Latest Progress in the Characterization of Neutron Flux Monitors for the SPARC Tokamak

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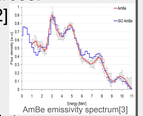
BF3 Proportional Counter

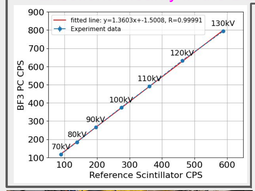
Introduction & Setup

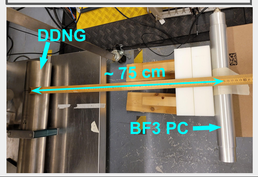
- LND 20352: High sensitivity for calibration range
- Electronics:
  - ORTEC 142PC pre-amplifier
  - ORTEC 590A main-amplifier
  - CAEN DT5730S & N6724B digitizers
- Applied voltage +2200 V (or otherwise stated)
- Neutron generators (NG) and sources:
  - DT NG: ~1e8 n/s, 14.1 MeV [2]
  - DD NG: ~1e7 n/s, 2.45 MeV
  - AmBe source: ~2.2 x 10^4 n/s
- OpenMC simulations:
  - Absorption rates in BF_3 tallied
  - DDNG: 2.45 MeV isotropic point source
  - AmBe: point source with true spectrum
- Low gamma sensitivity verified

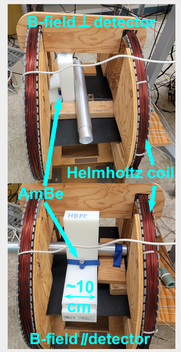


Detector Linearity

- Detector response should be linearly proportional to incident neutron flux
- Source rate tuned by DDNG voltage
- 10 cm HDPE moderator used
- Liquid scintillator used as reference [4]
- Excellent linearity in the DDNG range

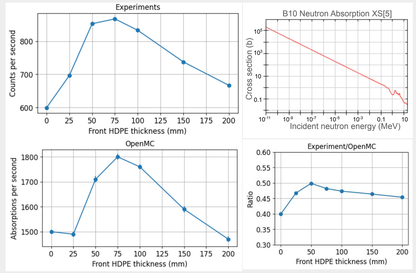






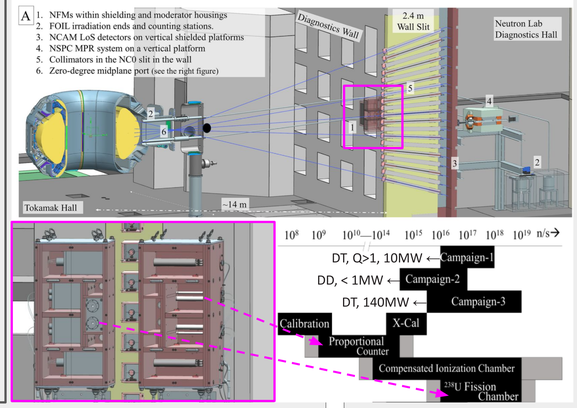
Moderator Thickness (DD Neutron)

- High density polyethylene (HDPE) moderates fast neutrons to B10's sensitive thermal range
- HDPE: C_2H_4, density = 0.98 g/cc
- Sensitivity tuned by HDPE thickness
- Maximum signal strength with ~7.5 cm HDPE
- Experiment/OpenMC: consistent overall, ~10% deviation for thin HDPE



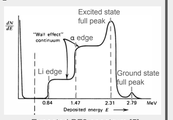
SPARC Neutron Flux Monitors

- Measure local neutron flux / rate and convert to real-time fusion power via cross / calibration
- Different NFM types cover wide dynamic range [1]

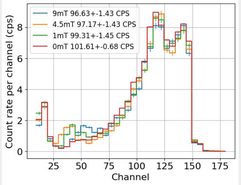


Magnetic Field Response

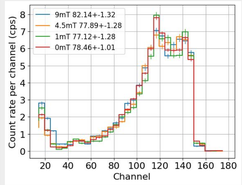
- B-field at NFM in SPARC: < 25 mT
- Helmholtz coil at MIT: 0 - 9.5 mT
- Source: AmBe + 5 cm HDPE
- Spectra match vendor specification
- Parallel B-field decreases CPS, and perpendicular B-field increases CPS
- 9 mT B-fields affect CPS by ~5%. 25 mT to be explored



