National Aeronautics and Space Administration

FY24 Strategic Initiatives Research and Technology Development (SRTD)

Miniaturized Gamma Ray and Neutron Spectrometer

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Strategic Focus Area: Miniaturized Gamma-ray and Neutron Spectrometer (GRNS) | **Strategic Initiative Leader:** Insoo Jun

Objectives: The objective is to develop a miniaturized gamma-ray and neutron spectrometer (mini-GRNS) with a Mars Helicopter mission as initial mission target. For such mission, the primary science measurement objective of the mini-GRNS is to estimate hydration level in the subsurface (2 – 8 weight % of water content). The secondary measurement objective is to determine the measurement capability of the Mini-GRNS for the elemental composition of some major elements (e.g., Si – 1779 keV, Al – 2110 keV) and a natural radioisotope (e.g., Th – 2610 keV). The target accuracy for both measurements is 20%. The mini-GRNS can simultaneously measure both gamma-rays and neutrons, leveraging the flight experience of a new neutron spectrometer, named Mini-Neutron Spectrometer (NS), that is based on a scintillator material Cs_2LiYCl_6:Ce (CLYC) and that has been successfully flown on the LunaH-Map (LMAP) mission (an Artemis I CubeSat) as a tech demo mission. Measuring both gamma-rays and neutrons with one type of detector material will provide a huge advantage over the other existing instruments. The mass and power target of the mini-GRNS is ~1kg and ~3W which is >60% reduction compared to the LMAP. We aim to achieve Technology Readiness Level (TRL) 5 by the end of FY26.

Table 1. Comparison to state-of-the-art of previously flown neutron and gamma-ray instruments.

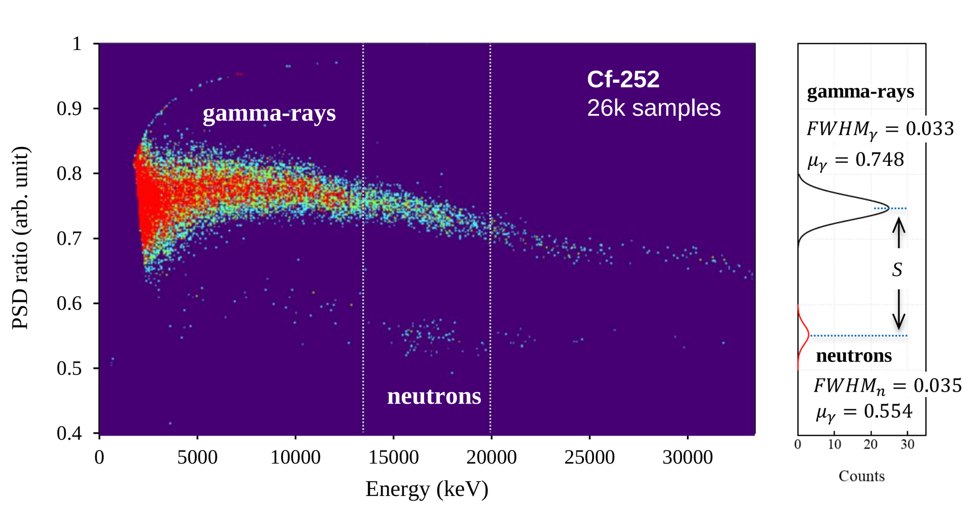
Mission	Detector	Mass (kg)	Power (W)	Capabilities
Lunar Prospector	He3 for neutron BGO for gamma	3.9 8.6	2.5 3	Thermal (<0.1 eV) & Epithermal (0.1-1 keV) neutrons 0.3-9 MeV, 10% at 662 keV for gammas
MSL DAN	He3 for neutron	1.9	3.5	Thermal & Epithermal neutrons No gammas
Mars Odyssey	He3 for neutron HPGe for gamma	3.6 23	5.7 32	Thermal & Epithermal neutrons <10 MeV, 10% at 662 keV for gamma
LRO LEND	He3 for neutron	26.3	13	Thermal & Epithermal neutrons No gammas
MESSENGER	Scintillators for neutron HPGe for gamma	3.9 9.2	6 23	Thermal & Epithermal neutrons 0.06-9 MeV, 0.3% at 662 keV for gammas
LunaH-Map	CLYC for neutron	3.4	10	Thermal & Epithermal neutrons No gammas
Mini-GRNS (This SRTD)	CLYC both for neutron and gamma	~1 target (0.8 CBE)	~3 target (2.5W CBE)	Thermal & Epithermal neutrons 6% at 622 KeV, 25°C, 0.1 - 3.5 MeV for gammas

