Advanced Concept Team Biomimetics Study Proposal 2 and preliminary application for ISSEF

DUST – IT'S EVERYWHERE……

"… one of the most aggravating, restricting facets of lunar surface exploration is the dust and its adherence to everything no matter what kind of material, whether it be skin, suit material, metal, no matter what it be and it's restrictive friction-like action to everything it gets on" [1].
Eugene Cernan, commander of Apollo 17.

Using cilia from human nasal cells and their beat frequency of cilia as a tool to investigate:

A) possible deleterious effects of the space environment on mucus clearance and hence respiration.

B) the evolution of nanotechnology (molecular motors) as a possible method of removing space dust from surfaces under microgravity conditions e.g. lunar/Mars missions/bases and beyond.

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During long-term space voyages and for successful establishment of planetary colonies, one of the biggest environmental problems to overcome will be dust [1].

Current removal of dust in lunar modules relies on filters and several types of filters are being developed. These are suitable for bulk removal but of course filters clog up and it does not adequately address/deal with the possible toxicity [2] or more properly *reactivity* or what has been referred to as the *'unsatisfied state'* of this particulate matter [3]. However, efforts are focusing on developing ion/plasma guns as a possible method of removal i.e. exploiting electrostatics [4].

Yet dust on earth would also be an omnipotent problem in the environment but for the fact, air-breathing mammals have evolved an ingenious, robust, self repairing mechanism for ensuring only pure air is used for gaseous exchange – the mucociliary elevator. Necessary because the 70m^2 of respiratory tract is virtually in direct contact with the air. Briefly, this system works by having mucus in the respiratory tract first trapping inhaled particles, then ciliated epithelial cells [cells with finger like projections] push, rhythmically and synchronized, the mucus upwards towards the throat where it is swallowed or expectorated. Given it is a system employed by multiple species it would be prudent to examine the possibility of mimicking this system in some way for dealing with the much more reactive moon/space dust. Mimicking this system – illuminates a way to use the tackiness of space dust against itself – by exploiting the now well known fact about lunar dust…*'it sticks to everything'.*

The respiratory cilia are driven by what is often called a molecular motor – a dynein ATPase [5]. Thus mimicking could only be done by using nanotechnology. The 'bottom-up' approach of nanotechnology from Feynam's 1959 talk entitled *"There's Plenty of Room at the Bottom"* [6] is a very powerful tool for solving problems like this – because you are only limited by ones imagination. In summing up on his own seminal paper on nanotechnology, K. E. Drexler, in 1981, said the following:, *'Development of the ability to design protein molecules will, by analogy between features of natural macromolecules and components of existing machines, make possible the construction of molecular machines'.* Hence, the power of biomimicry was uppermost in his mind for driving nanotechnology forward. A point further emphasized by Drexler's 'comparison table' in that paper – see Table 1 below [7].

Table 1. Comparison of macroscopic and microscopic components (Drexler, 1981).

Technology	Function	Molecular example(s)
Struts, beams, casings	Transmit force, hold positions	Microtubules, cellulose, mineral structures
Cables	Transmit tension	Collagen
Fasteners, glue	Connect parts	Intermolecular forces
Solenoids, actuators	Move things	Conformation-changing proteins, actin/myosin
Motors	Turn shafts	Flagellar motor
Drive shafts	Transmit torque	Bacterial flagella
Bearings	Support moving parts	Sigma bonds
Containers	Hold fluids	Vesicles
Pipes	Carry fluids	Various tubular structures
Pumps	Move fluids	Flagella, membrane proteins
Conveyor belts	Move components	RNA moved by fixed ribosome (partial analog)
Clamps	Hold workpieces	Enzymatic binding sites
Tools	Modify workpieces	Metallic complexes, functional groups
Production lines	Construct devices	Enzyme systems, ribosomes
Numerical control systems	Store and read programs	Genetic system

Encouragingly developments with 'artificial red blood cells' – termed *'respirocytes'* reviewed in [8] taken in consideration with the recent construction of an artificial 'molecular gear' [9] indicates that we are on the way 'up'. Yet, the current status of artificial nanomotors appears to be several years from constructing a molecular motor which could mimic the work of the cilia. An artificial nanomotor system being a different proposition altogether because it will require an energy supply/distribution, helper units, such as the helper cells that make the liquid in which cilia are immersed and of course co-ordination between these nanomotors.

