Demonstration of an Advanced Neutron Spectrometer for Crewed or Science Missions

Introduction

Much of the data available on neutrons in space are derived from neutron instruments that do not measure the energy of the neutron or do not measure to identify the incident particle as a neutron. These two characteristics are paramount for fully exploiting the detailed information neutrons can provide on future missions to the lunar and Martian surfaces. The ANS measures both of these characteristics of the neutron environment using a composite scintillator that measures a response to the neutron's energy and positively identifies the incident particle as a neutron. This complete measurement is then available for scientific analysis of the environment as well as calculation of the neutron contribution to dose experienced by crews.

The ANS technique makes use of the fast neutron measurement technique, gate-and-capture (Knoll), developed and used by many experimenters to study neutron spectra and combines it with a clean neutron capture technique developed for terrestrial purposes to distinguish neutrons from other incident particles.

The ANS was launched to the International Space Station (ISS) in Dec 2016 and has operated nearly continuously for 6 years deployed at different locations within the ISS. The data acquired during the mission has been analyzed and used to calculate the ambient dose-equivalent at various locations within the ISS volume. The ANS results have been compared with the operational detector onboard the ISS (Rad-ISS), and the two agree within 20%.

The Neutron Measurements on the Lunar Surface (NMLS) investigation (HaviLand) uses a detector based in part on the ANS technique and will be deployed to the lunar surface aboard the AB-1 CLPS mission, planned for 2024. The NMLS will count the thermal & epi-thermal fluence during its 1 lunar day mission. Additional designs of the ANS technique have been studied and tested in laboratories for instruments suitable for the lunar gateway observatory and human landing systems. The current TechDemo on the ISS has provided a solid bases for expanding the utility of the ANS approach to meet future NASA science and operational needs.

ANS Team: M.J. Christl[1] (Mark.Christl@NASA.Gov), J.A. Apple[1], C.M. Benson[1], P.F. Bertone[1], J.A. Caffrey[1], K.L. Dietz[1], B.F. Gibson[1], H.F. Havilandl[1], M.A. Rodriguez-Otero[1], G.S. Thornton[1], P.N. Bhat[2], E.N. Kuznetsov[2], J.W. Watts[2], and M.S. Sabra[3].

Affiliations: [1]NASA/MSFC (320 Sparkman Dr, Huntsville AL. 35805)
[2]Univ. of Alabama in Huntsville (320 Sparkman Dr., Huntsville, AL. 35805)
[3]Univ. Space Research Assoc. (320 Sparkman Dr. Huntsville, AL. 35805)

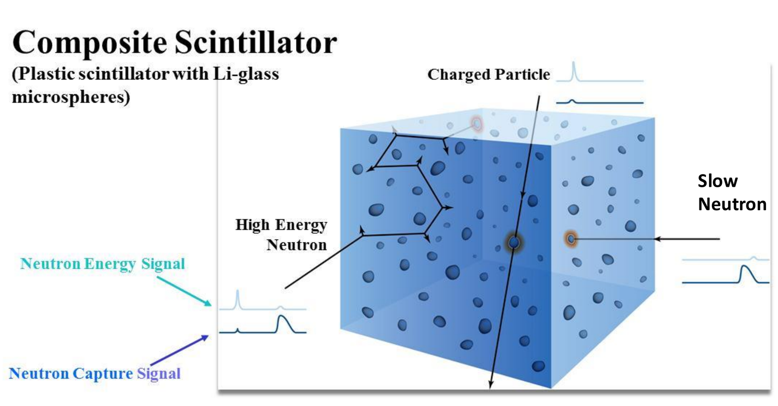
Acknowledgments: This work is supported by NASA/AES at NASA/MSFC and is one element of the RadWorks Project managed at JSC with support from MSFC & LARC.

