Fast Neutron Backgrounds As A Function Of Depth Underground

LRT 2015

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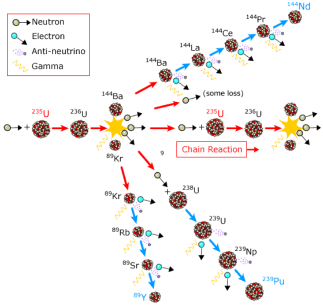
Outline

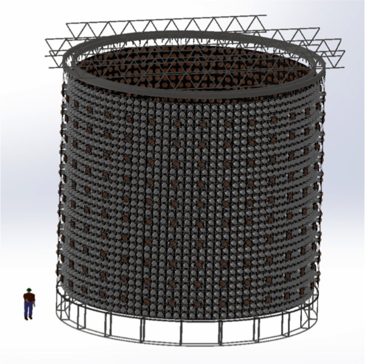
Monitoring Weapons Usable Material in Reactors

WATer CHerenkov Monitor of AntiNeutrinos



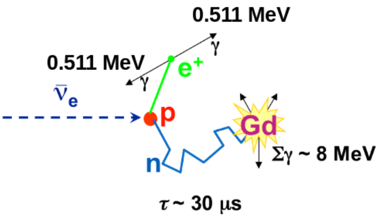
1. $\sim$6 antineutrinos per fission
2. $\sim$2x10^{17} antineutrinos per second per MegaWatt thermal

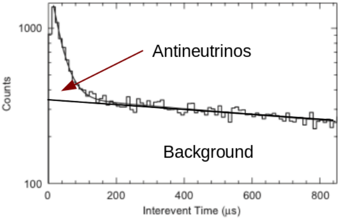
1. 16m x 16m 304 SS tank
2. Optically clean water
3. 0.1% Gd by weight



If It Barely Interacts How Do We Detect It?

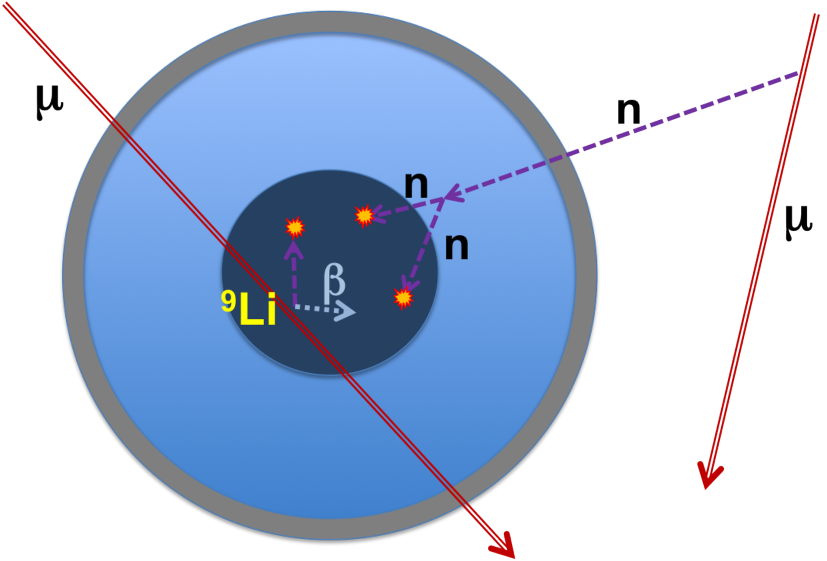
1. Antineutrino occasionally undergoes inverse-beta decay
2. Positron then the neutron each produce a short pulse of light
3. Light is detected with a sensor in the detector
4. Coincident light pulses are a nearly unique signature of an antineutrino interaction





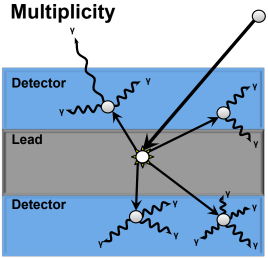
N.S. Bowden et. al, NIM A **572** *(2007) 985-998*

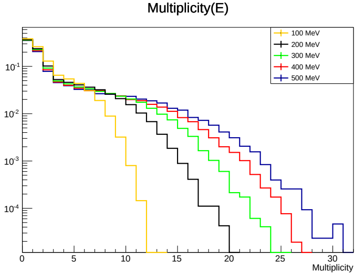
Time Correlated Backgrounds Are Initiated From Nearby Or Through-Going Muon



