Boron-lined neutron detectors for mobile soil moisture measurements

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A ^{3}He alternative for environmental applications

Innovative Neutron Detection

- radation type & background discrimination
- low cost & low power consumption
- lightweight and modular

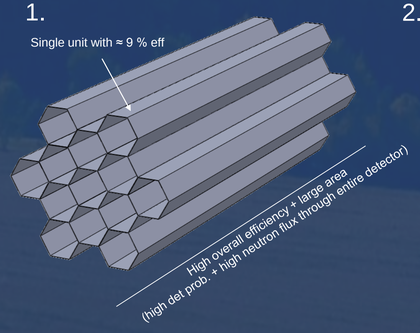
We present a boron-lined proportional counter for mobile and especially air-borne detection of environmental neutrons. The choice for solid boron as neutron converter limits the efficiency of single proportional counters to roughly 12 %. This is why we propose a modular detection system composed of a multitude of hexagonal-shaped counting tubes. Each tube can work as a standalone neutron detector but also can be combined with others to form a high-count rate detection system especially suitable for mobile measurements where high temporal resolution is the primary criterion.

The walls of the counting tubes are composed of 300 µm thick aluminum sheets making them very light and most suitable for airborne applications. Moreover, the system will feature all important measurement devices for the application in soil moisture sensing but will still have lower power consumption as comparable systems. By combining pulse-height and pulse-shape information of detection events, the read-out electronics is capable of differentiating between different radiation types. This allows for a high signal-to-noise ratio and thus for precise soil moisture evaluation.

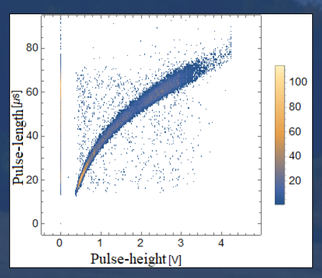
Concept

Demands in environmental neutron detection
- High count rate
  → high temporal resolution
- Appropriate energy dependent efficiency
- Efficient discimination of radiation types
  → high signal-to-noise ratio, precise soil moisture monitoring
- Low power consumption
- Robust and weatherproof
  → long-term use

1.

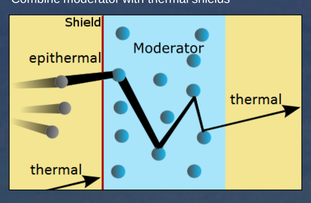


2.

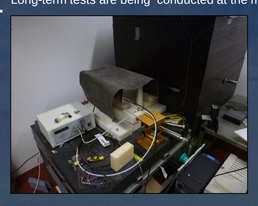


Combination of (1.) pulse-height and (2.) -length
(1.) reject other He- or Li-cores with diff energy
(2.) reject other radiation types

3. Combine moderator with thermal shields

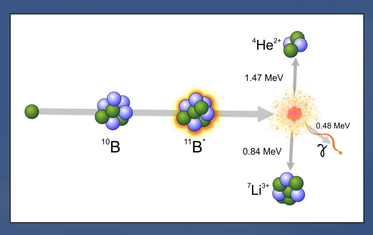


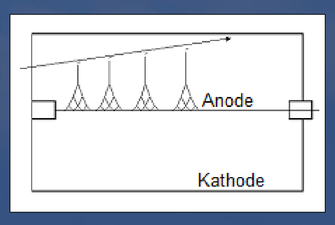
4. Long-term tests are being conducted at the moment



Detection Method

Neutron conversion by boron-10 + Charge amplification in CO_2/Ar gas

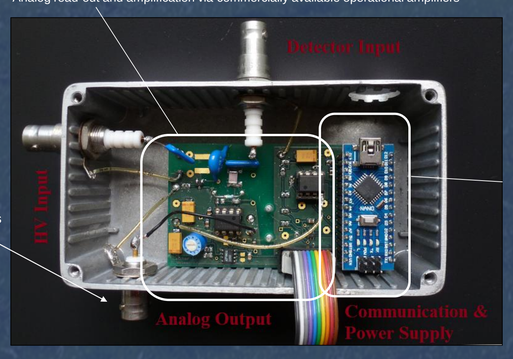




Electronics

Read-out unit (Pulse Analyzer)

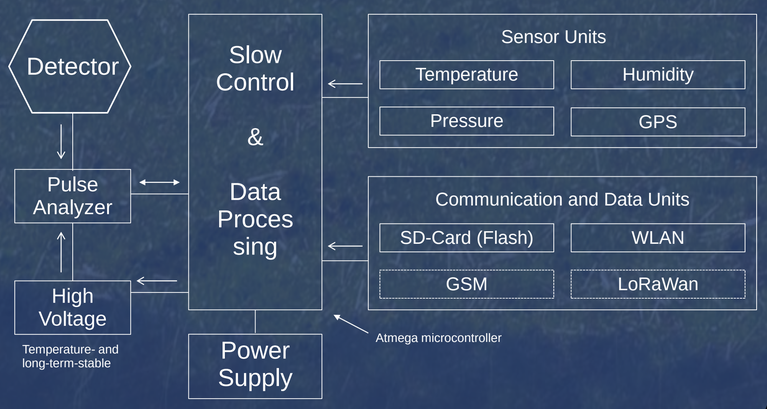
Analog read-out and amplification via commercially available operational amplifiers



