The PERSEO Project
PErsonal Radiation Shielding for intErplanetary missiOns

G. Baiocco *on behalf of the* **PERSEO** *collaboration*

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PERSEO is funded by the **Italian Space Agency (ASI)**, coordinated by the **University of Pavia** and involve scientists from **Thales Alenia Space – Italia**, **SMAT**, **AVIOTEC**, **ALTEC**, **University of Roma Tor Vergata**, **Kayser Italia** and **ARESCOSMO**. Full list of contributors is at the end of this presentation.

The *PERSEO* Project, *a brief "history" (not over yet…)*

- **UNIPV** and **TAS-I** participated to the Ariadna call for ideas by the European Space Agency - **ESA** on
  INNOVATIVE RADIATION SHIELDING APPROACHES
  proposing a material and design study for a wearable radiation protection spacesuit

Life Sciences in Space Research 15 (2017) 69–78

Contents lists available at ScienceDirect

Life Sciences in Space Research

journal homepage: www.elsevier.com/locate/lssr

ELSEVIER

Exploring innovative radiation shielding approaches in space: A material and design study for a wearable radiation protection spacesuit

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The PERSEO Project, *a brief "history" (not over yet…)*

- a consortium coordinated by **UNIPV** with **TAS-I, SMAT**, **AVIOTEC**, **ALTEC** and **Uni Roma Tor Vergata** participated to the call by the Italian Space Agency - **ASI** for experiments to be performed on board the International Space Station - **ISS** in the framework of NASA - ASI long duration missions

- **ASI** funded the design and realization of the first prototype of a wearable radiation protection garment, with embedded containers to be filled with water as shielding material, to be tested on board the ISS for practicality of use and wearability by the ESA astronaut Paolo Nespoli during Expedition 52/53 – mission VITA

- The **PERSEO** garment prototype has been successfully manufactured, launched and delivered to the ISS by SpX-12 Dragon. We are currently waiting for the planning of the experimental session on board.

Outline

GENERAL CONTEXT:

Possible risk scenarios for the use of the garment

The feasibility study funded by ESA:

- *Selection of the radiation environment*
- *Simulation environment*
- *Material study - with 1D simulations*
- *Selection of the phantom for 3D simulations and validation*
- *Development of suit models*
- *3D simulation setups*
- *Results*

The realization of the PERSEO prototype for the ASI Experiment

- *Preliminary conception scheme*
- *Selection of materials and suppliers for the manufacturing*
- *Configuration for launch*
- *The flexible water container - a parallel experiment by TAS-I*
- *Summary of on-board operations*
- *Experimental validation of the shielding strategy*
- *PERSEO - perspectives for deep-space exploration missions*

Possible risk scenarios for the use of the garment

- the prototype is designed to be worn during **Intra Vehicular Activities - IVA** in the **space habitat**
- during a **Solar Particle Event - SPE**, astronauts are required to stay confined in a **radiation shelter**
- duration of the SPE: hours to days
- need of **direct interventions** of the **astronauts** during the SPE

  (e.g. to re-start electronics because of failures possibly due to the SPE itself)
- astronauts **obliged to leave the shelter**
- outside the shelter and during the SPE:
  1. dose rates high enough so that permissible **short term dose limits** are rapidly reached
  2. onset of **symptoms of radiation sickness**

NECESSITY

to explore shielding strategies **complementary to** the design of **radiation shelters** (and to habitat shielding), oriented towards **personal radiation protection**, as e.g. wearable shielding spacesuits.

GOAL

a **radiation protection garment** could allow to stay **outside the radiation shelter for a longer time,** keeping exposure below permissible limits and preventing immediate health consequences

OPTIMIZATION AS DRIVER

Exploitation of **resources already available in the space habitat**, or even of **waste materials**

avoids the logistic and cost constraints associated with the need of extra material solely for shielding

ThalesAlenia Space
a Thales / Leonardo company

UNIVERSITÀ DI PAVIA

The feasibility study funded by ESA

Material candidates:

→ **water, organic wastes** and their derivatives

→ coupled to **materials already in use in space**

• *Selection of the radiation environment*

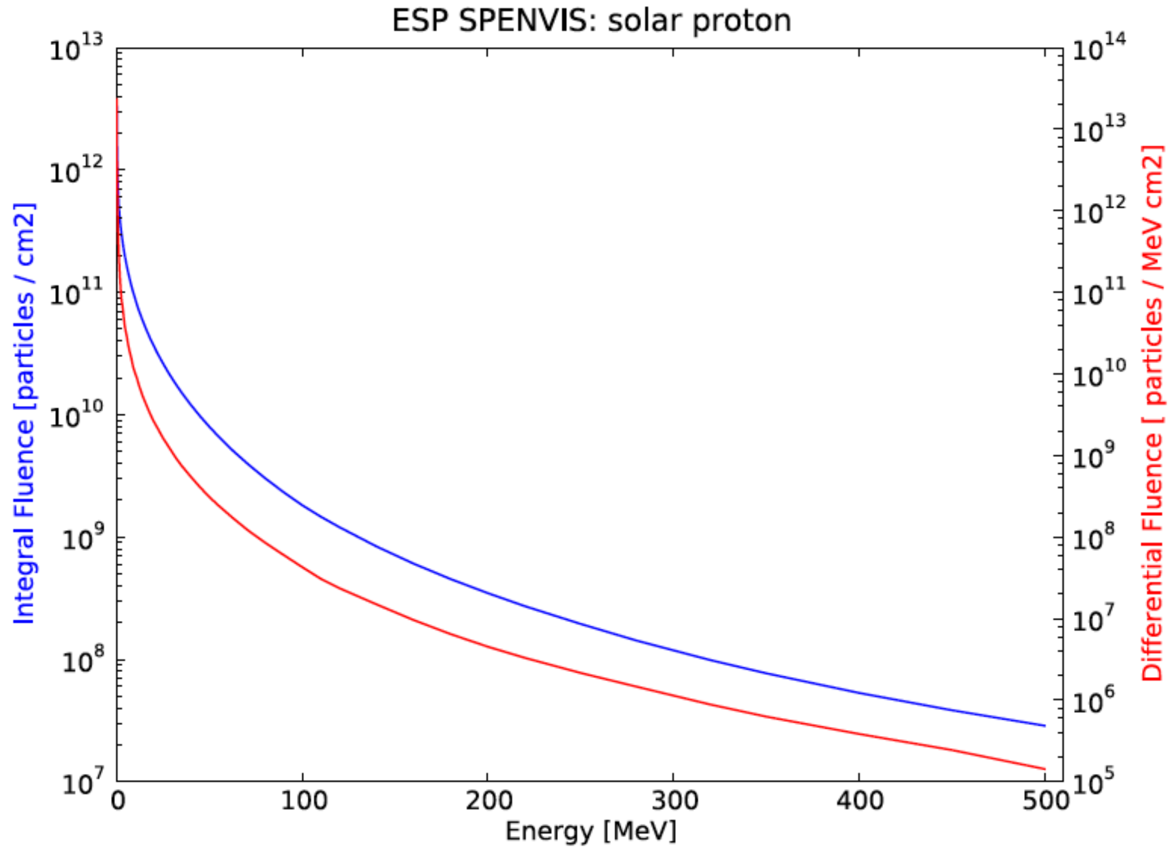


Fig. 1. Energy differential fluence (particles/cm^2/MeV) and integral fluence (particles/cm^2) used in this work for solar protons in a SPE, as obtained with the ESP model from the ESA SPENVIS website, with a 90% confidence level for a 1 year mission without considering the Earth magnetic shielding (SPENVIS).

+ further normalization to a worst hour flux using OMERE (ONERA) yielding 1.3 10^{11} protons/cm^2/hour