Approach and Results: The goal of FY24 was to **develop a low power (<3W) GRNS electronics while maintaining figure-of-merit (FOM) higher than 2**. This requires more than 50% power reduction compared to the state-of-the-art instrument (LMAP). **We proceeded with two different electronics design approaches to meet the power and FOM target**, one of which will be implemented on the breadboard in FY25. Table 2 summarizes power reduction strategy and measured data of two different Pulse shape discrimination (PSD) circuits. **Based on the power consumption and FOM, the analog PSD circuit was selected for the breadboard implementation in FY25.**

Mini-GRNS instrument CBE Power: 2.5W
Figure-of-Merit: 2.85
CBE instrument mass: ~800g

Table 2. Comparison of two different PSD circuit architecture developed and tested in FY24.

	LunaH-Map (LMAP) (Reference)	Low-power Pulse Shape Discrimination (PSD) Circuit Designs (This SRTD)	
		Digital PSD (Heritage HW with lower sampling speed)	Analog PSD (New analog circuit with event driven ADC)
PSD method	Charge Integration	Charge Integration	Pulse Gradient Analysis
Low-power Electronics Design Strategy	High-Speed Digital PSD (multiple sampling) *Note: Not designed for low-power, but for high performance.*	Digital PSD (multiple sampling) • Operate ADC and FPGA at slower speed. • Minor design change from LMAP.	Analog PSD (2-point sampling) • Measure pulse peak voltage and sometime later. • Event driven with two samples. • Major design change from LMAP.
ADC	Free running, 250 MSPS	Free running, 54MSPS	Event driven, 10 MSPS
Analog Front End	Charge sensitive amplifier (CSA)	Charge sensitive amplifier (CSA)	50Ω shunt with amplifier
FPGA	Zynq XQ7Z020 (666MHz) DDR clock (533MHz)	Zynq XQ7Z020 (666MHz) DDR clock (533MHz)	ProASIC3 (100MHz)
Figure of Merit (**SRTD target: > 2**)	**4.6**	**2** (Worst case estimate at 50MHz)	**2.85** (Measured on test board)
Total Power (**SRTD target: < 3W**)	**6.4 W** (1 sensor head) **10 W** (2 sensor heads)	**3.7W** (1 sensor head)	**1.75 W** (1 sensor head, Measured) **2.5 W** (2 sensor heads, with a new sensor head)
CBE Weight (**SRTD target: < 1kg**)	**3.4 kg**	-	**~ 0.8 kg**
CBE Volume	Instrument total: **~10cm x 8cm x 30cm**	-	Sensor Head: **3.5cm x 3.5cm x 8cm** Electronics: **3.5cm x 6cm x 8cm**



$$PSD\ ratio = \frac{V_{peak}}{V_{peak} + V_{delay}} \qquad FOM = \frac{S}{FWHM_{\gamma} + FWHM_{n}} = 2.85$$

Figure 1. PSD scatter plot created by the analog PSD circuit using a Φ25.4mm x 25.4mm CLYC crystal and Cf-252. Confirmed instrument capability of measuring both neutrons and gamma-rays using the same sensor material.

