PING GAMMA RAY AND NEUTRON MEASUREMENTS OF A METER-SCALE CARBONACEOUS ASTEROID ANALOG MATERIAL. J. G. Bodnarik[1,2], J. S. Schweitzer[3], A. M. Parsons[1], L. G. Evans[4], R. D. Starr[5], [1]NASA Goddard Space Flight Center (8800 Greenbelt Road, Code 691, Greenbelt, MD 20770; Julia.G.Bodnarik@nasa.gov), [2]Vanderbilt University, [3]University of Connecticut, [4]Computer Sciences Corportation, [5]Catholic University of America.

Introduction: Asteroids are the remnants from the formation of the Solar System about 4.6 billion years ago. The study of the organic and inorganic geochemistry of these ancient bodies is a window into the formation of the planets and of life itself. However, our understanding of asteroids is severely limited.

Our current knowledge about asteroids shows us how much we don't know about them. Ultraviolet (UV), Visible (VIS), and Infrared (IR) spectral reflectance measurements, used for asteroid taxonomy, are not particularly informative. With two exceptions, the asteroid to meteorite connection is weak. For example, a given meteorite is determined to be from a C-spectral family of asteroids, but we don't know which asteroid taxonomic type it belongs to. Finally, UV, VIS, and IR measurements are limited to probing the first few microns of the surface of asteroids. However, we know that these top microns are strongly space-weathered, from solar wind exposure, micrometeorites, etc., and are substantially different from the bulk material.

Given our limited understanding of asteroids, there is still much that we need to know about them. We still need to understand asteroid orbits, the difference between the space-weathered surface and the pristine subsurface organic and inorganic composition and distribution of asteroids, and the internal structure, density and porosity of asteroids that tells us about their impact and accretion history. We can aid in addressing these questions, since our group has developed instrumentation that can measure *in situ* the surface and subsurface elemental composition of asteroids that we use to infer mineralogy.

Studying the Subsurface Elemental Composition of Asteroids Using PING: Gamma ray and neutron instrumentation techniques have been used extensively in oil and scientific well logging applications to determine the bulk elemental composition of subsurface geology [1]. Our group is developing the Probing In situ with Neutrons and Gamma rays (PING) [2] instrument at NASA Goddard Space Flight Center's (GSFC) Astrochemistry Laboratory to land on the surface of a carbonaceous (spectral type C or C-type) asteroid and use the penetrating nature of fast neutrons and gamma rays to probe the subsurface soil composition without the need to drill.

PING Instrument Description. PING, shown on a planetary rover in Fig. 1, uses a 14 MeV pulsed neutron generator (PNG) to excite material at and below a planetary surface. A gamma ray spectrometer measures the resulting characteristic gamma rays that are emitted by the excited elements; neutron detectors measure the properties of the resulting low energy epithermal and thermal neutrons that reach the surface.

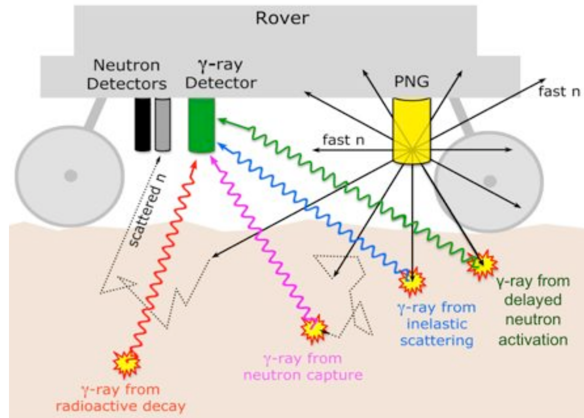

Fig. 1. Illustration of PING mounted on a rover showing how it can be used to determine the bulk elemental composition over a ~ 1 m^2 surface area and down to 30 to 50 cm below the surface of an asteroid.

Testing PING on Earth. In order to optimize PING for an asteroid lander, we are testing PING on a known and well-characterized meter-scale test sample or simulant, due to the large volume probed by PING noted in the Fig. 1 caption. Ideally, we would like to use 3 m^3 of primitive carbonaceous chondrite meteorites, analogs to C-type asteroids. However, only 9 of the most primitive carbonaceous chondrite meteorites have been found on Earth thus far, for a total of only about 21 kg. Even if we relaxed our constraints to include more common, less primitive, altered meteorites like CV3 carbonaceous chondrites, it would cost approximately $57,000,000 [3]. Clearly neither option is viable so we need to develop an appropriate C-type asteroid simulant.

Asteroid Simulant Requirements. We require that an asteroid simulant appropriate for testing PING must have nearly the same neutron response as the C-type asteroid we want to study. The asteroid simulant must have an equivalent neutron spatial distribution within the volume (similar neutron moderation properties) and equivalent neutron absorption processes (similar average macroscopic neutron absorption cross-section) as that of a C-type asteroid. In addition, the asteroid simulant must be located far from any physical structures that could interact with neutrons and gamma rays to produce background signals in the PING detectors. This isolation is easily achieved at our outdoor, planetary neutron and gamma ray instrumentation test facility.

