

SIGMA Threat Injection Methodology

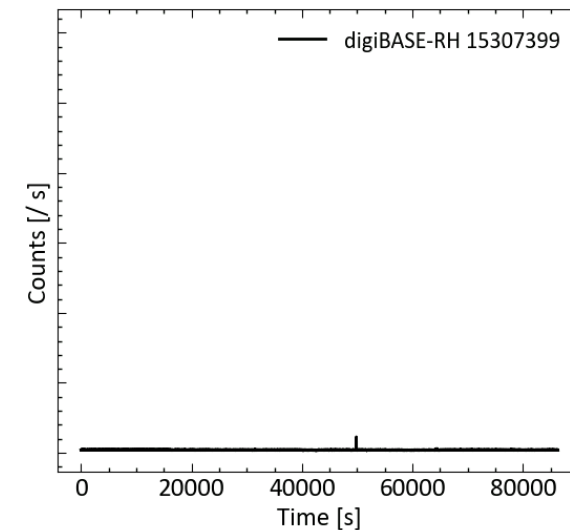
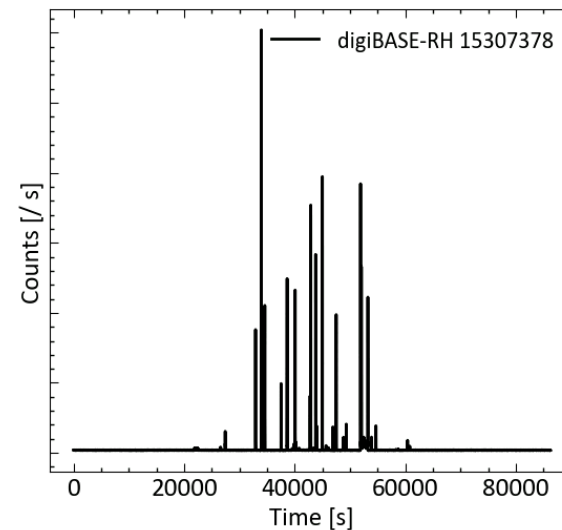
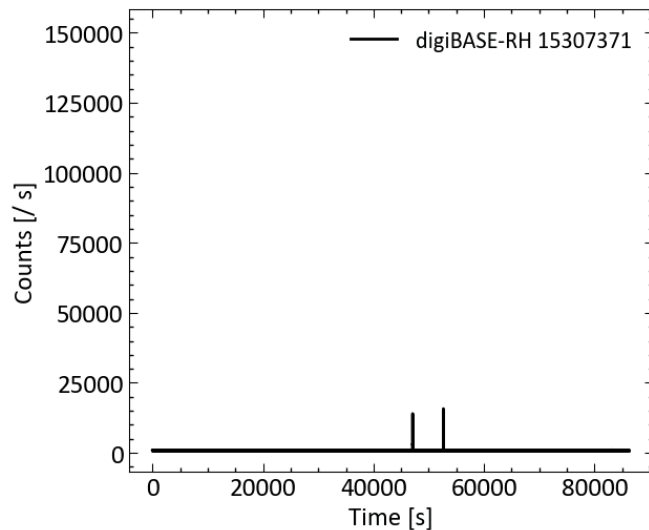
Nuclear Threat Reduction, Detection Science, Data Assessment

Dr. Rafael Hunt-Stokes

rafael.hunt-stokes@awe.co.uk

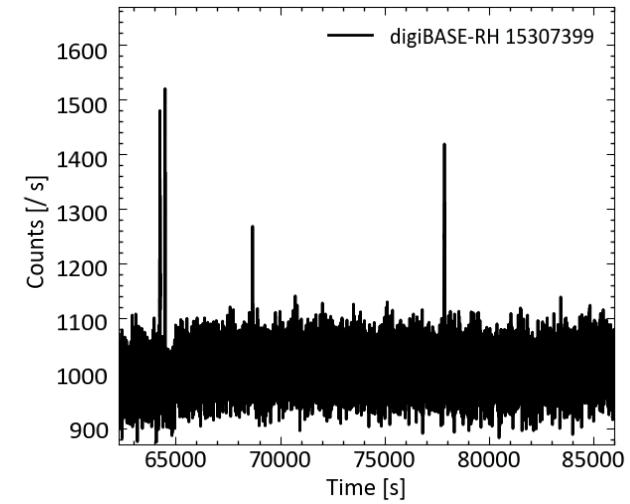
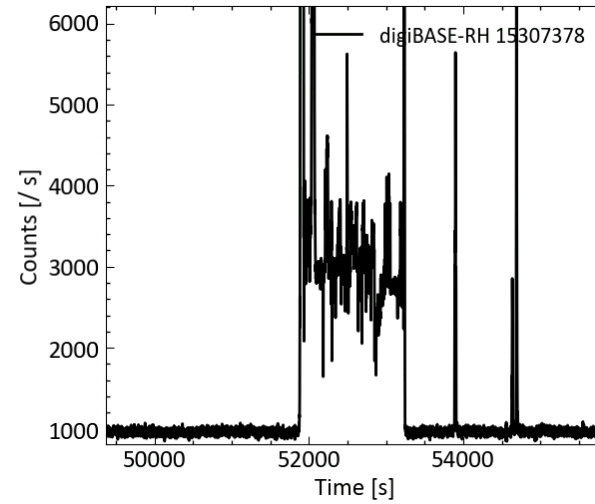
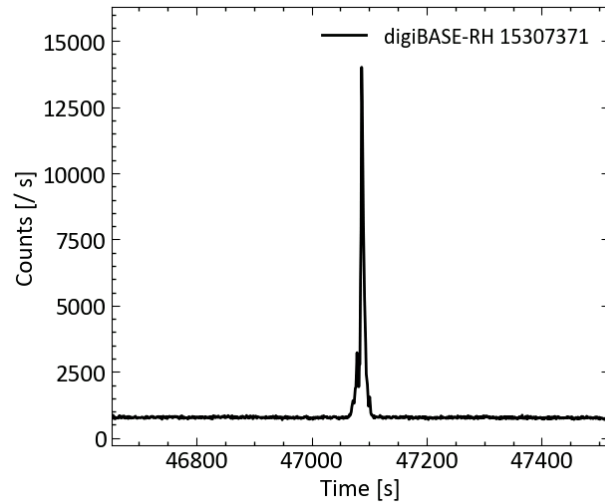
Overview

- SIGMA p3 data collected Aug. 2018 – Feb. 2019
- ~ 140 days of data
- 11x NaI detectors in various locations (outside hospital, bus stops, tube stations)
- Data made available to academic community



Many interesting features – no ground truth!

