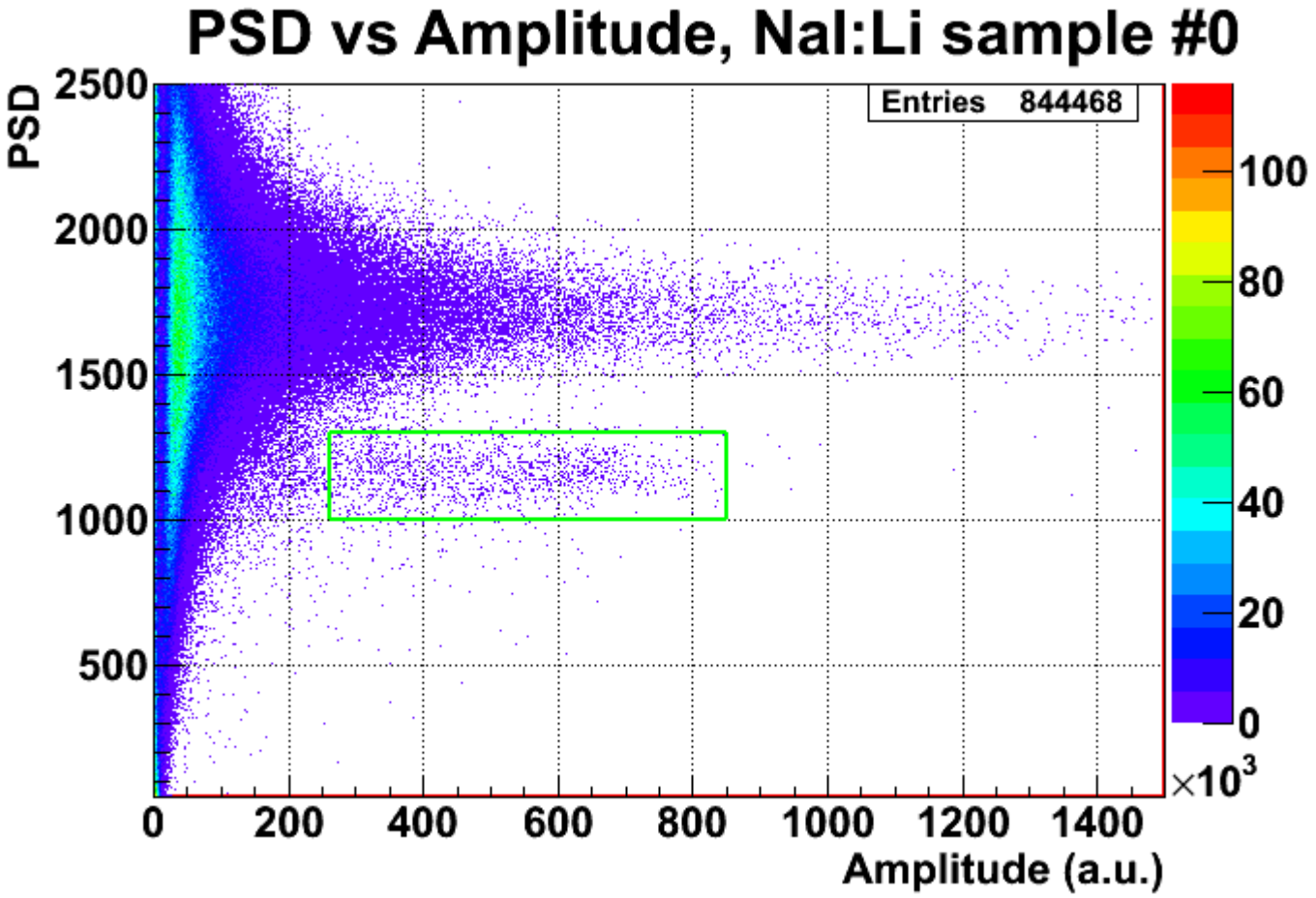
^{6}Li in alkali halides with PSD

Sample PSD vs Amplitude plot



NaI(Tl):LiI PSD FOM: ~1.5

^{6}Li in alkali halides with PSD

Thermal neutron efficiency

- Generate thermal neutrons from Cf-252 source in a HDPE “cave”.
- He-3 detector rate 1090 Hz, sensitivity 89.1 cps/nv.
- Conclude 12.2 ± 1.2 n/cm^2/s
  - Uncertainty from variation with time & position.
- Replace He-3 detector with each sample in succession. Assume thermal neutron flux is constant.

