MOONLITE* – TECHNOLOGICAL FEASIBILITY OF THE PENETRATOR CONCEPT.

A. Smith[1], I. A. Crawford[2], A. J. Ball[3], S. J. Barber[3], P. Church[4], , Y. Gao[5], R. A. Gowen[1], A. Griffiths[1], A. Hagermann[3], W. T. Pike[6], A. Phipps[7], S. Sheridan[3], M. R. Sims[8], D. L. Talboys[8], N. Wells[9], [1]Mullard Space Science Laboratory, University College London, Holmbury St Mary, RH5 6NT, UK, E-mail: as@mssl.ucl.ac.uk, [2]School of Earth Sciences, Birkbeck College, London, UK, [3]Planetary and Space Sciences Research Institute, The Open University, Milton Keynes, UK, [4]QinetiQ Ltd, Fort Halstead, UK, [5]Surrey Space Centre, University of Surrey, Surrey, UK, [6]Department of Physics, Imperial College, London, UK, [7]Surrey Satellite Technologies Ltd, Surrey, UK, [8]Department of Physics, University of Leicester, Leicester, UK,, [9]QinetiQ Ltd., Farnborough, UK. *MoonLITE is a UK-led initiative which is currently the focus of a joint UK-NASA study.

Introduction: While the surface missions to the Moon of the 1960s and 1970s achieved a great deal, scientifically a great deal was also left unresolved. The recent plethora of lunar missions (flown or proposed) reflects resurgence in interest in the Moon, not only in its own right, but also as a record of the formation of the Earth-Moon System and the interplanetary environment at 1 AU. Results from orbiter missions have indicated the possible presense of ice within permanently shaded craters at the lunar poles [1] – a situation that, if confirmed, will have profound impacts on lunar exploration.

MoonLITE [2] is a proposed, UK-led lunar science mission comprising 4 scientific penetrators that will make *in-situ* measurements at widely separated locations on the Moon.

MoonLITE will address key issues related to the origin and evolution of planetary bodies as well as the astrobiologically important possibilities associated with polar ice. The principal scientific objectives of the MoonLITE penetrator mission are:

- To further our understanding of the origin, differentiation, internal structure and early geological evolution of the Moon;
- To obtain a better understanding of the origin and flux of volatiles in the Earth-Moon system;
- To obtain ‘ground truth’ geochemical data to complement orbital remote-sensing observations;
- To collect *in situ* surface data that will help in the planning of future lunar exploration.

Further details of the MoonLITE science case are given in the accompanying abstract by Crawford et al.

The penetrators will be globally dispersed (unlike the Apollo missions) with proposed landing sites on the nearside Procellarum KREEP Terrain, shaded craters at the lunar poles and farside, and will operate 2-5m beneath the lunar surface for 1 year.

Each penetrator will include a suite of scientific instruments including micro-seismometers, a geochemistry package, a water/volatiles detector, a heat flow experiment, and accelerometry & tilt sensors. Other payload instruments are presently under consideration.

The penetrator delivery to the lunar surface will take place in two stages:

- The Penetrators will be transferred to lunar orbit as the payload of a polar orbiting communications relay satellite;
- Release, de-orbit and descent. Each penetrator will have an attached de-orbit motor and attitude control systems (both of which are ejected before impact)

MoonLITE will fill an important gap within the proposed international lunar mission portfolio and facilitate the future scientific and ultimately manned exploration of the Moon.

MoonLITE will undergo a Phase A study during the spring/summer of 2008. In this paper a status report of that study will be presented with an emphasis on the technological issues associated with the penetrators themselves.

Development methodology: MoonLITE is envisaged as both a lunar science/exploration mission and as a ‘Penetrator Demonstration Mission’ and the development methodology reflects both of these aspects. While it is essential that the mission achieves its scientific objectives, it is also anticipated that the technological developments therein will have direct application to other Solar Systems bodies, whether or not they have an atmosphere. The adopted development methodology is characterised by the following:

- A scalable, modular design around a core data and power distribution network;
- Model-based impact stress prediction, validated through impact trials, leading to a well defined payload element environment;

- Inclusion of well proven technologies brought in from outside of the space domain;
- 'Pick-and-mix' payload selection to match specific mission opportunities.

