THE PSYCHE GAMMA-RAY AND NEUTRON SPECTROMETER: UPDATE ON INSTRUMENT DESIGN AND MEASUREMENT CAPABILITIES.

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Introduction: The Psyche mission's spacecraft will orbit the M-class asteroid (16) Psyche with the goal of understanding planetary iron cores, examining the interior of a differentiated planetary body, and exploring for the first time a metal-rich planetary body [1]. The payload includes a Gamma-Ray and Neutron Spectrometer (GRNS), which will measure the elemental composition of Psyche's regolith to <1 m depths. Specifically, the GRNS will measure Psyche's abundances for the elements Ni, Fe, Si, K, S, Al, Ca, Th, and U, as well as the spatial distribution of Psyche's metal-to-silicate fraction (or metal fraction). Without changes in design or operation, the GRNS is also capable of measuring other physical parameters – high-energy gamma rays [2], hydrogen, Co [3], isotopic content of ^{54}Fe [4], and energetic particles – all of which provide additional information about Psyche's composition and/or space environment. The GRNS is currently in the preliminary design phase, and its design has been matured based on various requirements, constraints, and opportunities. Here, we present the current GRNS design, including updated features, along with the reasons for these updates.

The Psyche Gamma-Ray and Neutron Spectrometer (GRNS): The general design of the GRNS remains the same as originally proposed [5]. It consists of a high-purity germanium (HPGe) gamma-ray spectrometer (GRS), surrounded by a borated plastic anticoincidence (AC) shield, and a ^{3}He gas-proportional-sensor-based neutron spectrometer (NS). The exceptional gamma-ray energy resolution and sensitivity provided by the HPGe sensor enables the GRS to measure all the required gamma-ray lines. The borated plastic scintillator and ^{3}He sensors provide robust measurements for neutrons ranging in energies from <0.1 eV up through a few MeV. Both sensors are located on a boom to reduce spacecraft-induced gamma-ray and neutron backgrounds. As has been demonstrated on many prior planetary missions, combined gamma-ray and neutron measurements provide comprehensive elemental composition information for airless or nearly airless planetary bodies [6]. During the preliminary design phase of the GRS, aspects of both the GRS and NS have matured, and the current designs of each are given below.

GRS: The current view of the GRS is shown in Figure 1. The overall concept is based on the MESSENGER GRS [7] with modifications derived from updated developments and lessons learned from the MESSENGER mission. The gamma-ray sensor is a 5-cm diameter by 5-cm long cylindrical Ge crystal, which is identical in size and shape to the MESSENGER GRS. It is housed within a stand-alone cryostat that thermally isolates the cryogenically cooled Ge crystal from its surrounding environment [8]. The cryostat is surrounded by the AC shield that both rejects charged particle background in the Ge sensor and measures high-energy (fast) neutrons. The Ge sensor is cooled to cryogenic temperatures (90 K) using a long-life pulsed tube cryocooler.

Updates to the GRS include the following aspects. First, the radiator, which rejects waste heat from the cryocooler, has been designed to accommodate the thermal environment of the GRS on the boom, and the spacecraft at Psyche. Second, the orientation of the GRS is arranged such that the asteroid is viewed through the AC shield instead of through the top of the Ge crystal, as was done on MESSENGER. This arrangement has little effect on gamma-ray attenuation, since the gamma rays only need to pass through the housing and low-density plastic prior to detection. The orientation of the GRS also offers multiple benefits. These include a simplified arrangement of connector ports, and a more uniform angular response for rotations around the spacecraft z-axis. This latter feature reduces the

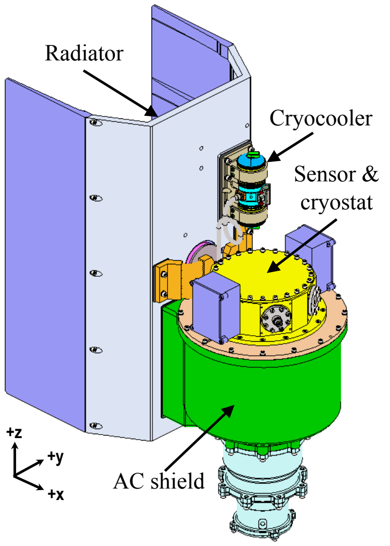

Fig. 1. The Psyche GRS, with the spacecraft coordinate system shown. The boom is oriented along with z axis, and the Psyche nadir direction is along the x axis.

magnitude of corrections for measurement geometry and attenuation, which ultimately improves systematic uncertainties. Finally, significant work has been done to better understand and quantify the annealing procedures used for reversing the effects of radiation damage in the Ge crystal from space-based energetic particles [9]. To this end, when the Ge sensor requires annealing, it will be carried out using a temperature of 105 °C, which is a higher temperature than used for MESSENGER (85 °C), but the same as for the INTEGRAL gamma-ray sensors currently in Earth orbit making astrophysics measurements [10].