Measurement Concept For The Neutron Energy

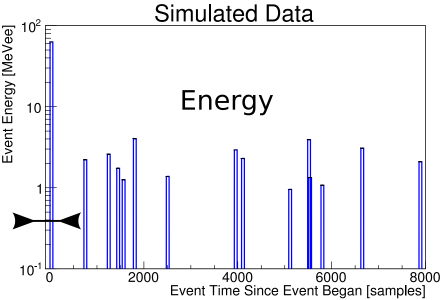
1. Use spallation reaction (n,kn)
2. k ∝ Energy of neutron
3. Use hydrogenous media to quickly thermalize neutrons
4. Neutrons capture on Gd dopant





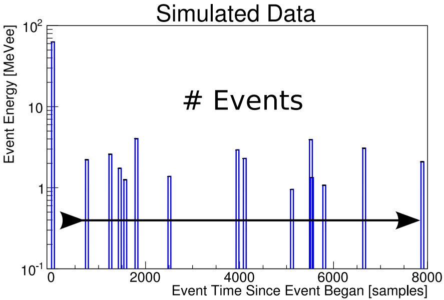
Unfolding Requires More Information Than Just Multiplicity

1. Initial elastic scatter energy



Unfolding Requires More Information Than Just Multiplicity

1. Initial elastic scatter energy
2. Gd captures and showers ($\sim$8 MeV) "multiplicity"



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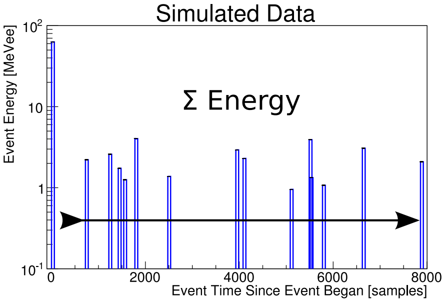
3. Total energy from Gd shower in multiplicity sequence



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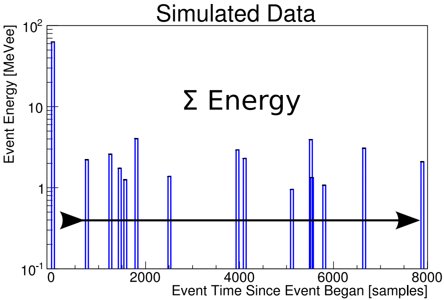
4. Solve using MLEM approach



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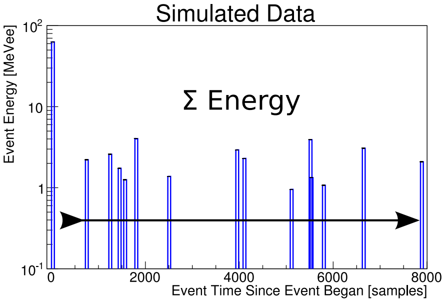
4. Solve using MLEM approach
5. Detector response from simulation+calibrations

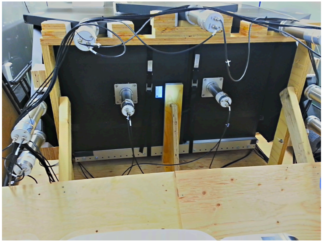


MARS Design: Capture-Gated Spectrometer and Multiplicity Meter

1. 12 1.0x0.75x0.025m^3 plastic scintillator sheets
2. Plastic sheets coated with white Gd doped paint
3. 16 PMTs split between 2 sides per detector
4. Lead neutron amplifier between two detectors

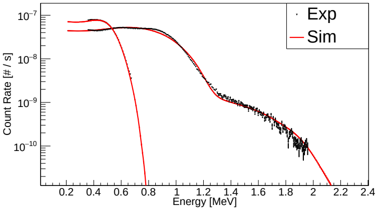
MARS Neutron Measurement Campaign at KURF

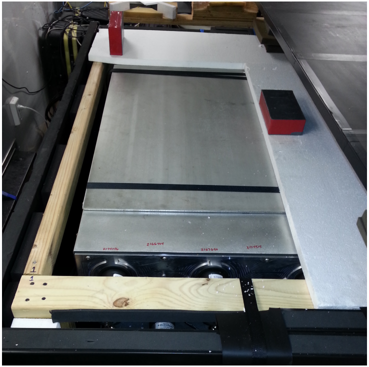
1. Measurements taken at 380 and 600 m.w.e.
2. Several thousand high energy neutron events at both 380 and 600 m.w.e.
3. Ongoing measurement at 1450 m.w.e.