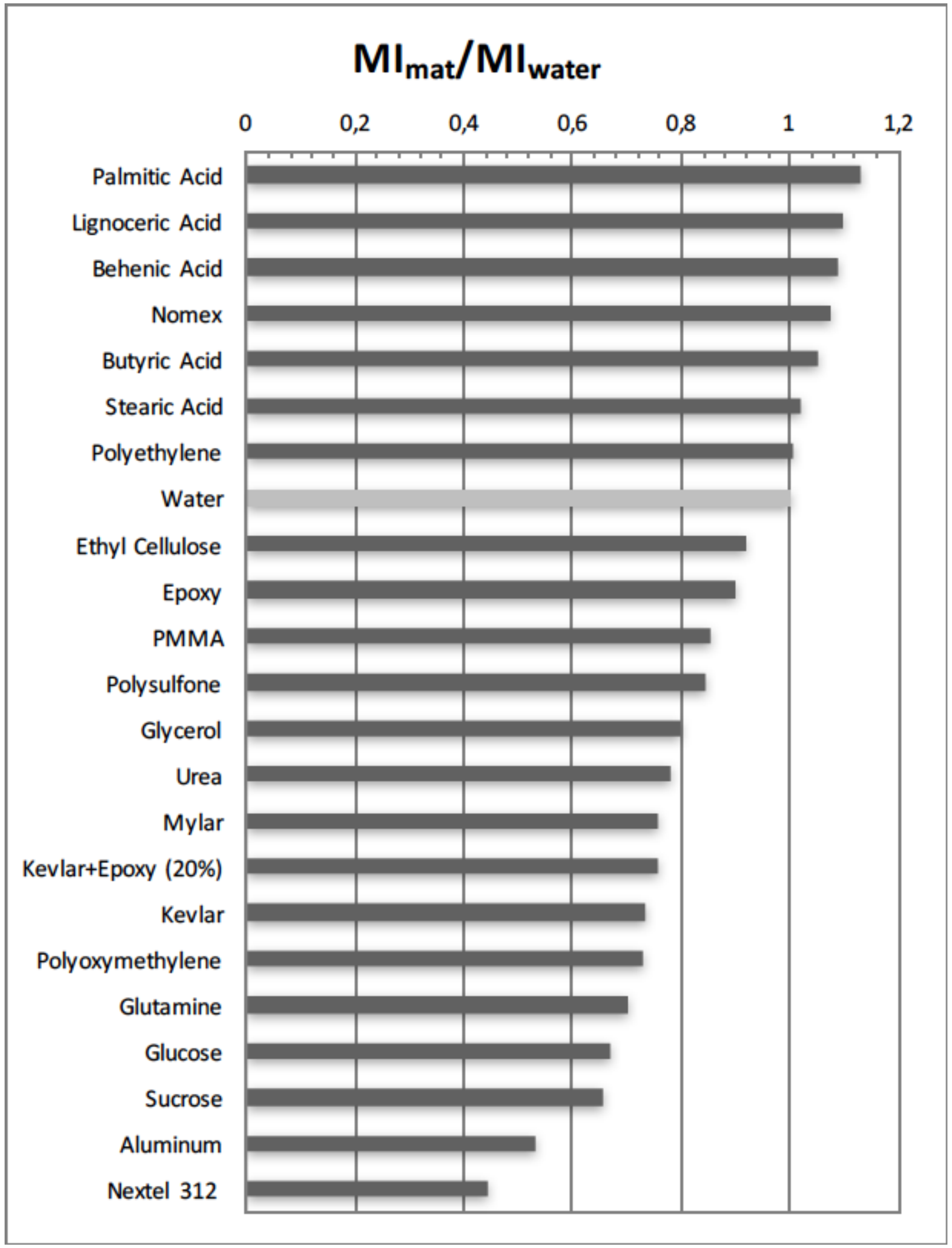
• *Simulation environment*

GRASv3.3 code (Geant4 Radiation Analysis in Space), based on Geant4.9.6.p03.

Physics list QBBC suggested by SPENVIS (ESA's Space Environment Information System).

QBBC includes BIC (Binary Ion Cascade), BIC-Ion, BERT (Bertini), CHIPS (CHiral Invariant Phase Spase), QGSP (Quark-Gluon String Precompound) and FTFP (Fritiof Precompound) models.

• *Material Study*



Ranking of materials based on their **Material Index (MI)** (norm. to water MI)