^{6}Li in alkali halides with PSD

Efficiency Results

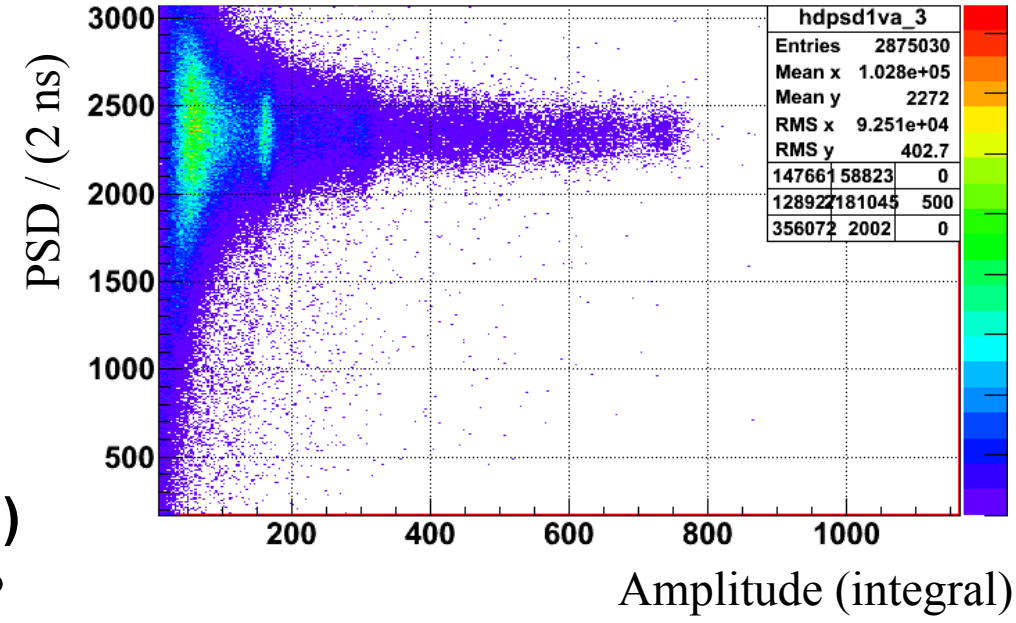
Sample	Active area	Thermal n efficiency	
		Measured (nat. Li)	Extrapolate 100% Li-6
NaI(Tl) + Li foil	5 cm^2	0.7%	8.4%
CsI(Tl) + Li foil	5 cm^2	0.6%	7.2%
CsI(Na) + Li foil	5 cm^2	0.3%	3.6%
NaI(Tl):LiI	1.3 cm^2	3.4%	37%
		± 20% (rel)	± 30% (rel)

- **Signal regions drawn by eye.**
- **Corrected for fast neutron contribution where possible.**
- **Uncertainties ±20%, dominated by thermal neutron flux.**
- **Assume foil capture eff. 1.5% (nat Li) → 18% (100% Li-6).**
  - **±20% on extrapolation.**

^{6}Li in alkali halides with PSD

Gamma rejection

- High-intensity gamma run shows no gamma-induced signal.
- Some poorly reconstructed events fall inside signal box.
  - Misreconstructed baseline.
  - Other pathological cases?
- Gamma/triton separation is excellent for CsI (FOM ~ 3), good for NaI (FOM ~ 1.5). Misreconstructed events can be cleaned up/rejected.
- Improved γ rejection from:
  - Coincidence signal (foil)
  - Thin scintillator layers (foil)
  - Different Tl concentration?
- Bottom line: 10^{-4} – 10^{-7} possible.



