ESA Contract No. 4000126066/18/NL/RA ----- 6000522052
"Materials Selection for Surface EVA Suit Development"

PExTex

Final Presentation at ESTEC

Materials Selection for Surface EVA Suit Development

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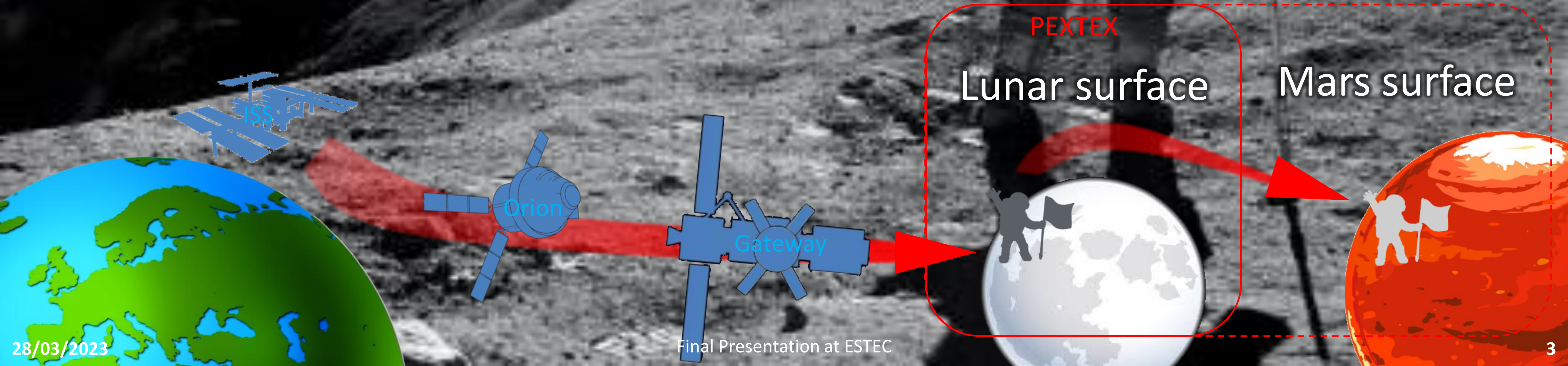
Agenda

- Introduction
- Project Team
- Project Objectives
- Project Steps
- Task 1. Requirements review and candidate materials selection
- Task 2. Development of a testing plan including new testing platforms
- Task 3. Manufacture and testing of samples
- Task 4. Final recommendations and future roadmap

Introduction

- Return to the Moon for ESA and its international partners, 50 years after Apollo Missions
- Intention to establish permanent infrastructures on the surface
- Not permanently crewed but some of the materials will remain on the surface
- Lessons learned of previous space suit (A7L)
- New data on harsh lunar planetary conditions
- Half a century of extreme textile technology improvement

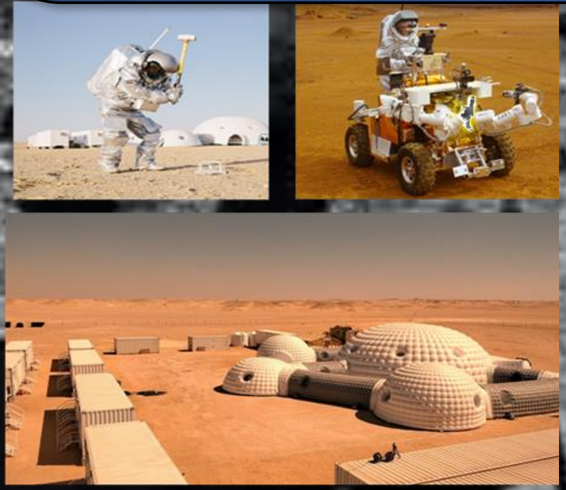


Project Team

COMEX has heritage in extreme environment suit development (Nuclear and deep sea) and has built the Europe's first spacesuit simulator.

DITF is the Europe's largest textile research center. With their research and development projects, they are the only textile research institute in the world to cover the entire textile production and value chain.

ÖWF is a research organization in the field of space exploration and has 20 years of experience in conducting analogue missions.



PExTex
Planetary Exploration Textiles

PExTex Objectives

1. To identify (novel) materials (note : textile, not mechanisms) for future EVA space suit developments in Europe

2. To propose a testing strategy to verify that such materials meet the conditions of future missions to the lunar surface.

3. To manufacture and test the samples

4. To give a final recommendation on the highest performing materials

PExTex Steps

The work in PExTex was separated in the following four main tasks:

Task 1. Requirements review and candidate materials selection :

A - Literature research and update of requirement

B - Establish list of potential spacesuit materials

C - Selection of materials for Test campaign

Task 2. Development of a testing plan including new testing platforms

A - Development of test plan

B - Custom Test platform

Task 3. Manufacture and testing of samples

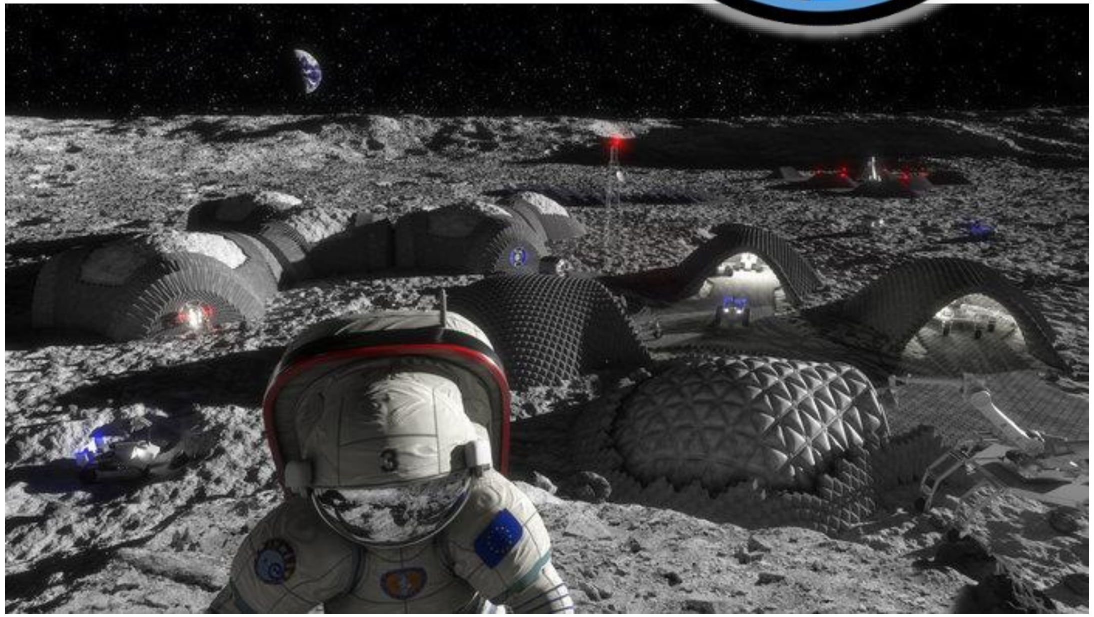
A - Procurement and manufacturing of samples

B - Test campaigns

Task 4. Final recommendations

A - Post data analysis

B - Roadmap development



Task 1. Requirements review and candidate materials selection

A - Literature research and update of requirement

➔ Provide a comprehensive literature survey on advanced materials
➔ identify candidate materials

1/ Past EVA Suit Designs

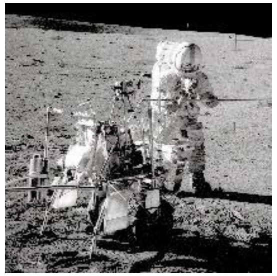
State of the art of previous spacesuit detailled composition, layer by layer
Identification of fabric materials which have been used very frequently

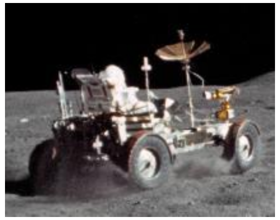
Task 1. Requirements review and candidate materials selection

A - Literature research and update of requirement

2/ Missions scenarios

- Generic planetary exploration task
- scientific exploration scenarios
- Technology test support and ISRU
- EVA suit stowage / storage
- Human Robot/Machine interfaces
- Likely mission scenario location

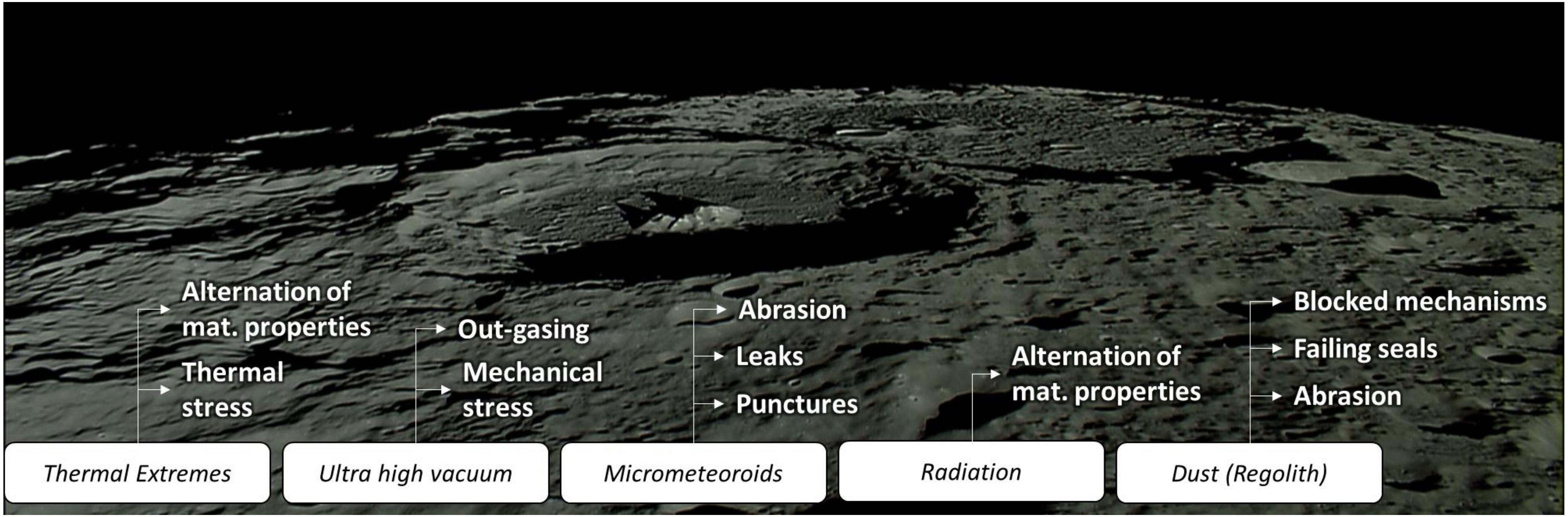




Task 1. Requirements review and candidate materials selection

A - Literature research and update of requirement

3/ Requirements for future space suit materials
Harsh conditions of lunar space environment

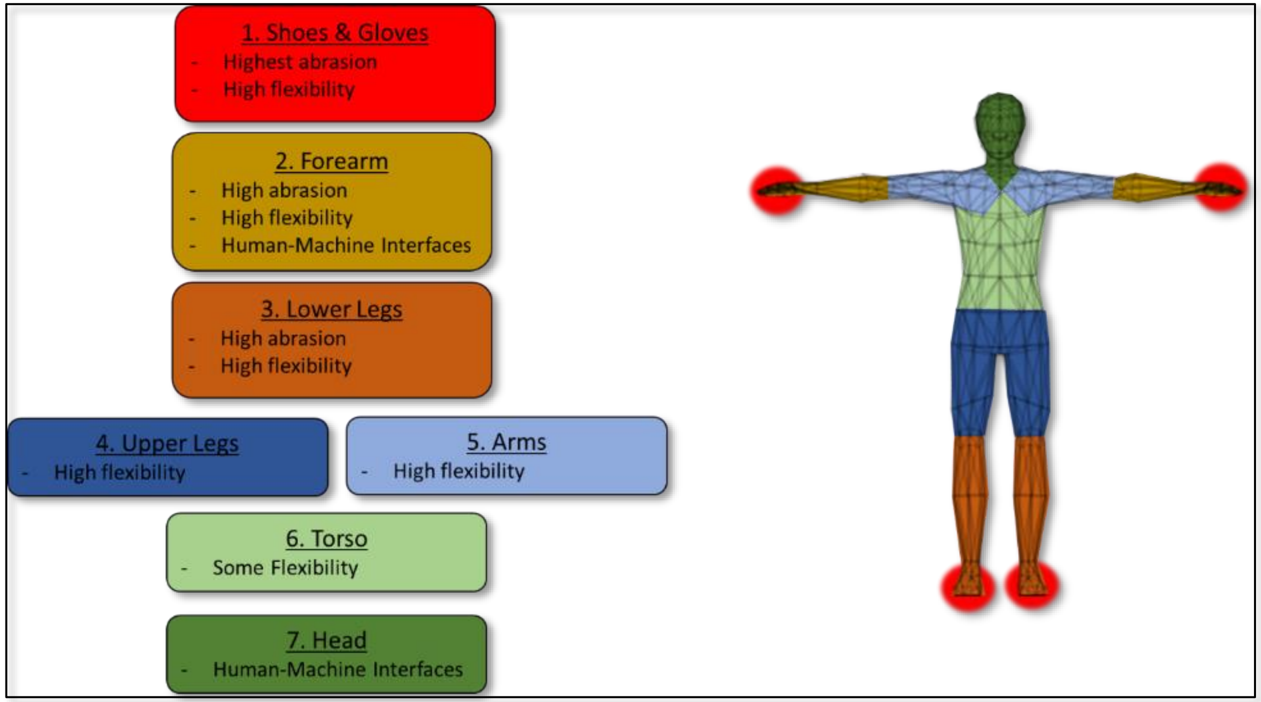


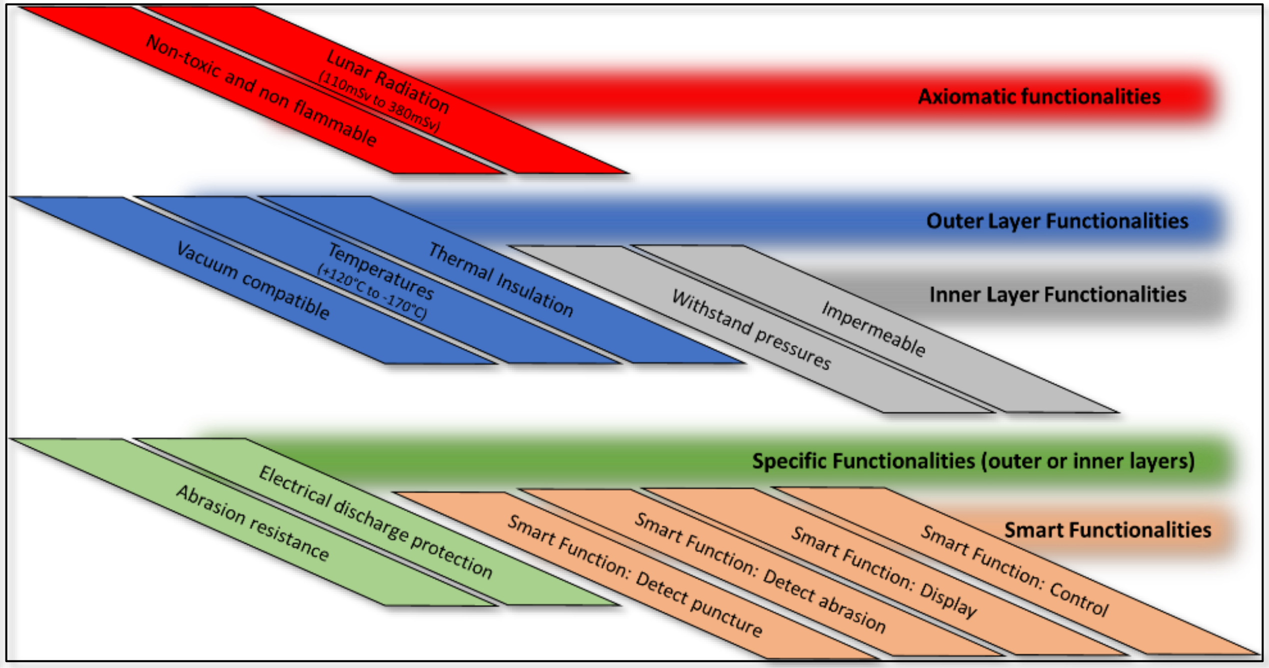
Task 1. Requirements review and candidate materials selection

A - Literature research and update of requirement

3/ Requirements for future space suit materials

Clustering of materials





Task 1. Requirements review and candidate materials selection

A - Literature research and update of requirement

SOW Requirements list

[RQ1] Demonstrated compatibility with the expected environmental conditions for 2500 hours with lunar temperature range (+120°C in sunlight, -170°C in darkness).

