Astronaut-Assisted Neutron Mapping

Artemis Science Definition White Paper submitted to the Science Definition Team

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Executive Summary: The ambient neutron flux at the surface of the Moon bears on issues of astronaut health, hydrogen prospecting, space weather, and flux of galactic cosmic rays. The only ground truth we have on this flux comes from the last astronaut-assisted experiment conducted on the Moon. Artemis missions could build efficiently on this foundation.

Lunar neutrons: Free neutrons have a lifetime of about 15 minutes, so they are only found in proximity to a radiogenic event. In the Solar System there are virtually no neutrons present in galactic cosmic rays (GCRs), or in the solar wind at distances beyond 1 AU.

Neutrons are produced by spallation collisions of GCRs with matter. A GCR particle incident on the Moon deposits its energy within about a meter of the lunar surface, producing around 1000 neutrons. The ambient neutron flux near the surface due to GCRs is around 10 neutrons per square centimeter per second. These are all averaged values, subject to significant variation in space and time. Indeed, evidence for water near the Moon's poles comes from observation of the modification of the energy spectrum of GCR-induced neutrons by large spatial concentrations of hydrogen, possible in the form of water ice.

Neutron detection is a preferred technique for remote sensing of deposits of hydrogen encased in dense media, and is widely used in hydrocarbon prospecting on Earth. Mobile arrays of neutron detectors could be deployed to find subsurface hydrogen on the Moon, or to peer from crater edges into permanently shadowed regions (PSRs) where surface water ice might be found.

Fixed arrays of neutron detectors could provide time records of neutron flux on the Moon. This is of interest in quantifying neutron radiation exposure constraints on human endurance on the Moon. It also serves as a proxy for the history of GCR activity, and can serve as an early-warning system for extreme space weather events as well as a component of an Earth-Moon space weather station network.

The role of Artemis: The only neutron detector yet fielded on any airless planetary body, and the last instrument to be used in any astronaut-assisted experiment on the Moon, is the Lunar Neutron Probe Experiment (LNPE) [1]. Carried to the Moon and back by Apollo 17 in 1972, LNPE provides *the only ground truth we have* for neutron distributions on the Moon's surface.

Those who know of LNPE admire its elegance and simplicity. It was a completely passive detector wound around a 2 meter-long staff of 4 centimeter diameter, effectively a photographic film recorder that detected energetic fragments of the neutron absorption reaction of boron-10 and neutron-induced fission of uranium-235. The LNPE staff was installed in an astronaut-drilled shaft during the first Apollo 17 extra-vehicular activity (EVA), exposed for 49 hours, and returned to the Lunar Module at the end of the third (and final) EVA. Brought back to Earth by Apollo 17, LNPE was analyzed in the laboratories of the California Institute of Technology. The lead investigator, Dr. Dorothy S. Woolum, is now in active retirement. It seems most fitting for an Artemis mission to follow her lead!

Indeed, a simple repeat of the LNPE experiment, using some optimized modern variation of the original concept with multiple rods, is arguably worthy in itself. It is a low-overhead activity that has been successfully deployed on the Moon before, but in a much different location. At the Artemis landing site, multiple rods could be placed around a region the size of a few hectares. Three rods would alone yield a record of lunar neutron flux in three dimensions (LNPE was a vertical, one-dimensional measurement).

The best approach to neutron measurements is to use time-, space- and energy-resolving neutron detectors. There are limits to such an approach within the context of an Artemis mission. We have identified candidate neutron detectors with low mass, power consumption, and voltage requirements. These might be configured with solar-cell power for long-term operation during lunar days, with ability to communicate their data over an area of several hectares by WiFi. If an appropriate telemetry link were provided, this data might be sent back to Earth for analysis.

A prepackaged system of this type could be sent ahead by one-way autonomous vehicles. Artemis astronauts would add critical value by close-up reconnaissance of positions of opportunity, e.g. locations along a crater rim, precise and stable positioning and final configuration. Subsequent missions to different locations might establish planetary capabilities for neutron monitoring in aid of dosimetry, GCR observation and space weather applications.

[1] Woolum, D. S., Burnett, D., Furst, M., Weiss, J. R. (1975). "Measurement of the lunar neutron density profile," *Moon* **12**, 231.

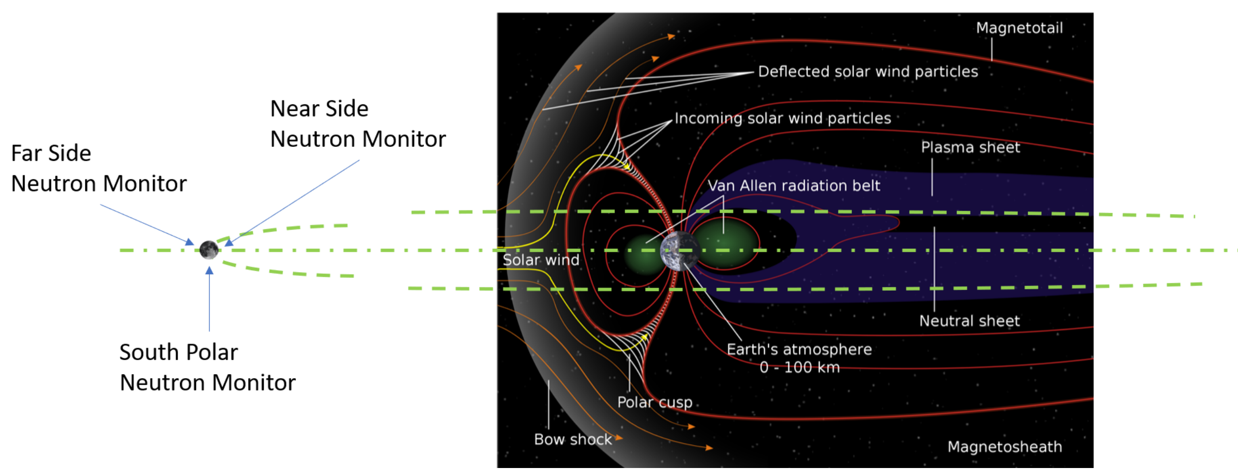

Figure: Concept of a lunar space weather station based on coordinated neutron detectors.