BULK ELEMENTAL COMPOSITION MEASUREMENTS OF METEORITES VIA NEUTRON-INDUCED GAMMA RAY SPECTROSCOPY. Mauricio Ayllon Unzueta[1,2], Ann Parsons[1], Patrick N. Peplowski[3], Arun Persaud[4], Jack Wilson[3], [1]NASA Goddard Space Flight Center, Greenbelt, MD; [2]Oak Ridge Associated Universities, Oak Ridge, TN; [3]Johns Hopkins University Applied Physics Laboratory, Laurel, MD; [4]Lawrence Berkeley National Laboratory, Berkeley, CA; (mauricio.ayllonunzueta@nasa.gov).

Introduction: Meteorites are mostly classified based on their bulk elemental compositions, which serve to constrain their origin and formation processes. Additionally, many of the new geochemical data from planetary bodies are limited to the bulk elemental composition of major elements that are obtained remotely from orbital neutron and gamma-ray spectrometers [1]. In particular, there is a lack of bulk compositional data from metal-rich meteorites, which is needed to build a database to aid in the interpretation of data from the Gamma Ray Spectrometer (GRS) onboard the upcoming NASA mission Pysche to a metal-rich asteroid [2]. Therefore, the analysis of already existing and future GRS data, as well as the improved understanding of the formation process of meteorites, require precise measurements of their bulk elemental composition. However, current methods, albeit extremely precise and sensitive, lack the ability to measure the elemental composition of the entire sample given that they either probe a very small region or grain of the material (non-representative sampling) or they only measure the topmost surface layer, which can be affected by weathering effects and other chemically altering processes. See [3] for an example of the large variability of various techniques to measure elemental composition on the same meteorite. Consequently, we developed a nondestructive, quick turn-around technique based on fast neutron-induced gamma ray spectroscopy that can precisely measure the composition of major elements (>1% concentration) of medium-sized meteorites.

Experimental Method: Prompt Gamma-ray Neutron Activation Analysis (PGNAA) is a widely used technique to probe the composition of a sample by exciting their nuclei with neutrons and detecting their subsequent de-excitation via prompt gamma ray emission. These gamma rays have energies that are specific to the element that produced them, and their intensities are proportional to the element's quantity in the sample. As such, PGNAA can be used for both elemental identification and absolute abundance measurements. However, this technique has some limitations, including the inability to collimate the neutron beam, which leads to an increased background and decreased precision and sensitivity.

To address these issues, we use a variation of PGNAA called Associated Particle Imaging (API) [4]. This technique enables the electronic collimation of neutrons through coincident measurements of both the emitted neutron and the detected gamma ray. As a result, we are able to achieve higher precision and sensitivity in our elemental composition measurements than those obtained using traditional PGNAA methods.

Procedure and Analysis: We designed a proof-of-concept experiment that consisted of irradiating high-purity samples (standards) of Fe, Ni, Si, SiO_2, and MgO as well as a $10\times10\times1.5$ cm^3 sample of the stony-iron Pallasite meteorite Admire. Figure 1 shows the experimental setup showing the location of the gamma-ray detectors as well as that of the samples. The iron sample and the meteorite are shown for illustration purposes.

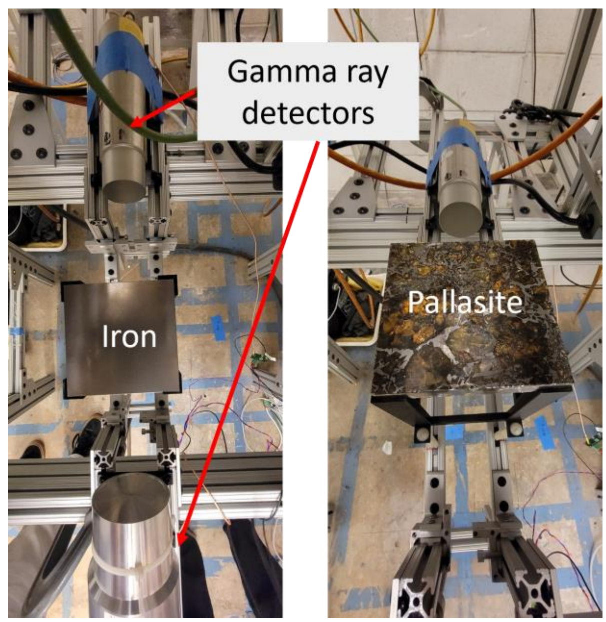

Figure 1: Experimental setup showing the location of the gamma-ray detectors, one of the elemental standards (iron), and the meteorite sample.

These elemental standards are used to obtain the bulk elemental composition of the meteorite, which is achieved mathematically through a linear combination of their response functions and a minimization technique known as Weighted Least Squares (WLS) fitting. This experiment was simulated using a neutron and gamma ray transport software tool called MCNP6, and the results are shown in Figure 2.

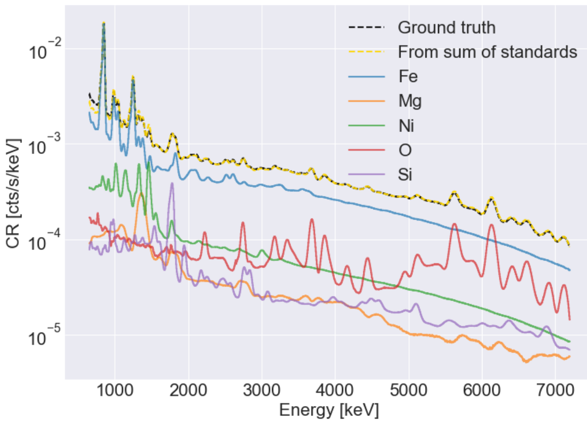

Figure 2: Results of an MCNP simulation showing how we obtain the bulk elemental composition of a meteorite based on a linear combination of its elemental standards.

The experiment is currently ongoing, and we plan to present preliminary results at the conference.

Some challenges with this technique come from both neutron and gamma-ray multiple scattering within the sample, which varies depending on the different material properties. However, we can measure and simulate this effect by measuring a stack of a mix of elemental standards.

Conclusion: Current state-of-the-art techniques fall short of accomplishing "true" bulk elemental composition measurements because they either sample a very small piece of the meteorite or just the top surface layer. Most meteorites are not homogeneous in composition, and therefore, there are large discrepancies in compositional measurements depending on the technique being used.

We showed that an API system can overcome this technical challenge and measure bulk elemental compositions of medium-sized meteorites in a few hours depending on the target statistical precision. 20-40 times faster measurements are possible with future improvements on the readout electronics and the addition of more gamma-ray detectors straddling the sample.

API has the potential to become a standard tool not only for classifying meteorites and interpret data from orbital and in-situ nuclear spectrometers, but also to constrain the underlying cosmochemical and geochemical processes which led to compositional variability [1]. Additionally, API can become a contender to priority instruments that will be used for the analysis of future returned samples given its non-destructive capability. M. Kimura et. al. [5] stated that "The bulk chemical compositions of meteorites are one of the most significant data to characterize and classify meteorites". Hence, there is a growing need in the planetary science community to perform these kinds of measurements with increasing accuracy.

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