PRESCOUTER **2022**

CARBON NANOTUBES

from Space Suits to Protective Clothing

The carbon nanotube technology is a largely untapped solution that has the potential to revolutionize the protective clothing industry.

The protective clothing market in the military & defence space is projected to grow at a CAGR of 6.9%. Market growth can be attributed to the increased conflict around the globe, continuous R&D, and the procurement of new advanced wearables and smart & protective fabrics.

CHALLENGE

PreScouter identified a problem and a solution used for space applications - dust on the surface of the Moon that had to be mitigated.

APPROACH

PreScouter interviewed subject matter experts (SMEs) to gather insights into solutions that are tangential to Earth application.

OUTCOME

Carbon nanotubes implemented in the development of military-grade textiles could protect against chemical warfare threats.

Lunar dust

Lunar dust is a major environmental challenge to overcome in space exploration.

A close-up view of an astronaut's boot print in the lunar soil, photographed with a lunar surface camera during the Apollo 11 extravehicular activity (EVA) on the Moon. Credits: NASA

Lunar dust is electrostatically charged due to solar wind and exposure to UV irradiation.

Lunar dust easily sticks to fabric.

NASA has been trying to solve the dust issue ever since Apollo when the astronauts first discovered moon dust.

"We learned from Apollo that lunar dust can be less than 20 microns (about 0.00078 inches) in size. The dust is very fine, abrasive and sharp, like tiny pieces of glass, making it more of a dangerous threat than just a simple nuisance."

Sharon Miller, the passive dust shedding material program's principal investigator at NASA Glenn.

Advanced materials, namely carbon nanotubes, helped revolutionize spacesuits to mitigate the dust problem. The SPIcDER System is the most advanced dust mitigation solution to date.

In 2018, the Spacesuit Integrated Carbon nanotube Dust Ejection/Removal system (SPIcDER) was conceptualized and tested [1]. The SPIcDER system consists of parallel yarns made of Carbon Nanotube (CNT) flexible fibers embedded into the outerlayer of the spacesuit that act as electrode wires. These CNT fibers, when activated utilizing a multi-phase alternating current (AC) voltage signal, would levitate and push the dust off the surface of the material.

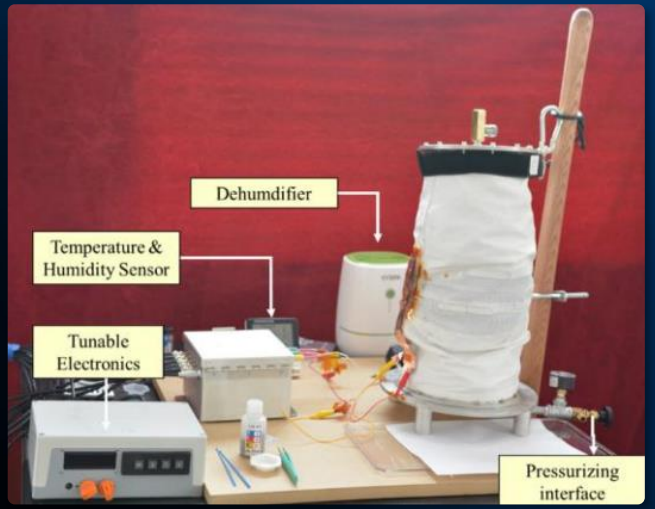

Image: SPIcDER experimental set-up of the scaled prototype

SPIcDER

Anti-dust Space Suit System

NASA

Spacesuit Integrated Carbon Nanotube Dust Removal System: A Scaled Prototype - Anti-dust System

NASA, academia, and industry must develop methods to protect astronauts from potentially lethal radiation in outer space. Future planetary exploration missions will expose astronauts to constant galactic cosmic radiation (GCR), which poses a serious threat to astronauts' health and could lead to death if exposure occurs too soon. In addition to radiation, the environment on the Moon presents the astronauts with an additional hazard - lunar dust.

In 2018, NASA presented the results of a prototype spacesuit outerlayer material composed of carbon nanotubes with the goal of dust removal. It will be fitted with insulation thermal layers in the final spacesuit [2][3].

Summary of findings:

Spacesuit Integrated Carbon Nanotube Dust Removal System: A Scaled Prototype (Peltz and Gaier, 2018) [2].

- Previous investigations used Carbon Nanotube (CNT) yarns as electrode wires inserted in spacesuit outerlayer coupons. When a multiphase Alternating Current (AC) voltage signal was supplied to this material, it **repelled 80% of lunar dust simulant in ambient settings**.
- A scaled prototype of a planetary spacesuit knee was created using the NDX-2 lunar spacesuit from the University of North Dakota. This prototype's outerlayer has a CNT dust cleaning mechanism and test provide promising results.