^{6}Li in alkali halides with PSD

Future work

- **Li foil approach:**
  - **Quantitative gamma rejection measurement.**
  - **Investigate the use of thin scintillating crystals for improved gamma rejection.**
  - **Investigate multiple foil configurations for improved thermal neutron efficiency.**
  - **Acquire ^{6}Li-enriched foil for testing.**

- **Li doping approach:**
  - **Continue to refine ceramic formation process.**
  - **Investigate melt growth and/or solution growth of Li-doped alkali halides.**
  - **Investigate CsI/LiI solid solution & crystal growth—potentially higher solid solubility, crystal plasticity & improved fluorescent decay characteristics.**

^{6}Li in alkali halides with PSD

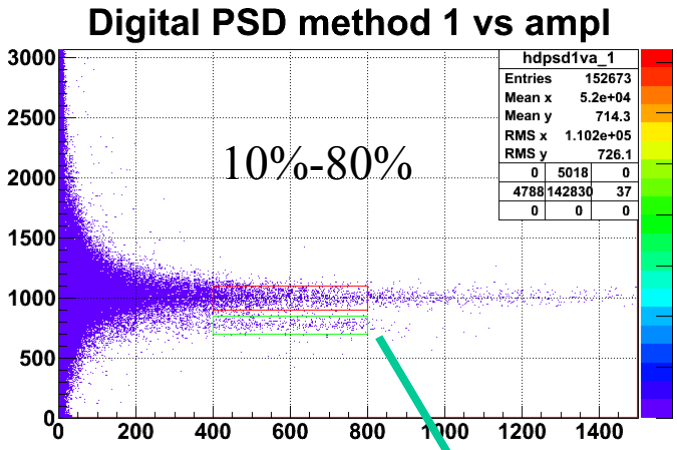
Conclusions

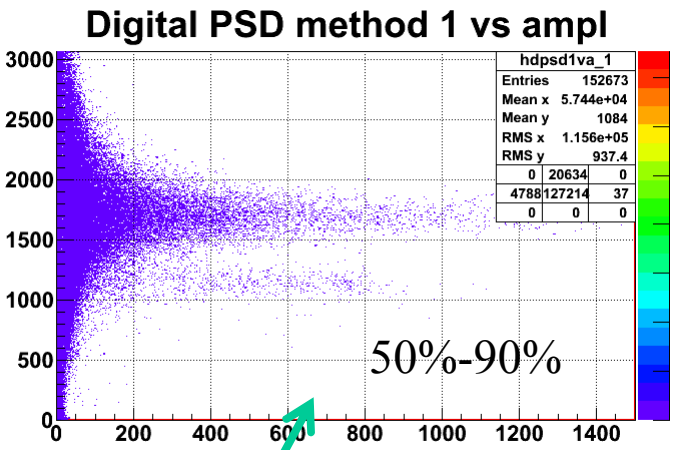
- **Alkali halide scintillators with Li-6 foil conversion layers show near-term promise as thermal neutron detectors for He-3 replacement.**
  - **Demonstrated efficiency of ~0.6% with nat. Li foil.**
  - **Extrapolated single-foil efficiency of 5-10%.**
  - **Gamma sensitivity of 10^{-4}–10^{-7} possible using just PSD with CsI crystals; for NaI possibly need geometry help.**
- **Alkali halide scintillators doped with Li-6 are an interesting system with potential, but need more R&D.**
  - **Refine & standardize process.**
  - **Characterize scintillators.**
  - **Optimize doping levels, etc.**
  - **Potential for simultaneous gamma & thermal neutron detection with high efficiency, energy resolution (γ), and γ/n separation.**