[RQ2] Demonstrated compatibility for 2500 hours with lunar radiation environment (annual exposure to ca. 380 mSv at solar minimum and 110 mSv at solar maximum).

[RQ3] Demonstrated compatibility for 2500 hours with lunar vacuum environment.

[RQ4] The material shall sustain repeated pressure-vacuum cycling, considering a max. pressure up to 420 hPa over 312 pressurisation cycles.

[RQ5] Demonstrated EMC and discharge protection during lunar EVA activity for at least 8 hours (from friction during movement of the suit and from the external environment).

[RQ6] Demonstrated resistance to wear by abrasive regolith (considering lunar environment) for exposure of EVA suit over 2500 hours.

[RQ7] Demonstrated bendability to 180° (for flexibility of astronaut movements, e. g. in knees and elbows).

[RQ8] Demonstrated fatigue integrity over the expected suit life (120 cycles/hour, 2500 hours).

[RQ9] The material shall ensure thermal insulation for EVA activities under external environment defined in [RQ1-RQ3]. and targeted max. temperature 25°C inside (with minimum at 17°C).

[RQ10] The material shall not off-gas toxic substances.

[RQ11] The material shall be non-flammable.

[RQ12] Demonstrated dust mitigation strategy.

[RQ13] Demonstrated compatibility (limited degradation) with long-term storage for 2 years at a space station / habitat. Folding of the suit shall be taken into account.

[RQ14] Demonstrated impermeability to water and fluids.

Task 1. Requirements review and candidate materials selection

A - Literature research and update of requirement

Additional Requirements list

The requirements of the SoW were completed by Additional Requirements proposed by the consortium:

~~[A-RQ1] Demonstrated reparability over the expected service lifetime.~~ → Not performed because of remaining project time available

~~[A-RQ2] Demonstrated possibility to monitor the material integrity status (level of damage or remaining functionality) during the use of the EVA suit.~~ → Finally not performed, due to low TRL level of materials

~~[A-RQ3] High velocity impact tests (MMOD). The requirement is mentioned in the SoW. It is proposed a 7km/s impact with projectiles of 0.5 to 1.5mm (0° and 45° angles). This requirement can be combined with A-RQ2 (monitoring).~~ → Finally not performed, due to cost over project budget

[A-RQ4] Punctuation risk evaluation (against rocks, tools)

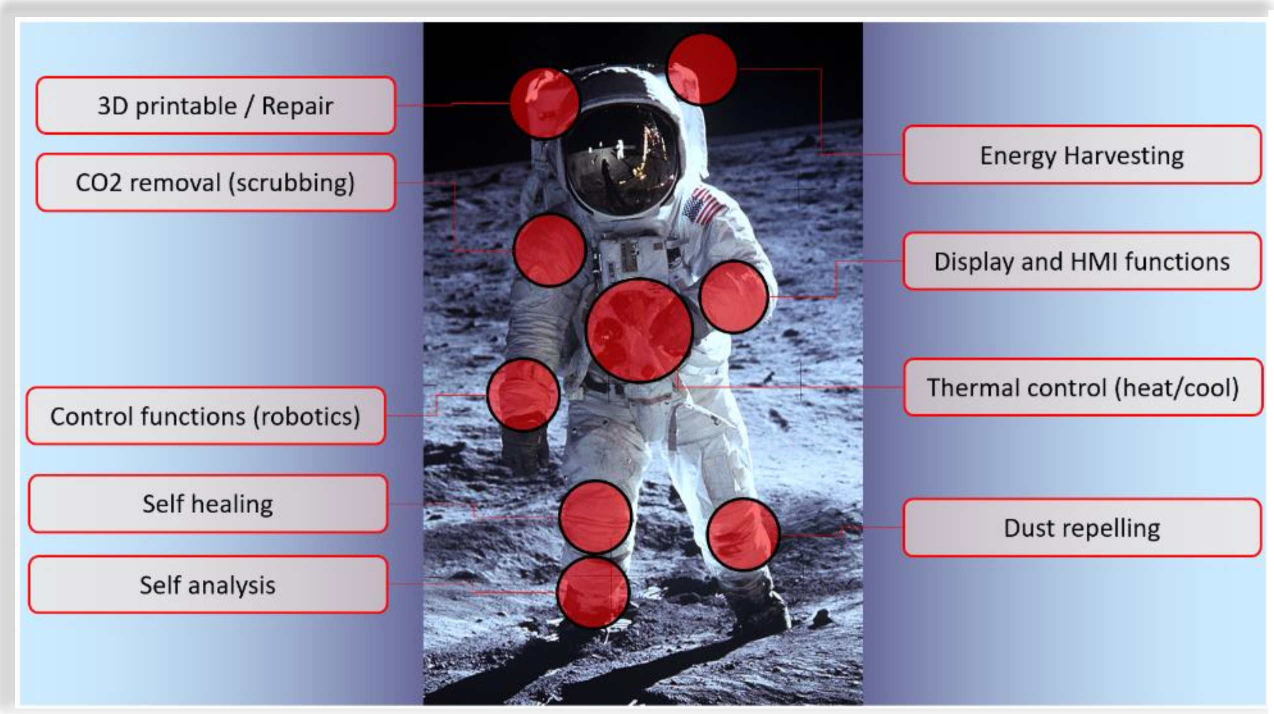
~~[A-RQ5] Capability to clean the material from (lunar) dust~~ → Finally not performed, due to low TRL level of materials

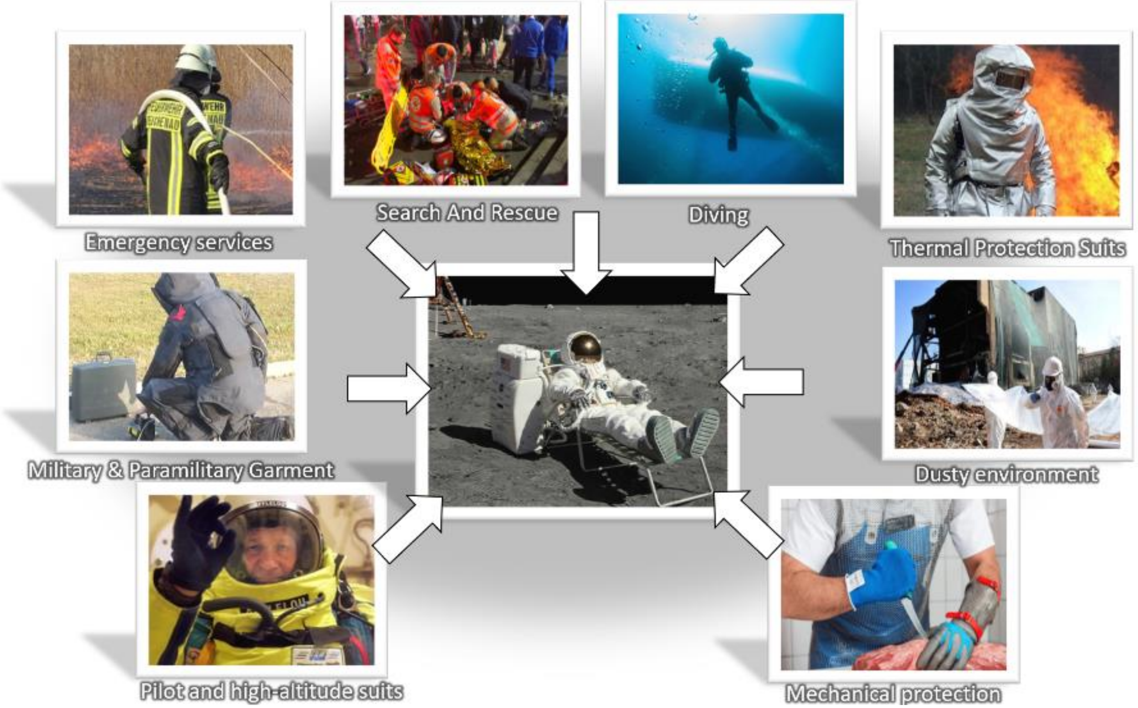
[A-RQ6] Test of the biological growth potential (for inner layers)

Task 1. Requirements review and candidate materials selection

B - Establish list of potential spacesuit materials

Novel and Smart Suit Materials : Some potential novel application materials and spacesuit candidate material drawn from various terrestrial novel applications





Task 1. Requirements review and candidate materials selection

B - Establish list of potential spacesuit materials

PExTex MRF : Material Request Form, introducing PexTex and asking for material solution

➔ Industrial survey ➔ Collect data (European entities were prioritized)

125 entities identified

15 positive replies

Materials Selection for Surface EVA Suit Development:
Planetary Exploration Textiles (PExTex)

Dear Sir/ Madam,

After more than 17 years of operations on the International Space Station ISS, ESA and its international partners are working on a return to the Moon with the now starting construction of the Gateway, that will serve to perform robotic and human excursions to the surface of the Moon. Aiming for a permanent human presence on the Moon and it is to be expected that extra-vehicular activity (EVA) will last longer and on a more regular basis than those performed by the Apollo astronauts.

The development of materials for a European EVA spacesuit is part of ESA's exploration strategy to land on the Moon, ESA has tasked a group of industrial and research partners under the lead of COMEX SA (DITF and OeWF being other partners) to identify potential spacesuit materials for lunar surface activities.

The project is implemented through identifying different candidate materials, of which the selected candidate materials will go through series of lunar environment and operation requirement test cycles. The test results will be analysed with the intention of producing a material solution for future EVA suits.

The objective of this activity is not to develop a solution based on existing space suit materials alone, but also to identify novel textiles with additional functionalities (e.g. self-heal, dust repellent, integrity monitoring)

The candidate materials could be used under these conditions, self-standing or as part of multilayered assemblies:

- Ability to withstand lunar temperature range (+120°C in sunlight, -170°C in darkness) and lunar vacuum (targeted 2500 hours).
- Provide thermal insulation (targeted max. temperature 25°C inside and with minimum at 17°C).
- Compatibility with lunar Radiation environment (annual exposure to 380 mSv at solar minimum and 110 mSv at solar maximum).
- Resistance to wear by abrasive regolith (lunar soil; targeted for at least 2500 hours)
- compatibility with vacuum and pressure vacuum cycle (considering a max. pressure up to 420 hPa over 312 pressurisation cycles)
- Electrical discharge and EMC protection (targeted for at least 8 hours)
- Material shall be Non-toxic and non-flammable (targeted compliance with standards ECSS-Q-ST-70-29C and ECSS-Q-ST-70-21C)
- Impermeability to water and fluids
- Bendability to 180°

If your entity has a textile solution which could be used under these conditions, we kindly invite you to fill out attached form and send it to the project coordinator (pextex@comex.fr). Multi-layered material assemblies could also be proposed.
Please reply by 29 March 2019. We guarantee full confidentiality to the institutes concerning their inputs.
Thank you in advance for your support.

Dr Peter Weiss,
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Dr Malgorzata Holynska,
PExTex Technical Officer
Materials and Processes Engineer,
ESA/ESTEC

Planetary Exploration Textiles (PExTex)
Materials Selection REQUEST FORM for Surface EVA Suit Development

Name: Click or tap here to enter text.

Position: Click or tap here to enter text.

Institute / Company: Click or tap here to enter text.

Proposed solution Materiel name: Click or tap here to enter text.

Current Technology/ market readiness level: Click or tap here to enter text.

Has it been used in Space, if yes details: Click or tap here to enter text.

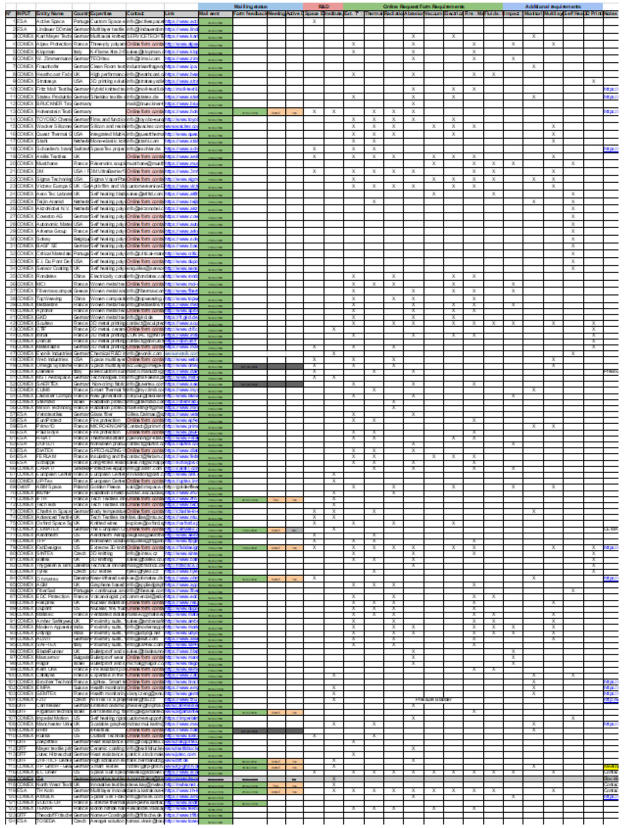
Requirements Meet:

- Ability to withstand lunar temperature range (+120°C in sunlight, -170°C in darkness) and lunar vacuum (targeted 2500 hours). ☐
- Provide thermal insulation (targeted max. temperature 25°C inside and with minimum at 17°C). ☐
- Compatibility with lunar Radiation environment (annual exposure to 380 mSv at solar minimum and 110 mSv at solar maximum). ☐
- Resistance to wear by abrasive regolith (lunar soil; targeted for at least 2500 hours) ☐
- compatibility with vacuum and pressure vacuum cycle (considering a max. pressure up to 420 hPa over 312 pressurisation cycles). ☐
- Electrical discharge and EMC protection (targeted for at least 8 hours). ☐
- Material shall be Non-toxic and non-flammable (targeted compliance with standards ECSS-Q-ST-70-29C and ECSS-Q-ST-70-21C). ☐
- Impermeability to water and fluids. ☐
- Bendability to 180°. ☐
  - Other - added advantage of the material:

Click or tap here to enter text.

If you are also the supplier, what will be lead-time required to produce sample materials:
Click or tap here to enter text.