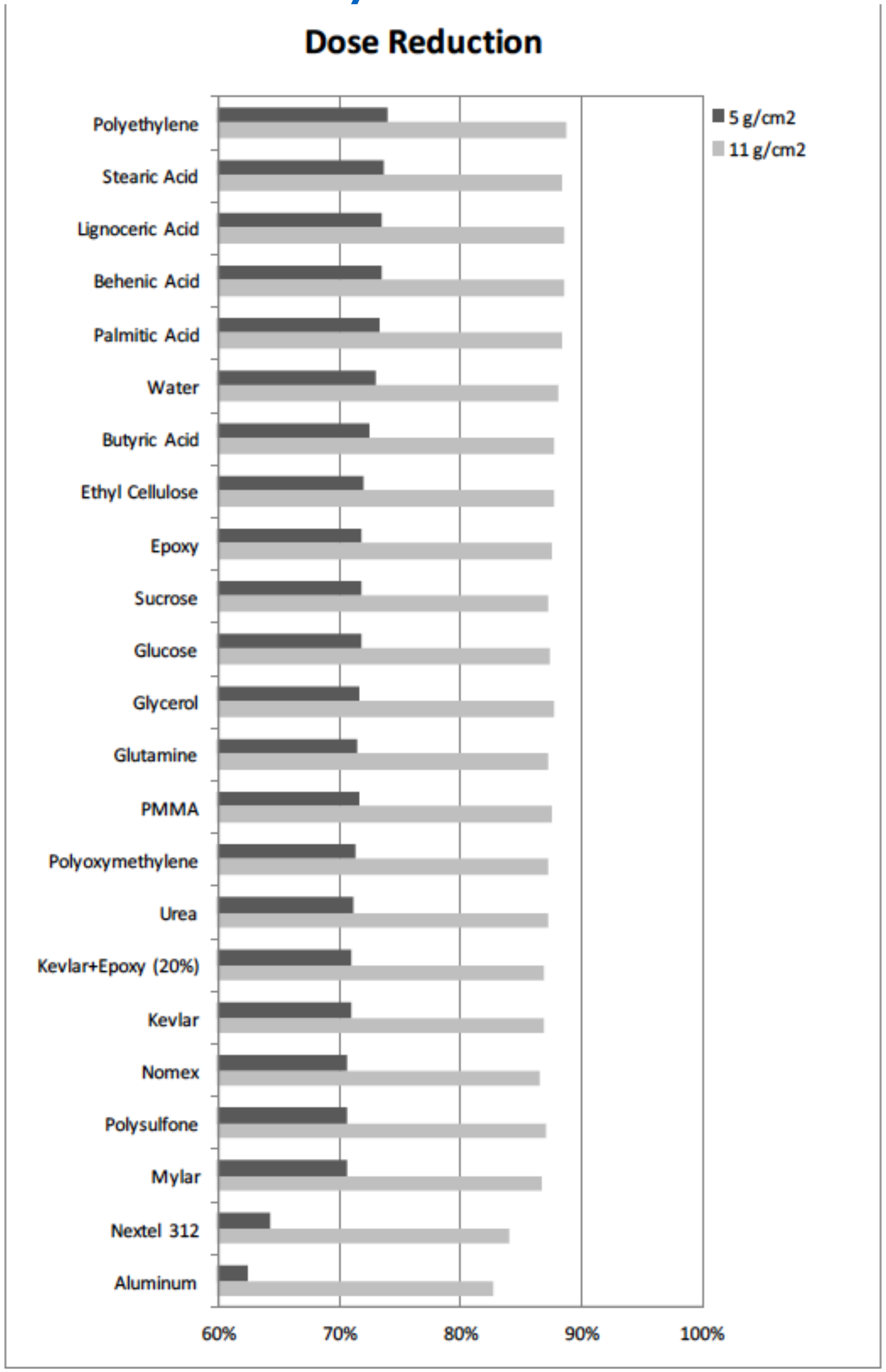
$$MI = Z\ A^{-2/3} \rho^{-1}$$

defined as the ratio of ***electronic stopping power*** to ***nuclear interaction trasmission***

$$\mathrm{MI} = \frac{\rho^{-1}\ Z\ A^{-1}}{\sigma\ A^{-1}}$$

with $\sigma \sim A^{2/3}$

• *Material Study with 1D-simulations*



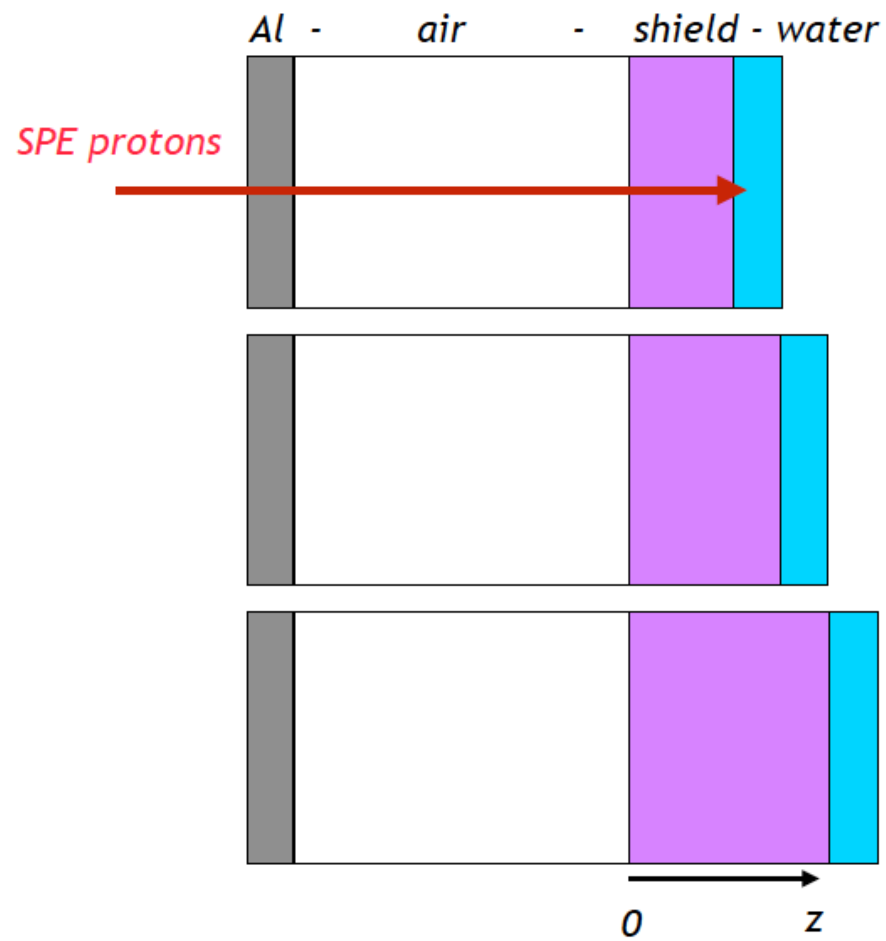
Comparison at fixed reference values of 5 and 11 g/cm^2