NASA

Spacesuit Integrated Carbon Nanotube Dust Removal System: A Scaled Prototype - Anti-dust System

Experimental setup & Prototype:

The electrodes are installed within the fabric and input voltage of 880-970 V is applied (see figure 3). The dust particles are repelled and the fabric was observed to be free of dust (Figure 2).

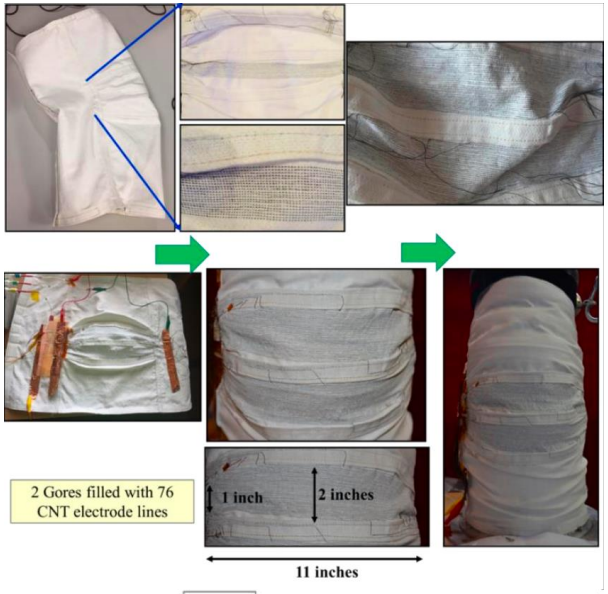

Figure 1. CNT electrodes are placed in a joint-knee portion [2].

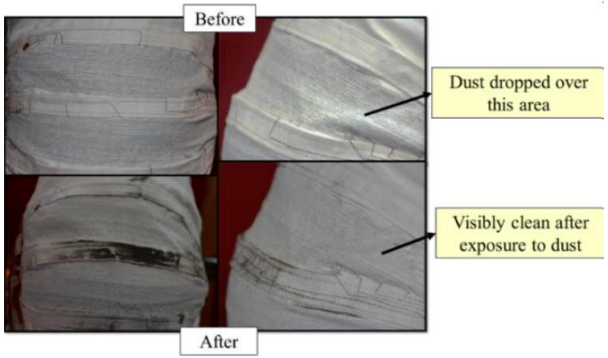

Figure 2. Knee demonstration for dynamic cleaning procedure [2].

Carbon Nanotube Applications

Military Applications

Protection from chemical warfare

NIST

Functionalized, carbon nanotube material for the catalytic degradation of organophosphate nerve agents

Scientists at the National Institute of Standards and Technology (NIST) have demonstrated a way to engineer carbon nanotubes to dismantle the molecules of organophosphate nerve agents. In principle, the nanotubes could be woven into clothing that destroys the chemicals on contact before they reach the skin [4].

NIST
National Institute of Standards and Technology

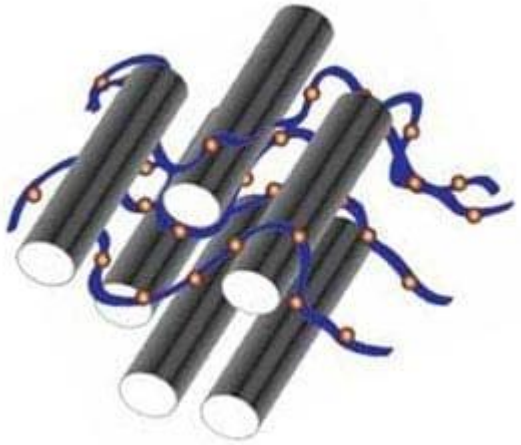

Figure 6. Single-walled carbon nanotubes, represented by the gray cylinders, can be combined with a catalyst (purple ribbons) that is capable of breaking down Sarin and related toxins into less dangerous components [4].

NIST

Functionalized, carbon nanotube material for the catalytic degradation of organophosphate nerve agents

National Institute of Standards and Technology

Nanotubes can be combined with a copper-based catalyst able to break apart a key chemical bond in organophosphates, such as Sarin. A small amount of catalyst can break this bond in a large number of molecules, potentially rendering a nerve agent far less harmful.

Chemical modification of carbon nanotube threads and fabrics could lead to multifunctional materials that merge mechanical strength with chemical functionality, such as catalytically active materials that degrade Chemical Warfare (CW) agents *in situ*.

Self-decontaminating, single-walled carbon nanotubes (SWCNT) derived materials can ultimately be incorporated into a wearable fabric or protective material to minimize dermal exposure to organophosphate nerve agents [5].