After filling out the form please forward the completed form (or for any query) to pextex@comex.fr



Task 1. Requirements review and candidate materials selection

C - Selection of materials for Test campaign

PExTex pre-candidate material selection / stacking approach

Expert recommandation ➔ Top 3-5 materials for each functional layer from the materials identified

Functional layers

	Abrasive resistance	Dust mitigation	Discharge protection	Thermal Insulation	Radiation protection	Impact protection	Pressure retention
Candidate Stack A	Material Choice A1	Material Choice A2	Material Choice A3	Material Choice A4	Material Choice A5	Material Choice A6	Material Choice A7
Candidate Stack B	Material Choice B1	Material Choice B2	Material Choice B3	Material Choice B4	Material Choice B5	Material Choice B6	Material Choice B7
Candidate Stack C	Material Choice C1	Material Choice C2	Material Choice C3	Material Choice C4	Material Choice C5	Material Choice C6	Material Choice C7
Candidate Stack D	Material Choice D1	Material Choice D2	Material Choice D3	Material Choice D4	Material Choice D5	Material Choice D6	Material Choice D7
Candidate Stack E	Material Choice E1	Material Choice E2	Material Choice E3	Material Choice E4	Material Choice E5	Material Choice E6	Material Choice E7

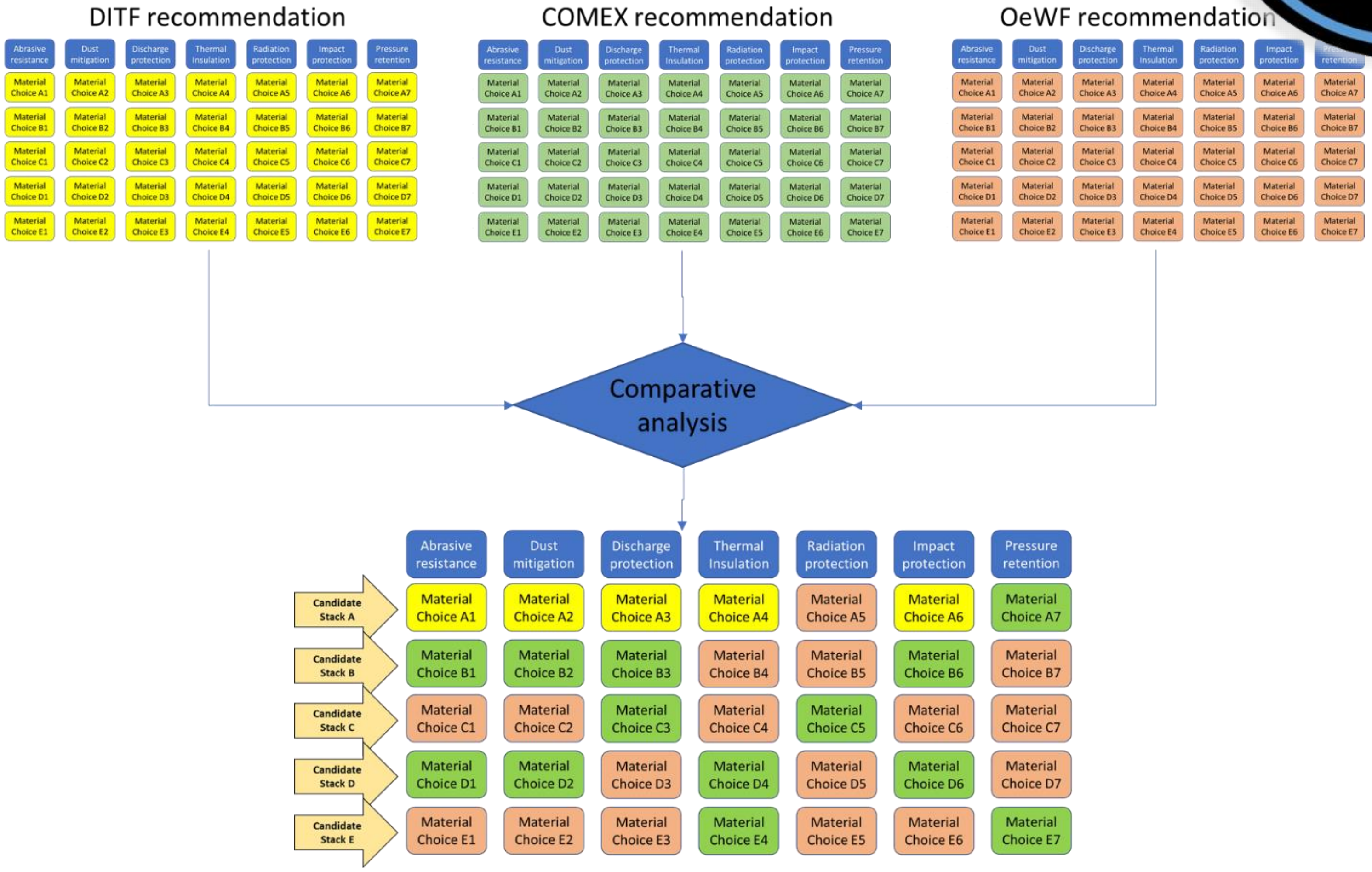
Task 1. Requirements review and candidate materials selection

C - Selection of materials for Test campaign

PExTex candidate material selection method

<u>Comparative Analysis :</u>
Recommendation from each partner + discussions of the merit and demerits of materials

➔ Selection of the top 3-5 materials for each functional layer



Task 1. Requirements review and candidate materials selection

C - Selection of materials for Test campaign

PExTex candidate material selection method

Quantitive Analysis :

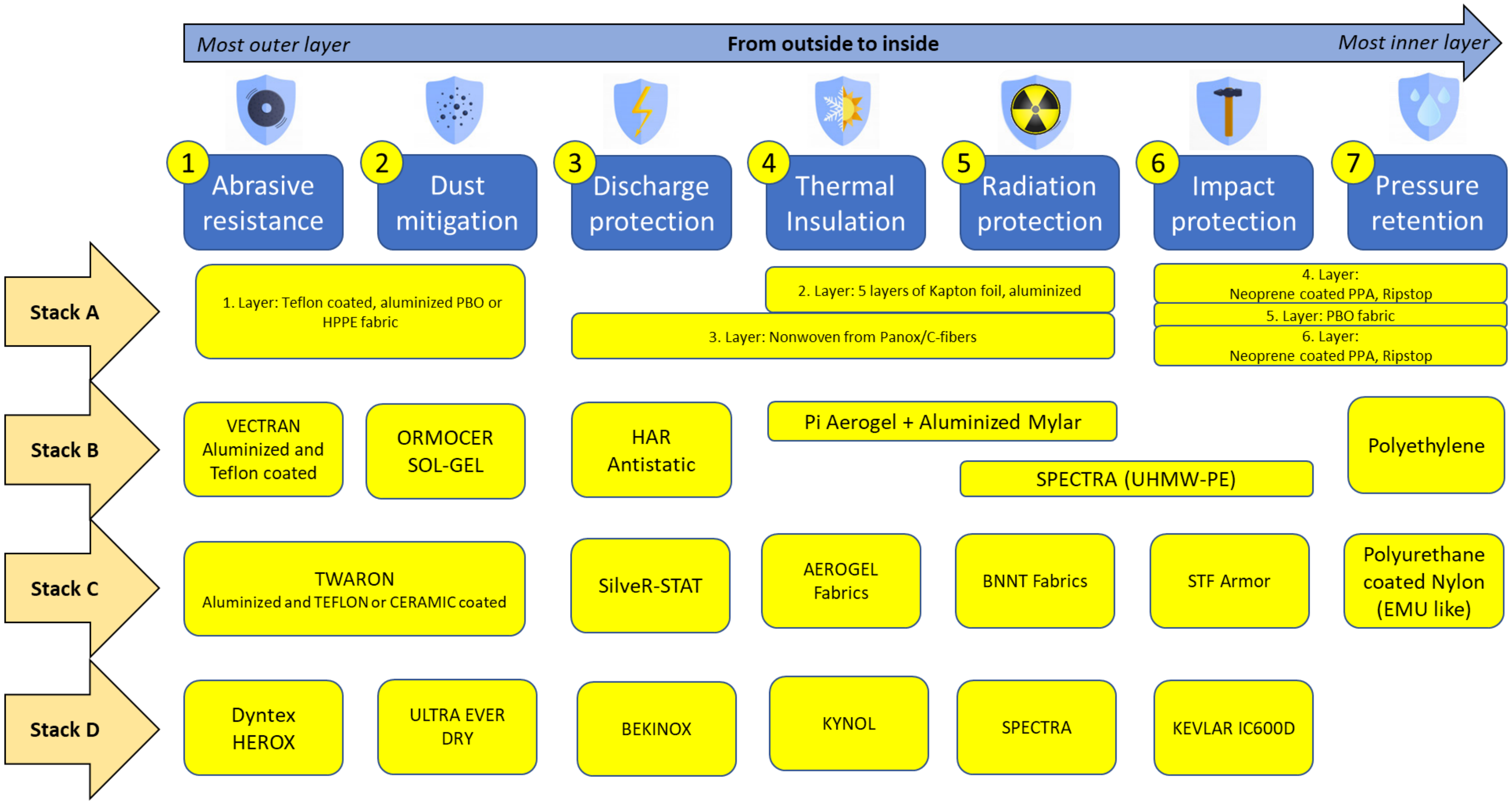
Scoring system for each layer (e.g. abrasive resistant layer)

Parameter	Weightage	Justification
Abrasion resistance against regolith	5	Mandatory layer requirement: All recommended materials have good abrasive resistance, however the material with stronger fiber strength property are rated higher.
Temperature	4	The abrasive layer is the outermost layer of the spacesuit and i is directly exposed to the lunar temperature. The outer layer material with higher operational temperature range will allow the astronaut to perform task longer time (extended time limit when facing the Sun or the opposite), hence higher the temperature ranger higher the grade.
Flexibility	4	Generic spacesuit material requirement: It is important for all spacesuit layer material to have high degree of bendability to allowhigher degree of ergonomics for the astronauts.
Radiation degradation	3	As the outermost layer, it is also exposed directly to the lunar radiation environment (before radiation protection layer). The material with slow degradation rate (longer material life) is rated higher
Vacuum compatibility	3	Materials ability to not to lose its property when exposed to vacuum are rated higher.
UV protection	3	As the outermost layer is also exposed directly to Sun (before radiation protection layer), the material with slow degradation rate against UV (longer material life) is rated higher
Light weight	3	Space system generic requirement, as lighter weight material will have low launch cost.
Already used in space	2	Materials that are already used in Space will be rated high. However, the parameter was given low weightage as the objective of the project is to look into new novel materials.
Added value	2	Materials that bring added benefits such as dust repletion etc. are rated higher

Task 1. Requirements review and candidate materials selection

C - Selection of materials for Test campaign

Result of PExTex pre-candidate material selection



Task 1. Requirements review and candidate materials selection

C - Selection of materials for Test campaign

Result of PExTex pre-candidate material selection

Fail safe layer:

PExTex Expert workshop ➔ add a “fail safe layer to the current layering approach”

Either :

(a) minimum an additional impact layer right next to the abrasion layer to avoid regolith going into the inner layer once the outermost layer is damaged
(b) reinforcing the outer layer fabric with Kevlar
(c) repetition of “critical layers”: minimum number of layers is needed to keep astronauts safe during catastrophes.

Consortium decision :

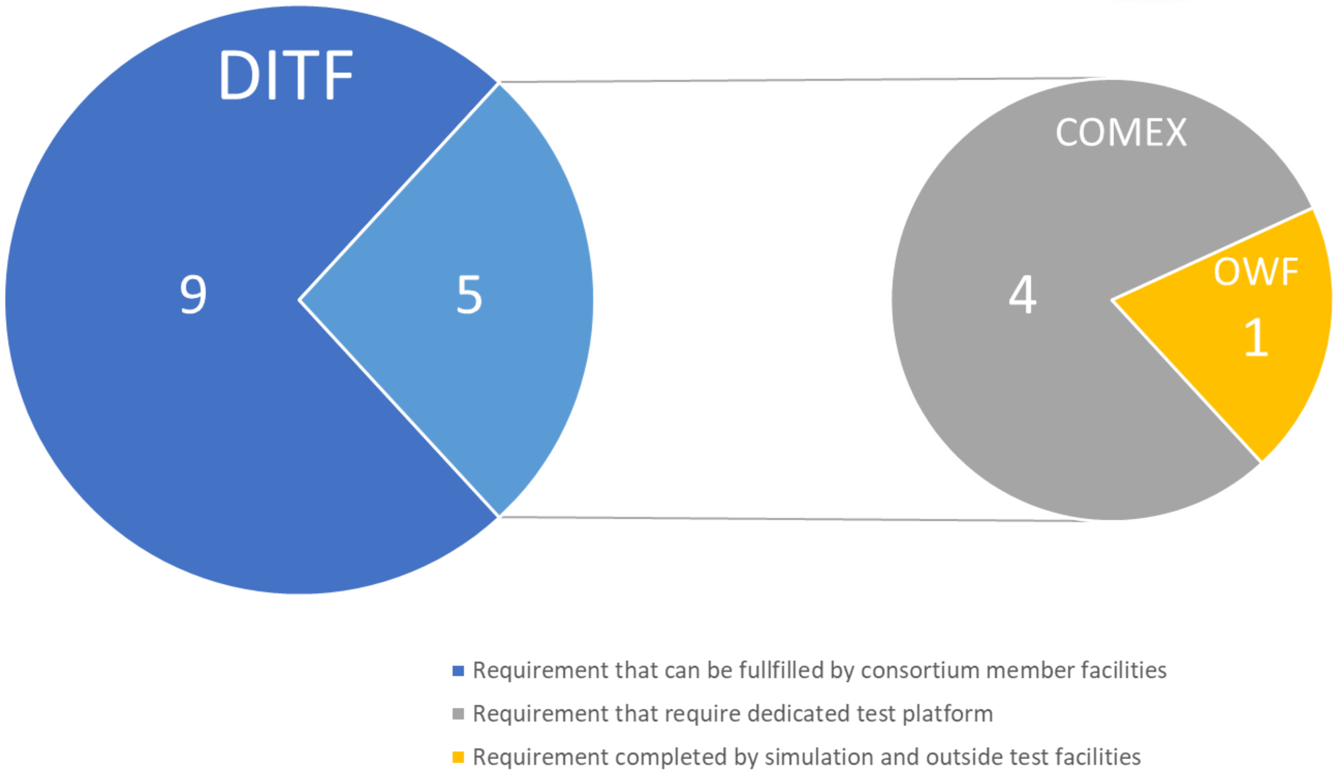
- Stack A: Neoprene coated Vectran ➔ repeated twice as the failsafe layer
- Stack B: Spectra material ➔ either before or after discharge protection layer depending on depending on the Spectra material influence over the discharge protection layer.
- Stack C: STF Armor (TBD) or Neoprene coated nylon ➔ added behind the TWARON layer.
- Stack D: Kevlar material ➔ added behind the Dyntex material.

Task 2. Development of a testing plan and new testing platforms

A - Development of test plan

Test facilities

- 9 requirements done using a combination of 16 in-house DITF facilities
- Radiation requirement test was performed in two stages by OeWF:
  1) GEANT4 simulation
  2) Particle Accelerator at MedAustron
- For the 4 remaining requirements ➔ dedicated test platform designed and built by COMEX
- 1 of those requirements was finally done in ESA ESTEC facilities

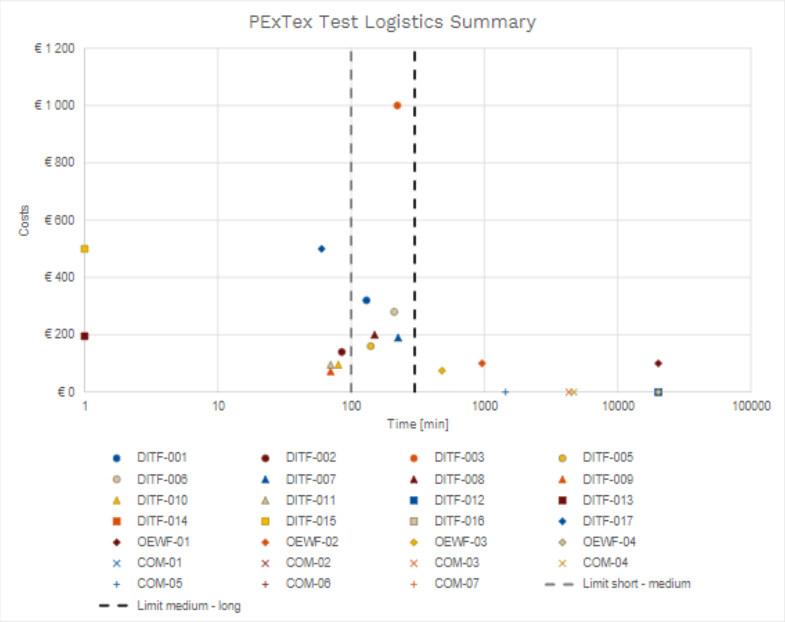


Task 2. Development of a testing plan and new testing platforms

A - Development of test plan

Testing plan

Test information template ➔ collecting the test facility data initially to identify the gaps in requirement.