To meet our requirements, we constructed our asteroid simulant using 16-alternating layers of Columbia River basalt and high-density polyethylene on top of a Columbia River basalt monument located at our test facility. Fig. 2 shows the PING components on top of the basalt layered asteroid simulant.

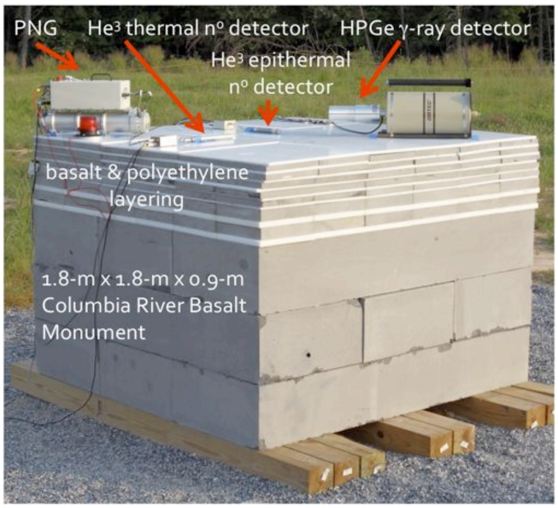

Fig. 2. Image of PING components on the asteroid simulant.

Equivalent Neutron Spatial Distribution. To study how best to use PING to measure the subsurface elemental composition of a carbonaceous asteroid, we need to create a simulant that has the same response to PING's 14 MeV neutrons as the actual asteroid material. We thus used the Monte Carlo N-Particle eXtended (MCNPX) computer modeling tool [4] and the known elemental assay information [5] of the Columbia River basalt to study the neutron and gamma ray response of potential simulant configurations. For the simulant to be useful, both the 3-D spatial distribution of the fast neutrons throughout the material and the depth distribution of the epithermal and thermal neutron fluxes need to be essentially identical for both systems. The final basalt-layered asteroid simulant configuration and material selection was determined by comparing the neutron spatial distributions for the different configurations to the simulation results for a true homogenous C-type asteroid.

Equivalent Neutron Absorption Properties. We experimentally tested and verified the absorption properties on different structures (the granite monument and the basalt monument), including the

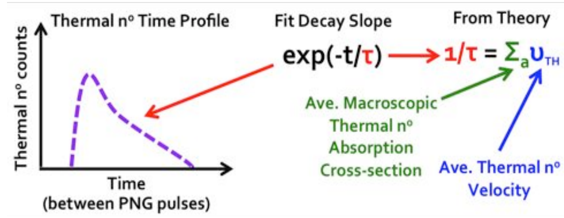

Fig. 3. Cartoon illustrating the comparison of the average macroscopic thermal neutron absorption cross-sections for experimental and calculated data.

basalt-layered asteroid simulant, by studying the time profile of thermal neutron absorption between PNG pulses using a ^{3}He thermal neutron detector at the surface. Fig. 3 is a cartoon demonstrating how we can compare the average macroscopic thermal neutron absorption cross-sections of the fitted experiment data to that of the calculated data (from known elemental composition, density, and cross-section information) for the bulk material. Since the calculated average thermal neutron absorption cross-sections were based upon homogenous basalt and granite elemental assays, we were able to verify that if the experimental data for both the homogenous granite and basalt monuments were in agreement with calculated data, then any layered simulations using these materials are reliable.

In this paper, we will present experimental data from using PING with the asteroid stimulant, the bare basalt, and the bare granite. A comparison of these data with the computer simulation results for a true homogenous carbonaceous asteroid will show that the response of our layered basalt sample is an excellent simulant of a real carbonaceous asteroid. Thus, this high-fidelity simulant may be used for future studies of PING's capabilities for *in situ* measurements of carbonaceous asteroids.

References:

[1] Grau J. A. et al. (1993) *Int. J. of R. Apps. & Inst.. Part E. Nuc. Geo.. Ind. Rad. & Radioiso. Meas. Apps., 7,* 173-187.

[2] Parsons A. M. et al. (2011) *NIM-A*, *652*, 674–679.

[3] The estimate for the total cost to obtain the amount of meteorite material needed for our asteroid simulant experiments is based upon the price of $271.80 for 15.1g grams of the Allende meteorite found for sale at http://www.meteorites-for-sale.com.

[4] Pelowitz D. B., et al. (2005) *MNCPX User's Manual, Version 2.5.0*, LANL, Los Alamos, LA-UR-05-0369.

[5] A complete elemental assay of samples of the granite and basalt was perforemed by Activation Laboratories Ltd. of Ancaster, Ontario, Canada.