Reference: Glenn F. Knoll, Radiation detection and measurement 4th Ed., 2010, Wiley & Sons, ISBN: 978-470-13148-0
Haviland H., et al., *Neutron Measurements at the Lunar Surface. LEAG 2020.* Poster #5039
NucSafe , 601 Oak Rideg Tpke, Oak Ridge, TN 37830

Technology Demonstration Details

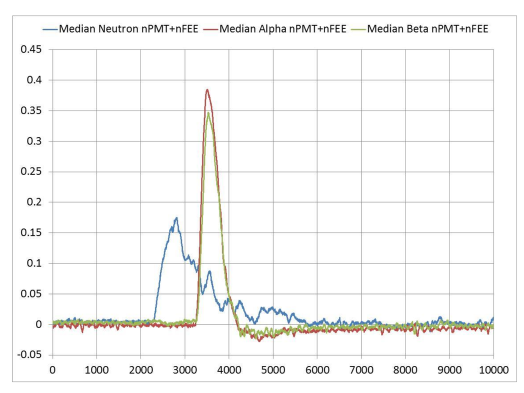
- Objective: Develop candidate neutron spectrometer for exploration missions
- Conduct ground-based and spaceflight testing and operations
- Launched to ISS: Oct. 2016
- Primary operations: Jan-June 2017 (USLab, Node1, Node2)
- Extended Operations: Sep 2017- April 2023 (USLab, Node1, Node2, Columbia)
- Operations and Data analysis: Continuing

ANS Detection Concept



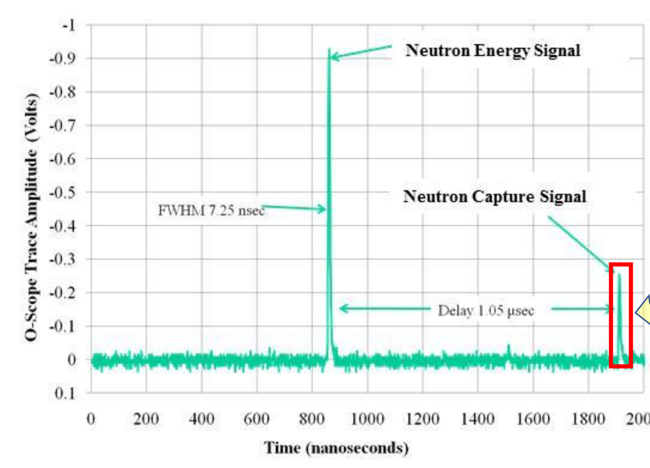
Pictorial of how the composite scintillator responds to different particle types. The color coordinated traces for each particle represent the responses of the two types of scintillators: plastic (light-blue), glass (dark-blue)

Sample signals in composite detector

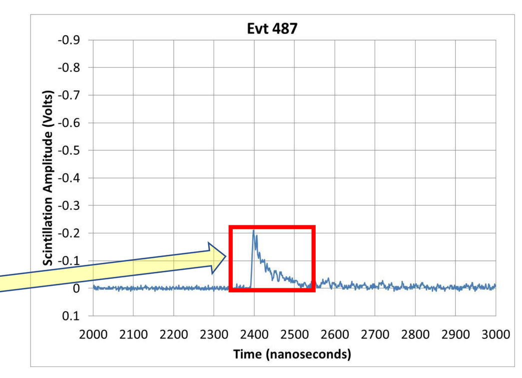


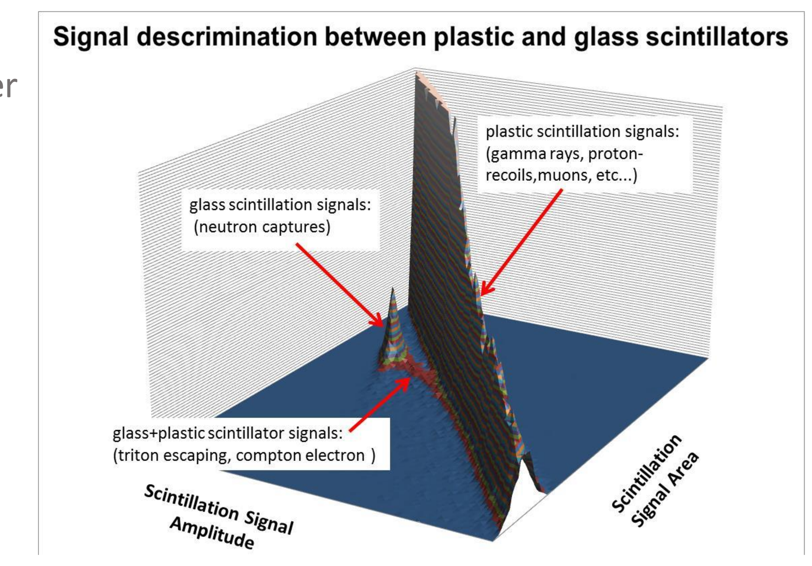
Signal traces for 3 particles types in a small composite scintillator. The plastic scintillator has a narrow pulse width, the glass scintillator has a broad pulse.