PExTex Material Test Logistics		
Draft version, fecit: DITF		
Test Number	**DITF-006**	
Name of test	**LOI**	
Test description	**Determination of the Limiting Oxygen Index (LOI)**	
Requirement tested	**RQ11**	
Test location	DITF Denkendorf, Germany	
Test lead	Dr. Frank Gähr frank.gaehr@ditf.de Tel. +49 (0)711 9340-132	
Industrial test standard	ASTM D2863 Part B	
Required sample size	10 textile samples, 10 x 4 cm	
Required test materials		
Required ressources	1 person	
	280 €, 10 single tests for each material	
Test duration	1 hour sample preparation	
	1.5 hrs for testing	
	1 hr for reporting/documentation/sample archiving	
Success criteria	LOI should be at least 28	
	No structural damage affecting bendability	
Dependabilities	Shall be done after sample storage 24 hrs. in standard climate (20°C/50% rel. hum.)	
Destructive test	yes, samples cannot be used elsewhere	
Sample archive post-test	Locally at DITF sample archive, Denkendorf Germany	
Documentation	Electronic test report electronic as well as hardcopy in office no. G139 (Dr. Gähr)	
Comments	Determination of the Oxygen Index according to DIN EN ISO 4589 is possible too	

Task 2. Development of a testing plan and new testing platforms

A - Development of test plan

Testing plan

<u>Workflow :</u>

Starting the campaign with basic tests

➔ screening of all materials and the potential

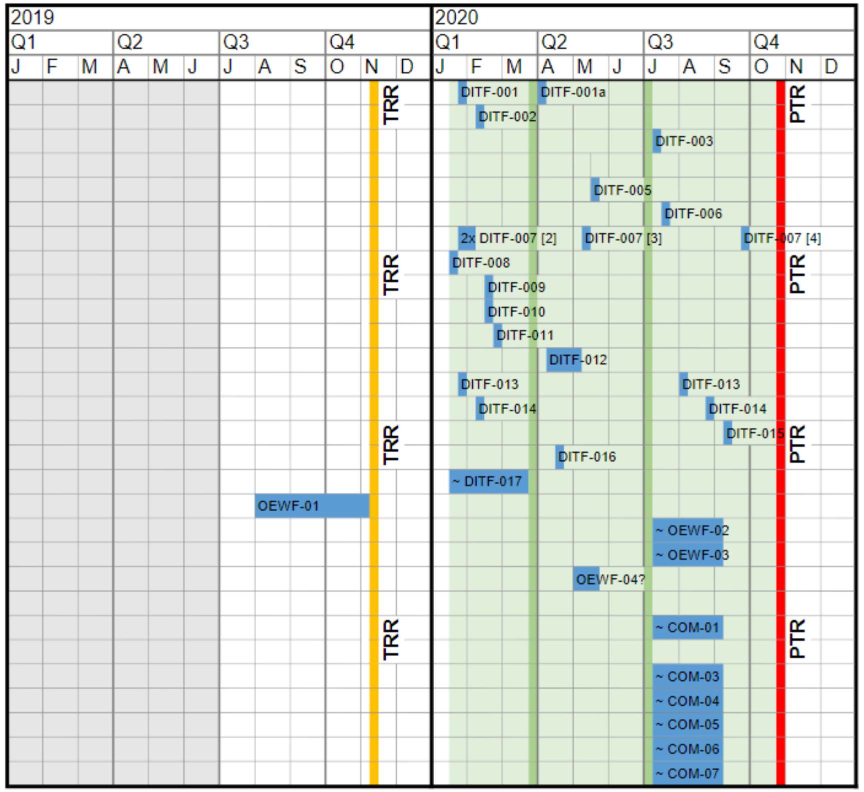
➔ early elimination of unsuitable candidates.

More complex tests

➔ later stages of the project

➔ performed on a reduced set of textiles, which excelled in the first tests

Test ID	Priority	Test Name
DITF-001	H	Rotary Platform Double Head Abraser
DITF-002	H	Alambeta Test (thermal conductivity)
DITF-003	H	Bose (buckling and tension)
~~DITF-004~~	~~H~~	~~Burning behaviour [1]~~
DITF-005	H	Cantilever (bending stiffness)
DITF-006	H	LOI
DITF-007	L	Tensile Test
DITF-008	H	Tumbler Test
DITF-009	H	Air permeability
DITF-010	H	Hydrostatic pressure test
DITF-011	L	Bursting properties
DITF-012	H	Ageing chamber
DITF-013	H	Discharge protection (resistance)
DITF-014	H	Discharge protection (triboelectric)
DITF-015	H	EMC (electromagnetic shielding)
DITF-016	L	Impact (cut) test [5]
DITF-017	L	Thermal desorption analysis
OEWF-01	H	Radiation simulation
OEWF-02	H	Radiation - material fatigue
OEWF-03	H	Radiation - shielding
OEWF-04	L	Biological growth [5]
~~OEWF-05~~	~~H~~	~~Offgassing~~
COM-01	H	Outgassing test 1
~~COM-02~~	~~L~~	~~High velocity impact [6]~~
COM-03	H	Outgassing test 2
COM-04	H	Pressure cycling test
COM-05	H	Thermal insulation test
COM-06	H	Offgassing test
COM-07	H	Discharge behavior in vacuum



Task 2. Development of a testing plan and new testing platforms

B - Custom Test Platform

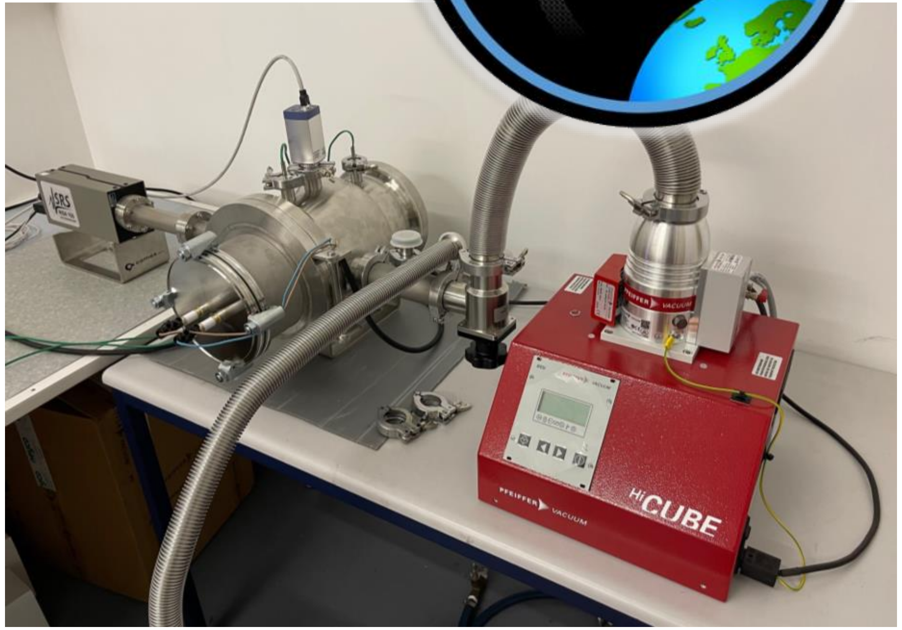
A dedicated PExTex Test Platform was developed to meet the following remaining test requirements that are neither completely nor partially fulfilled by existing facility:

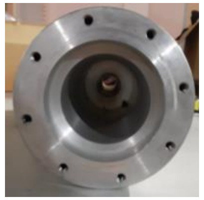
Two aluminum pressure chambers were built (Heat / cold dedicated)

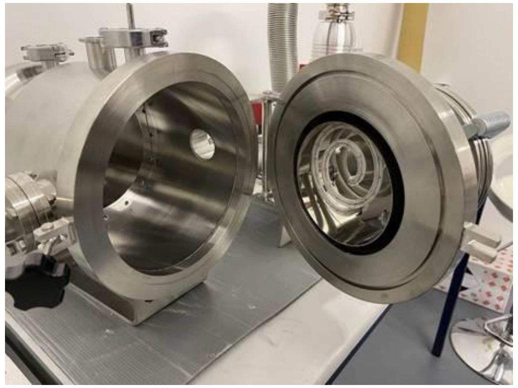
Emptied using Hi Cube pump from Pfeiffer (maximum 10^{-8} mbar)

The heat vacuum chamber is equipped with :

- ✓ capacitance diaphragm gauges
- ✓ T-Type temperature probes
- ✓ Integrated ceramic IR lamp as heat source
- ✓ Live temperature regulator
- ✓ Vacuum Residual Gas Analyzer from SRS







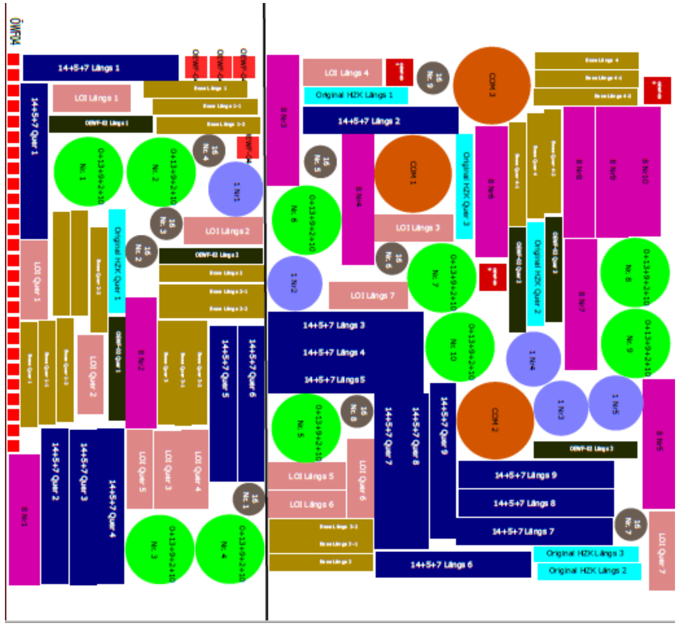
Task 3. Manufacture and testing of samples

A – Procurement and manufacturing of samples

Sample required size : 1m x 4,2m to perform all the tests

➔ Budget or IP rights wise, some of the material cannot be procured :

- × ORMOCER SOL-GEL – restricted by company IP rights. Consortium tried without success to obtain samples under NDA.
- × HAR Antistatic, Pi-Aerogel and Aerogel fabrics: Are discontinued for test campaign (cost around 60k euro per sq.m.)
- × BNNT fabric: High cost as the product is still at R&D phase.
- × STF Armor: Discontinued from further investigation as it requires export regulation from US Army.

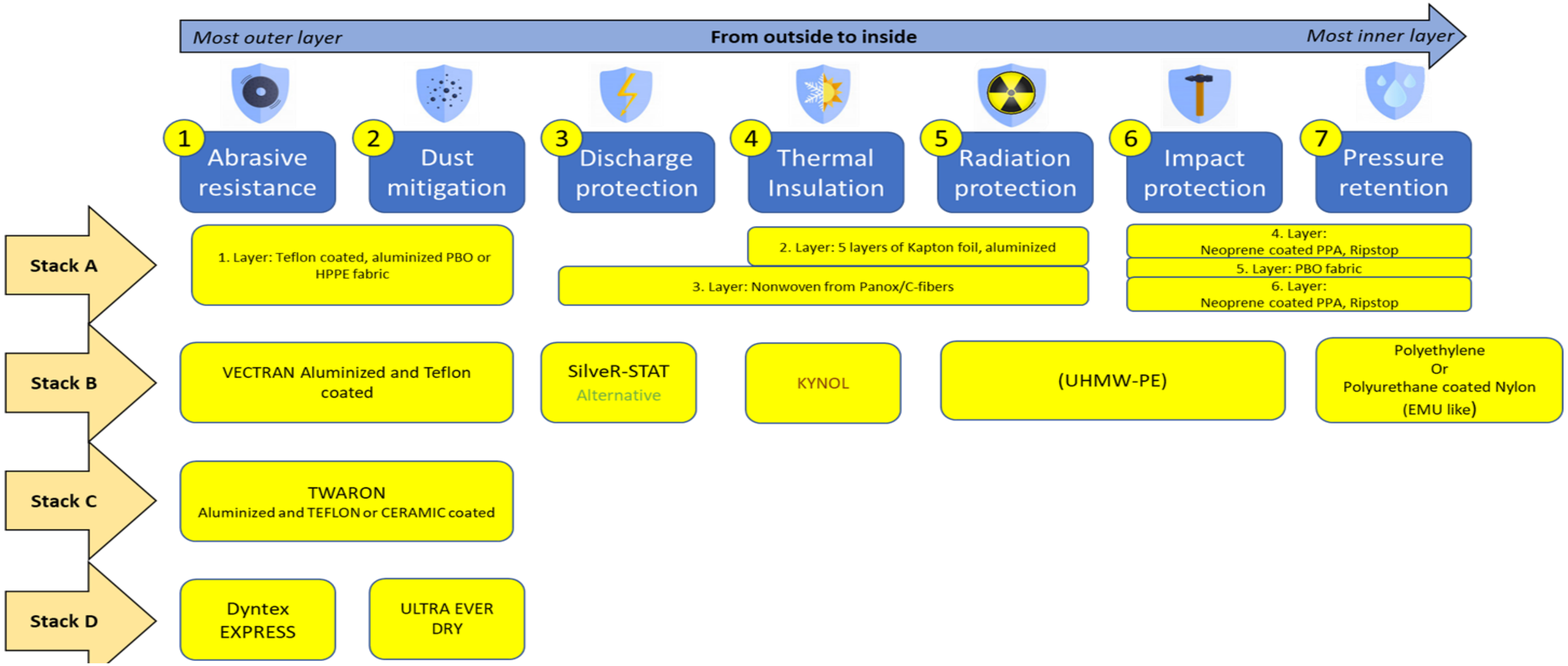


Task 3. Manufacture and testing of samples

A – Procurement and manufacturing of samples

<u>Final candidate materials updated</u>

After filtering the sample materials for test campaign, they consortium ended up with two stacks for all layer material and four material option for the first layer :



Task 3. Manufacture and testing of samples

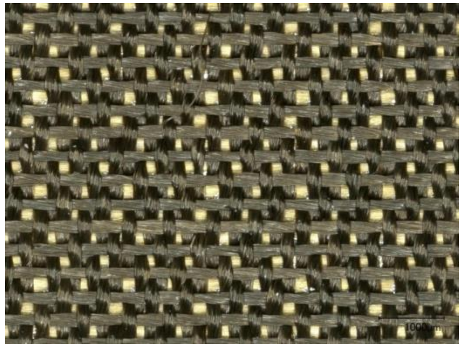
A – Procurement and manufacturing of samples

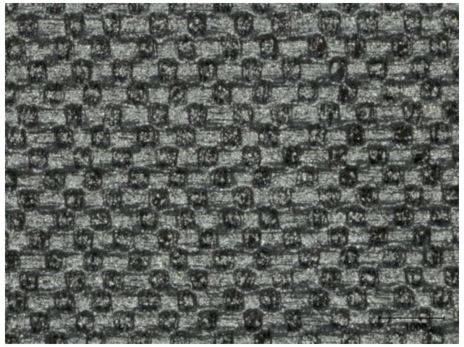
Final candidate materials updated

Aluminized Vectran/PTFE

Liquid crystal polymer (LCP) is an high-performance multifilament yarn, produced from Vectra LCP polymer and is called Vectran®. Due to its crystal structure, it exhibits very low creep, good abrasion resistance, and low elongation at highest breaking loads.

