Advanced Thermal Techniques and Systems Design Enable Long Duration, Continuous Day/Night Operation of Robotic Science Landers and Payloads on the Lunar Surface. J. F. Farmer[1], A. Alavarez-Hernandez[2], S. P. Breeding[1], J. E. Lowery[1], [1]NASA MSFC, Huntsville AL, [2]NASA JSC, Houston TX.

Introduction: Recent developments in NASA and commercial space capabilities and plans support and call for increased exploration of the lunar surface. Lunar exploration objectives vary widely ranging from geophysical research to human exploration and resource prospecting. The slow rotation of the Lunar surface and polar orientation relative to the sun along with the regolith thermo-optical and thermos-physical properties and vacuum conditions combine to create a unique and very challenging thermal environment for any extended lunar surface activity requiring operation during the approximately 28 earth day lunar day/night cycle, where day time temperatures of the lunar surface can reach 400K (near the equator) and night time temperatures can drop to 100K (even colder in permanently shadowed regions and craters). A set of risk reduction studies were performed in support of early phase mission design activities for various science and exploration missions, one of which was the ILN (International Lunar Network), to investigate potential approaches that enable continuous operation in this environment. These studies have led to the development of advanced thermal control technologies and designs, extended testing of battery capabilities, and a viable systems approach to survive the night for extended mission durations. This report summarizes the targeted missions, the overall design approach, the enabling technologies, and the risk reduction studies including the associated analyses and testing used to investigate their viability.

Driving Missions: The first mission that drove the initial investigations was ILN. This mission was intended to develop and position robotic landers equipped with an array geophysical and electromagnetic experiments, globally dispersed on the lunar surface. These landers were required to operate continuously during lunar day/night cycles for up to 6 years.

General Assumptions and Design Approach: Both of these missions targeted a minimum cost approach and, as such, high energy, continuous power generation options including a nuclear reactor and a radio-isotope power source were prohibited. Consequently, lunar cycle variant photovoltaic power was assumed, and thermal based solutions that conserved heat during the cold lunar night were critical. The general approach for achieving this consisted of using a warm electronics enclosure that contained all critical electronic components and energy storage batteries expected to operate over the duration of surface portion of the mission. This enclosure was insulated with high performance thermal insulation and isolated with low conductance structural mounts to minimize heat loss and gain. The components within this enclosure were mounted on a baseplate designed to share heat between the components and acquire heat to be rejected when necessary. The plate was connected via an advanced variable thermal link to a lunar radiator to reject this heat. The variable link would passively vary between a highly conductive heat transport path and a thermal isolator as the conditions dictated.

Enabling Thermal Technology Options: While the insulation and isolation techniques and the thermal baseplate used in the design were high performance and somewhat novel, the more advanced technologies investigated for this application were those related to the variable link. The technologies investigated included: (1) a hybrid wick, variable conductance heat pipe, (2) a loop heat pipe with a passive bypass valve, and (3) a hybrid loop heat pipe with variable conductance heat pipe. Each of these technologies provides efficient two phase heat transport when "on" to support heat rejection during lunar day, but also provides a passive, temperature driven means of isolation to conserve heat. This "turn-down" feature of these links along with the insulation/isolation features of the enclosure minimizes the amount of power used during the long lunar night to minimize the mass of the battery required; analysis during these mission studies estimated that each watt of power used during the lunar night required approximately 5kg of battery to supply the needed energy.

Risk Reduction Activities: A variety of activities have been performed to assess this lunar night survival capability. *Thermal trade studies* were conducted to identify and select overall thermal approaches and technologies. *System level thermal and power analyses* have been conducted to predict night time heat loss, daytime heat rejection, and power management performance. *Ground and in-space thermal development testing* have been conducted to assess the performance of the variable link technologies, and their integration with baseplate and radiator concepts, as well as to assess long term battery performance and lifetime at more extreme temperatures and depths of discharge necessary for this application.