Capture-Gated Technique using B^{10}



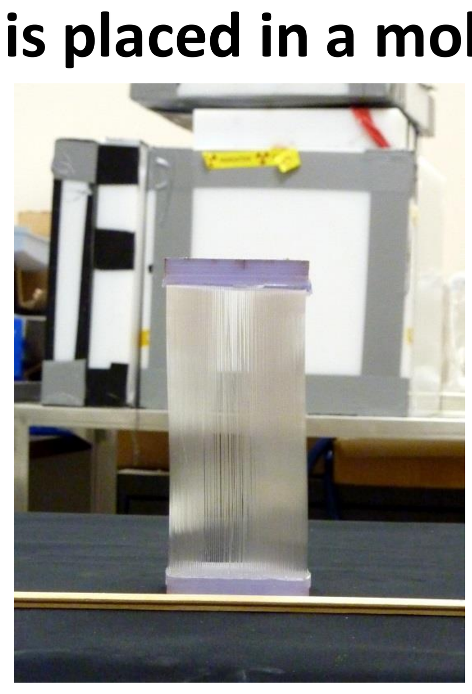
Neutron captured signal in glass fiber



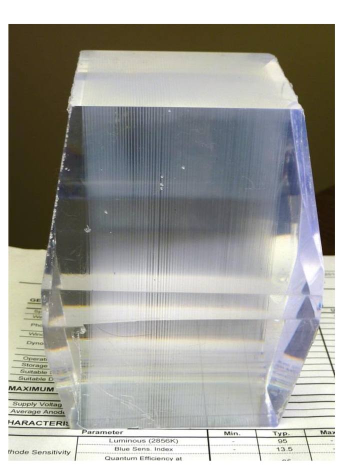


The measurement approach follows that of the neutron-gate-capture technique in plastic scintillators doped with elements having high thermal neutron cross sections (Boron-10 or Lithium-Gadolinium-Boron). A fast neutron loses energy primarily through elastic collisions with hydrogen producing recoil protons until the neutron is thermalized. ANS uses thin glass scintillating fibers loaded with Lithium-6 (NucSafe) embedded in a plastic scintillator (BC490). A neutron enters the composite detector and is moderated by hydrogen until it is capture by the lithium and decays: $n + Li^6 \rightarrow H^3 + He^4$. These decay products are mostly confined to the glass fiber. The plastic and glass scintillator pulse shapes are sufficiently different to discriminate between them in real time.

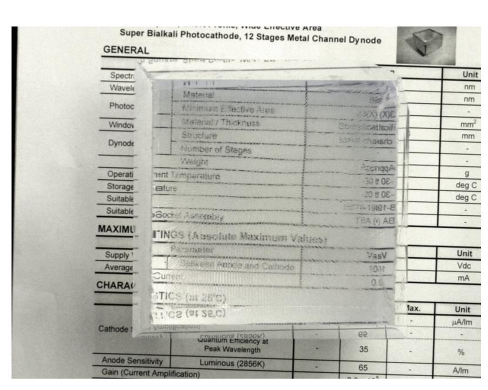
Fabrication: A bundle of carefully spaced fibers is placed in a mold before casting the detector