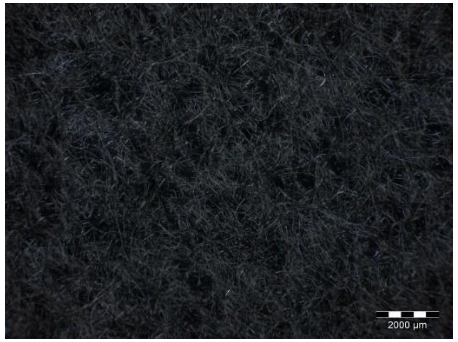
In order to increase its abrasion resistance, it was woven in the weft as a double weave with Polytetrafluoroethylene (PTFE). As a further modification, the inner side was coated with aluminum particles and pressed. Since Vectran has already been used in space, for instance by Bigelow Aerospace, it is already well examined for extravehicular activities.





Panox (Nonwoven)

Panox is an oxidized polyacrylonitrile (PAN) fiber which does not burn, melt, soften or drip. The sample material is a nonwoven fabric with the aim to increase the thermal insulation.



Task 3. Manufacture and testing of samples

A – Procurement and manufacturing of samples

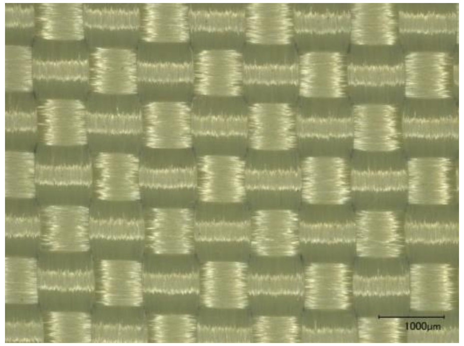
Final candidate materials updated

Aluminized PBO/PTFE

Poly(benzoxazole) (PBO) is the further development of the para-aromatic polyamides using a so-called liquid crystal polymer solution. Besides its heat-resistance, it exhibits little creep and an excellent strength-to-weight ratio. A drawback is its sensitivity to Ultraviolet-light (UV-light) that has to be taken into account while handling the material. As Vectran, it was woven with PTFE and aluminized on inner side

Ceramic-coated Twaron

Twaron® (registered product of Teijin) is a para-aramid, similar to Kevlar® and exhibits great tenacity. On a weight basis, it is stronger than steel wire and stiffer than glass. Due to the chain morphology, Twaron has both, low creep, and linear coefficient of thermal expansion. The densely woven Twaron is modified with a polymeric coating containing ceramic particles.
Twaron has been examined concerning its application in NASA's space gloves.
In 2020, Teijin is partnering with the International Lunar Exploration Working Group (ILEWG) to investigate a lunar EVA space suit layer consisting of Twaron. [7]



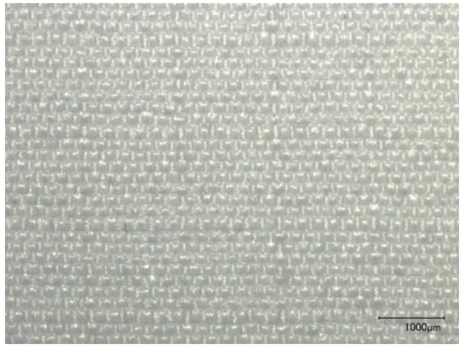
Task 3. Manufacture and testing of samples

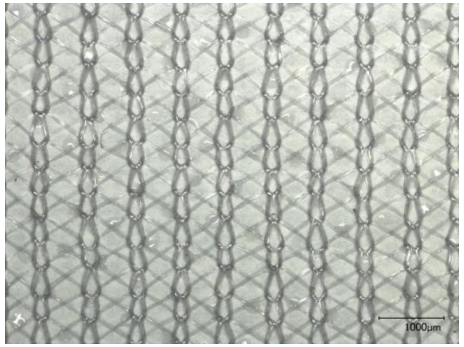
A – Procurement and manufacturing of samples

Final candidate materials updated

Dyntex

Dyntex's private label Herox® is a three-layered mix of fabrics of different processing and finishing technologies. Applied materials are polyester, polyamide and elastane. The upper layer is a woven structure and shows -according to manufacturer's instructions- high wear resistance (Martindale > 50.000 abrasion cycles). Underneath the woven structure, a membrane-like fabric is laminated and further bonded to the subsequent knitwear. Concerning outer materials, Dyntex is the only fabric, that has not been modified further and is obtained directly from the manufacturer. Dyntex has never been used in space.





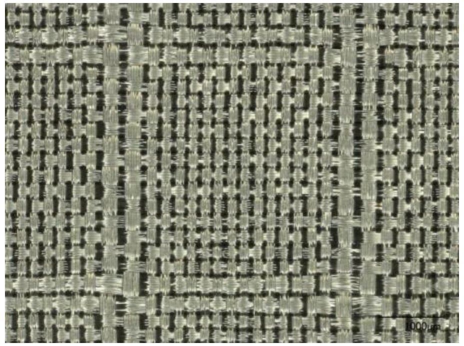
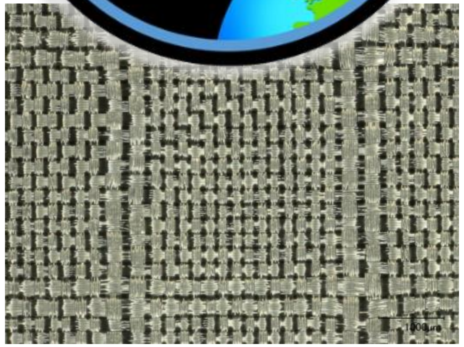
Aluminized (full) Kapton Foil

Kapton® polyimide film has been used in space several times, mostly in combination with an aluminized polyester Mylar® foil. Advantages are its preservation of its properties over a wide temperature range or its low weight. In space, an aluminized polyimide film (H-Kapton) was used as blankets in the Apollo Lunar Module to provide thermal insulation and for instance in space suits of the Apollo 11 mission and was the first material to touch the lunar surface. In this work Kapton is laminated with aluminum foil from both sides.

Task 3. Manufacture and testing of samples

A – Procurement and manufacturing of samples

Final candidate materials updated

Shieldex

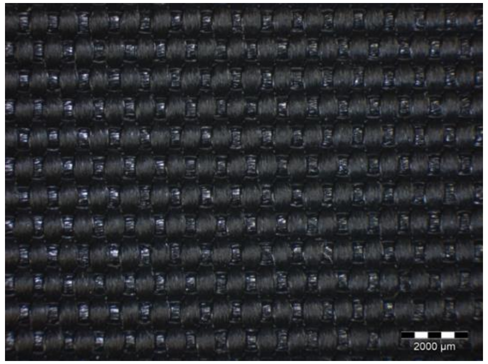
The selected fabric Shieldex® is the second layer of stack B and substructure two. It is a woven fabric made of a silvered polyamide filament yarn that is commonly used for smart or home textiles due to its antistatic and bacterial properties. The material has never been used in space.

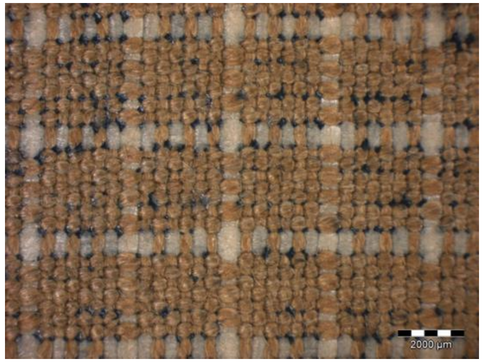
Kynol

Kynol is a woven fabric made of cured poly-aldehyde fibers. Functionalities include high flame resistance, no toxic off-gassing, and excellent electrical and thermal insulation. Kynol has not been examined or used in space.


Neoprene Vectran

Vectran woven ripstop-fabric coated with neoprene. Neoprene (also polychloroprene) is a family of synthetic rubbers that are produced by polymerization of chloroprene. Neoprene exhibits good chemical stability and maintains flexibility over a wide temperature range.





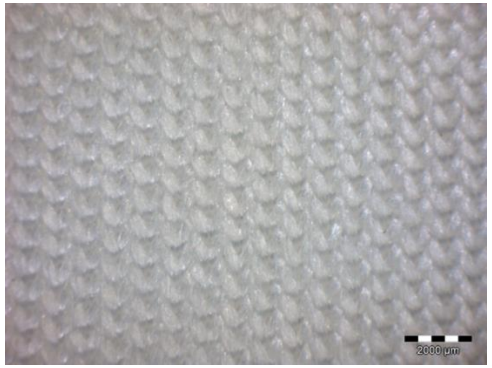
Task 3. Manufacture and testing of samples

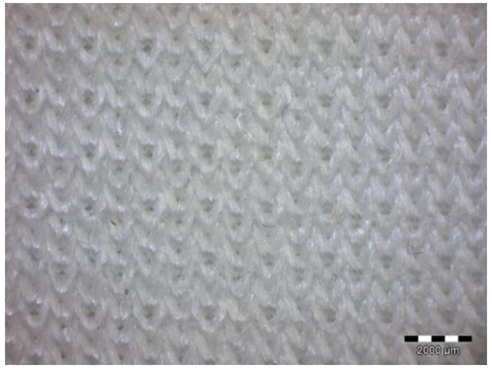
A – Procurement and manufacturing of samples

Final candidate materials updated

Dyneema

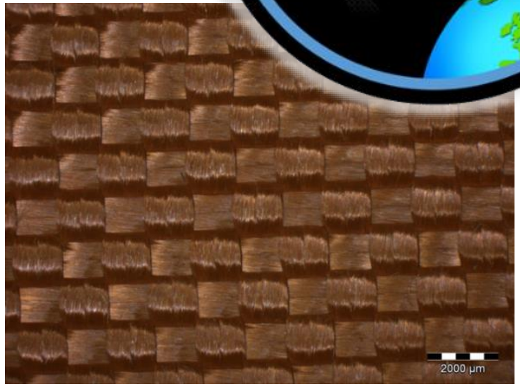
Dyneema fibre, which belongs to the HPPE (High Performance Polyethylene) fibres, has tensile strength values of 3 to 4 GPa. These very high strength values result from the strong parallel orientation of the PE linear molecules, which is greater than 95 %, and has a degree of crystallinity of up to 85 %. The Dyneema test material is a knitted fabric optimized on puncture force. The knitted mesh structure leads to high elongation rates, which is not due to the Dyneema material itself.





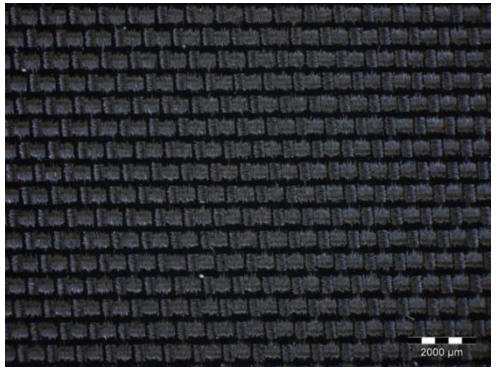
PBO

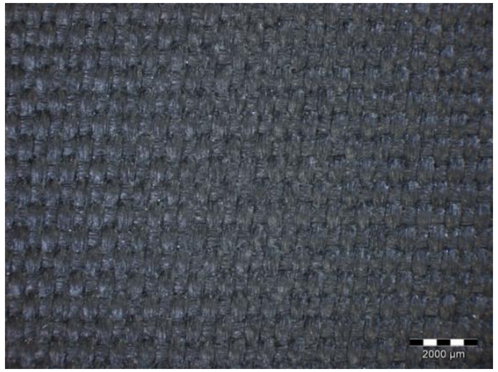
The PBO fabric for the inner layer is a woven fabric (Panama binding) from PBO filaments. PBO fiber is regarded as the super fiber in 21st Century due to its unique molecular structure, extremely high strength, excellent modulus, outstanding heat resistance and flame resistance.



Nylon PU

PU coated Nylon is already used in space suits as pressure retention layer. The material tested in the project is a woven fabric of Nylon coated with a thin layer of PU.



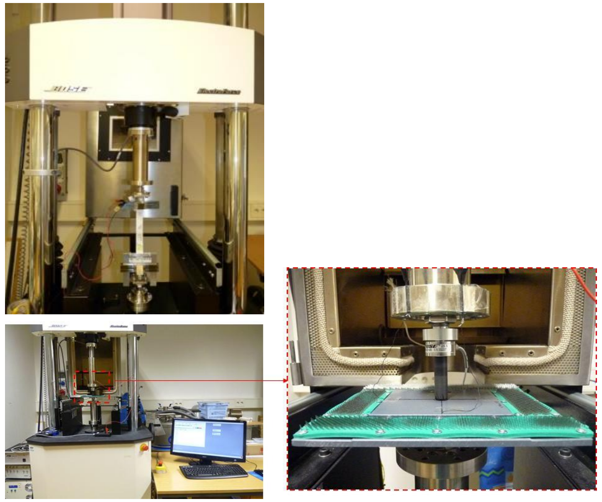


Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ1] Demonstrated compatibility with the expected environmental conditions for 2500 hours with lunar temperature range (+120°C in sunlight, -170°C in darkness).

Test Number: DITF-003
Name of Test: Bose



Exposed to temperature chamber (+130°C to -160°C) followed by RQ8 fatigue test

Result (RQ8) : intact after 120cycles of the test and evaluation maximum fracture load.

Layers: single and the Stack (wrinkles resulting in false result)

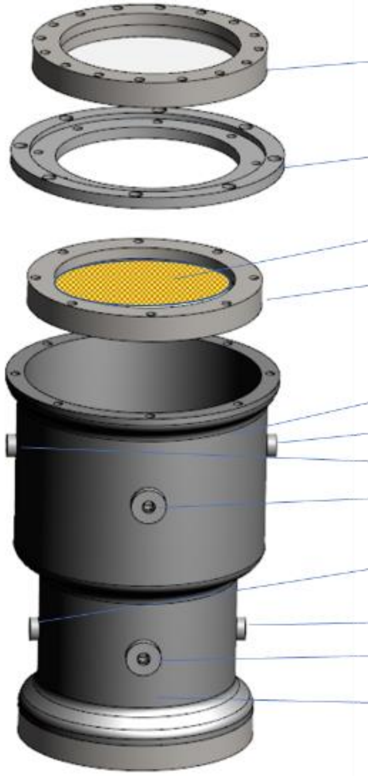
Test Number: COMEX-01
Name of Test: Outgassing test

Combined test with RQ3 following ECSS Q-ST-70-02C & ECSS-Q-ST-70-04C.

Material exposed to artificial sun (infra red lamp) for 24hr in vacuum condition (10-5 mbar)

Result (RQ3) : TML value less than 1.0% with and without heat source

Layers: Only impact layer or stack



B – Test Campaigns detailed by requirements

[RQ2] Demonstrated compatibility for 2500 hours with lunar radiation environment (annual exposure to ca. 380 mSv at solar minimum and 110 mSv at solar maximum).