Ranking of materials based on

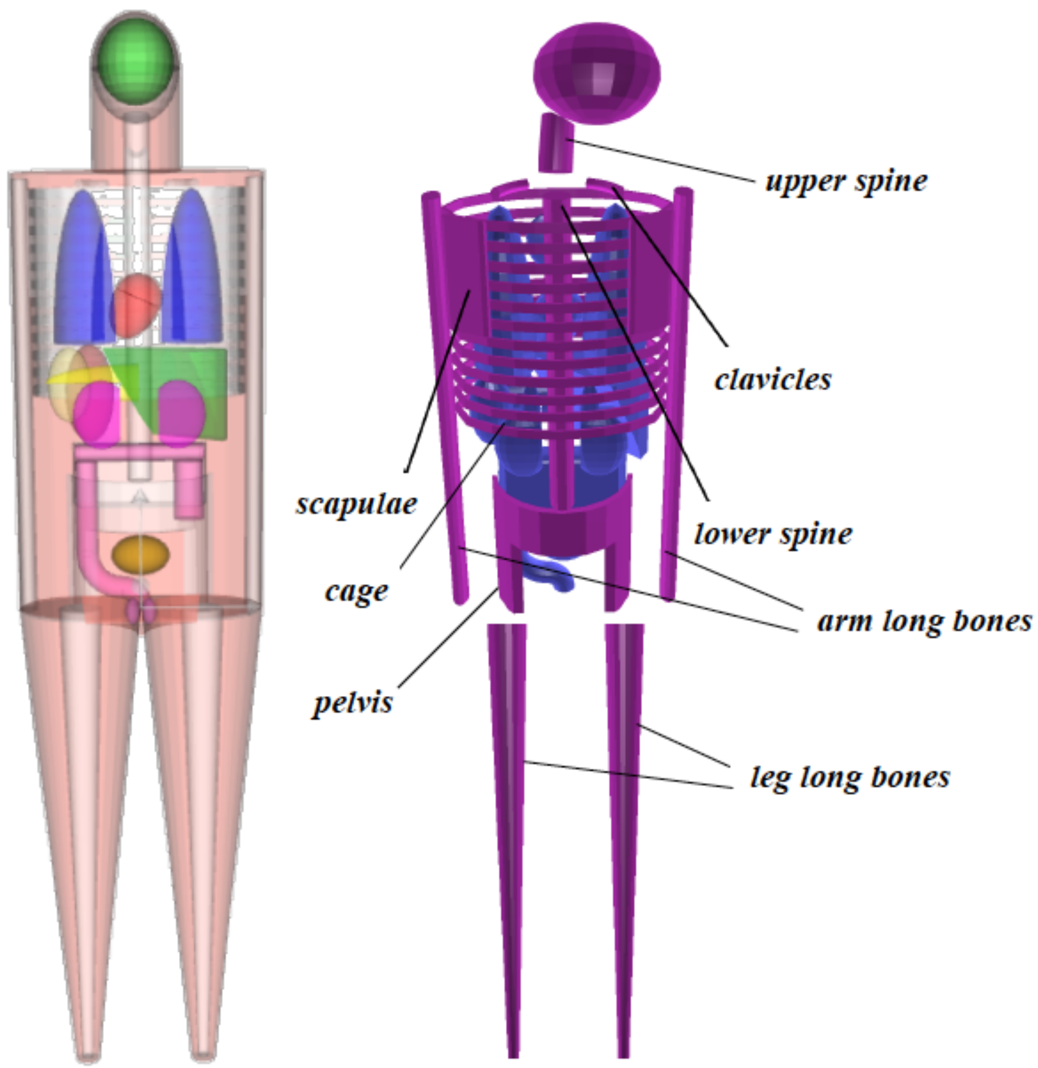
Dose reduction in a water phantom

after increasing

areal density of shielding



• *Selection of the phantom for 3D simulations*



Bone	$mass_i$ [kg]	rbm_i [kg]	rbm_i / $mass_i$ [%]
Upper spine	0.19	0.05	25.8%
Lower spine*	1.12	0.36	32.2%
Pelvis	0.91	0.17	19.0%
Leg bone (left/right)**	2.08	0.01	0.3%
Arm bone (left/right)**	1.22	0.03	2.6%
Scapula (left/right)	0.15	0.01	4.0%
Clavicle (left/right)	0.02	0.00	4.7%
Cage***	0.89	0.21	23.6%