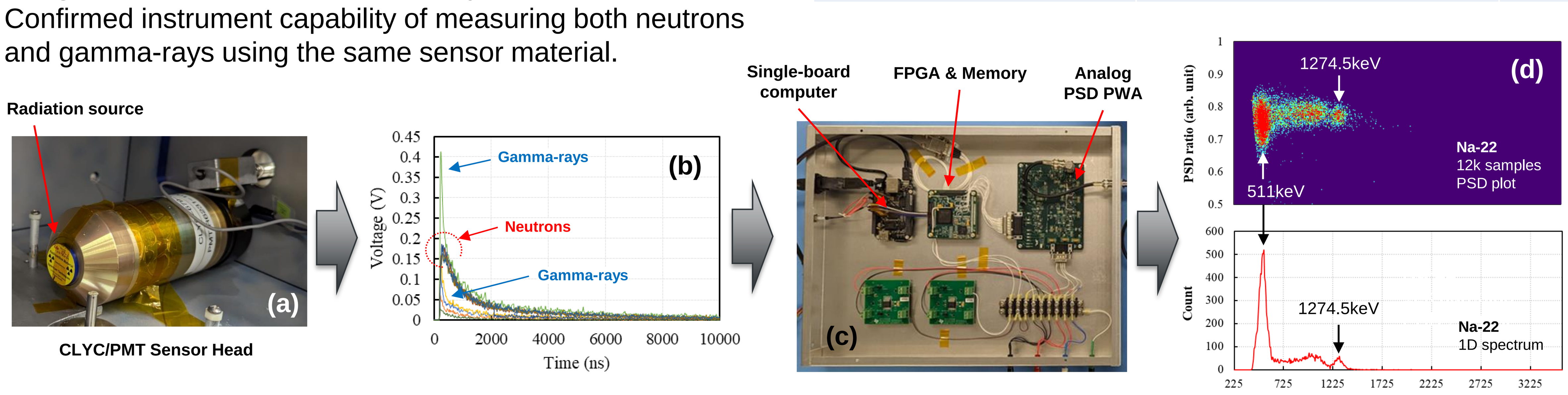


Figure 2. Analog PSD based mini-GRNS instrument tested at JPL's Dynamitron Lab. (a) Sensor Head, (b) Typical gamma-ray and neutron waveforms, (c) box level assembly of the analog PSD circuit, (d) 2D PSD plot and 1D spectrum of Na-22.

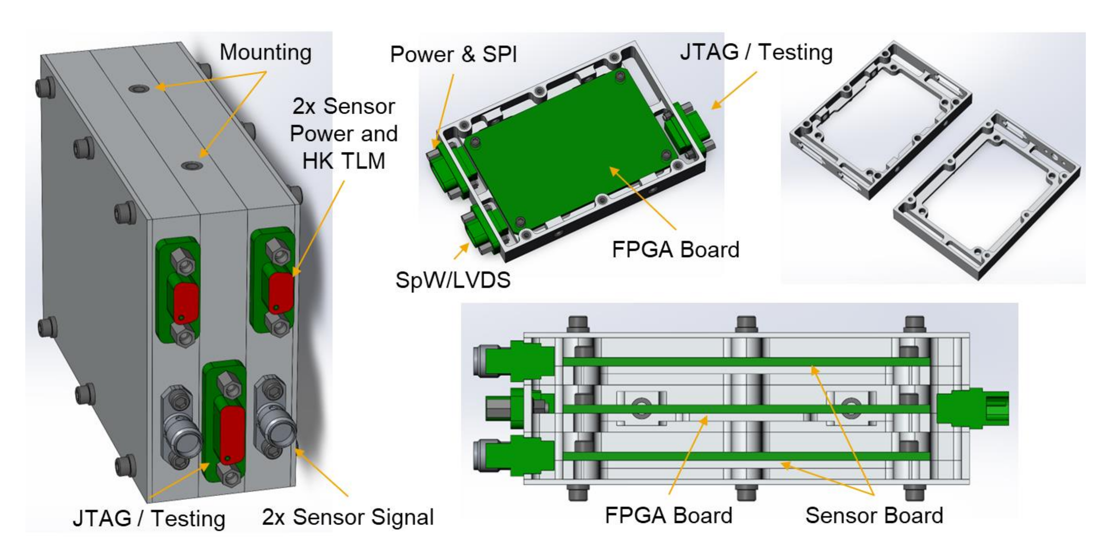


Figure 3. Initial chassis design concept. Three stacked PWA slices with removable outer lids allow access to both side of all three PWAs.

Significance/Benefits to JPL and NASA: We have verified that our instrument is capable of measuring both neutrons and gammas using the same sensor material, which has not been demonstrated in all other previous GRNS designs. We met both power goal (less that 3W) and FOM goal (higher than 2) with the test assembly. The CBE instrument mass is 800g which is below our mass target of 1kg. The newly developed low-power PSD circuit enabled 75% power reduction compared to the state-of-the-art instrument (LMAP with 2 sensor heads: ~10W, This work with 2 sensor heads: 2.5W). It is also obvious that miniaturization and low-power design will enable new infusion paths for future planetary missions at JPL and outside JPL.

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Publications:

Craig Hardgrove, Insoo Jun, Erik Johnson, Yuki Maruyama, Wousik Kim, Giacomo Mariani, Luz-Maria Martinez-Sierra, "Miniaturized Gamma-Ray and Neutron Spectrometer for the Endurance Rover," Endurance Science Workshop – Cahill Center, Caltech August 10th, 2023

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