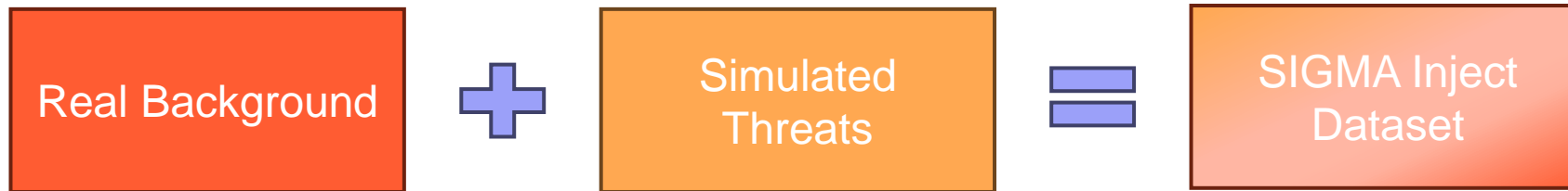
Overview



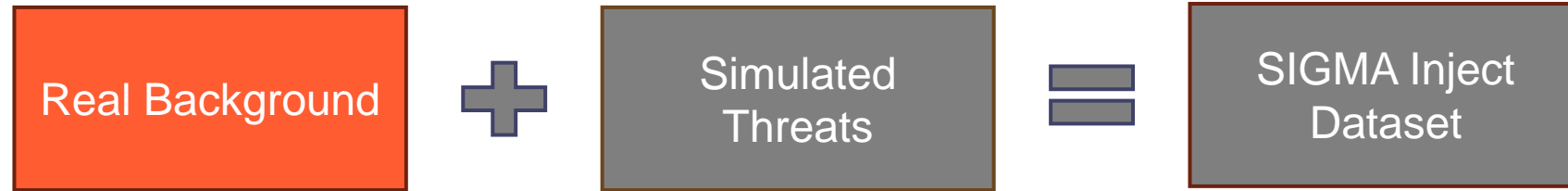
Many interesting features – no ground truth!

Overview

- SIGMA Inject Dataset (IJD) provides testbed for detection and source ID algorithms, with ground truth information provided

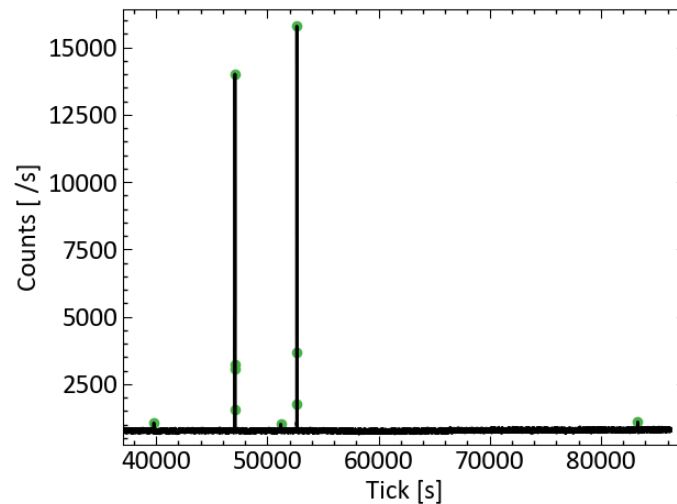


- IJD data will replicate SIGMA p3 format: 0 – 3 MeV binned energy spectra read out once per second
- Saved in hdf5 format

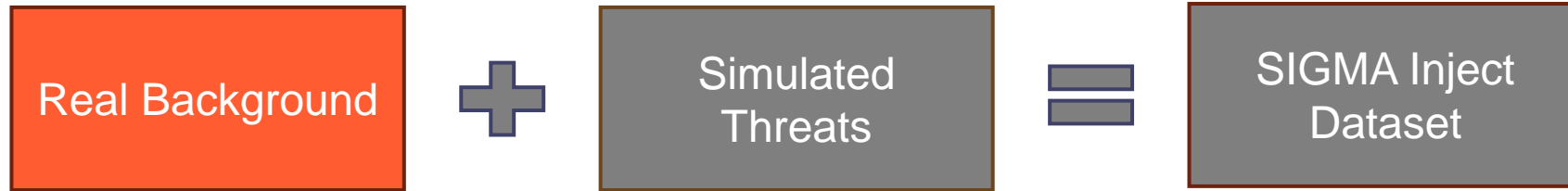


- Selecting regions of background to inject within needs three steps:

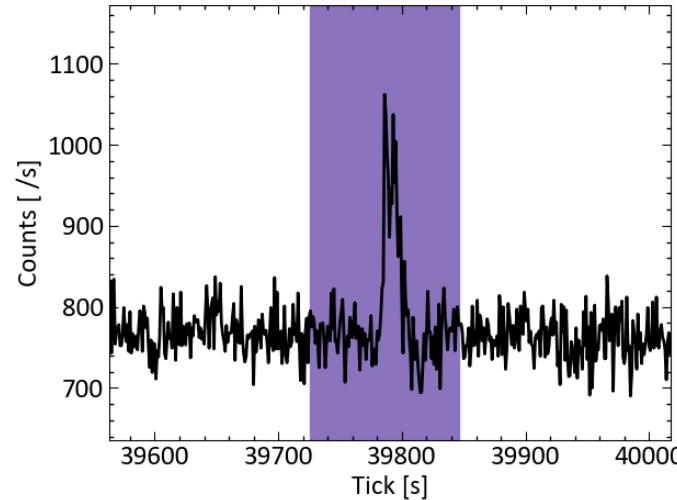
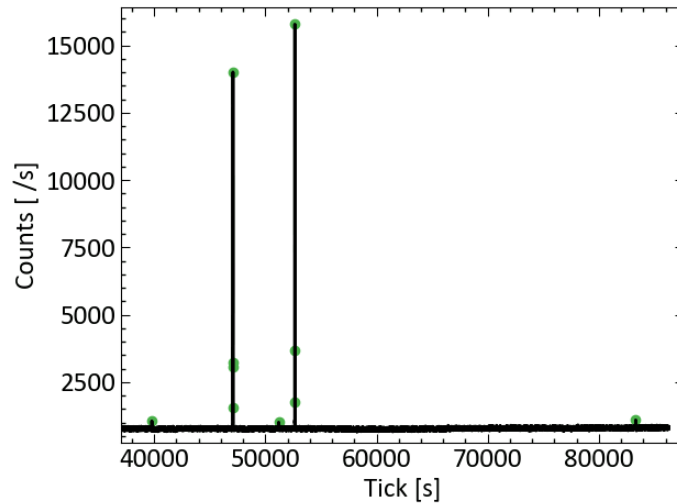
Anomaly
Detection



- Peak prominence used to ID bursts in rate
- `scipy find_peaks()` func.

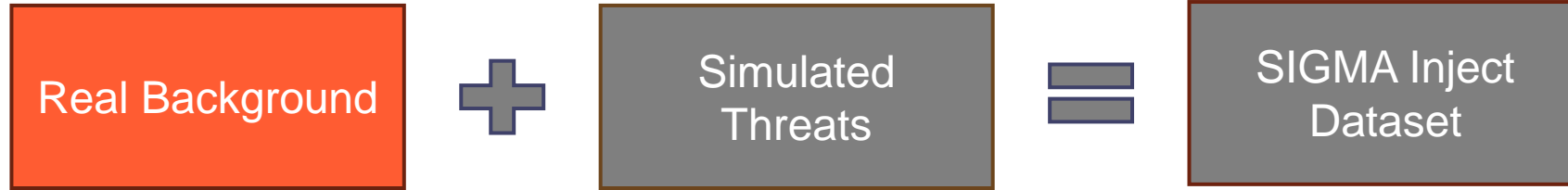


- Selecting regions of background to inject within needs three steps:

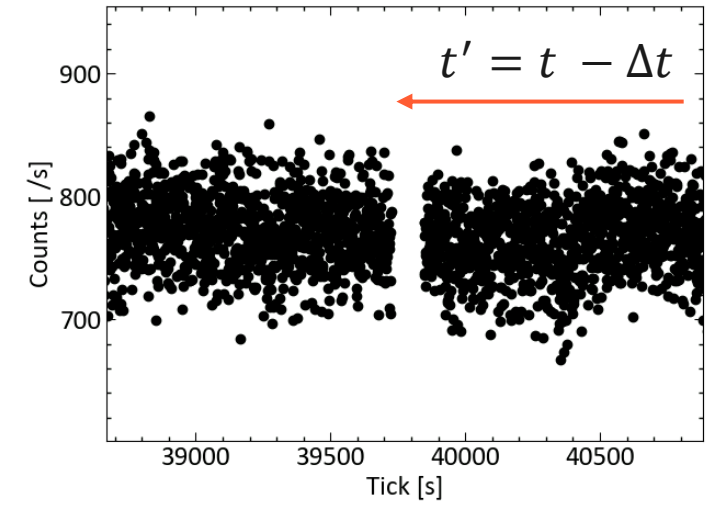
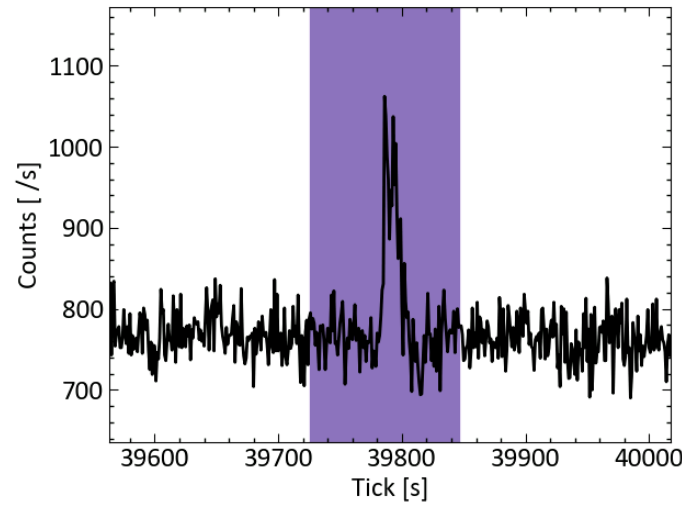
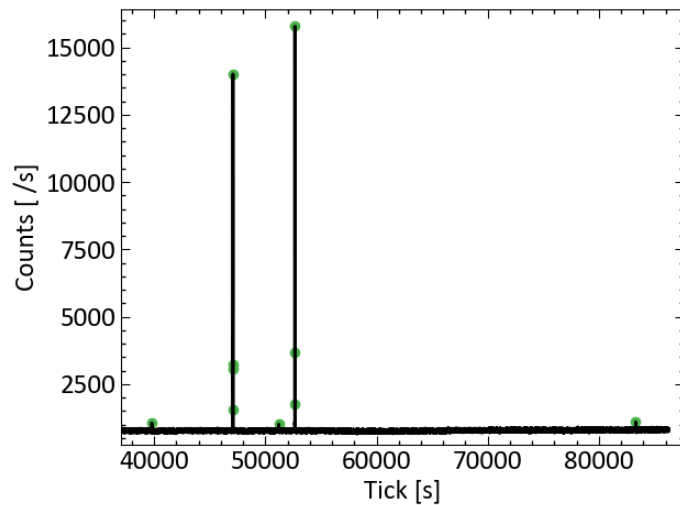
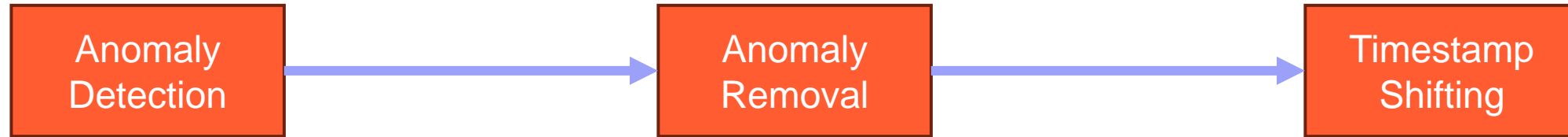