GRAS phantom and RBM weights to bones from ICRP110

Evaluation of shielding performance based on
Dose reduction
to Blood Forming Organs - BFO

Indicator chosen taking into account the proportion of **Red Bone Marrow - RBM** in different bones

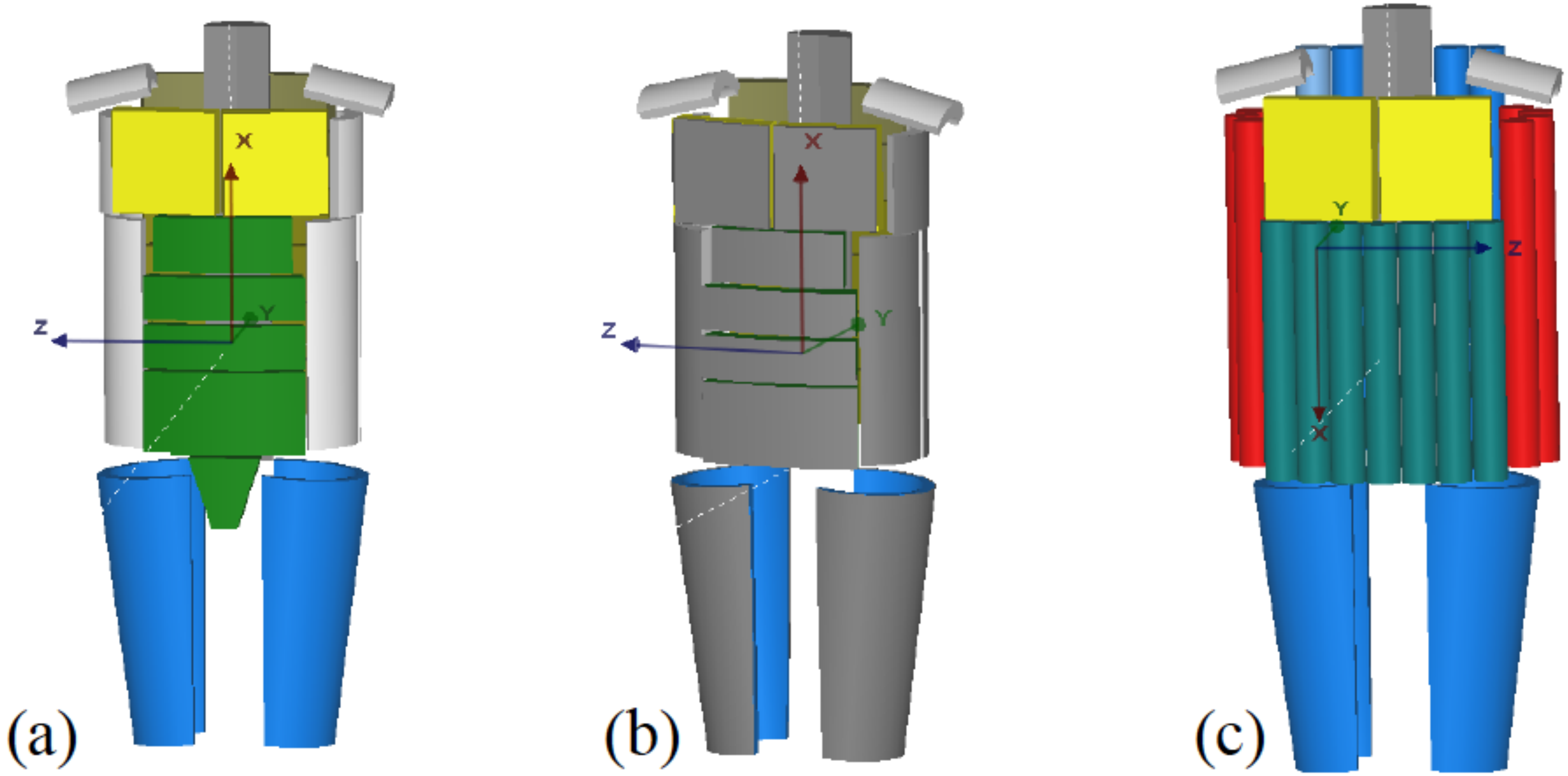
$$Dose_{\ BFO-rbm} = \frac{\sum rbm_i D_i}{\sum rbm_i}$$

Physical dose (Gy)
multiplied by **proton RBE = 1.5**
for **short term effects**
to obtain dose in **Gy-Eq**