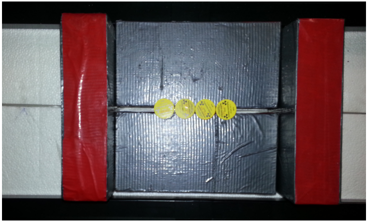


Measuring The Position Dependent Response

1. Mapped response
   - 5x5 grid on the top detector
   - 3 positions in the long 2 PMT vetoes
   - 2 positions in the square 1 PMT vetoes
2. Collimated Cs137/Co60 source
3. Smear simulated response
4. Minimize χ^2

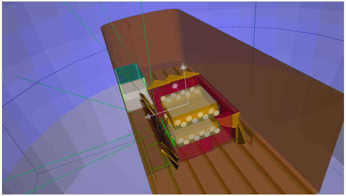


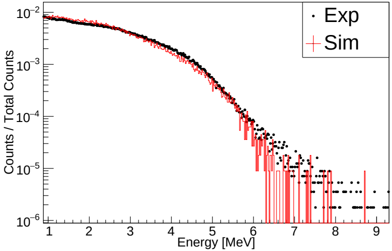




Detector Characterization Of Tagged Cf252 Source

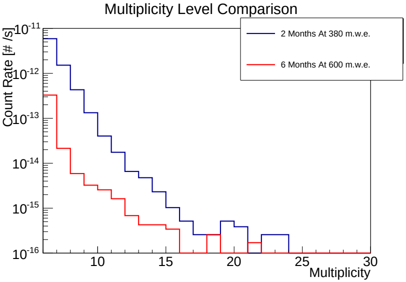
1. Apply detector response to simulation
2. Require >3 events between 100ns and 100μs after tag
3. Calculate total efficiency based upon ratio of higher order multiplicity events
4. Able to tune Gd concentration based upon capture time and total efficiency

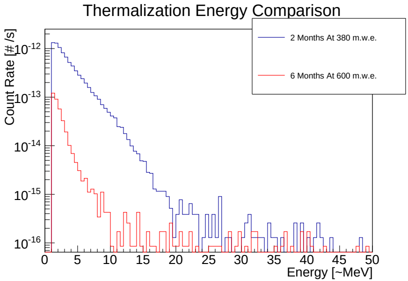


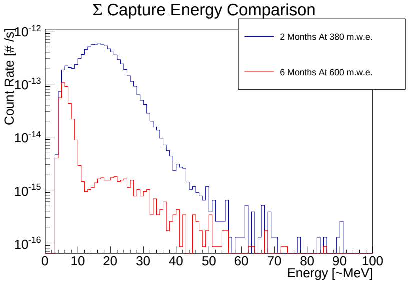


Experimental Results At KURF

1. Require 6 multiplicity, 500 keV per deposition
2. Count rate decreases as a function of depth

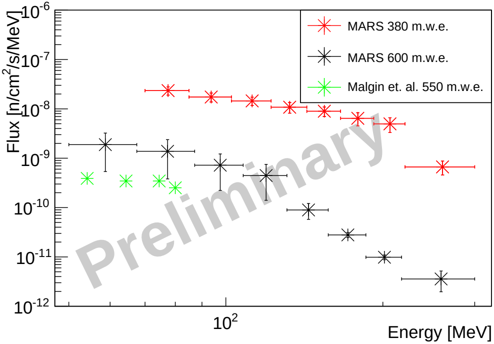






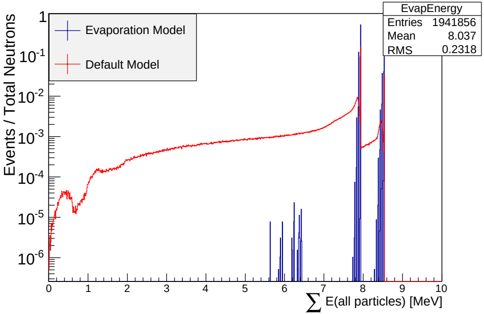
Preliminary Results

1. Assume one neutron per interaction
2. Assume smooth result
3. Use MLEM to reconstruct spectra
4. Generate error bars from different multiplicity requirements



Why The Preliminary Results Are Wrong

1. Uncertainty in depth at 600 m.w.e. measurement
2. Poor background rejection at 600 m.w.e.
3. Default Geant4 Gd capture model does not conserve Q value
4. Geant4 evaporation model changes tuned capture time → different Gd loading



Conclusions

1. A spallation based multiplicity detector has been constructed to measure the high energy neutron flux as a function of depth underground
2. The detector response has been characterized by gamma ray sources and thermal neutrons
3. MLEM has been used to unfold preliminary results

Future Work

1. Tune Gd loading based upon Cf252 response
2. Re-simulate detector response with correct Geant4 models
3. Use detector singles data to simulate background contamination
4. Unfold results with updated model at all 3 levels
5. Perform surface measurement next month to validate underground results