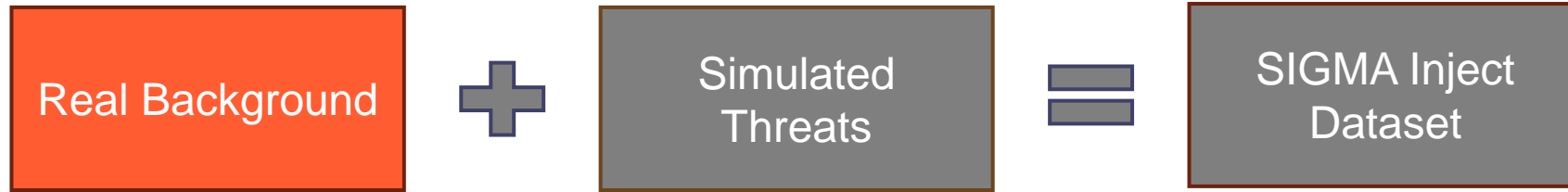
- ± 60 s around each anomaly is flagged for removal

OFFICIAL

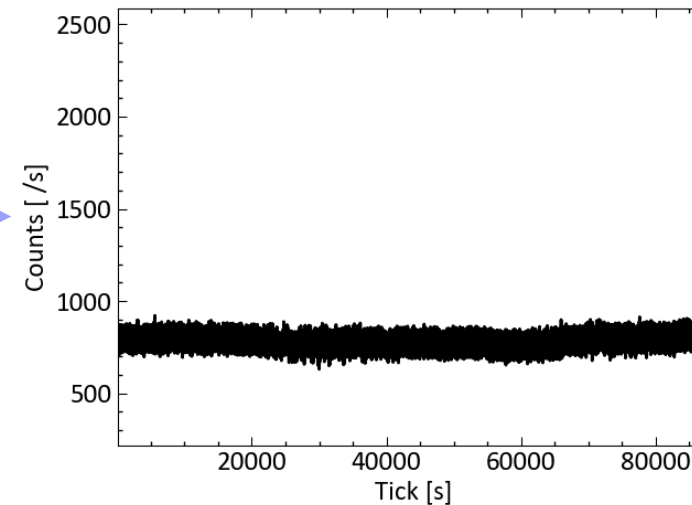
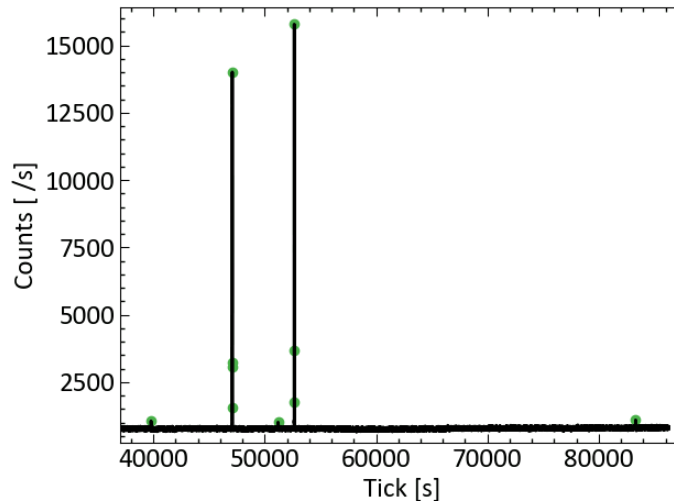
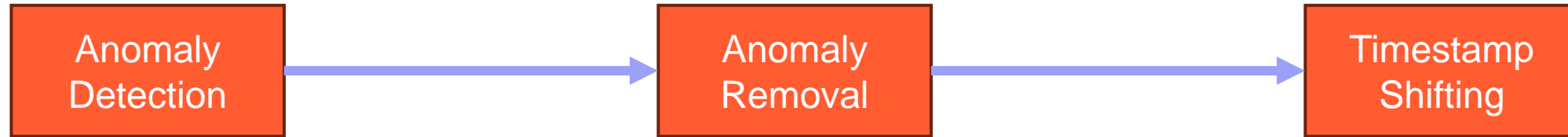


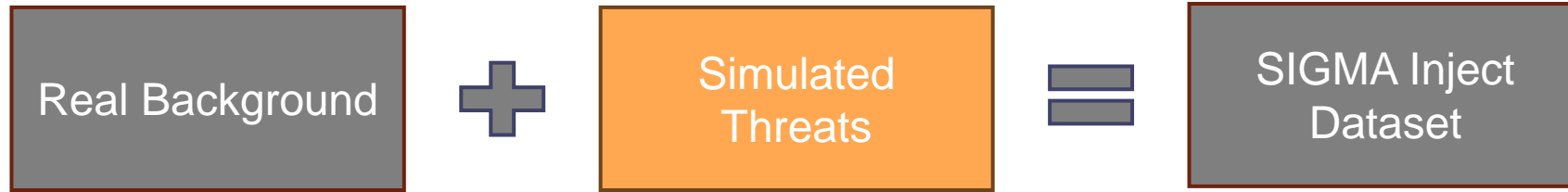
- Selecting regions of background to inject within needs three steps:



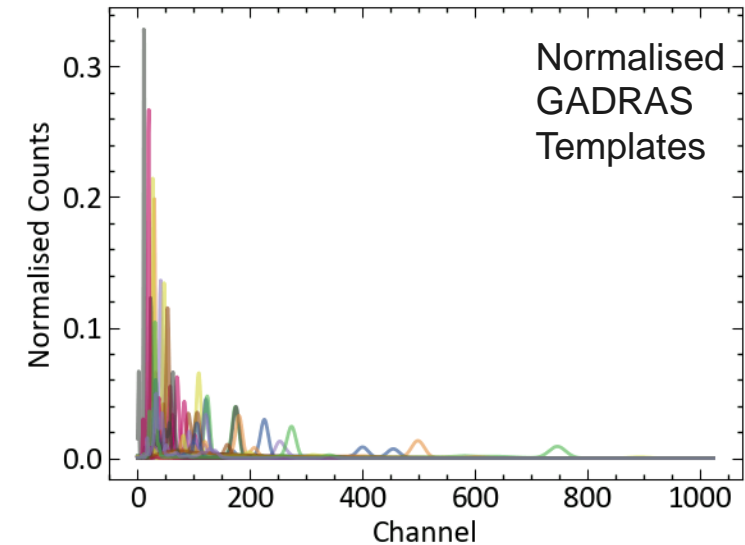
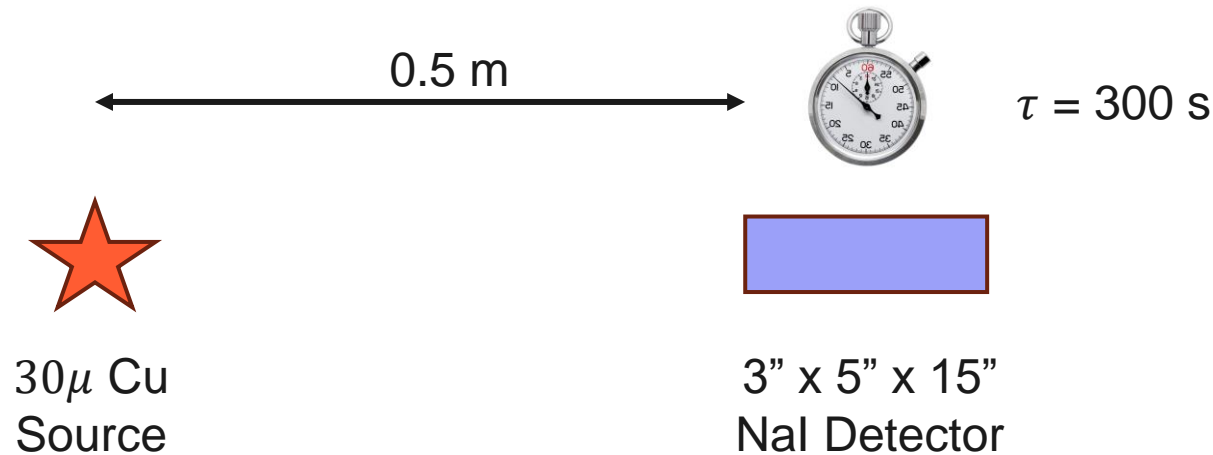


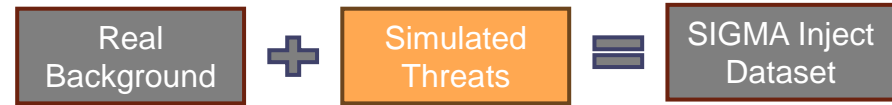
- Selecting regions of background to inject within needs three steps:





- Ready to inject simulated sources into the background data
- A library of 34 source templates simulated using GADRAS for comparable NaI detector geometry
 - See appendix for full list
- Templates are binned into 1024 channels (0 – 3 MeV) to match SIGMA data
- Templates are 'mis-calibrated' to match K-40 peak position in data



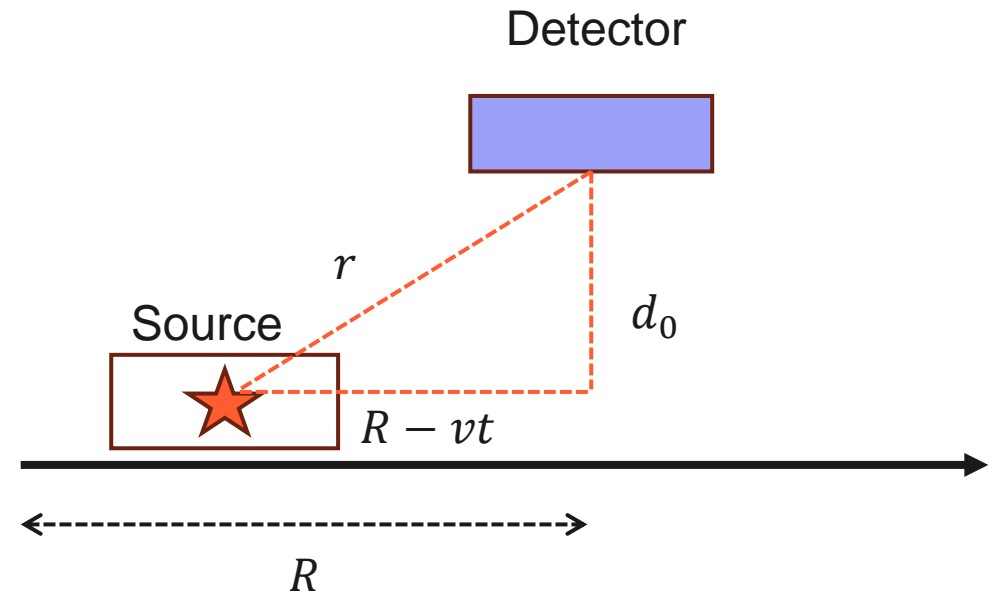


Simulating a Source Transit

- Assume detector by roadside (bus stop, etc.)
- Source transit Input:
 - Isotope
 - Activity
 - Speed
- Assume transit begins and ends far from detector ($\pm R$)
- Detector at fixed perpendicular distance d_0 from roadside
- Total simulated length is $2R$, taking $\frac{2R}{v}$ seconds
- Expected photon rate at detector given by:

$$\lambda(E, t) = \frac{A}{A_0} \times \frac{1}{t_0} \times \frac{r_0^2}{r^2} \times p(E) \times e^{-\mu(E)(r-r_0)}$$