• *Development of suit models*

GDML geometry of suit models under investigation

SUIT 1	*SUIT 1-ML*	*SUIT 2*
Ideal WATER elements only	*Multi-Layer elements with WATER content*	*"inflatable" WATER elements*



TOTAL MASS : 35 kg

MASS :
38.1 (Al) 37 (HDPE) 38.3 (kevlar) Kg

TOTAL MASS : 42.6 kg

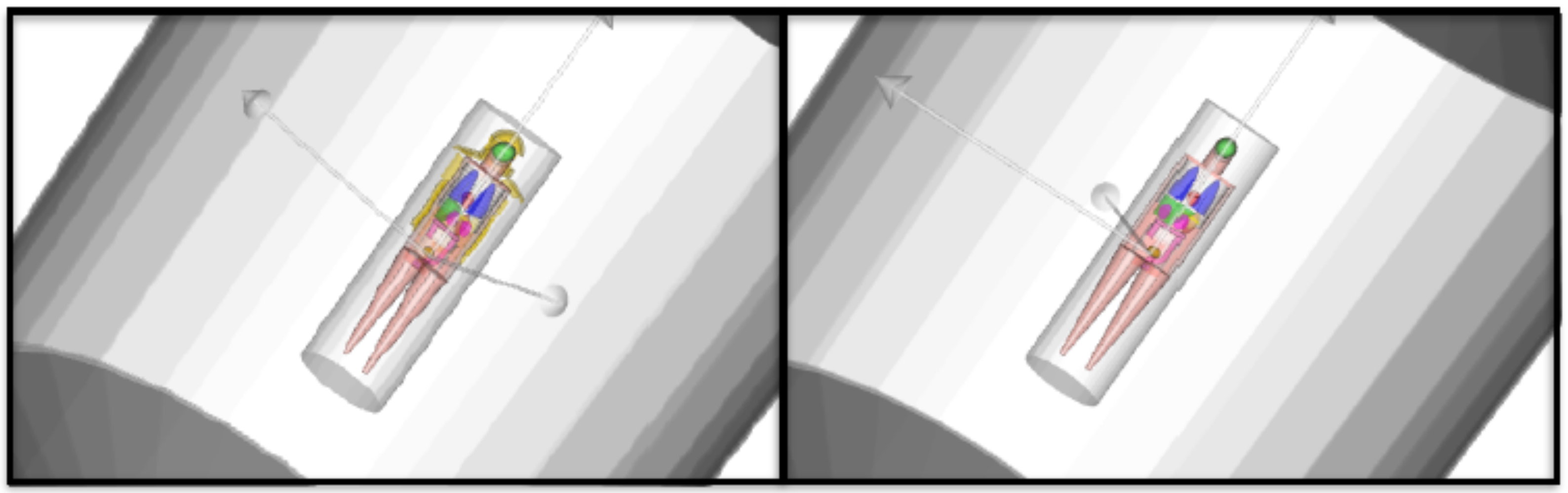
Plaques and horizontal bars on the front (**4cm**), horizontal bars (**4cm**) and a vertical protection for the spine on the back (semicircular in shape, **6cm**), lateral and shoulder protections (**3cm**), legs (**2cm**)

Plaques (**4cm**) and vertical (from **4** to **6cm**), **2cm** on the legs

• *3D simulation setups*

Module (1.5 Al thickness) in isotropic SPE radiation environment

IVA scenario



phantom with suit in module ***phantom w/o suit in module***

Dose reduction to BFO

$$Dose\ Red\ \% = \frac{Dose_{\text{Phantom in module}} - Dose_{\text{Phantom with suit in module}}}{Dose_{\text{Phantom in module}}}$$

- Main results given as percentage of dose reduction
  independent on specific characteristics of the SPE event as its fluence
- Results for phantom wearing the garment in free space are also included in the paper, but intended to be purely indicative as no realistic element of a EVA suit is modeled

- *Results*

Table 3

IVA case results summary: dose (Gy-Eq/h, corresponding to absorbed dose in Gy/h multiplied by 1.5) and dose equivalent (Sv/h) rates to the BFO for the phantom with/without the suit and corresponding dose/dose equivalent reduction, for each suit model.

