DUST DETECTORS ON THE APOLLO MISSIONS AND THE TOP 2 CM OF THE MOON. Brian J. O'Brien, School of Physics and Aerophysics, University of Western Australia, 35 Stirling Hwy, Crawley, WA 6009, Australia. E-mail address: brianjobrien@ozemail.com.au Tel: +61 8 9387 3827 https://brianjobrien.com

Introduction: The Author became involved with Lunar Dust by serendipity on January 12, 1966. In 1965-1966 the Author's Charged Particle Lunar Environment Experiment (CPLEE) (O'Brien and Reasoner, 1971) was included in the first group of 7 experiments for ALSEP chosen from among 90 proposals. On 11 and 12 January 1966 MSC insisted that a retractable dust cover be added to CPLEE. The author found it unacceptable that neither NASA nor aerospace bidders to construct ALSEP planned to measure dust even on the first Apollo expedition. So the Dust Detector Experiment (DDE) was invented and proposed to NASA as both a scientific and engineering experiment on all ALSEPS. [1] Proposed before either American Surveyor or Russian Lunar spacecraft had made successful soft landings, the bolt-on DDE, weighing only 270 g, was deliberately a minimalist experiment to enable hitchhiking on ALSEP with space-proven elementary sensors. It measured basic factors making dust a threat to temperature controls, but as will be shown, enabled science.

The DDE proposal included vertical East-facing and West-facing solar cells to supplement a Horizontal cell for long-term scientific studies of dust, particularly at Lunar Sunrise and Sunset. Only Apollo 12 and 13 carried our original design with orthogonal cells. A small thermometer was attached on the back of each of the 3 solar cells on our original invention (and thus on our original Apollo DDE) so that each would record both cause and effect.

The DDE experiments flown on Apollo 11, 14 and 15 were modified DDE's with 3 solar cells half the size, all horizontal and different from each other, with one bare and two with thinner silicon protective plates, 0.15 or 0.51 mm thick, with one pre-irradiated. Bellcom added a resistance thermometer to measure lunar temperature.

The modifications were made 4 months before Apollo 11, in the mistaken belief by Bellcom and NASA Manned Spacecraft Center (MSC), now Johnson Spacecraft Center (JSC), that Jet Propulsion Laboratory (JPL) tests of rocket exhausts by Surveyors on the Moon had shown very little dust. Actually, in the 1967 Annual Report (p 7), JPL had shown a photograph of before and after severe dust contamination caused by a small vernier rocket on Surveyor 6. This was, in reality, a foreshadowing of what later occurred during the Lunar Module ascent of Apollo 11. [2]

In this report, no attempt is made to discuss many errors in official reports about dust. Reference instead is suggested to the website constructed for celebration of the 50th Anniversary of Apollo 11 in 2018 https://www.brianjobrien.com. Similarly, no discussion is included here of the significant reasons for the lapse of time before we resumed analyses of lunar dust in 2009. [3] Again, such details and previously unpublished MSC documents from 1969 are given in our website. We emphasise again that the original Apollo 11 computer tapes were never lost. We simply could not get the accurate analyses of the digital data published until 2009.

The objective of this report is to highlight most recent discoveries with about 100 million digital measurements by the 4 DDE's and their implications to assist the outcomes of these workshops. Similarly, early understanding of lunar dust was significantly corrupted by some 40 years neglect in the literature of either reference to either the DDEs or the Apollo 14 thermal degradation samples (TDS) experiment and the discovery by Tommy Gold [4] of the strong cohesive forces of lunar dust verified by photographs such as Apollo Image AS14-77-10367. Further information on the delightful animated photographs of cohesive dust are given in our website (https://www.brianjobrien.com/cohesive-studies).

Review of DDE measurements: A comprehensive review of measurements of dust movements on the Moon by the DDEs is given by O'Brien [5].

Figure 3 O'Brien [5] provides the digital plot of 3 solar cells during the ascent of the Apollo 11 Lunar Module and shows beyond doubt the extensive contamination by dust. This led to overheating of the passive seismometer by more than 50 degrees F above its nominal maximum and the deterioration to the point of failure to receive commands. The entire active Early Apollo Surface Experiments Package (EASAP) was terminated after 21 days.

Bates et al [6] reported there was no significant degradation. This fallacy was carried also on page 100 of SP-214 with consequent misinformation to the 142 Principle Investigators awaiting receipt of the invaluable samples from Apollo 11. The misinformation could have involved either spatial disturbance of samples or chemical contamination or both.

A detailed analysis of the extensive discoveries with the Apollo 12 DDE is given in O'Brien et al (2011) section 4.4 and 4.5.

Apollo 12 DDE was the only one of four on the Moon that almost replicated the orthogonal design originally proposed by O'Brien (1996). Consequently, extensive use was made of the Horizontal Solar Cell (HSC) and the Vertical Solar Cell East (VSCE). To our knowledge, VSCE continues to be the only measurements, on the Moon, of sunrise and the dawn Moonscape.

The great analytical strength of the orthogonal design of Apollo 12 DDE is the fact that HSC measures the accumulation of dust, whereas VSCE measures dawn, the rising sun and the scattering of early morning sunlight from dust particles levitated between its height of 100 cm and the sun. While the resultant effects were discovered by O'Brien in 1970, the submitted manuscript could not be published because of concern that active advocates that the Apollo missions were all fake could have seized upon such a manuscript to demean the reputation of the publishing journal. The difficulty was that the Apollo 12 Preliminary Science Report did not include the report on the dust detector, which would have proved it was there. Although O'Brien had been invited by Stan Freden of MSC and the editor of the NASA Apollo 12 Preliminary Science Report to submit a dust report, and while such a report was submitted, it was not published. No reason was revealed.