Scaling from GADRAS
detector simulation result

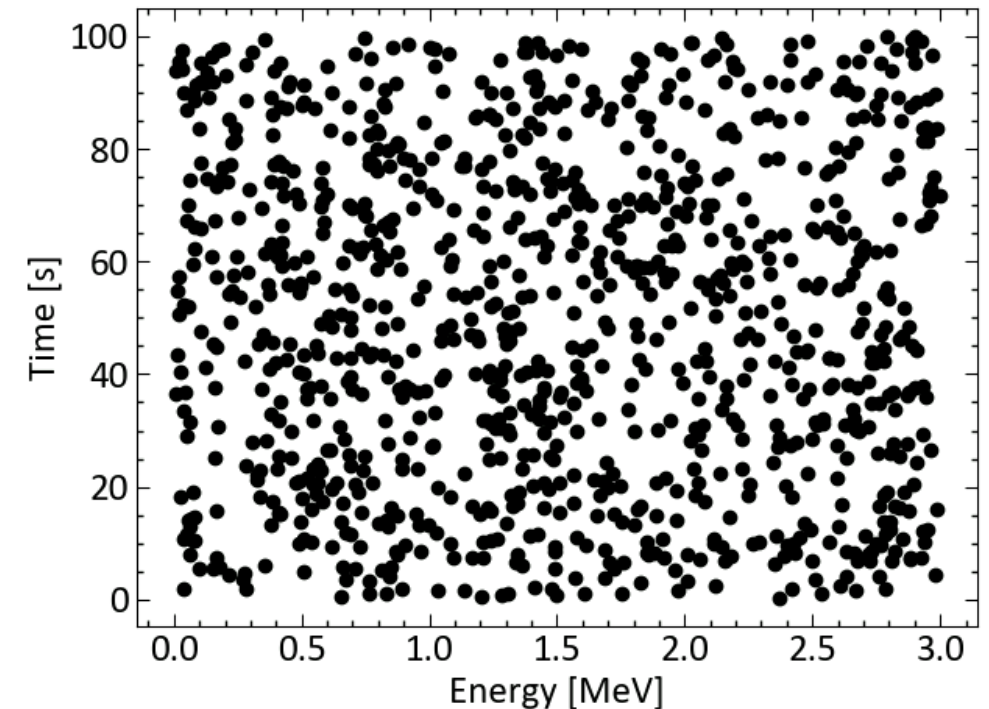


Real
BackgroundSimulated
ThreatsSIGMA Inject
Dataset

Poisson Thinning

- Poisson thinning provides an accept / reject sampling method to generated data **following expected energy and time profiles**
 - 1 s binned energy spectra and listmode data naturally fall out of this method!
- 1) Calculate $\lambda_{max} : r = d_0 , E = E_{mp}$
 - 2) Sample $N \sim Pois(\lambda_{max} \times (E_{max} - E_{min}) \times t_{max})$
 - 3) Sample N points uniformly across (E, t) domain