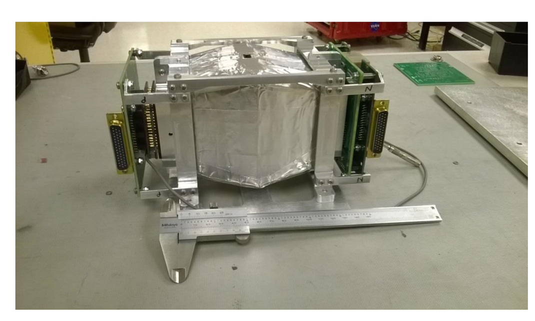
Fiber array:
72×73 fibers; 120 um dia.;
1.1 mm spacing; 15 cm length



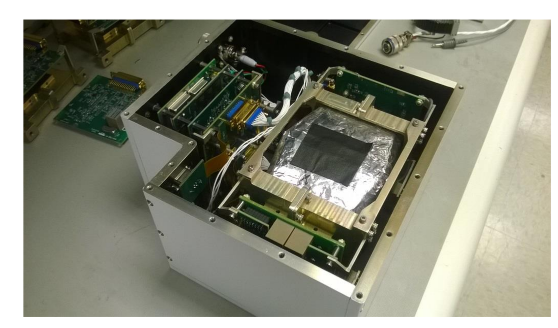
View through composite detector along the fiber lengths



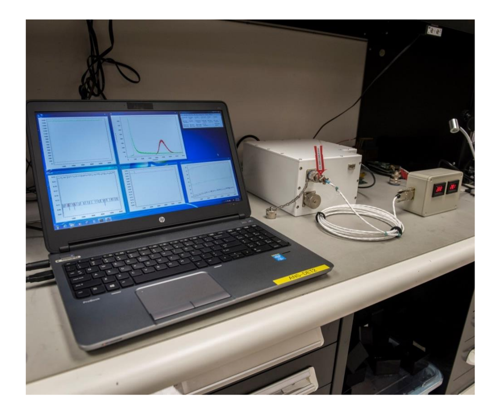
ISS Flight Unit



Detector mounted in its enclosure with PCBs that perform the neutron trigger and digitization functions

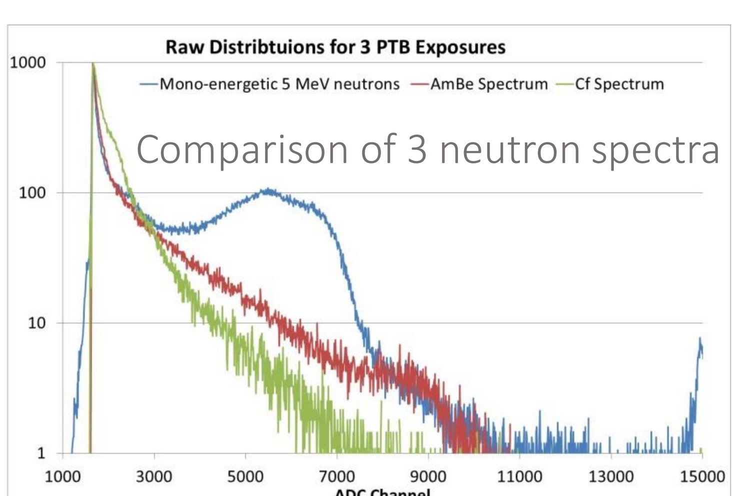


PMTs optically coupled to the composite scintillator and optically isolated from outside light