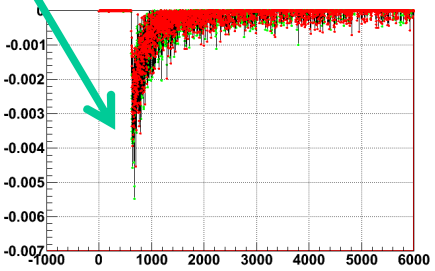
ADDITIONAL SLIDES

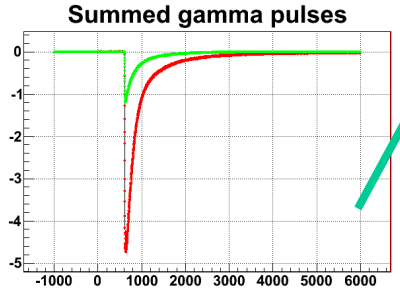
^{6}Li in alkali halides with PSD

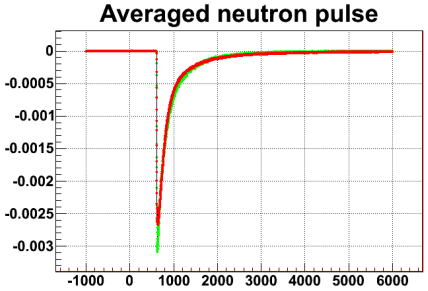
Improve PSD

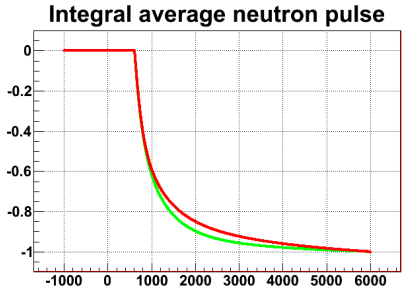