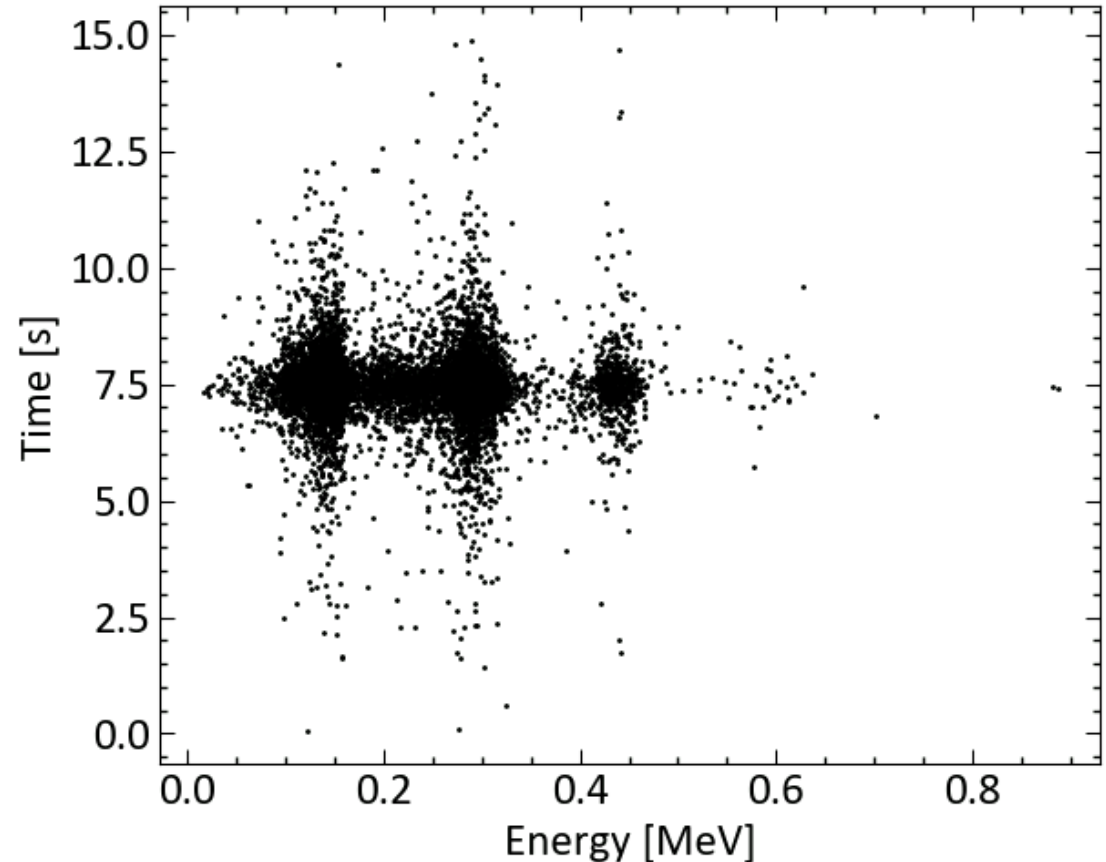
N Uniform Samples in Energy
and Time



Real
BackgroundSimulated
ThreatsSIGMA Inject
Dataset

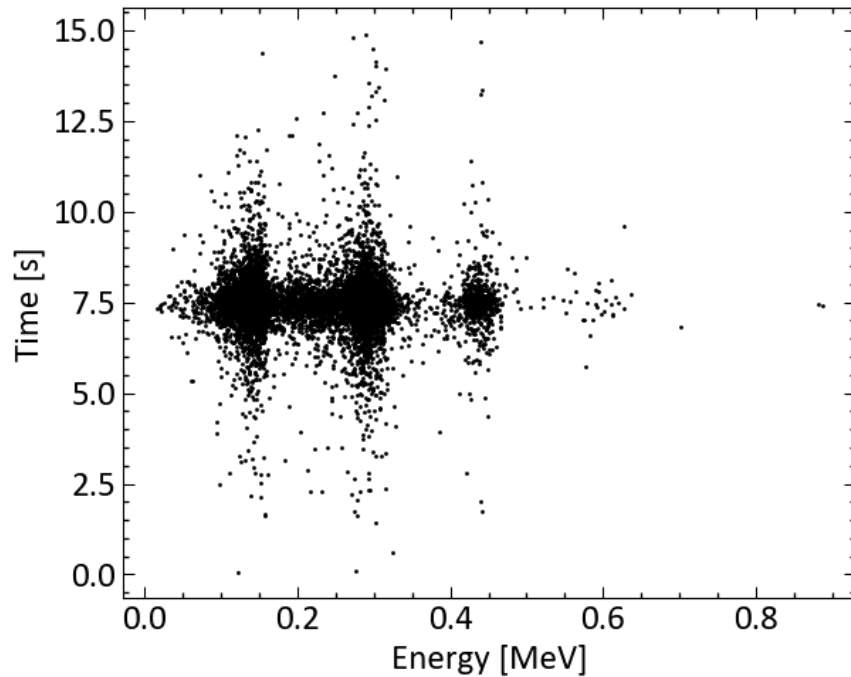
Poisson Thinning

- Poisson thinning provides an accept / reject sampling method to generated data **following expected energy and time profiles**
 - 1 s binned energy spectra and listmode data naturally fall out of this method!
- 1) Calculate $\lambda_{max} : r = d_0 , E = E_{mp}$
 - 2) Sample $N \sim Pois(\lambda_{max} \times (E_{max} - E_{min}) \times t_{max})$
 - 3) Sample N points uniformly across (E, t) domain
 - 4) Calculate acceptance criteria, $p = \frac{\lambda(E,t)}{\lambda_{max}}$
 - 5) Sample $U \sim [0, 1)$ for each point
 - 6) Reject if $U > p$