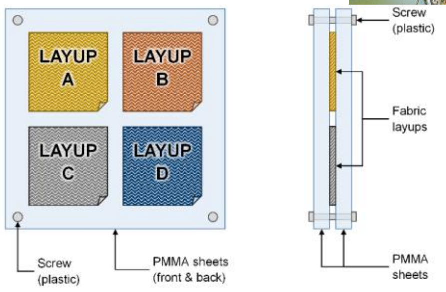
Test Number: OeWF-001
Name of Test: GEANT4 analysis

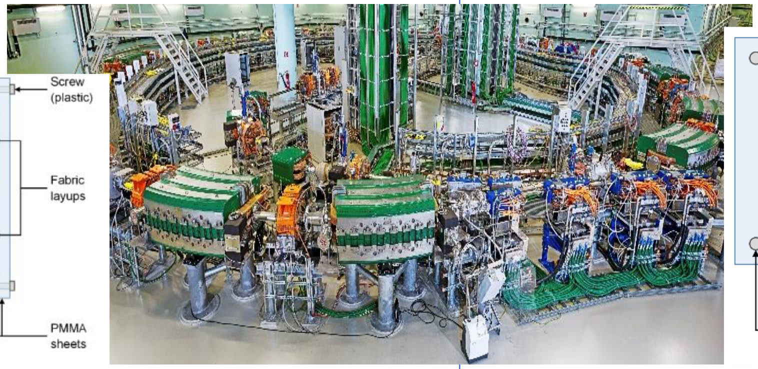
Monte Carlo simulations proton beam, consisting of 10 000 primary particles, with an energy spectrum corresponding to the mean SPE spectrum from 0 to100 MeV

Result : Evaluation / plotting of samples particle energy distribution

Layers: Individual layers and stack (possibility for different configuration)

Test Number: OeWF-002
Name of Test: Material fatigue test



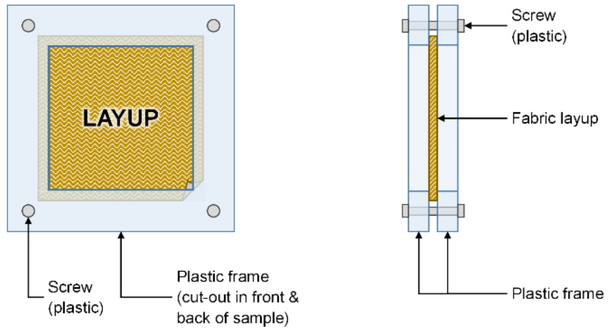


Expose to dose of ~ 1 kGy, (approx. for ~ 16 h) at MedAustron particle accelerator. And followed with RQ8 fatigue test

Result : RQ8 to be repeated with after exposure

Layers: Multiple layers

Test Number: OeWF-003
Name of Test: Radiation shielding test



Expose to 30 MeV and measure the radiation behind the sample material

Result : Evaluation of dosimeter measurement

Layers: Individual

Task 3. Manufacture and testing of samples

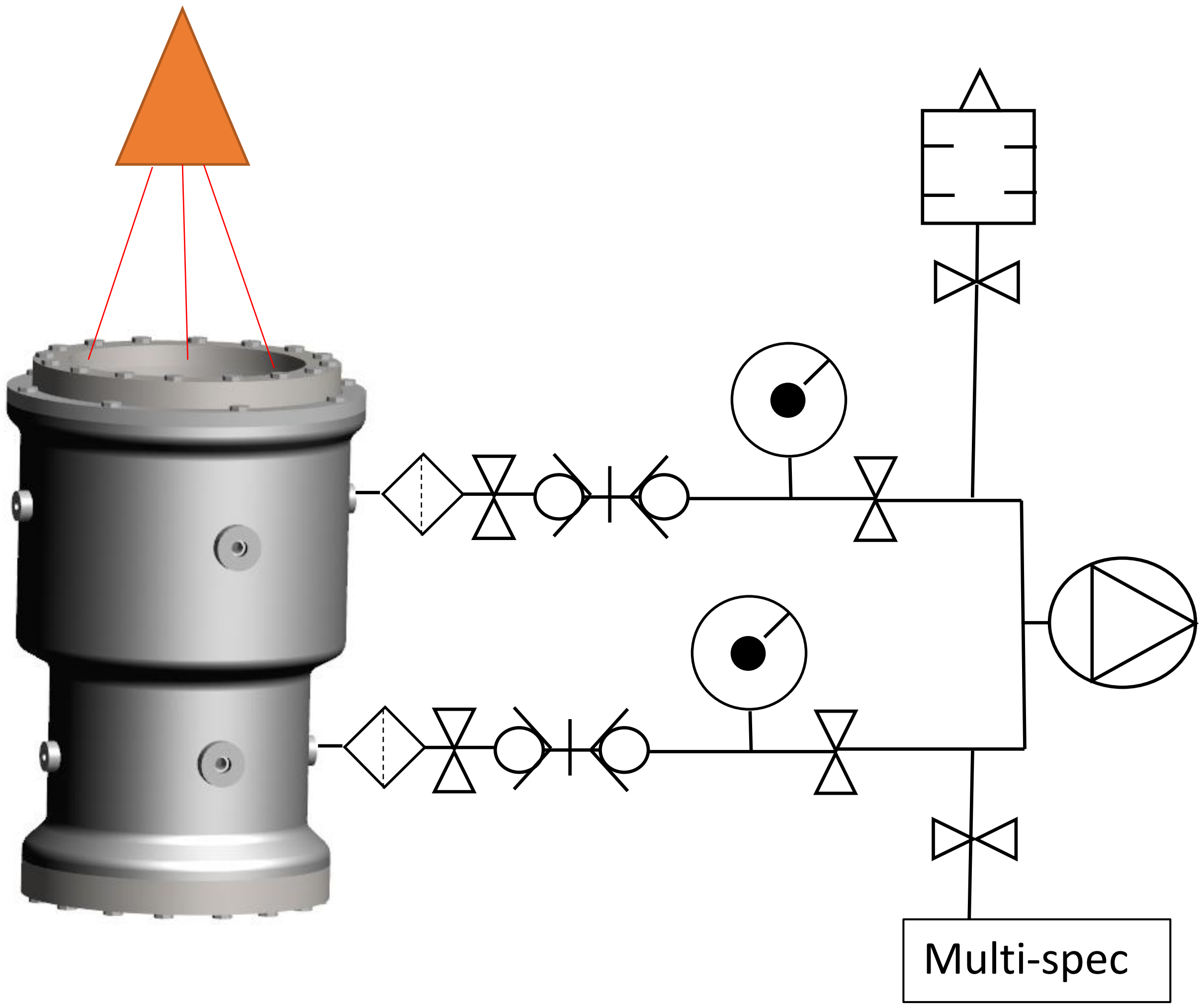
B – Test Campaigns detailed by requirements

[RQ3] Demonstrated compatibility for 2500 hours with lunar vacuum environment.

Test Number: COMEX-03
Name of Test: Outgassing test

Pre-conditioning (24 hours at 22°C) followed by thermal test (125°C for 24 hours) and post conditioning (24 hours at 22°C)

Instrument: Pressure sensor and temperature sensor.
Weigh scale trade-off ongoing
(vacuum rated micro balance vs mass flow sensor vs extended collector plate)



Result (RQ3) : TML value less than 1.0% with and without heat source

Layers: Only impact layer or stack

B – Test Campaigns detailed by requirements

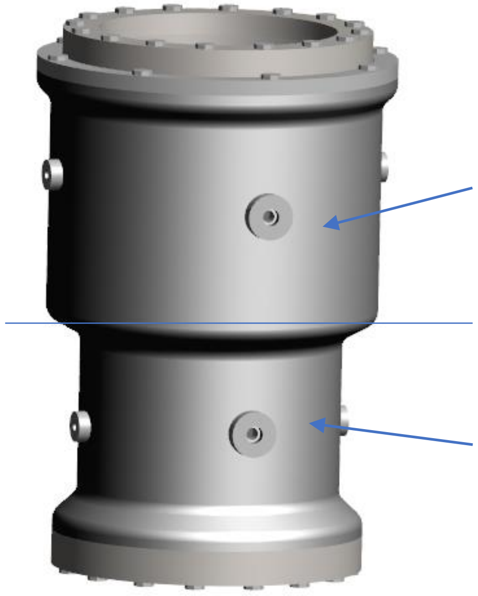
[RQ4] The material shall sustain repeated pressure-vacuum cycling, considering a max. pressure up to 420 hPa over 312 pressurization cycles.

Test Number: COMEX-04
Name of Test: Pressure Cycling Test

320 cycle between .4bar and 10-5 mbar.
15min per cycle or the time required to reach the stagnation line from previous test .

Instrument: Pressure sensor

Objective: Pressure retention layer ability [(2 RQ14) +air bursting test+ existing space material]? Or material integrity to survive 320 pressure cycle



Result : Vacuum fatigue (same TML value for 320 cycle) or pressure retention value

Layers: Only pressure retention or stack

Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ5] Demonstrated EMC and discharge protection during lunar EVA activity for at least 8 hours (from friction during movement of the suit and from the external environment).

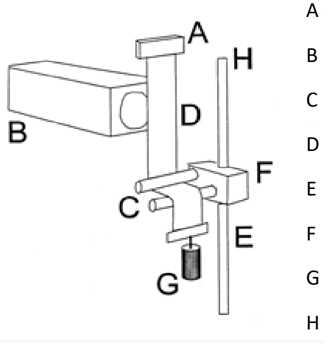
Test Number: DITF-013
Name of Test: Discharge protection

The sample is placed between the 2 electrodes and a voltage of 100 ± 5 V or 10 ± 0.5 V is applied.

Result : Discharge behavior .

Layers: Outer layer (abrasive layer to discharge protection)

Test Number: DITF-014
Name of Test: Discharge protection



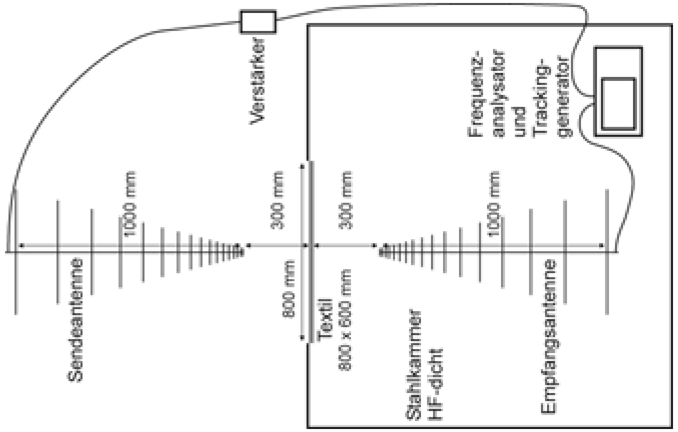
A ...... Fixed clamp
B ...... Induction E-field meter
C ...... Cylindrical rods
D ...... Test Specimen
E ...... Guide rail
F ...... Slider in end position
G ...... Tensioning device (weighted clamp)
H ...... Start position of slider

The sample is rubbed against polyethylene rods by suspending weight on one side.

Result: Maximum charge level and the charge dissipation are measured by using an electrostatic field meter

Layers: Individual layers

Test Number: DITF-015
Name of Test: EMC



The transmitting antenna generates polarized electromagnetic radiation that penetrates the textile.

Result: terials ability to provide shielding of electromagnetic fields until 3 GHz

Layers: Complete stack

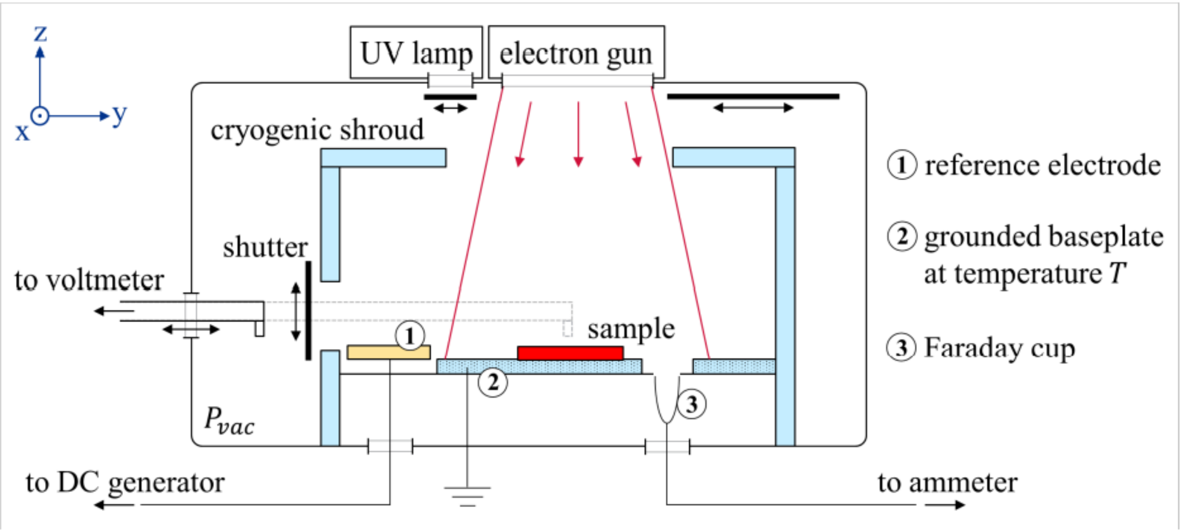
Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ5] Demonstrated EMC and discharge protection during lunar EVA activity for at least 8 hours (from friction during movement of the suit and from the external environment).

Test Number: COM-007
Name of Test: ESD Test

Test finally performed ESD Facility at ESA/ESTEC/TEC-QEE laboratories



The objective was to determine the bulk electrical conductivity of the Panox textile at RT and at -70°C Vacuum <1*10-6 mBar

Result : Bulk electrical conductivity of the textile

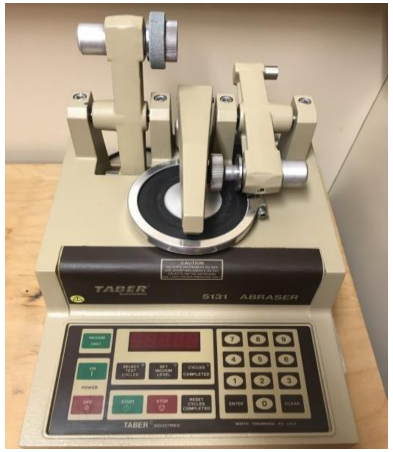
Layers: Only Panox

Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ6] Demonstrated resistance to wear by abrasive regolith (considering lunar environment) for exposure of EVA suit over 2500 hours.

Test Number: DITF-001
Name of Test: Rotary Platform Double Head Abraser



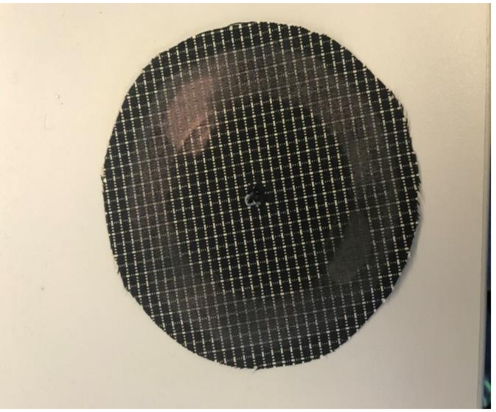
Friction wheels spinning against sample.

Result : Sample ability to withstand abrasion behavior by measuring weight loss and microscopic inspection

Layers: Abrasive layer

Test Number: DITF-001 Vers.2
Name of Test: Rotary Platform Double Head Abraser With simulant

CHENOBI vs EAC-1



DITF -001 with simulant between sample and the wheel

Result: Microscopic investigation on the penetrated simulants

Layers: Abrasive layer

Test Number: DITF-008
Name of Test: Tumbler test

The samples are placed together in a glass with dust and tumbler. The glass is then inserted into the instrument and moved for a certain time.

Result: Microscopic investigation on the penetrated simulants

Layers: Complete stack (to evaluate the penetration level of simulants)

Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ7] Demonstrated bendability to 180° (for flexibility of astronaut movements, e. g. in knees and elbows).

