SCIENCE PACKAGES AND TOOLS DESIGNED FOR THE LUNAR SURFACE. P.E. Clark[1], P. S. Millar[2], B. Beaman[2], M. Choi[2], L. Cooper[2], S. Feng[2], R. King[2], L. Leshin[2] R. Lewis[2], P.S. Yeh[2], E. Young[2], J. Lorenz[3] [1]Catholic University of America (Physics Department), [2]NASA/GSFC, [3]Northrop Grumman; all at NASA/GSFC, Greenbelt, MD 20771, Correspondence: Pamela.E.Clark@NASA.gov.

Introduction: Implementation of lunar science goals [1] will require delivering science packages to lunar sites remote from human occupation. Such packages must be capable of surviving extreme cold and thermal variations, as well as operating autonomously with stand-alone power systems [2]. During the Apollo era, radioisotope (Pu238) based power systems supplied both the power and heat required for operation, but availability of radioisotope based power systems over the next decade and a half is now highly uncertain. The efforts described in detail here demonstrate that alternative state-of-the-art design and components for generic state-of-the-art science packages can meet the power and mass constraints of earlier packages.

Instrument packages: We consider packages that have been through preliminary system and subsystem design at the GSFC IDL (Instrument Development Laboratory) facility using conventional and non-conventional approaches, including an environmental monitoring station (LEMS) and 2 different LSSO packages, which will not be considered here.

LEMS, a lunar environmental monitoring station, is a stand-alone automated package concept powered by solar panels with batteries with a suite of instrument and instrument capable of providing comprehensive measurements critical to understanding the interactions between radiation, plasma, solar wind, magnetic and electrical fields, exosphere, dust and regolith [2]. Some version of LEMS would be a primary candidate for early deployment before contamination of the lunar exosphere. Instruments include spectrometers to measure neutral gas species of the exosphere, X- and Gamma-radiation, energetic neutrons and protons from the solar and galactic radiation environment; particle analyzers to measure the spatial and energetic distribution of electrons and ions; a dust experiment to measure diurnal variations in the size, spatial, and velocity distribution of lunar and micrometeorite dust; and electric and magnetic field instruments to indicate changes resulting from variations in solar activity, and terrestrial magnetic field interactions.

Using a Conventional Design Approach: LEMS would be required to be operational for a minimum of five years, to survive the extreme cold (<100K) and thermal cycling during dark periods (up to 5 days at the poles due to umbral shadowing in otherwise 'permanently' illuminated locations or 14 days elsewhere due to diurnal variations.) These lunar surface conditions are quite different from conventional deep space

Comparison of Design Requirements for LEMS

Design Regime	Conventional Electronics	Cold Electronics	New Packaging Concept
Operational limit C°	-10	-40	-40
Survival limit C° Battery Mass kg	-20 240	-50 120	-50 30
Remaining Mass kg	260	260	70
Total Mass kg	500	380	100
Minimum Power W	60	30	10

conditions where one side of the spacecraft is almost always illuminated and heat dissipation is the thermal issue. The LEMS battery mass was driven by the need for power for survival heating during periods of prolonged darkness and became the overwhelming driver of the total mass to 500 kg with only 19% allocated for the instrument payload and 53% for the power system (**Table**). The power allocation was 180W (85W for the instruments) during the day, 60W for thermal heaters alone at night with the instruments turned off, even though measurements made during periods of darkness are essential. As a result of this study, we decided to pursue other approaches to thermal and power system design, which would allow the development of instrument packages with mass and power requirements comparable to ALSEP which had a mass of <150kg..

High Performance Electronics: Simply introducing rad-hard electronics capable of operating at colder temperatures reduced the required battery power required for LEMS by a factor of 2, (**Table**). Although not 'standard' for deep space operations now, electronics operating at cold temperatures are frequently used in military applications, including polar operations. Radiation hard cold electronics have also been used in scientific applications, on astronomical spacecraft requiring cryogenic operations for sensor systems, including IRAS, COBE, ISO [3]. We have assumed the universal incorporation of such digital and analog electronic components in the instrument package.

Improvements from Alternative Thermal Design: Our thermal packaging design requires the use of multiple layer thin (MLT) insulating fiberglass (G10), a material used on JWST [3]. Our models indicate that 2 such layers surrounding the 2.5 mm aluminum box which typically encloses and shields instrument components (**Figure 1**), is adequate. To save mass, instruments can be packaged together, except where detection of charged particles and fields requires separation from other sources of interference, and the battery/PSE can be packaged to both shield the electronics and be thermally protected by surrounding solar panels.