NS: As with the GRS, aspects of the NS have been matured and updated during its preliminary design phase. The current view of the NS is shown in Figure 2. Two significant changes to the NS have been made to optimize its measurements at Psyche. First, instead of the cantilevered neutron sensor arrangement based on the Lunar Prospector NS [11], the Psyche ^{3}He neutron sensors will be placed on a flat plate. This arrangement both provides mass savings and simplifies the mechanical design.

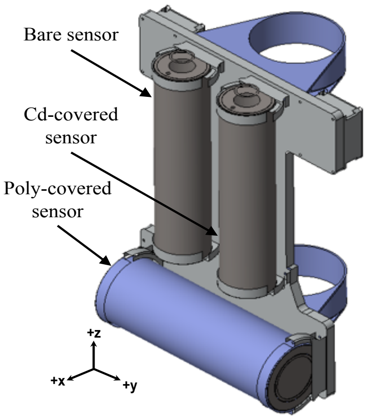

Fig. 2. The Psyche NS with the spacecraft coordinate system shown. The boom is oriented along the z axis and the Psyche nadir direction is along the x axis.

Second, with the new flat-plate mounting, a third ^{3}He neutron sensor can be added in a straightforward manner. A third ^{3}He sensor benefits the Psyche neutron measurements based on the following reasons. The expected metal-rich nature of Psyche's composition will significantly modify its equilibrium neutron flux compared to rocky silicate-rich bodies [5] (Figure 3). Specifically, the thermal neutron flux will be greatly suppressed if high concentrations of neutron absorbers Fe and Ni are present [12]. In addition, the flux of high-energy epithermal neutrons (>100 keV, grey boxes in Fig. 3) will be enhanced in comparison to silicate bodies. A clean measurement of epithermal neutrons is also important for quantifying hydrogen abundances on Psyche, which may be present with concentrations up to hundreds of ppm [13]. Hydrogen measurements are not required to meet specific mission goals; however, if hydrogen is present and spatially variable [14], mapping of hydrogen will reduce the systematic uncertainties of the other gamma-ray and neutron measurements. The original two neutron sensors measure thermal and low-energy epithermal neutrons using bare and Cd-covered sensors, respectively. A third ^{3}He sensor covered in 1 cm thick polyethylene can provide a clean and independent measurement of high-energy epithermal neutrons. The four neutron-energy bands of the GRNS (three ^{3}He sensor energy bands; one AC shield energy band) thus provide an optimal set of measurements for characterizing the neutron environment around a metal-rich body like Psyche [12].

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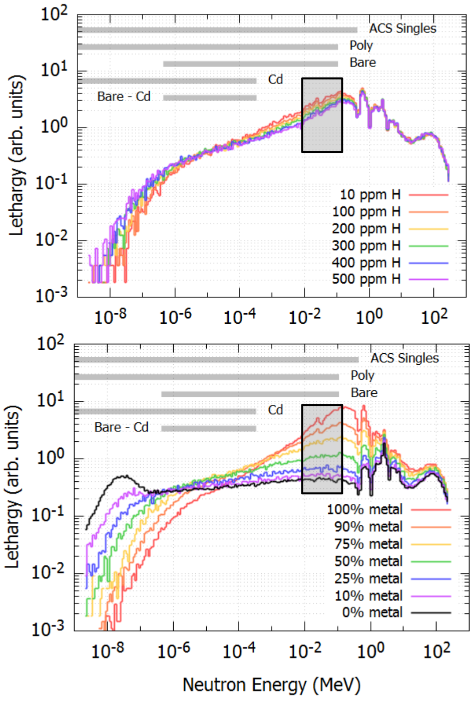

Fig. 3. Neutron flux variations (displayed as lethargy or flux times energy) for variations in hydrogen (top) and metal fraction (bottom). Neutron energy band-pass filters are shown as gray lines at the top of each panel. Grey boxes show the high-energy epithermal region discussed in the text.