Test Number: DITF-005
Name of Test: Cantilever (bending stiffness)

For this determination the sample, that lies between a supporting surface and a slider, is moved uninterrupted to a defined marking. Out of the “excess length” of the sample considering the mass per unit area, the stiffness in bending B is calculated in mN·cm2

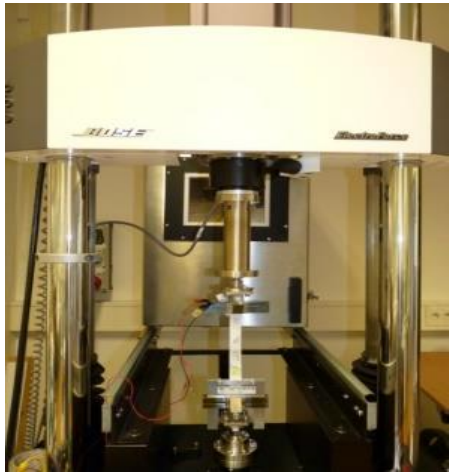
Result : Material ability to bend 180°

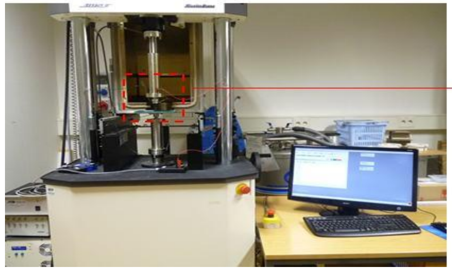
Layers: Individual layer and stack

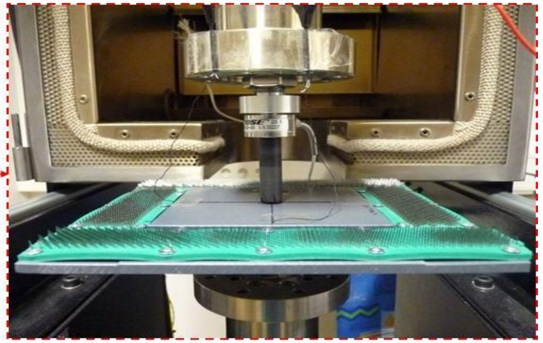
[RQ8] Demonstrated fatigue integrity over the expected suit life (120 cycles/hour, 2500 hours).

Test Number: DITF-003
Name of Test: Bose

To determine the value, the specimen is clamped in the tensile testing machine and pulled to fracture. Furthermore, a force drops over time can be determined by cyclic loading.







Result : 1)Materials ability to remain intact after 120cycles of the test and
2)Evaluation maximum fracture load.

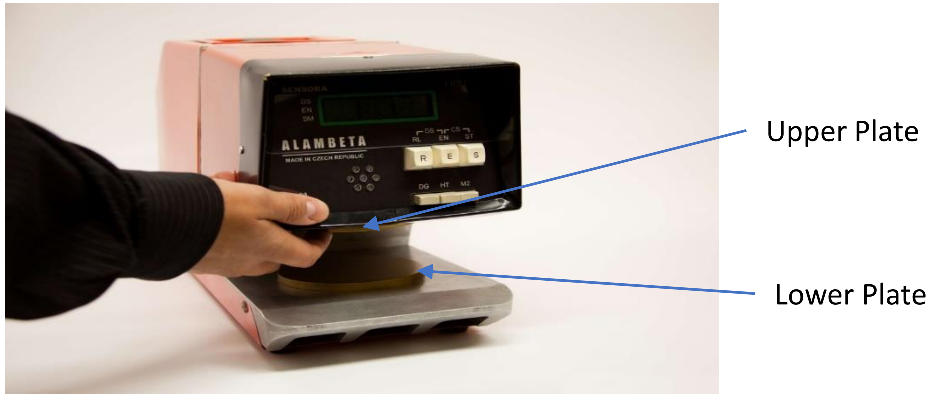
Layers: Individual layer and stack

Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ9] The material shall ensure thermal insulation for EVA activities under external environment defined in [RQ1-RQ3]. and targeted max. temperature 25°C inside (with minimum at 17°C).

Test Number: DITF-002
Name of Test: Alambeta Test



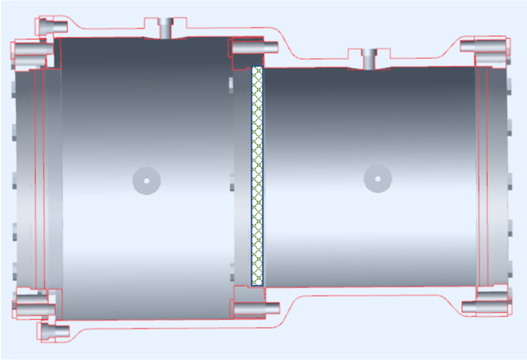
Test sample with a test area of 100 cm2 is placed on the lower plate of the measuring instrument. The upper heated plate (temperature difference 10 K or 40 K) is lowered and pressed with a measuring pressure of Press 2 cN/cm2 onto the test sample.

Result : Samples ability to maintain the inner layer temperature within 25°C.

Layers: Stack

The thermal conductivity in 10^{-3} [$Wm^{-1}K^{-1}$] and the thermal resistance in 10^{-3} [Km^2W^{-1}] are determined by temperature and heat flow sensors.

Test Number: COM-05
Name of Test: Thermal Insulation test



Repeating COM-03 with temperature sensor on the inner layer of the stack.
(Upper segment of the chamber is sealed from lower segment with the sample in the middle.

Result: Samples ability to maintain the inner layer temperature within 25°C.

Layers: Stack

Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ10] The material shall not off-gas toxic substances as per [AD6].

Test Number: COMEX-06
Name of Test: Off gassing Test

- 1 Primary pump (1)
- 1 Turbo molecular pump (TMP) (2)
- 1 Vacuum chamber (3)
- 1 Pressure Penning-sensor (4)
- Sampling with fixing brackets (5)
- 1 Thermal source (IR heating up to +125°C) (6)
- 2 temperature sensors in front and rear sample (7)
- RGA analyzer (8)

Emptying at <$1x10^{-5}$ mbar in order to degas each material until + 125 ° C during 24h.
RGA Analysis and sample weighing (TML)

Instrument: RGA Analyser (Monitoring of the partial pressure (in Torr) of 10 residual compounds)

Result : [Material shall have off gas level Carbon Monoxide level of less than 25 µg/g of material tested.
Layers: Single

Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ11] The material shall be non-flammable as per [AD7].

Test Number: DITF-004
Name of Test: Burning behavior

Screening Test 1: Upward propagation test

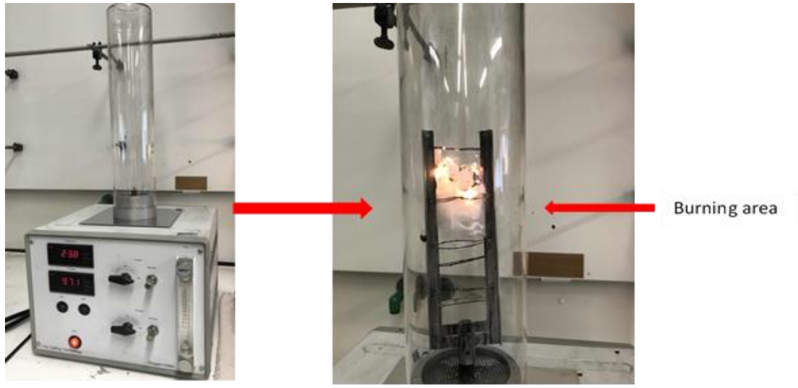
Ignition flame acts on a vertically applied fabric for a certain time. The flame propagation time =time in seconds that a flame takes to travel between the applied-characteristic cords.c

Result : a)The combustion zone propagates less than 150 mm into the sample within minimum use thick-ness and the time of burning does not exceed 10 minutes.
b)There shall be no sparking, sputtering, or dripping of flaming particles from the test sample

.

Layers: Single or Stack

Test Number : DITF-006
Name of Test: Limiting Oxygen Index



Screening Test 2: Standard test method for the determination of the oxygen concentration limit during the combustion of polymer materials

It is the minimum oxygen concentration of an oxygen-nitrogen mixture under which combustion continues under the test conditions

Result: The determination of the oxygen concentration limit (LOI shall be at least 28 following standard practice)

Layers: Individual and Stack

Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ12] Demonstrated dust mitigation strategy.

Test Number: DITF-008
Name of Test: Tumbler Test

Tumbler test followed by cleaned sample can be analyzed for optical changes / destruction. Determination of different binding mechanism?

Result : Test result and additional strategy development

Layers: Outer layer and stack (determining different binding mechanism)

B – Test Campaigns detailed by requirements

[RQ13] Demonstrated compatibility (limited degradation) with long-term storage for 2 years at a space station / habitat. Folding of the suit shall be taken into account.

Test Number: DITF-012
Name of Test: Ageing Chamber

The samples to be investigated are exposed to climatic cycles in order to simulate the temperature stress in an intensified way. Temperature and humidity can be selected comparable with the real stress. The desired acceleration can be achieved by tightening the conditions.

Define Temperature cycle + humidity levels + duration

Result : Material property remain intact

Layers: Stack

Task 3. Manufacture and testing of samples

B – Test Campaigns detailed by requirements

[RQ14] Demonstrated impermeability to water and fluids

Test Number: DITF-009
Name of Test: Air permeability

Test area

For the determination of the air permeability the sample is exposed to a drawing airstream. Depending of the materials permeability properties, a loss of pressure will be resulted when faced with the air-stream, which is measured as pressure difference

Result : Determination of air permeability on the sample

Layers: Only pressure retention layer

Test Number : DITF-010
Name of Test: Hydrostatic pressure test

Water droplets that penetrate the fabric

water pressure is judged against which the fabric is still tight with a defined constant pressure increase. The number of water drops penetrating the textile fabric depending on the time and pressure are considered.

Result: Determination of fluid permeability (determination at which pressure water bubbles are formed) on the sample

Layers: Individual

B – Test Campaigns detailed by requirements

[RQ14] extended basic test

Test Number: DITF-011
Name of Test: Ageing Chamber

A sample is clamped over a rubber membrane with a circular bell. The membrane with the sample is arched from below with steadily increasing air pressure. The pressure is increased until bursting of the sample is achieved.

Result : a) Pressures retention ability to withstand a min 2bar difference
b) Evaluation of samples bursting strength

Layers: Pressure retention layer and by individual layers

[A-RQ6] Test of the biological growth potential (for inner layers)

Test Number: OeWF-004
Name of Test: Biological Growth Test

Suggested tests

Quantitative tests

Textiles: A test of each potential suit material layer to evaluate the efficacy of each textile individually to repress microbial growth.

Layers: A test of the stacked layers arrangement of a suit material selection to understand how biocontamination propagates through the various suit layers;

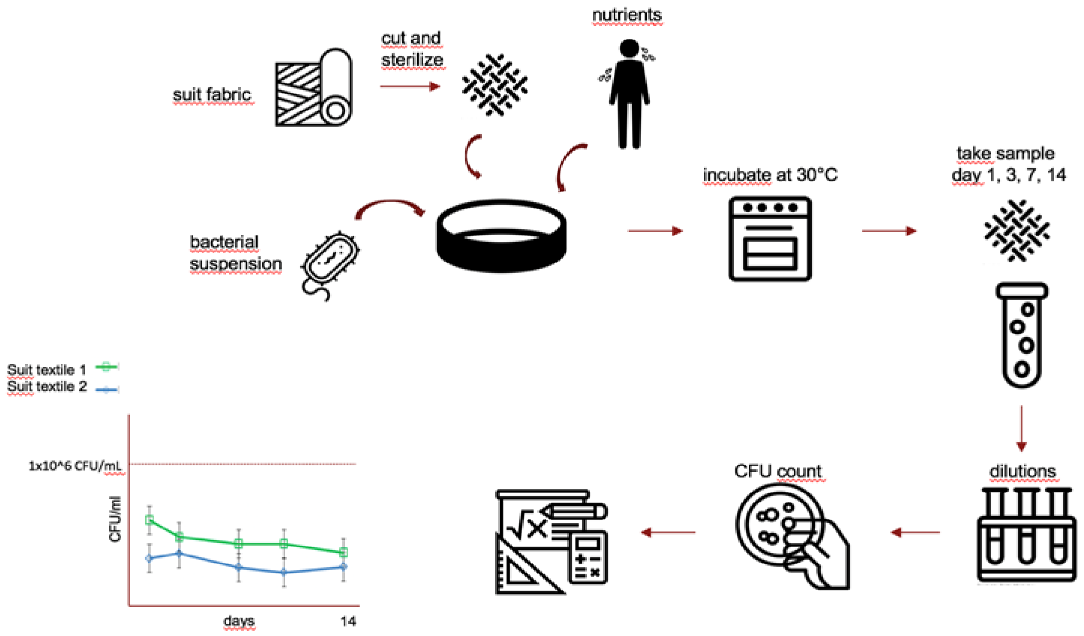
Cleaning: An efficacy test for the suppression of microbial growth by cleaning agents on each of the current suit bladder materials.

→ Absorption or quantitative methods provide values of antimicrobial activity based on the reduction of bacterial growth.

Qualitative tests

Easy qualitative test with agar diffusion or qualitative methods are simple to perform, quick and useful when a large number of samples have to be screened. These methods consist of placing the textile samples in contact with nutrient agar (NA) plates containing bacterial cells (Gao and Cranston 2008).

→ Qualitative methods to quickly test a big number of samples

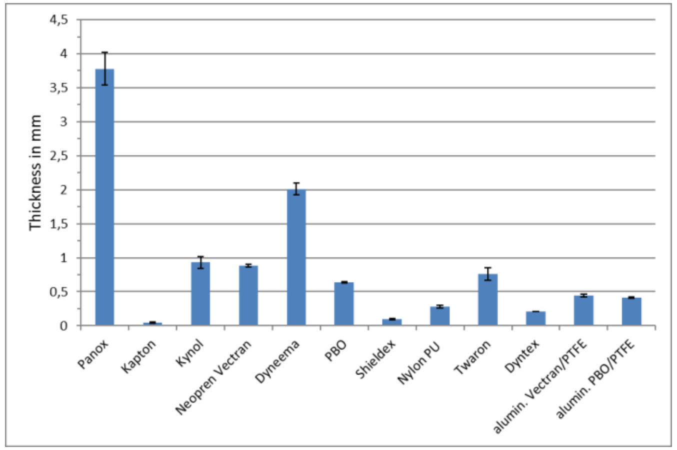


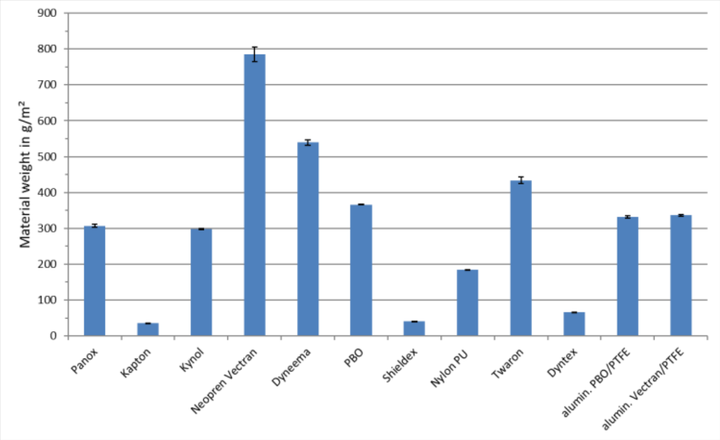
Task 4. Final recommendations

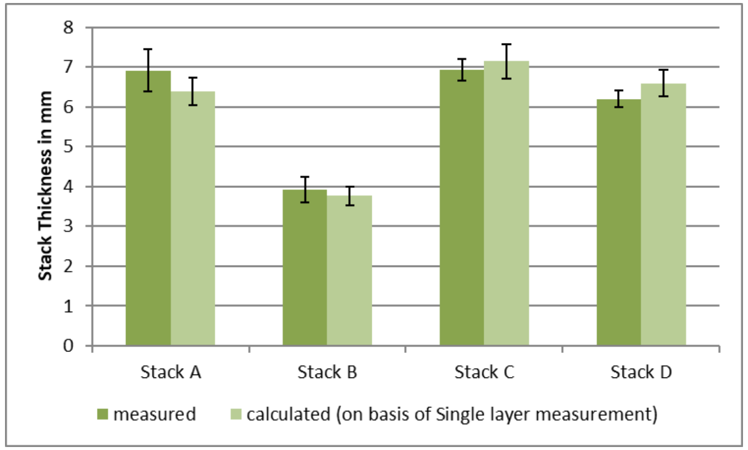
A – Post Data Analysis

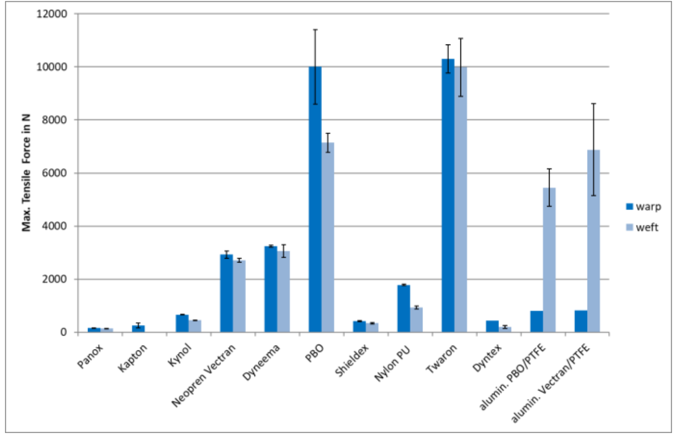
Basic Properties have been measured for all material :

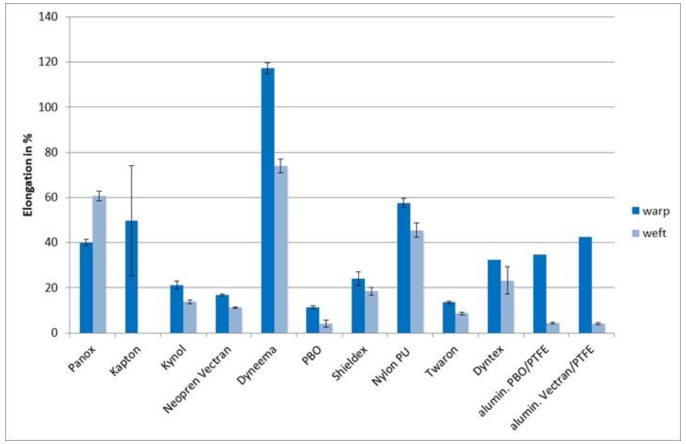
Thickness, mass, tensile test and bursting properties.