Analog ouput allows for immediate read-out at the tube

Arduino Nano (Microcontroller)
- ADC: pulse-height measurement
- Time over threshold: pulse-length measurement
- Communication with data loggers possible via I²C/SPI

Entire electronics setup



Summary/Advantages

- Modular detection system of boron-lined proportional chambers
- Simple, robust and temperature-stable electronics (based on open hardware)
- High count rate by
  1. large effective area
  2. overall high efficiency
- Modular system allows for easily upgrading/ downgrading the system if detectors are needed elsewhere
- Lightweighted: future application for airborne neutron detection
- Advanced discrimination of background radiation
- Shielding against thermal neutron leakage
- Ar/CO_2 counting gas: cheap and hazard-free

Physics: Neutron Conversion in solid Boron

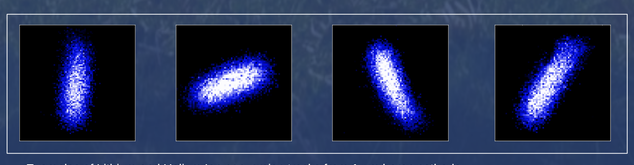
- Nuclear reaction takes place inside solid coating
- reaction products lose energy on their path through boron layer
- only energy deposited in gas volume can be detected
→ Critical compromise between neutron absorption and absorption range of reaction products determines efficiency of detection unit

→ Limited efficiency of a single boron-lined detection unit
(boron layer thickness is the crucial parameter)

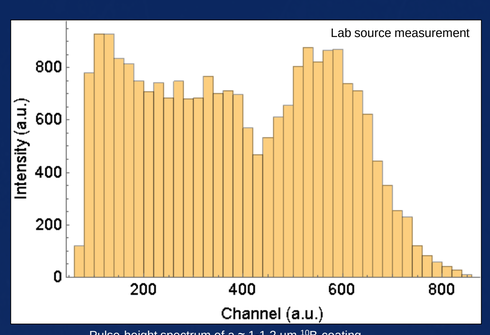
Efficiency for neutron conversion:
- *Black/red*: efficiency for neutrons coming from backward or forward direction
- *Green*: overall absorption of neutrons
- *Blue*: absorbed **but** not detectable neutrons

Neutrons are reflected at the moderator wall and traverse detection volume several times + detection system composed of several units
→ Amount of „lost" neutrons has to be minimized (*blue*)

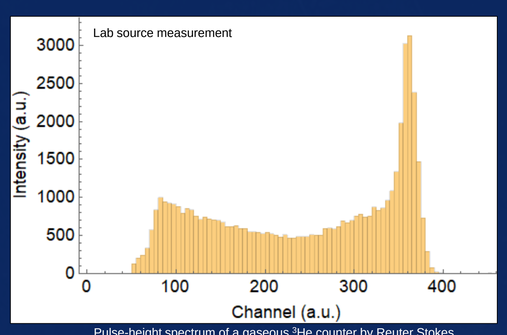
→ Optimum of boron layer thickness depends on amount of units and geometry of the detection system



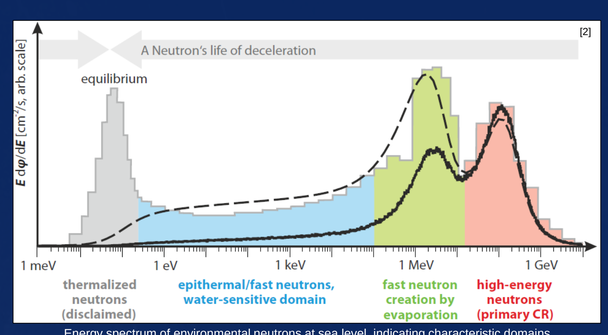
Examples of Lithium and Helium Ion conversion tracks from 1 µm boron cathode (from high resolution GridPix (Timepix +InGrid) readout with 50 µm pixel size)



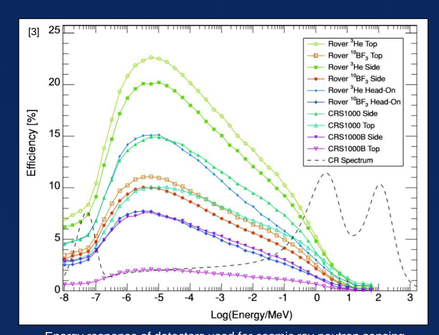
Pulse-height spectrum of a ≈ 1-1.2 µm ^{10}B-coating



Pulse-height spectrum of a gaseous ^{3}He counter by Reuter Stokes



Energy spectrum of environmental neutrons at sea level, indicating characteristic domains



Energy response of detectors used for cosmic ray neutron sensing

Additional Information

[1] Köhli et al.: Efficiency and spatial resolution of the CASCADE thermal neutron detector, In: Nuclear Insturments and Methods 828 (2016)
[2] Köhli et al.: Footprint characteristics revised for field-scale soil moisture monitoring with cosmic ray neutrons, In: WRR 51 (2015)
[3] Köhli et al.: Response Functions for Detectors in Cosmic Ray Neutron Sensing, In: ArXiv (2018)

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