Hence in the meantime, it would be prudent to look now at how the 'natural' molecular motor system (the respiratory cilia) copes with space dust and/or microgravity. This can be done by measuring the frequency of the beat of cilia of human airways. Crucially doing this provides two avenues to develop: **1)** an immediate window of how such nanomotors may be used in future space exploration e.g. a 'surface dust trap and conveyor system' thus no filters to block and **2)** an assay for possible deleterious effects of lunar/martian dust and microgravity on the astronaut's respiratory system.

The assay can be done (and is still routinely done) by collecting epithelial cells collected (brushed from) from the nose then measuring the frequency at which the cilia beat on these cells via a video system. This method has three distinct advantages: **i)** it provides a source of ready-made 'molecular motors' with a tag (cilia) to measure the nanomotors' physical properties **ii)** the measurement of the frequency of the cilia itself is straightforward and lends itself to being performed over and over again (allowing assays of chronic and acute exposure of lunar/martian dust) and **iii)**experiments require relatively little equipment, generally needing an image analysis system, hence it could be developed to be extremely lightweight. The relative ease and sensitivity of this assay is why it was, and remains, a popular tool of investigation into respiratory disorders [10, 11]. Furthermore, as we can use human cells it neatly sidesteps the laborious and perhaps unnecessary use of animal models/testing to test lunar dust toxicity as was reviewed in [12] and perhaps such assays set out here may set a trend for lowering the use of animals testing lunar regolith and its artificial simulants.

Indeed, this study may serve as driver to encourage and direct the development of nanotechnology. As Drexler said: ' ***.....****the long-range promise should tend to increase interest in undertaking the early steps……,'* [7]. Furthermore, by encouraging academic involvement (e.g. undergraduates) this may present a way to utilize (after careful preparatory work and experiments see below), in an engaging and novel way, the allocated 1% of ESA time and resources on the ISS set aside for education. For example an education sub-project may be titled *'Help - My cells are in space'*, or *'Astrocells'* or such similar things. The experimental pathway also fits in well with the 'Space Education Pyramid' [13].

Study Objectives

In summary the study objectives are:

- A review of spacedust – causes, effects on personal and life support, methods of removal and future plans.
- A review on current status/knowledge of cilia, with emphasis on most suitable methods of measuring their beat frequency, as such equipment may ultimately have to operate on the

ISS.

- A review of nanotechnology – focus on aiming for a timeline for construction of rotor like motors similar to those that drives respiratory cilia.
- Contact and establish academic partner(s) for operational readiness. Generally to help set up equipment which could be set up at the institution and/or ESTEC.

- **Experimental approaches:**

- **Option A)** Earth based study with dust (if possible artificially induced unpacified particulate matter contaminated media *is* continually fed through a perfusion chamber – whilst continually monitoring the frequency at which the cilia beat. Similar studies on human alveolar macrophages [specialized lung cells] used Hawaiian volcanic ash to mimic lunar soil as they were stated as having similar mineral properties [14]. Additionally or alternatively a *'lunar simulant'* if obtainable could be used [15].
- **Option B) i)** send up previously isolated cells and time viability (how long cells remain/can be kept alive) followed by, **ii)** if successful, send previously isolated cells and equipment – ' ready to go' – up with launch.
- **Option C) i)** Securing removal of astronauts nasal cells safely in microgravity **ii)** Transferring to container and iii) fixing to camera equipped with CBF monitoring capabilities, **iii)** measuring CBF with current technology in ISS whilst under microgravity **iv)** introduce space/moon dust to cilia.

Time, costs and sheer practical considerations suggest Option A as most likely followed by B and then it may be followed by option C when a routine is well established and technology/equipment is refined for the ISS.

- **Option D)** Kick-off work with fastest possible slot for a launch of cultured or collected ciliated cells – cells monitored before and then after a short spaceflight. Hence, raising the profile of ESA-education and outreach perhaps via a competition.

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