Apollo 12 DDE sunrise effects: The combination of the vertical and the east facing solar cells on Apollo 12 DDE gave a powerful tool for investigation of sunrise effects on dust on the Moon. These are reported extensively and analysed by O'Brien and Hollick [7]. Our interpretation of sunrise effects was that we consider that Apollo 12 DDE measured levitated dust to a height above 100 cm. The forward Eastern facing cell measured scattering of sunlight at sunrise, which we believe is the equivalent of the long sought horizon glow photographed by Surveyor spacecraft on the Moon after sunset.

O'Brien developed a 5-step model to explain transport of the dust on the Moon which we consider also explains the smoothness of the lunar surface, another long sought mystery.

Our 5 step analysis begins with the acceptance of the strong cohesive forces of lunar dust as reported by Gold [4].

Step 2 is that at lunar module ascent the rocket exhausts penetrate below the surface and free the previously bound dust particles.

Step 3 is that at sunrise the blast of high energy sunlight including x-rays and ultra-violet will create massive photoelectric effects causing free dust particles to be charged positively as will the surface.

Step 4 is that there will be mobilisation and transport of the freed dust particle as a result of Couloumb forces of repulsion between like-charged particles.

Step 5: from one sunrise to the next we assume that the population of free dust particles gradually reduces as more fall to the surface and are recaptured by the cohesive forces.

To date, we have received few significant comments, perhaps in part because our 5 step model does not have any equations. However, preliminary advice by Phil Metzger is that such a process may explain previously unexplained discolouration of the Surveyor 3 equipment sampled on the Moon by the Apollo 12 astronauts after 30 months exposure.

Apollo 14 and 15 carried 3 horizontal solar cells, as did Apollo 11 DDE, and are the modified form of the DDE which focussed, from an abandoned radiation experiment by MSC, on radiation damage. Analysis by Hollick and O'Brien [8] made use of this capacity and the heavy shielding of the Apollo 12 DDE to make the first lunar weather measurements at 3 Apollo sites. In summary, this was the first study which enabled discrimination between the effects of lunar dust and radiation on degradation of solar cells on the Moon.

We draw attention here to the reality that Apollo 12, 14 and 15 DDEs may represent the greatest source of information at the present time of the degradation of solar cells over a long period (5-6 years) on the surface of the Moon. This and one other factor may be invaluable in consideration of proposals to equip polar bases on the Moon with solar powered devices. The other consideration for such bases is that the Apollo 12 DDE has several years' accumulation of information about sunlight intensity at very low elevation angles and its significant variation caused, we believe, by levitated dust. We are unaware whether such issue is taken into consideration in current planning of polar bases on the Moon, or for that matter analyses of volatiles at such stations. The variation of sunlight at low elevation angles can be several percent – see numerous charts in O'Brien and Hollick [7] and Supplementary.

Apollo 16 and 17 carried no dust detector experiments although they were the largest ALSEPs and carried on the most extended missions. We are advised (J Bates, pers.comm. 2015) that Apollo 16 did have DDEs built for it but not flown for reasons unknown. Indeed, the only surviving accurate flight unit model of a modified dust detector is one found by Jim Bates in Houston. We have no idea why DDEs were not flown.

Recent comments regarding Apollo DDEs and lunar dust: O'Brien [9] has carried analysis of movements of inescapable fine lunar dust through to suggestion that the studies are now sufficiently mature that the

Kuhn cycle can be used to describe the evolution of the movements of lunar dust from a pre-science stage through a paradigm shift into the 5 step cycle of transport of dust on the Moon.

O'Brien has advocated and received significant support for the concept that an Apollo 12 DDE be routinely flown on every lunar mission as a fungible bolt-on dust experiment with space proven capabilities. Many arguments can be made in favour of having such a device on international payloads such as the ready capability of comparison of dust at new sites to dust at Apollo 12, 14 and 15 sites.

Most recently, at the AMES celebration of the 50th Anniversary of Apollo 11, O'Brien et al had the pleasure of announcing the pending publication of China's Chang'e-3 successful publication of measurements of dust, using a new quartz crystal which measured the weight of dust. We therefore update our recommendation for future payloads to the Moon to include both an Apollo 12 DDE and such a quartz crystal device provided only that its temperature control within the payload is very carefully stabilised.

References: [1] O'Brien, B.J. (1966) NASA SC Control 44-006-054. [2] O'Brien, B.J. Freden S.C. Bates J.R. (1970) Journal of Applied Physics 41, 4538-4541. [3] O'Brien, B.J. (2009) Geophysical Research Letters 36, L09201. Doi: 10.1029/2008GL037116. [4] Gold, T (1971) Apollo 14 Preliminary Science Report, NASA SP-272. [5] O'Brien B.J. (2011) Planetary and Space Science 59, 1708-1726. [6] Bates, J.R., Freden, S.C., O'Brien, B.J. (1969) Apollo 11 Preliminary Science Report, NASA SP-214. [7] O'Brien, B.J., Hollick, M (2015) Planet. Space Sci. 119, 194-199. [8] Hollick, M., O'Brien, B.J., (2013) Space Weather, Vol 11, 651-660. [9] O'Brien, B.J. (2018) Planetary and Space Science, Vol 156.