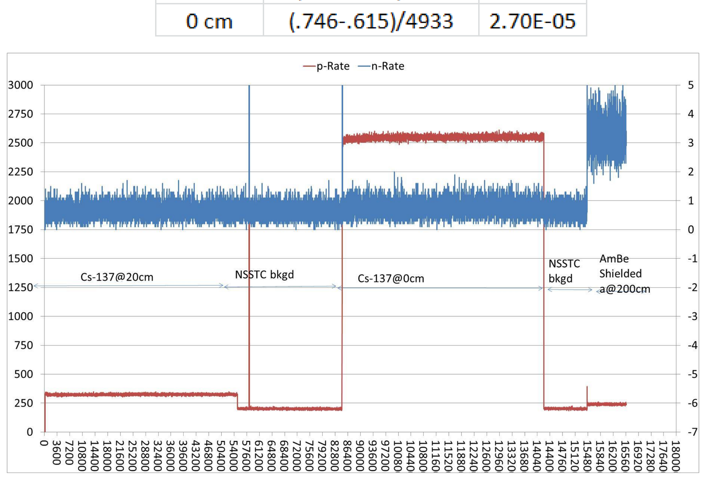


BenchTop testing of the ANS prior to delivery to NASA/JSC Patent no. 10908303

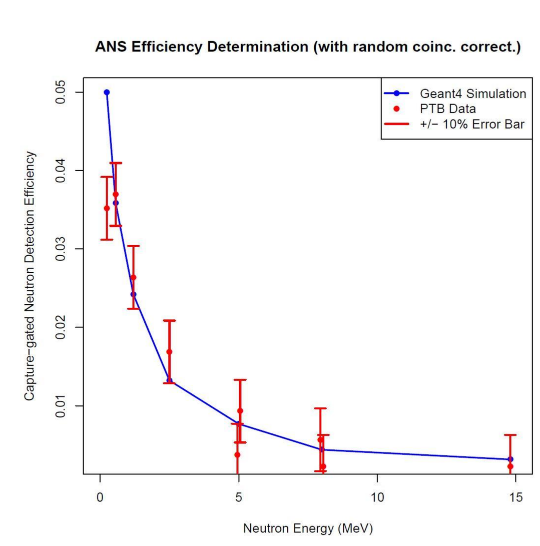
Performance Testing: Energy response and false trigger susceptibility