Institutions And Disclaimer

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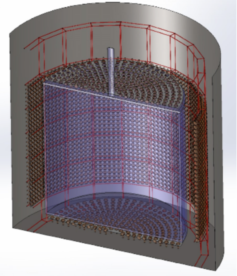
Backup Slides

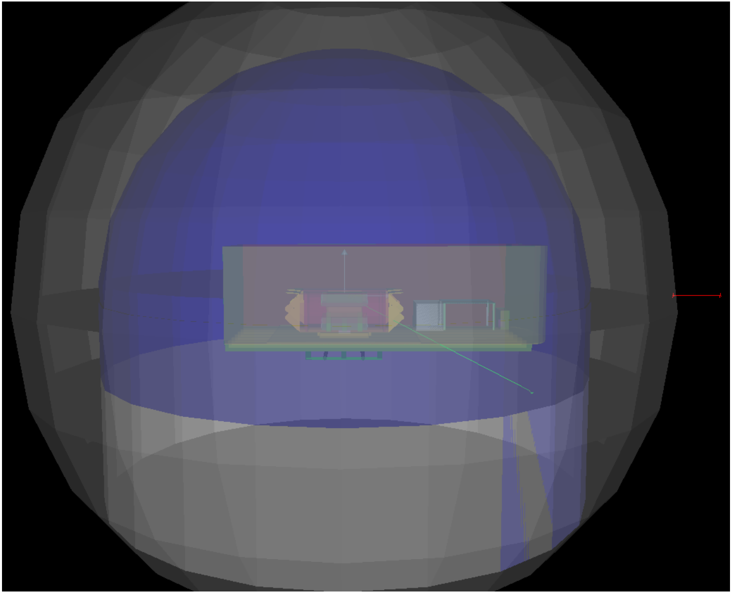
WATCHMAN Deployment Options

1 kton fiducial Gd-water detector

1. Low Power Reactor
   - Relatively shallow depth (100 meter)
   - Relatively high background
   - Relatively close (1 km)
2. High Power Reactor
   - Relatively deep depth (500 meter)
   - Relatively low background
   - Relatively far (10 km)



Geant4.9.6.p02 Simulation



How To Unfold A Signal That Is Not Directly Measured

Solve $g(\vec{y}) = \int A(E,\vec{y}) f(E)\, dE + b(\vec{y})$

1. g($\vec{y}$) is the measured data space
2. f(E) is the energy spectrum we want
3. A(E,$\vec{y}$) is the kernel from simulation: predicted relationship between energy and the measured data space
4. b($\vec{y}$) is the background, typically measured

Neutron Energy Spectrum Unfolding - MLEM

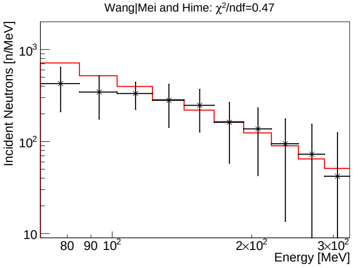
General Algorithm: Solve $g(\vec{y}) = \int A(E,\vec{y})f(E)\,dx + b(\vec{y})$

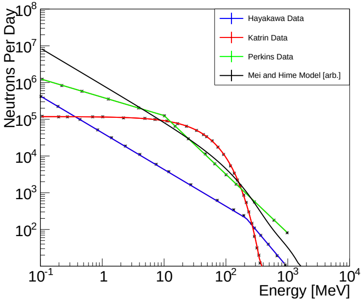
1. Discretize $\vec{g}_{meas} = \mathbf{A}\vec{f} + \vec{b}$, $\vec{g}^k_{pred} = \mathbf{A}\vec{f}^k$
2. Likelihood $L^k(f) = \prod_{i=1}^{n} P(g_{meas,i}|g^k_{pred,i})$
3. Find $Min\Big(-ln[L^k(f)]\Big)$ or $Min\left(-ln[L^k(f)] + \beta R(E)\right)$

$$f^{k+1}_{j,unreg} = \frac{f^k_j}{\sum_{i=1}^n \mathbf{A}_{ij}} \sum_{i=1}^{n} \mathbf{A}_{ij} \frac{g_{meas,i}}{g_{pred,i}},\ iff\ \beta = 0$$

Simulation Test Case Of Algorithm

1. Simulate kernel **A**
2. Separate simulation of expected spectrum
3. Require 6 multiplicity, 500 keV per deposition
4. Other spectra from Palo Verde paper





Simulated Unfolding Results

1. Initial kernel had sparse statistics at lower neutron energy
2. Good agreement above 100 MeV
3. No background in model