Expected BF3 spectrum [5]



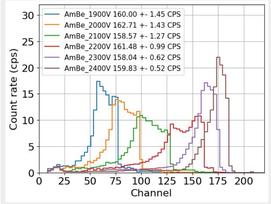
B-field parallel to detector



B-field perpendicular to detector

Operating Voltage

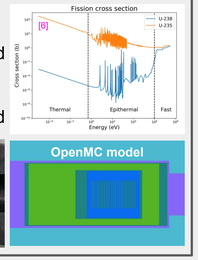
- Test this PC's voltage range
- Source: AmBe + 5 cm HDPE
- Applied voltage:[1900,2400] V
- Increasing voltage increases the energy of individual signals, but not total cps

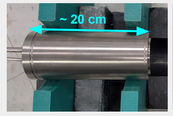


U238 Fission Chamber

Introduction & Setup

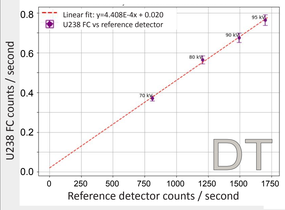
- U238 FC from Centronic Ltd, UK
- Parallel plate structure, UO_2 coatings
- Low sensitivity for high range (>10^{16} n/s)
- Primarily sensitive to ~MeV neutrons [5]
- Electronics:
  - Cooknell CPA60 pre-amplifier
  - CAEN digitizers (250 / 500 MSps)
- Applied voltage: +1000 V
  - 2 MIC leads
  - ~1 m long
  - 1 lead shorted to ground
- Low gamma sensitivity verified

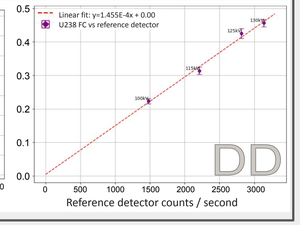




Sensitivity & Linearity: DD vs DT

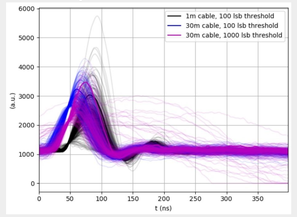
- Voltage scanned for DD and DT NGs [2]
- U238 FC linearity is superb when compared to reference detector
  - Reference detector: deuterated liquid scintillator [4]
  - Linear fit also passes close to origin (<0.02 cps)
- U238 FC positioned at
  - ~50 cm from center of DTNG → ~2.2k n/cm2/s at FC center
  - ~8 cm from center of DDNG → ~2.5k n/cm2/s at FC center
  - → *Very roughly*, FC is ~2x more sensitive to DT than DD neutrons as expected from U238 fast fission cross-section [5]





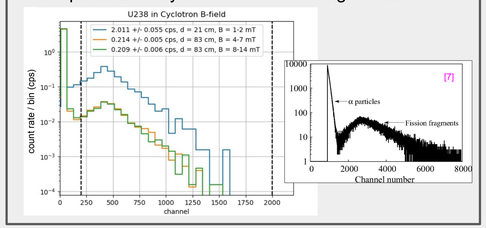
Signal vs Cable Length

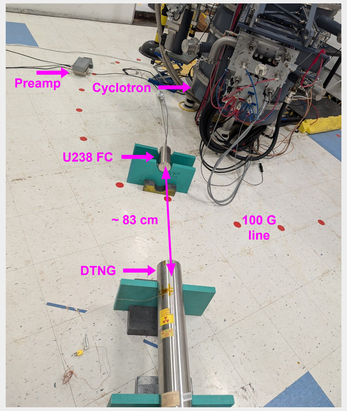
- Compare 1m vs 30m cable lengths between U238 FC and preamplifier
- Observe little difference in waveforms
- However, noise increases with longer cables → need to increase threshold
- This seems to slightly affect detector sensitivity, but this can be calibrated



Magnetic Field Response

- U238 FC was placed within the nominal 10 mT (100 G) line of the MIT PSFC cyclotron
- At ~83 cm from the DTNG target plane, cyclotron current was doubled, max B ~ 7 mT → 14 mT
- No effect seen on the measured pulse height spectrum or count rate (within error bars)
- Simple ExB analysis shows little change for 25 mT





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References

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[2] X. Wang, SOFE, 2025.
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[5] G. Knoll, ISBN 9780470131480, 2010
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