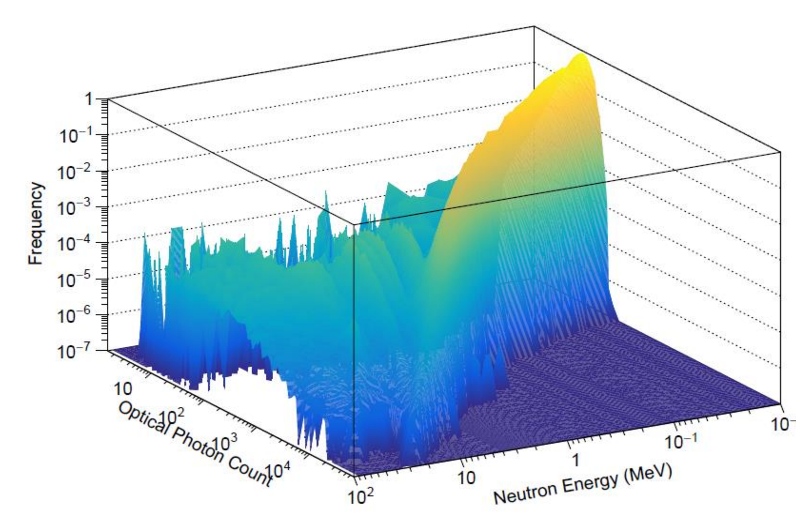


Test		False CPS
20 cm	(.638-.620)/290	6.20E-05
0 cm	(.746-.615)/4933	2.70E-05



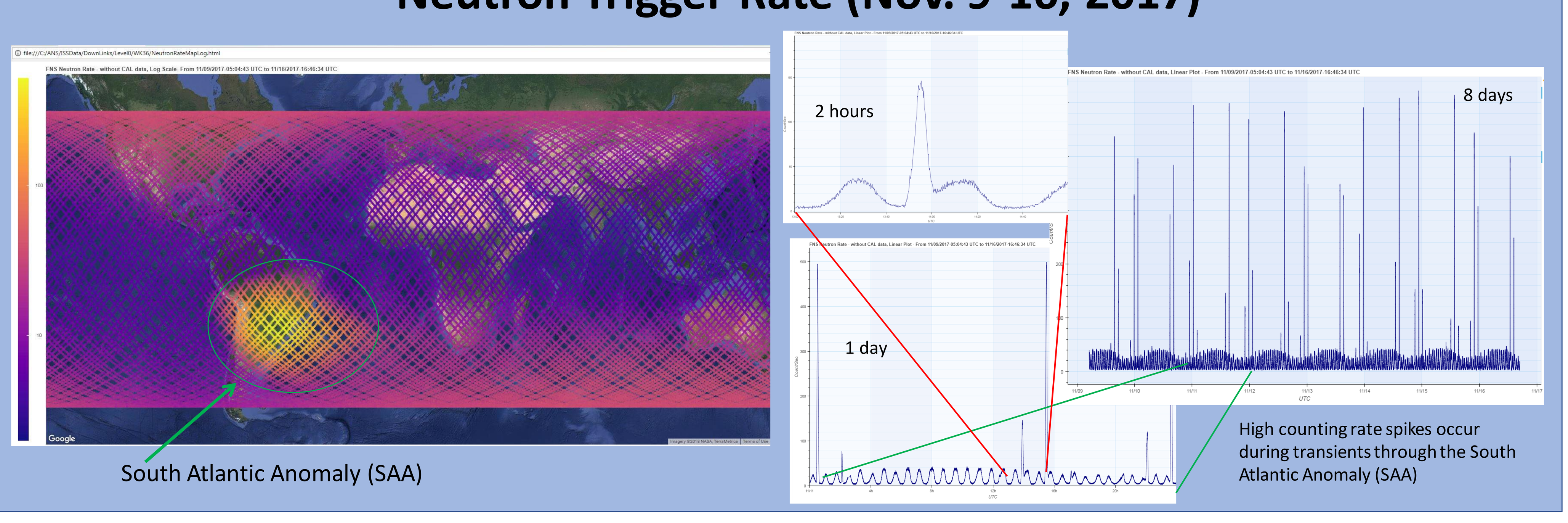
Detection Efficiency and Energy Response





The detector response is determined from GEANT4 simulations and checked with available PTB data. The neutron spectrum is derived from unfolding the acquired signal distribution with the response function.

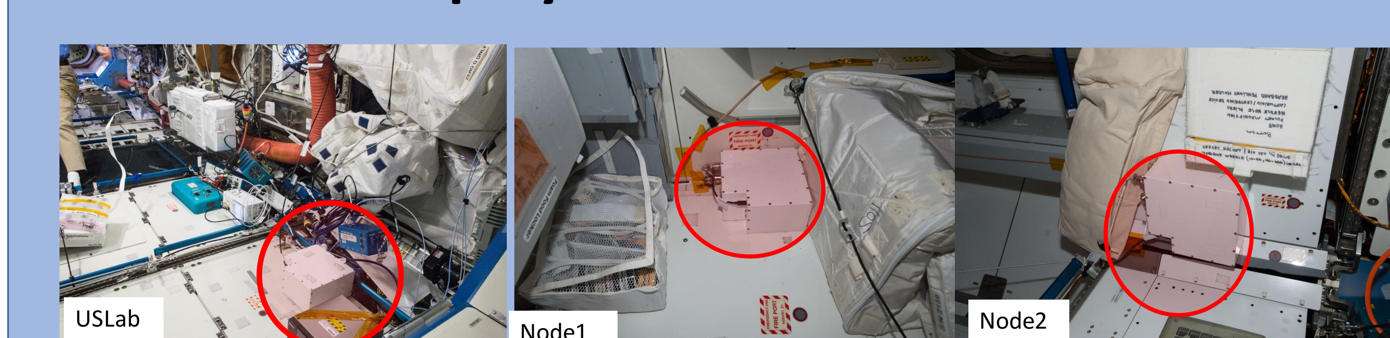
Neutron Trigger Rate (Nov. 9-16, 2017)