Impact: Each MoonLITE penetrator will impact the lunar regolith at a speed of ~300 ms^{-1} (equivalent to a free fall from 30km onto the lunar surface). It is entirely feasible for an instrumented package to survive an impact at such speeds and a vast amount of resource has been devoted to such conditions within a defense context. 'Penetrators' are common-place within that sector and a (limited) range of components are available off-the-shelf that will survive impacts of >50,000*g* (MoonLITE expects up to 10,000*g*). This expertise is by no means purely empirical in nature; a very sophisticated predictive modeling capability also exists. The MoonLITE project will tap this capability for a scientific end. Moreover, Mars 96 [3], DS-2 [4], [5] and Lunar-A [6] penetrator development programmes have overcome many key problems and demonstrated survivability in ground tests.

Lifetime: Each penetrator will be designed to operate for 1 year below the lunar surface. This has very significant consequences for total energy requirement. It is not proposed to have a detached aft body surface element (unlike DS-2) and therefore all power must be generated internally. Moreover, the temperature 3m below the lunar surface is estimated to be between 250K and <100K depending upon location – the latter figure referring to permanently shaded polar craters. Lithium based batteries (providing 500 Watt.hrs) together with Radioactive Heating Units (RHU) are proposed. Very low power electronics and power-saving operation strategies will also be employed.

Communications: A polar orbiting satellite will be used for two-way communications between ground control and each penetrator. For penetrators located away from the lunar poles communication passes will occur every 15 days with ~90 seconds of contact at each. For polar penetrators the frequency of contact will be much higher but in this case the amount of information is still limited by the available transmitter power. Each penetrator will be able to transmit 10 Mbits of data during its 1 year lifetime. A Lunar-A study [7] has analysed the likely affects of the overlaying lunar regolith and associated impact crater.

Payload: The baseline MoonLITE scientific payload comprises:

Accelerometers and Tilt-meter. 3 –axis accelerometers will be mounted at the head and tail of the penetrator to provide a complete motion history (position and orientation) during impact. A tilt-meter will be essential to provide for the interpretation of heat flow and seismic data.

Geochemistry package. A miniaturized X-ray flourescence spectrometer is proposed which will can detect and quantify the major, minor and trace rock-forming elements in the local regolith, e.g. Na, Mg, Al, Si, K, Ca, Fe, Ti, Y, Sr and Zr.

Water/Volatile Experiment. A number of techniques are proposed for this important measurement including: mutual impedance probe; calorimetric analyzer; pressure sensor; optical spectrometer; and miniature ion trap mass spectrometer.

Seismometer. 3-axis MEMS-based microseismometers are proposed. These will have a sensitivity and bandwidth comparable to that provided by the Apollo missions.

Heat Flow Experiment. To measure the heat flow in the lunar regolith both thermal gradient and thermal conductivity measurements are required. The current baseline choice for penetrator structural material is aluminium which represents a major challenge to thermal gradient measurements since the penetrator itself is manifest as a thermal 'short'. A number of alternative approaches are being studied to overcome this problem including a trailing thermal probe, external thermal insulation and deployed needle probes.

Sample acquisition. A drill is proposed to bring samples of the local lunar regolith into a common analysis chamber.

Descent camera. Part of the descent module to provide context images prior to impact

Acknowledgements: We thank Dave Parker (BNSC) for his pivotal role in initiating the MoonLITE study, and Chris Castelli (STFC) and other members of the UK-NASA Joint Working Group for their help and support in developing the concept. Part of the work presented here has been funded by the UK STFC.

References:

[1] Feldman, W.C., et al., *Science*, 281, 1496-1500, (1998). [2] Gao, Y. et al, Lunar science with affordable small spacecraft technologies: MoonLITE and Moonraker, *Planet. Space Sci*. (in press). [3] Surkov, Y.A., and Kremnev, R.S. *Planet. Space Sci*. 47(8/9), 1051-1060, (1998). [4] Smrekar, S., Catling, D., Lorenz, R., et al. J. Geophys. Res., 104(E11), 27013-27030, (1999). [5] Smrekar, S., Lorenz, R.D., and Urquhart, M., *Penetrometry in the Solar System*, Vienna, Austrian Academy of Sciences Press, 109-123, (2001). [6] Mizutani, H., Fujimura, A., Hayakawa, M., Tanaka, S. and Shiraishi, H., *Penetrometry in the Solar System*, Vienna, Austrian Academy of Sciences Press, 125-136, (2001). [7] Mizuno, T., Saito, H., and Ichikawa, M., *IEEE Trans. Aero. and Elec. Systems*, 36, 151-161, (2000).