THERMAL CONDUCTIVITY MEASUREMENT PLAN FOR SAMPLES RETURNED BY OSIRIS-REX.

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Introduction: The Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) mission collected geologic samples from the surface of (101955) Bennu, which will be returned to Earth in late 2023. These samples will enable the testing of many scientific hypotheses related to the origin, evolution, and current state of Bennu. In particular, the thermophysical properties of Bennu inferred from orbit indicate that the boulders that cover the surface have thermal conductivity and density values that are much lower than typical terrestrial rocks and all measured carbonaceous chondrite meteorites [1]. Furthermore, Bennu's surface is dominated by at least two dominant boulder types that are distinct in overall morphology, reflectance, spectral properties, and thermophysical properties [2]. The sample analysis team will measure the thermal conductivity, heat capacity, density, and multiscale mechanical properties of these two boulder types, should they be identified within the returned sample assemblage, in order to determine if the geologic materials on Bennu are indeed distinct from characterized meteorites and to better understand the relationship between the thermal, structural, and mechanical properties of carbonaceous astromaterials.

Considerations for the measurement of Bennu samples: Thermal conductivity measurements of the returned samples should be performed with the largest allowable specimens in order to minimize the effects of grain and pore heterogeneity so that results can be compared more directly to orbitally and telescopically determined values. The largest sample specimens, which are expected to be up to 3 cm in the longest axis [3], will be the least abundant and likely some of the most scientifically valuable in the returned sample assemblage. Thus, it is strongly preferred that any analyses that are performed with these sample pieces are effectively nondestructive and noncontaminating. Unfortunately, all well-known thermal conductivity measurement methods for solids (excluding thin films and fibers) rely on the sample having at least one flat, uniform face; geologic and meteoritic samples are typically cut for thermal analysis (e.g. [4, 5]). As such, we are developing a custom, noncontact method that can be adapted to irregularly shaped geologic samples of various sizes in the range of ~0.5–3 cm.

Thermal conductivity measurement method: We are prototyping a novel steady-state thermal conductivity measurement apparatus inspired by the guarded hot plate method. A sample is suspended by a thin fiber basket between two high-emissivity, metal hemispheres in a thermal vacuum chamber. The sample exchanges heat radiatively with the two hemispheres, one of which serves as a constant-flux heat source and the other as a constant-temperature heat sink. Once thermal equilibrium is achieved, the temperature of the heat source hemisphere is measured and related to sample thermal conductivity via a numerical simulation of the experiment. The experiment may be repeated across a range of temperature and flux set-points in order to obtain temperature-dependent data. Given that the experiment is sensitive to the size of the sample relative to the inner diameter of the hemispheres, a suite of hemispheres with different dimensions will be developed so that the optimal hemisphere set can be selected for a given sample size.

Idealized numerical simulations of the system have demonstrated that it can be used to determine sample thermal conductivity to within ~10% accuracy, based on a minimum measurable temperature differential of ~30 mK that is possible with a set of well-calibrated resistance thermometer in the heat source hemisphere. A numerical study of potential sources of error was used to inform required tolerances for the hemispheres and the required certainty of sample characteristics, such as size and emissivity, in order to maintain a 10% experimental accuracy. For example, sample diameter must be known to within 60 microns, for the case of a 1-cm-diameter sample approximated as a sphere. This is readily achievable with various 3D shape scanning methods (e.g., [6]). We will next determine experimentally the net impact of various sources of error by using simple spherical thermal conductivity standards before moving to nonspherical specimens and ultimately meteorites and simulant materials that have been independently characterized.

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Acknowledgement: This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program.