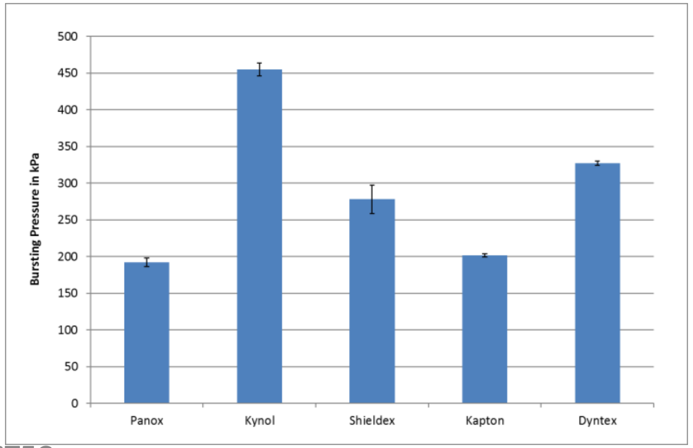












Task 4. Final recommendations

A – Post Data Analysis

<u>Material selected by consortium for a future spacesuit</u>

Depending on the properties targeted, we can select the best materials in consequences to create a stack.

Panox, Kapton, Dyneema and Twaron fit with the most requirements.

TEST	Panox	Kapton	Kynol	Neopran Vectran	Dyneema	PBO	Shieldex	Nylon PU	Twaron	Dyntex	alu. Vectran/PTFE	alu. PBO/PTFE
Basic properties												
RQ1 (temperature environment)												
RQ2 (radiation environment)												
RQ3 (vacuum environment)												
RQ4 (pressure-vacuum cycling)												
RQ5 (EMC and discharge protection)												
RQ6 (Resistance Regolith) /RQ12												
RQ7 (Bendability)												
RQ8 (Fatigue)												
RQ9 (Thermal conductivity)												
RQ10 (Thermal vacuum test)												
RQ11 (Flammability)												
RQ14 (impermeability)												
A-RQ4 (impact)												
A-RQ6 (Biological growth)												

Note: Dark green is used when the material is not the best for the requirement but has an interesting property.

Task 4. Final recommendations

A – Post Data Analysis

Consortium analysis and recommandations

It is clear that no combination of any two materials can meet all the requirements.
Hence stacking more materials together is expected to provide a more comprehensive coverage over all the requirements.
Several stacks are proposed based on the results of individual material test performance and expected compatibility between materials.

	Outermost Layer	Substructure				
Stack A	**Aluminized PBO/PTFE**	**5 x Kapton foil** aluminized	**Panox**	**Vectran** coated with neoprene	**PBO**	**Vectran** coated with neoprene
Stack B	**Aluminized Vectran/PTFE**	**Shieldex**	**Kynol**	**Dyneema**	**Nylon** coated with PU	
Stack C	**Twaron** coated ceramic	**5 x Kapton foil** aluminized	**Panox**	**Vectran** coated with neoprene	**PBO**	**Vectran** coated with neoprene
Stack D	**Dyntex**	**5 x Kapton foil** aluminized	**Panox**	**Vectran** coated with neoprene	**PBO**	**Vectran** coated with neoprene

Task 4. Final recommendations

A – Post Data Analysis

Stack conclusion

We have analyzed the results achieved on the different stacks.
However, it should be noted that it was not possible to perform each test on all the stacks.

- Stack C composed by Twaron, Kapton, Panox, Neopren Vectran and PBO seems to be the most promising stack.
- Stack A (Aluminized PBO/PTFE, Kapton, Panox, Neopren Vectran and PBO) is also a promising candidate which is not surprising since the only difference between the two stacks is the outermost layer (Aluminized PBO/PTFE for stack A and Twaron for the C).
- In stack C, we find Panox, Kapton and Twaron which are among the best materials studied individually, which could mean that the properties of each material do not necessarily deteriorate with stacking.

TEST	Stack A	Stack B	Stack C	Stack D
Basic properties (thickness)				
RQ2 (radiation environment)				
RQ6 (Resistance Regolith)				
RQ9 (Thermal conductivity)				
RQ11 (Flammability)				
RQ13 (storage)				
RQ14 (impermeability)		Not tested		
A-RQ4 (impact)			Not tested	Not tested

Task 4. Final recommendations

B – Roadmap development

Suggested actions for further development

➢ Material modification :

We have seen that some materials fit well with some requirements but not all. Maybe fabricants can improve some properties of these materials to fit with more requirements. To do so, space industry should for example take contact with industrials to explain their needs and ideas to their materials.

➢ Criteria modifications :

It would be interesting to define the different criteria of acceptation characteristics per characteristics. Indeed, there are not target values to validate a sample about each requirement. For example, to consider a sample as good performer in terms of max tensile strength, the comparison between selected materials is the focus. We additionally recommend determining a target value to reach. It is important to know if better materials are needed or if these materials are sufficient.

Task 4. Final recommendations

B – Roadmap development

Suggested actions for further development

➢ Test recommendations :

The needed further tests for another project could be remake or make differently in order to have additional interesting information.

- Bursting test : measurement range of test bench should be improved (e.g. hydraulic tester)
- Radiation – Material Fatigue : 50 Gy had no impact on most of the textiles ➔ higher dose for the next one
- Tensile test : to be adapted to allow measurements to be taken on the entire stack
- ESD test : Only Panox was tested. We have to carry this test for each material's behavior (isolative, dissipative and conductive).
- Tumbler Test : Kinking on some material could be prevented by optimizing the weaving process.
- Cantilever (bending stiffness) : The cantilever test is not suitable for stacks and coated materials. A bending test should be used that measures the force required to bend the material to a defined angle. The roll-up effect should be considered during sample preparation.
- Zwick (Bose) (buckling and tension) : fibers slipped out of the clamp, and as this test gives important information for two requirements (RQ1 and RQ8) so it could be interesting to find another way to fix these samples for a successful test.

Task 4. Final recommendations

B – Roadmap development

Suggested actions for further development

➢ Test recommendations :

The needed further tests for another project could be remake or make differently in order to have additional interesting information.

- Alambeta Test (thermal conductivity) : no benchmark values from existing space suits. An estimation of the heat transfer could help to interpret the values. Since DITF has no experience with the special conditions in a space suit and there are no comparable values found in the literature, a calculation of the temperature in the space suit was not possible.
- Air permeability : Erroneous measurements may be possible due to air leakage. For coatings and multi-layer tests, ensure exact clamping to reduce air leakage.
- Impact (cut) test : Stack C and D could not be measured because shortage of material.

It could be important to remake this test with missing stack especially with the stack C which seems the most promising.

- Biological growth : Kapton was damaged by the autoclaving procedure and showed surface alterations caused by microorganisms. In the case of any application, further tests are recommended by using different cutting methods to avoid fraying which has direct effect on water absorbance test results.

Task 4. Final recommendations

B – Roadmap development

Suggested actions for further development

- Material joining method :

There are various joining techniques such as welding, gluing and sewing. But which technique can be used depends on the one hand on the material and certainly also on the later application. An important note on the later joining technique: convex and concave surfaces such as sleeves can only be sewn. Gluing or welding is not possible here.

Conclusion: We can only try to treat the future stacks with suitable joining techniques. Afterwards, the result of the joining must be evaluated by suitable tests and it may be that different joining techniques are used for specific use of material stacks for specific areas on a potential suit level application. The DITF can support, depending on the requirements, with trials and tests. Details would have to be clarified in a potential follow-on activity.

Task 4. Final recommendations

B – Roadmap development

Suggested actions for further development

- Advanced test methods for long term technology maturation :

Two approaches are possible for future tests and each one has advantages and disadvantages:

- A stack is certainly always easier to test than an ergonomic demonstrator, which is certainly much larger. It is however unknown at this time as to scaling effects when increasing scale from coupons to ergonomic prototype of an EVA suit. The DITF can support here, depending on the requirements, with trials and tests for different stacking based test methods.
- Use of an ergonomic demonstrator, as we cannot estimate in where and which conditions within suit stack specimens will be exposed. On the other hand, integrated ergonomic test presents more information value and practical approach in relevant ergonomic scenarios such as human activity within lunar facility and/or analog mission. The OeWF can support here, depending on the requirements, with trials and tests. Use of an ergonomic prototype does not demonstrate the functionality of the EVA suit prototype in relevant space environments. Such a prototype would require a much higher level of manufacturing maturity of the stacked material options, which is likely many years in the future from today.

Further development of test methods would require input from EVA expert community, including NASA and ESA astronauts and other end-users of such products, to enable credible test requirements and test parameters.

xEMU and AxEMU last news (march 2023)

AxEMU textile (based upon the xEMU from previous work of NASA before entrusting the subject to Axiom) used are ortho fabrics of aromatic polyamid (paraaramid). These are materials such as kevlar, twaron (we used) or nomex. These are chemically the same, although we don't have information about the AxEMU weaving patterns.

can be found in published papers and results of those evaluations have been considered in the design of the EPG for the Artemis missions as detailed below. As previously stated, the xEMU is constrained to using heritage EPG materials for initial missions. Therefore, previous testing conducted on Ortho-Fabric, aluminized mylar insulation and neoprene coated nylon were of particular interest. Additionally, any testing done on surface coatings to enhance properties or a potential backer material that could be used behind the Ortho-Fabric as a dust barrier were keenly considered however no surface coatings will be incorporated into the DVT components. A few key takeaways relevant to the xEMU EPG design are summarized in this paper.

Over the past 25 years NASA has focused mainly on tumble testing as a means of simulating wear on the outer layer of the space suit fabrics. The tumble test method of abrading materials incorporates a large rotary drum tumbler with rocks and loose lunar simulant material to induce abrasion in fabric test layups to represent what might occur during long term planetary surface EVAs. Typically, test runs are eight hours long to simulate a worst-case EVA scenario. This method is preferred over standard abrasion test methods because it appears more representative of working in the lunar environment with the combination of particle sizes and contact forces. Tumble testing will be utilized for the down select of slip layer candidate materials.

In 1990, Joe Kosmo (NASA) used a tumbler test to screen five advanced suit materials[11]. After tumbling, the fabrics were inspected using SEM. Results were compared to an SEM of Alan Bean's Apollo 12 space suit. The result showed that Gore-Tex fabric with a 2 mil. FEP (Teflon) laminated back face out-performed the other four fabrics against abrasion. The other fabrics were Ortho-Fabric back face coated with 10 mil. Silicone, Gore-Tex front face laminated with 2 mil. FEP (Teflon) and Apollo Test Article Teflon (T162). Due to these results, Teflon will be considered for the slip layer in the EPG design.

In 2008, Glenn Research Center (GRC) developed a second method of evaluating fabrics for abrasion resistance to lunar dust. The objective was to develop a standardized set of procedures by which to compare the relative abrasion resistance of candidate EVA fabrics. Also included was a comparison to Alan Bean's Apollo 12 space suit. The final protocol was based on ASTM D 3884-01 with modifications to introduce loose lunar simulant onto the test apparatus. During development of the test protocol, GRC also evaluated several candidate EVA fabrics, including Apollo plain weave FEP, Apollo twill weave FEP, Ortho-Fabric, Tyvek, silicone coated Ortho-Fabric, silicone coated Kevlar, and silicone coated Vectran material. The final test protocol was only run on the latter four fabrics: Kevlar, silicone coated Ortho-Fabric, silicone coated Kevlar, and silicone coated Vectran. Results of the testing were documented in a test report, as well as published in a 2009 ICES paper (2009-01-2473)[12]. Out of the four fabrics tested using the final protocol, Tyvek reportedly performed the best, sustaining the least abrasive damage and blocking dust from penetrating the fabric. Therefore, Tyvek will be pursued as a candidate for the slip layer as well.

In 2009, a test methodology was developed for establishing comparative abrasion wear characteristics between various candidate space suit outer layer fabrics, characterizing the abrasive wear produced by two lunar simulants and evaluating the ability of heat-sealed seams to prevent dust migration through space suit components. The test incorporated a large rotary drum tumbler with rocks and loose lunar simulant material to induce abrasion, replicating what might be experienced on a long-term lunar EVA. Post-test visual inspections of the various test articles showed that three of the four candidate fabrics lost minimal strength after abrasion. The fabrics that performed well included Ortho-Fabric, the Gore-Tex 4 Harness Satin, and the Gore-Tex 3x1 Twill materials. One fabric, Tyvek, performed very poorly in comparison with the other candidate materials. However, it was difficult to characterize dust migration through the materials and the results were inconclusive[13]. It will be forward work for the EPG Team to determine why Tyvek tested well in 2008 but poorly in 2009 and will utilize that information to guide additional testing and characterization.

In 2014 an effort was undertaken by the High-Performance EVA Glove (HPEG) element of the Next Generation Life Support (NGLS) project to develop a lower cost testing method to evaluate material abrasion performance. Data was collected by visual inspections, pre- and post-test optical imaging and SEM, and un-abraded compared to abraded material strength measurements. Seven materials were tested: Ortho-Fabric, Super Fabric, Twaron, Silver Plated Ripstop Nylon, solution coated Vectran, Teflon and Coated Teflon. Ortho-Fabric demonstrated the highest tensile strength and least amount of elongation after exposure. Also noted was that dust migration through a TMG layup is difficult to evaluate with the proposed process and that the test process needs to be uniform throughout the entire series. Fabrics need to be cut in a consistent manner to ensure the same distribution of threads/materials throughout the samples. Ultimately it was concluded that this test method was found to tell only part of the story for space suit cover layer durability evaluation and should be combined with other tests such as cut resistance, puncture, tear, optical inspection, etc. to establish an overall material comparison benchmark[14]. As a result, the EPG Team will utilize these additional tests to characterize the EPG layup.

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International Conference on Environmental Systems

https://ttu-ir.tdl.org/bitstream/handle/2346/89783/ICES-2022-265.pdf?sequence=1&isAllowed=n

Question time !

THANK YOU!!!

PEXTex
Planetary Exploration Textiles