Manufacturing Applications

Anti-Static Gloves

TUBALL

Graphene nanotubes for anti-static latex

Tuball has developed graphene nanotubes that comply with international ESD safety standards for personal protective equipment (PPE) at automotive and electronic manufacturing facilities.

The nanotube technology applied as an agent solution outperforms competitive solutions in all elements of the uninterrupted grounding chain of industrial wear, including gloves, clothing, and footwear.

Thanks to their high strength, electrical conductivity, and flexibility, the working dosage of graphene nanotubes is 10-40 times lower than that of other solutions. A content of just 0.05-0.06% graphene nanotubes makes it possible to produce anti-static latex gloves [6] with an electrical resistance of 10^7 Ω.

Image: Anti-static gloves. Source: Tuball.

EXPERT INTERVIEWS

Insights from three subject matter experts (SMEs)

Expert Interview

Sarah Hargrove

Space Suit Life Support System Hardware Lead, MRI/NASA

Denver, Colorado

Leader of the Assembly and Integration team for the xEMU, (exploration extravehicular activities) as well as the Portable Life Support System team. Sarah became involved with space suits at the beginning of 2020.

Her previous experience with spacecraft life support systems is very relevant to space suits which operate on the same principles, with the exception of the size of the system. Her involvement includes both mechanical design operations and software support. In the last two years, focusing on assembly and integration, her team built a spacesuit from the ground up.

Expert Interview

Sarah Hargrove

We've learned a lot of lessons on maintainability and the lifespan of components and materials. Lessons are learned and materials are modified to be implemented in the new suit to make it require less maintenance, make the components last longer and easier to replace as well as easier to maintain.

The main design challenge and a problem that hasn't yet been solved for lunar missions is **dust mitigation**.

Lunar dust is very fine, and it gets into everything. So, how do you build a suit that's okay with that? How do you keep it off the suit or prevent dust from sticking to the suit in the first place? How do you get it off the suit when coming back into the vehicle?

There are a lot of ideas. Nothing has been finalized. There are many Small Business Innovation Research (SBIR) funds that NASA puts out. And that's always one of them. Gas sensors like CO_2 and humidity sensors are the innovation projects that have been awarded in the last few years. **Dust mitigation will be next**.

There are lots of innovation funds also within NASA trying to solve the dust issues. And the hatch entry was one of the things to help with that, in the sense that you have fewer joints that you open and close.

And then also **there's a concept for a rover, with what's called a *suit* port where the suit actually stays outside. The hatch attaches to the vehicle and the astronaut opens the hatch and climbs inside. So, basically, the suit stays outside. And I think that's one of the most promising solution options so far for the dust issue.**

Expert Interview

Thomas, Kenneth

Project Engineer - Spacesuit at Hamilton Sundstrand

Central Manchester, Connecticut | Author, "U.S. Spacesuits"

EMU project engineer in 1989 at the urging of his father who had worked on the Gemini, Apollo and Hubble Space Telescope programs.

Expert Interview

Kenneth Thomas

…And when we got to the moon, we found that the sand, and lunar dust stick like anything to the fabric. And so, consequently, they brought the dust into the lunar module, and then the lunar module went up into zero gravity to reconnect to the command module. And then the dust, which they hadn't really thought that much about, which was on the floor, all of the sudden was in the air or the oxygen they were breathing and the lunar soil is a texture that you don't want to breathe into because it tends to stick in the lung fibers.

Even worse than that, when one gets to Mars, there might be a life system that might be microbial. You wouldn't want to breathe it. It could be extremely dangerous for the explorers. And unfortunately, they could then bring it back to earth and it might be extremely dangerous to humans and it would be something that we've never seen before. So, consequently, we wouldn't understand what we're dealing with.

Not knowing what you don't know, you'd have to be prepared for any contingency.

Now, suit ports basically adorn the back of the hard upper torso that allows you to get out and get in. If you have a mechanism that keeps that sealed away from the habitat environment, the only part that you have to be concerned with is decontaminating: flowing a biocide through the interface between that backdoor and the hard upper torso which is the upper part of the space suit enabling you to control everything that you want. But the logistics of successfully moving that backdoor with probably life support on it and then re-attaching it without any possible leakage of anything is a real challenge.

Expert Interview

Kenneth Thomas

I had one concept which was tested in Haughton Mars in Arctic Canada. **But unfortunately, the interest in it didn't develop because NASA medical didn't feel it was necessary right now and they didn't necessarily need to have potentially Mars features on a lunar space suit plus NASA medical decided that lunar dust wasn't a problem (which I profoundly disagreed with). But that's okay, I can disagree and they are supposedly the experts**.