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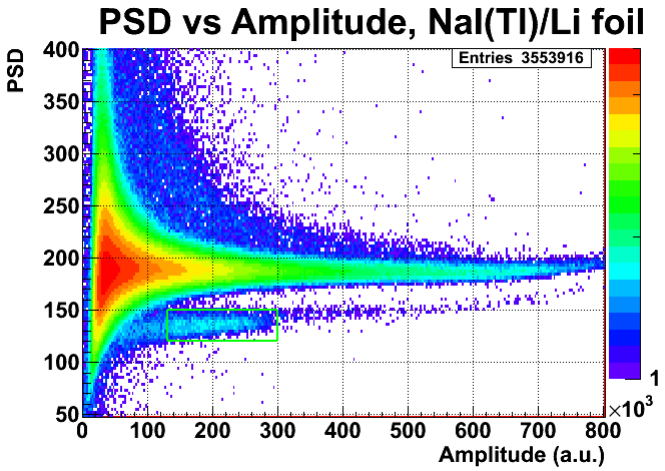
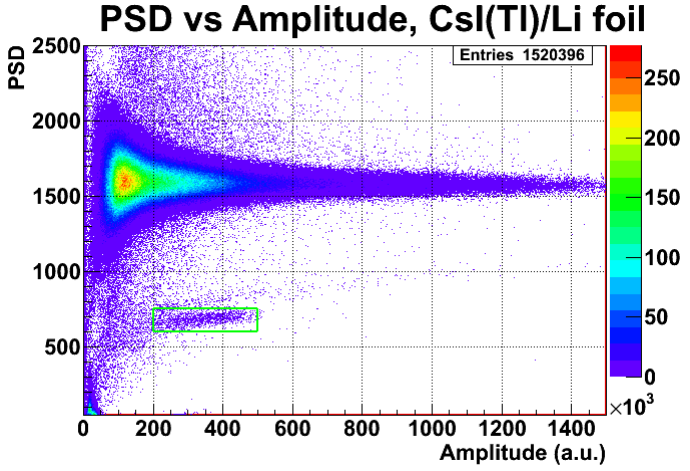
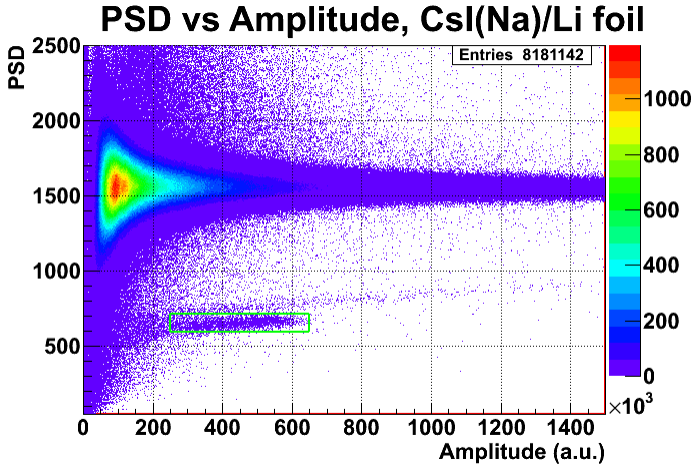
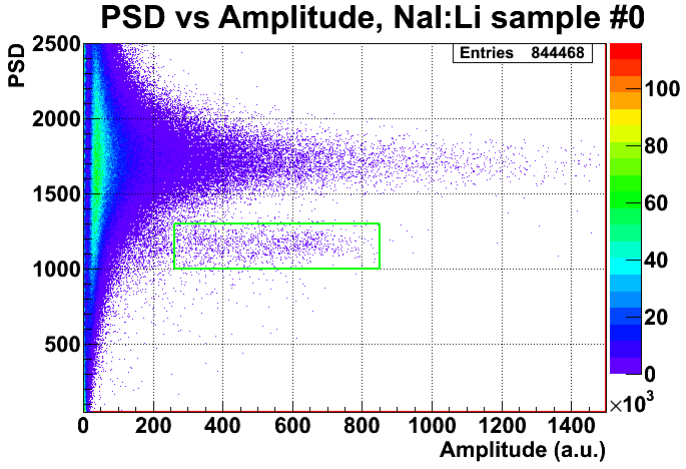
^{6}Li in alkali halides with PSD