At any given time during periods of illumination, one or more sides of the instrument package will be receiving full sun. In the polar environment the sun is at or near the horizon illuminating one side of the package, and travels all the way around the instrument (360 degrees) over the course of the diurnal cycle, thus need a radiator surface that faces directly 'up' to the 'cold' of deep space without the need for any moving parts. In order to prevent heat loss during periods of darkness, we attach the radiator to the chassis with a thermosiphon [4] which will shut down heat transfer by freezing at the condenser end just above the minimum survival temperature: about -40 degrees centigrade. The heat pipe does not require a wick or capillary tube to work as long as the evaporator is below the condenser in a gravity field. Because heat pipes require an amount of liquid much smaller than there total internal volume to operate, there is no danger of bursting when the liquid melts. To start up the frozen heat pipe, we run current through small resistors requiring minimal wattage. These strategies combined with operating instruments on 10 to 20% duty cycles, reduce thermal loss and the need for active heating, and thus the thermal and power system masses. The preliminary results of applying this strategy to the LEMS package shown in Table 1 indicate that we can reduce the total package mass of the package by a factor of 5. Even though we have 9 rather than the 5 instruments typical of ALSEP, we can operate in the ALSEP regime without the use of Pu238 at the poles.

Incorporation of ULP/ULT components: Another strategy that could allow reduced power and temperature operation would be the incorporation of Ultra-low power and low temperature (ULP, ULT) electronics [7], developed at GSFC and through partnerships with the University of Idaho and DoD. ULT/ULP chips are being used successfully and have demonstrated orders of magnitude savings in power consumption and thermal tolerance [5]. These systems include the use of CULPRiT (CMOS Ultra-low Power Radiation Tolerant) technology successfully flown on NASA's ST5 90 day mission in March 2006.

Power System: We are still in the process of determining how much we can mitigate heat loss by packaging micro-batteries with individual instruments. Alternative battery technology potentially capable of operating at ultra-low temperatures is becoming available for micro-battery applications [6]. These must be considered but may have drawbacks in terms of operating efficiency and mass when built for a small instrument package. The use of a distributed power system will require a much more sophisticated power management system. The replacement of solar panels with thin film solar cells, developed under NASA's auspices [7], could result in a considerable mass savings because of the inherently higher efficiency of the film and its ability to 'wrap' without structural support. An extremely thin film of amorphous silicon, 40 times more efficient than crystalline silicon used in traditional panels, is vapor deposited on flexible thermally stable support medium. The Nantenna technology which is finally coming of age harnesses mid-Infrared energy to produce electricity even more efficiently [8].

Conclusions: Overcoming thermal conditions even more demanding than those routinely experienced by spacecraft in deep space, we are designing instrument systems deployable at South Pole outpost with reduced power and mass requirements and capability of gathering data during periods of darkness, relative to the Apollo-era ALSEP. We have also determined that improvements needed to successfully deploy comparable packages in typical diurnal cycle lunar environments will require the incorporation of ultra low temperature and ultra low power components now under development, as well as the development of a managed and distributed power system with much greater capability for surviving at low temperatures.

References: [1] LEAG Lunar Science Roadmap (2008) https://www.lpi.usra.edu/survey/LER/; [2] Clark et al (2009) Proc SPESIF-09; [3] JWST Website (2008), http://www.jwst.nasa.gov/sunshield.html; [4] CES Library (2008) http://cipco.apogee.net/ces/library/twhtherm.asp; [5] Maki and Yeh (2003) ESTO, http://esto.nasa.gov/oldsite/ conferences/estc2003/papers/ A3P4(Yeh).pdf.; [6] West et al (2008) http://ieeexplore.ieee.org/iel5/62/20394/00942217.pdf ? arnumber=942217; [7] NASA Spinoff (2006) http://www.sti.nasa.gov/tto/Spinoff2006/er_4.html; [8] Kotter et al (2008) Nantenna, INL/CON-08-13925.

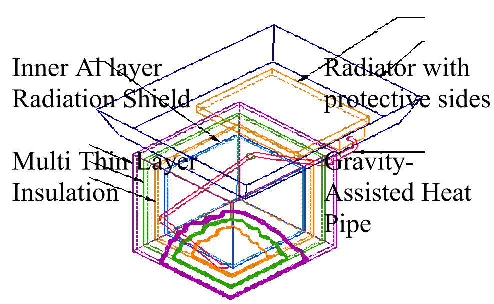

Figure 1. Thermal Packaging Concept.