I would think that any space suit going beyond the moon would have to have a rear entry system. This means you have to have a suit port system so the person can get in and out of the suit and the habitat without causing themselves problems.

Apollo was an excellent example of something we didn't know until we ran into it after which we tried building something. They issued a contract to design and build an Apollo space suit in 10 months. The contractor successfully did it and so they were happy.

They got it into man testing and found out that the suit didn't have adequate cooling, life support, or mobility. But they ran into all these things they didn't know only after testing it.

So, we went back to the drawing board, and unfortunately, the drawing board was more challenging than they wanted and it took them more time than they wanted. Consequently, you ended up making it just in time and fortunately, the Apollo space suit worked really well. **But then they got to the moon and discovered the lunar dust**.

Expert Interview

Anonymous

Axiom Space

Former NASA employee

Expert Interview

Anonymous

NASA is always looking to make the massive space suits lighter. So, **advanced materials are one or treatments to those materials that improve their performance specifically with dust**.

So, lunar dust is a huge, huge problem. I think everyone is aware of that now, but it really is a big problem. So, that's an area of continual research that really needs some better solutions.

There's so much focus on dust right now. That's really a big one.

I guess the other area NASA has been pushing is what they call "informatics system" which is an onboard assistant, if you will. So, it's almost like a computer on your space suit that has a heads-up display, and you can take field notes or pictures or it can show you your heart rate and all of this data like an app-based system. And if we go towards a Martian EVA, the way we can conduct the operations of a spacewalk on Mars can be very different than today because the communication is so distant. So, having an onboard what they call an informatics system would be helpful for giving the crew members real-time guidance and information and the ability to take science notes.

It's relatively new, so there's not much more I can say about it just because it really hasn't been developed yet. I **think there are companies out there that have made similar things for the military** but nothing for this particular application because it comes with the added challenges of having the system in a radiation environment. That's much harsher than what we deal with here on Earth. That, and then advanced displays would be probably another one. So, displays like LCD displays or OLED displays that can tolerate radiation, that's been a problem area where those don't typically survive very long in a radiation environment. So, that's another opportunity for some improvement.

Radiation is probably the number one problem we have in terms of being harsh.

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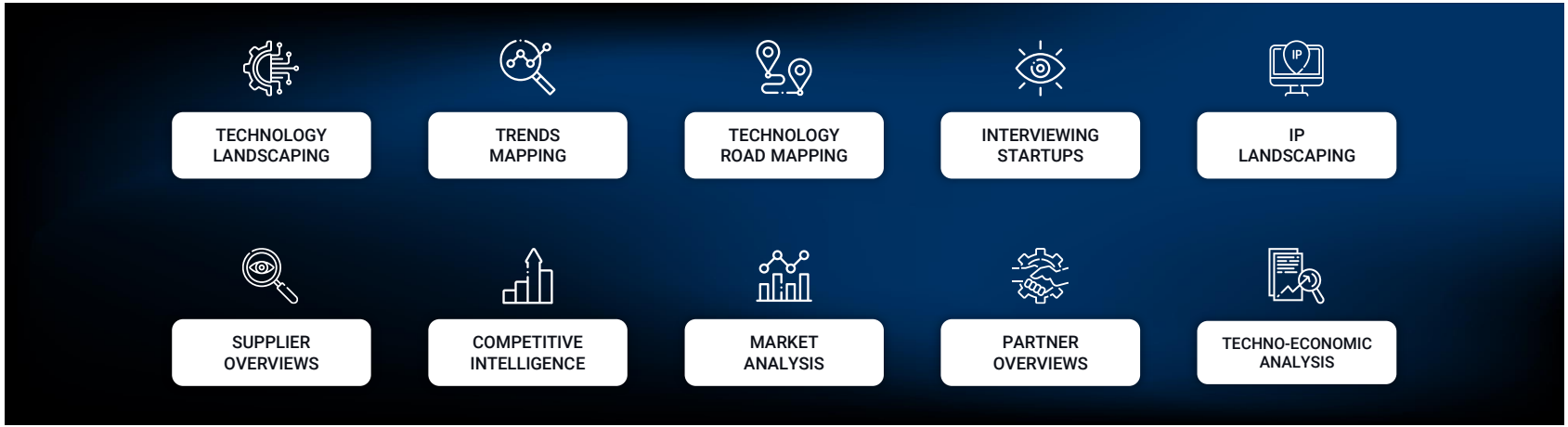
Potential Next Steps

- ✓ PreScouter can conduct anonymous interviews with companies profiled to help you learn more about their technologies processes, and partnership potential.
- ✓ PreScouter can identify the intellectual property position of these players and understand patent trend evolution.
- ✓ PreScouter can identify additional suppliers located in specific regions to source products and other services.



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