Neutrons fast and slow: Boron-based Large-scale Observation of Soil Moisture (BLOSM)

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Abstract

The ratio between slow or thermal (<2.2 km/s) and fast (>2.2 km/s) neutrons is known to be a good measure of the amount of water present in a radius of about 300m from the measurement. COSMOS detectors use this principle and measure neutrons by means of the helium isotope ^{3}He. COSMOS has been in use for some time now and its large-scale observations are central to bridging the scaling gap between direct gravimetric observation of soil moisture ($<<1\text{m}^2$) and the scale at which soil moisture is represented in hydrological models and satellite observations ($>100\text{m}^2$). The main sources of ^{3}He were nuclear warheads. The fortunate demise of nuclear weapons has had the less fortunate consequence that ^{3}He has become expensive, leading to a search for more affordable alternatives. Here, we present laboratory results of a boron-based neutron detector called BLOSM. About 20% of naturally occurring boron is ^{10}B, which has a large cross-section for thermal neutrons. When ^{10}B absorbs a neutron, it decays into lithium and alpha particles. Alpha particles can then be detected by ZnS(Ar), which sends out UV photons. Because real-estate is at a premium for most neutron detection applications, most boron detectors are based on relatively expensive enriched boron with >99% ^{10}B. In hydrology, space is usually less of an issue, so one innovation here is that we use natural boron in a detector that is simply a bit larger than one based on enriched boron but much cheaper. A second innovation, put forward by Jeroen Plomp of the Delft Reactor Institute, are wavelength shifting fibers that capture UV photons by downshifting the wavelength to green. Green photons have a wider angle of total internal reflection and tend to stay in the fiber until they exit at the end. Here, a third innovation comes into play, inspired by Spencer Axani's $100 muon detector, namely the use of simple electronics and silicon photon multipliers (SiPMs). Because we want to know the ratio between fast and slow neutrons, we need two detectors, one that just counts the thermal neutrons that continuously zap around and through us, and one covered by a moderator that slows down faster neutrons to thermal levels, so that they can be detected. Presently, we can build two detectors for about EU 1000. We expect that after the development of some custom electronics, this will come down to around EU 500. Ideally, we would like to build a network of these detectors in Africa in conjunction with the TAHMO network (www.tahmo.org).

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Abstract Text:

The ratio between slow or thermal (<2.2 km/s) and fast (>2.2 km/s) neutrons is known to be a good measure of the amount of water present in a radius of about 300m from the measurement. COSMOS detectors use this principle and measure neutrons by means of the helium isotope ^{3}He. COSMOS has been in use for some time now and its large-scale observations are central to bridging the scaling gap between direct gravimetric observation of soil moisture (<<1m^2) and the scale at which soil moisture is represented in hydrological models and satellite observations (>100m^2). The main sources of ^{3}He were nuclear warheads. The fortunate demise of nuclear weapons has had the less fortunate consequence that ^{3}He has become expensive, leading to a search for more affordable alternatives.

Here, we present laboratory results of a boron-based neutron detector called BLOSM. About 20% of naturally occurring boron is ^{10}B, which has a large cross-section for thermal neutrons. When ^{10}B absorbs a neutron, it decays into lithium and alpha particles. Alpha particles can then be detected by ZnS(Ar), which sends out UV photons. Because real-estate is at a premium for most neutron detection applications, most boron detectors are based on relatively expensive enriched boron with >99% ^{10}B. In hydrology, space is usually less of an issue, so one innovation here is that we use natural boron in a detector that is simply a bit larger than one based on enriched boron but much cheaper. A second innovation, put forward by Jeroen Plomp of the Delft Reactor Institute, are wavelength shifting fibers that capture UV photons by downshifting the wavelength to green. Green photons have a wider angle of total internal reflection and tend to stay in the fiber until they exit at the end. Here, a third innovation comes into play, inspired by Spencer Axani's $100 muon detector, namely the use of simple electronics and silicon photon multipliers (SiPMs).

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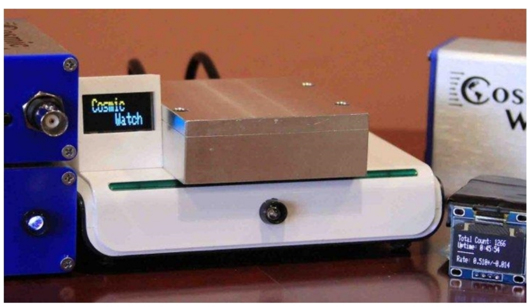
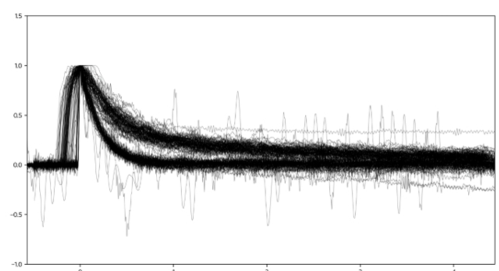
Wavelength shifting fibers are not unlike ice-cream spoons. Green light has a relatively large internal angle of reflection and the spoon becomes a wave-guide. A large number of photons come out at the edge, as if there is an internal light source. We call this the dicula effect.

Copy of first nuclear fission experiment. On the right, you see a source of fast neutrons (a radium and beryllium mixture) in a hydrogen-rich block of paraffin. The paraffin slowed down the neutrons so they could be "absorbed" by uranium nuclei, which then became unstable and split into barium and krypton. Similarly, we moderate fast neutrons so they can be captured by ^{10}B.



$100 muon detector by Spencer Axani



First laboratory results showing the detection of neutrons and gamma rays.

Plain-Language Summary:
There are very small parts that fly around us really fast all the time. Water slows down these small parts. The more water, the slower they fly. If we catch both slow and fast flying parts, we can see how much water there is in our area. If we catch many fast parts, the area is dry. If we catch more slow parts, the area is wet. The good thing is that this tells us something about a rather large area around us of almost ten hundred ball game fields. This has been done before but we built a small parts catching thing for little money. You can build almost one hundred of our small parts catching things for the money you pay for an old type of small parts catching thing. Several new ideas went into this small parts catching thing. We show the good things that happened when we built one on our kitchen table. Next time we will go to the field. (Thanks to the up-goer five editor.)

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