PSD vs Amplitude plots



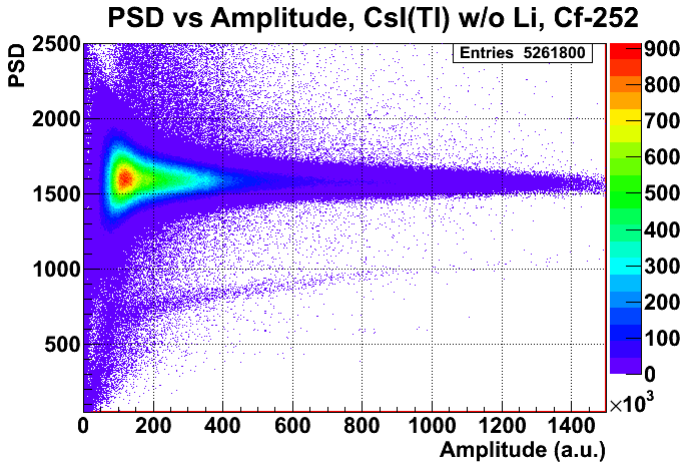




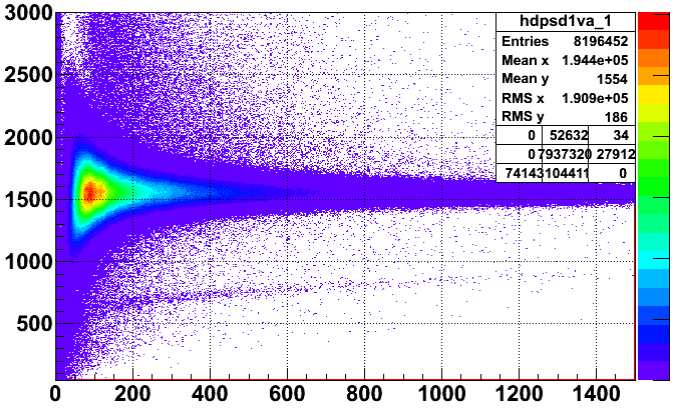


^{6}Li in alkali halides with PSD

Bulk crystal response to Cf-252



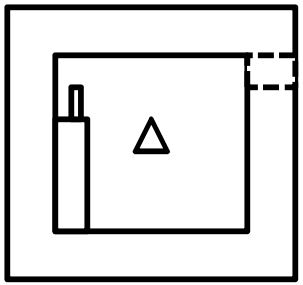
PSD vs Ampl, CsI(Na) w/o Li



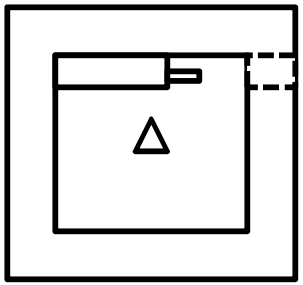
Configuration 17 (A-H)

Cf source position fixed in center of chamber, He-3 detector in various positions with counting rate monitored

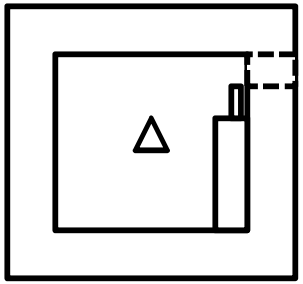
17-A



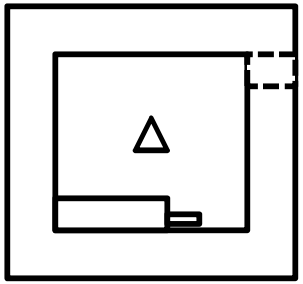
17-B



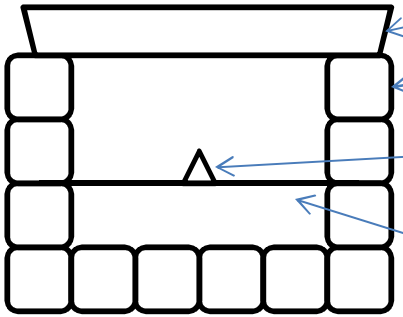
17-C



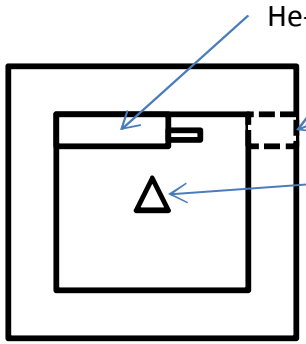
17-D



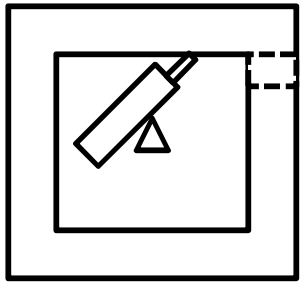
Side view



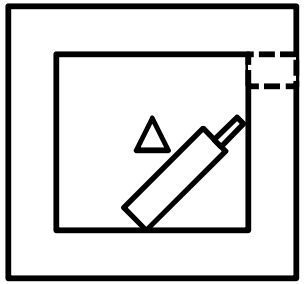
Top view, simplified



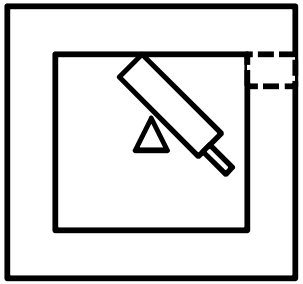
17-E



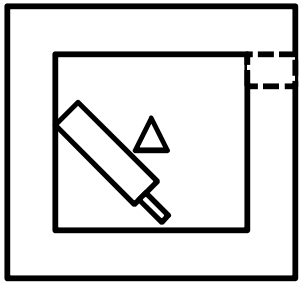
17-F



17-G



17-H



Expt	rate
A	902
B	918
C	922
D	922
E	1065
F	1052
G	1062
H	1056