Real
BackgroundSimulated
ThreatsSIGMA Inject
Dataset

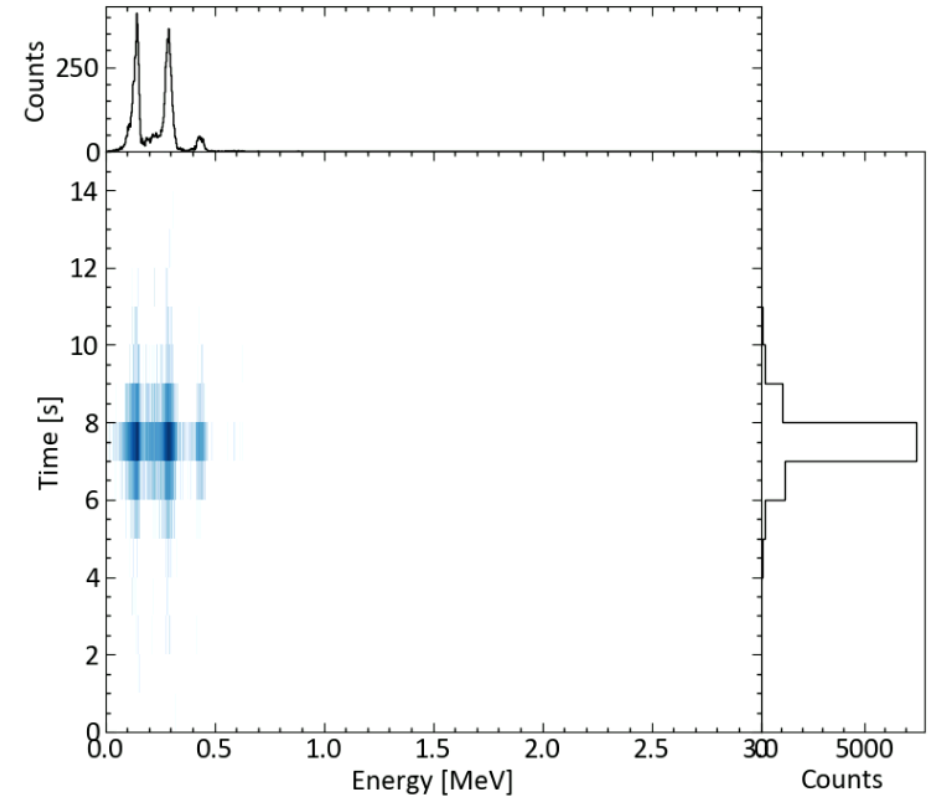
Poisson Thinning



Impose time
and energy
binning



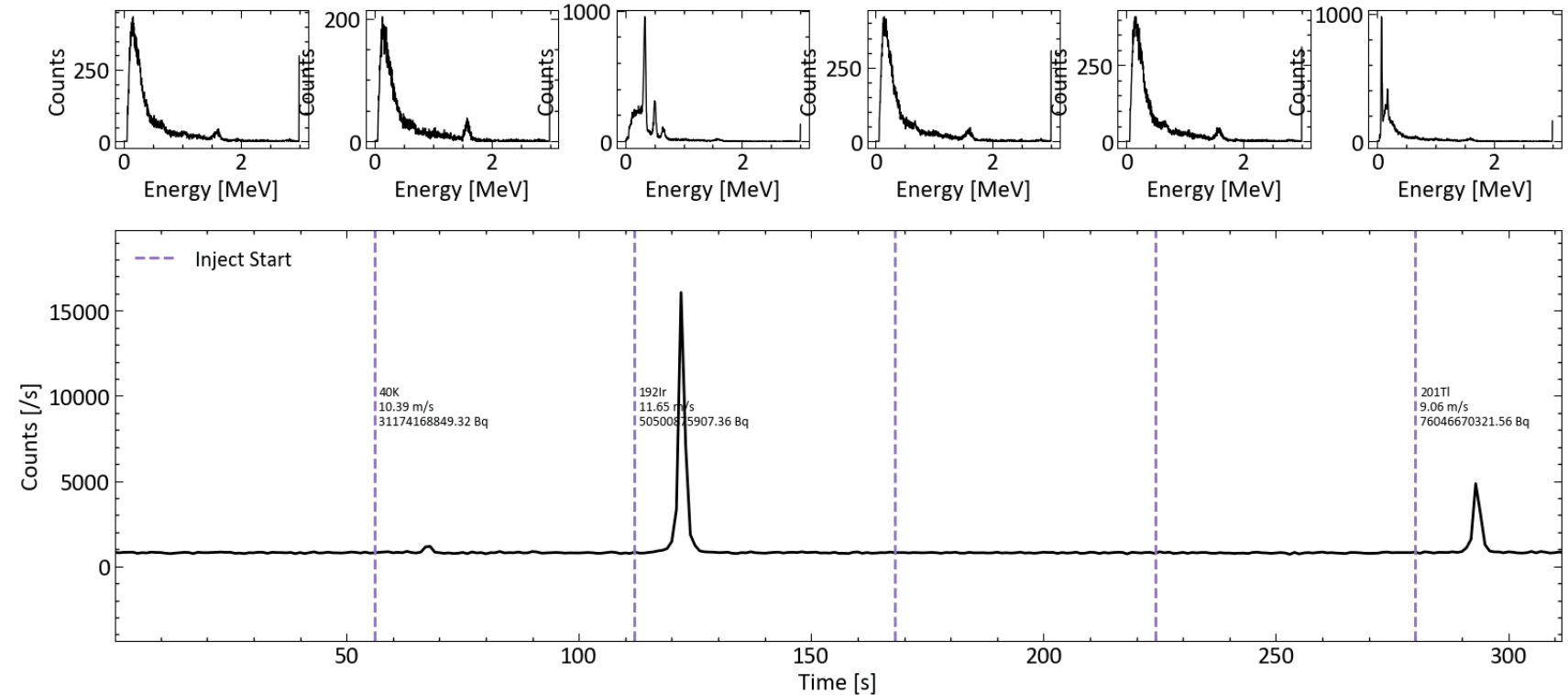
- Every 1s width row is a readout spectrum

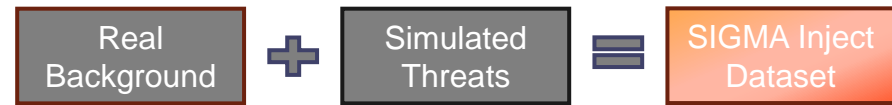


Real
BackgroundSimulated
ThreatsSIGMA Inject
Dataset

SIGMA Inject Dataset

- Speed and isotope uniformly sampled
- Activity sampled from triangle distribution to weight more strongly lower activity injects (more challenging)
- 50 % chance nothing is injected into a given window





Conclusions

- Developed codebase to create simulated source transits and inject into real SIGMA background data
 - Peak Prominence is used to identify anomalies
 - Anomalies are removed and timestamps shifted to make continuous background-only data
- Poisson Thinning is used to create the injected spectra
 - Assuming a perpendicular source transit with given speed and activity
 - Poisson Thinning gives natural way to create 1 s time sliced energy spectra according to simulated PDFs
 - An existing GADRAS template library for comparable NaI detectors are provide the energy PDFs
- Sigma Inject Dataset output is hdf5 format: one file per day, 1 group per detector
 - Matched the previously used format

Appendix

Source Template Library

```
[ '18F 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'57Co 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'40K 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'51Cr 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'60Co 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'67Ga 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'75Se 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'85Sr 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'90Sr 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'99Mo 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'99Tc 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'99Tcm 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'103Pd 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'111In 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'123I 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'125I 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'131I 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'133Ba 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'133I 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'133Xe 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'137Cs 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'177Lu 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'192Ir 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'201Tl 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'210Po 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'223Ra 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'226Ra 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'232Th 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'237Np 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'241Am 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'252Cf 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'235U 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'238U 20uC{an=26 ad=1.5748} @ 50cm H=100cm'  
'239Pu 20uC{an=26 ad=1.5748} @ 50cm H=100cm']
```