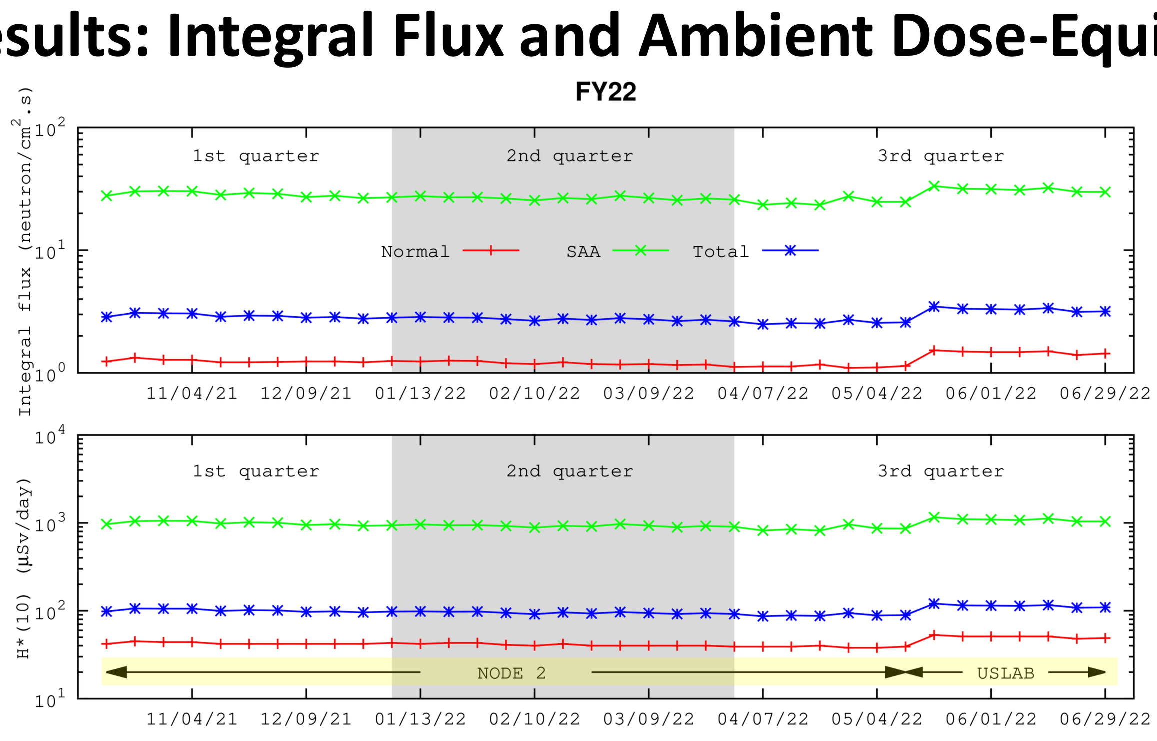
South Atlantic Anomaly (SAA)

High counting rate spikes occur during transients through the South Atlantic Anomaly (SAA)

Deployment around the ISS



Results: Integral Flux and Ambient Dose-Equivalent



The total exposure is determined by combining 6% of the SAA dose rate with 94% of the non-SAA rate.

Future Mission opportunities

- Lunar Gate-Way: operational unit to monitor crew radiation exposure
- Human Landing System: operational and scientific measurements to support crew safety and planetary science investigations

Technical Parameters for Exploration Model

Instrument Type	Plastic and Glass Scintillation Radiation Sensor
Data Product	Raw sensor output, reduced sensor output, or SW processed dose rate
Expected Flight Mass	4.25 kg (TBC)
Operating Temp Range	-30 to +70 degrees C
Survival Temp Range	-50 to +70 degrees C
Communication Interface	USB or RS422 Serial
Data transmission rate	Adjustable Rates - Science/Status (raw): ~50 MB/day - Science/Status (instrument processed): ~5 MB/day - Science/Status (vehicle processed): ~10 kB/day
Commanding	None required for nominal operation. - Full command set < 600 bytes
Power consumption	~6.4 watts
Input voltage	28VDC
Physical volume	~ 24.8 cm x 20.3 cm x 13.3 cm
Housing	TBD (current design modified per vehicle ICD)
Mechanical Interface	TBD (current design modified per vehicle ICD)
Launch, Acoustic, Shock Limits	prior designs: soft stow launch to ISS
Radiation Sensitivity (SEU)	FPGA – LET 2.8 MeV*cm^2/mg, COTS components
Energy Range	0.1 – 20 MeV