Suit Model	IVA					
	Suit		NO Suit		Dose red.	Dose Eq. red. (*)
	Dose [Gy-Eq/h]	Dose Eq. [Sv/h]	Dose [Gy-Eq/h]	Dose Eq. [Sv/h]	%	%
Suit 1	0.047	0.047	0.099	0.096	52%	51%
Suit 1ML HDPE	0.042	0.041	0.099	0.096	57%	57%
Suit 1ML Al	0.056	0.052	0.099	0.096	44%	45%
Suit 1ML Kevlar	0.051	0.052	0.099	0.096	48%	46%
Suit 2	0.047	0.046	0.099	0.096	52%	52%

"Dose Reduction"
when wearing different suit models
for IVA during the SPE

(*) comparing results in Gy-Eq and results in Sv from GRAS (Q(L) from ICRP60) we obtain <Q>~1.5

"Safe hours"
before reaching the
short term limits for acute effects to the BFO
set by NASA at **0.25 Gy-Eq**
and **"time gain"** when wearing the suit

Table 4

"Safe hours" in space during solar proton events, for IVA outside a radiation shelter. Details in the text.

Suit Model	IVA		
	Suit "safe hours"	NO Suit "safe hours"	Time gain %
Suit 1	5.3	2.5	109%
Suit 1 ML HDPE	5.9	2.5	134%
Suit 1 ML Al	4.5	2.5	77%
Suit 1 ML Kevlar	4.9	2.5	93%
Suit 2	5.3	2.5	110%

The realization of the PERSEO prototype for the ASI Experiment

- a technological demonstrator had to be manufactured in compliance with:
  1. all **requirements for use on board the ISS**
  2. given **limitations in terms of resources** made available to the space agency:
     payload mass, payload volume, crew time for operations

- we proposed a design and an experimental session based on a prototype:

1. to be **filled with water on board** and later **drained after use**

2. to be **worn by the astronaut** while performing simple activities

thus obtaining results on:

PRACTICALITY
of the system in terms
of chosen interfaces for filling/draining

VALIDATION
of the possibility of using
on board water
as **shielding material** and
make it available for re-use after

WEARABILITY
of the garment in terms
of **comfort,**
possible **hindering of movements,**
ease to move (control)
with augmented inertial mass

The realization of the PERSEO prototype for the ASI Experiment

Starting consideration:
design such that a desired thickness of water is reached, to protect astronauts' most radiosensitive organs
→ a **sleeveless garment** is easier to be worn and handled, allows frontal protection of the chest and the belly and protection of the back and helps in staying within constraints on available resources

Interfaces for **filling and draining** on board the ISS were indicated by NASA

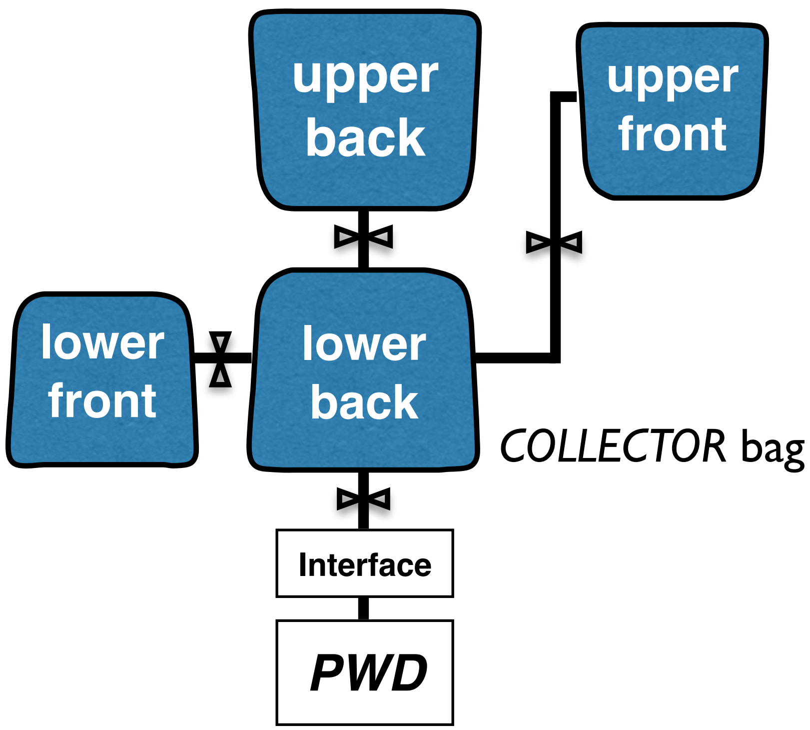
- **FILLING** - Aux port of the Potable Water Dispenser - PWD (not standard for payload operations!) through a dedicated hose with adapter and a QD interface
- **DRAINING** - High Flow Transfer pump to the waste water system

1. to optimize the filling/draining session, the prototype has been designed **to be filled/drained from a single interface**
2. the water containing system has to be manufactured with **safety margins** applied to the **max design pressure of the water dispenser** for being **filled without rupture or leak**
3. **leak of water** represents a **hazard** of varying entity depending on the water quantity
   e.g. more than 1 gallon of water represent a catastrophic (!) hazard

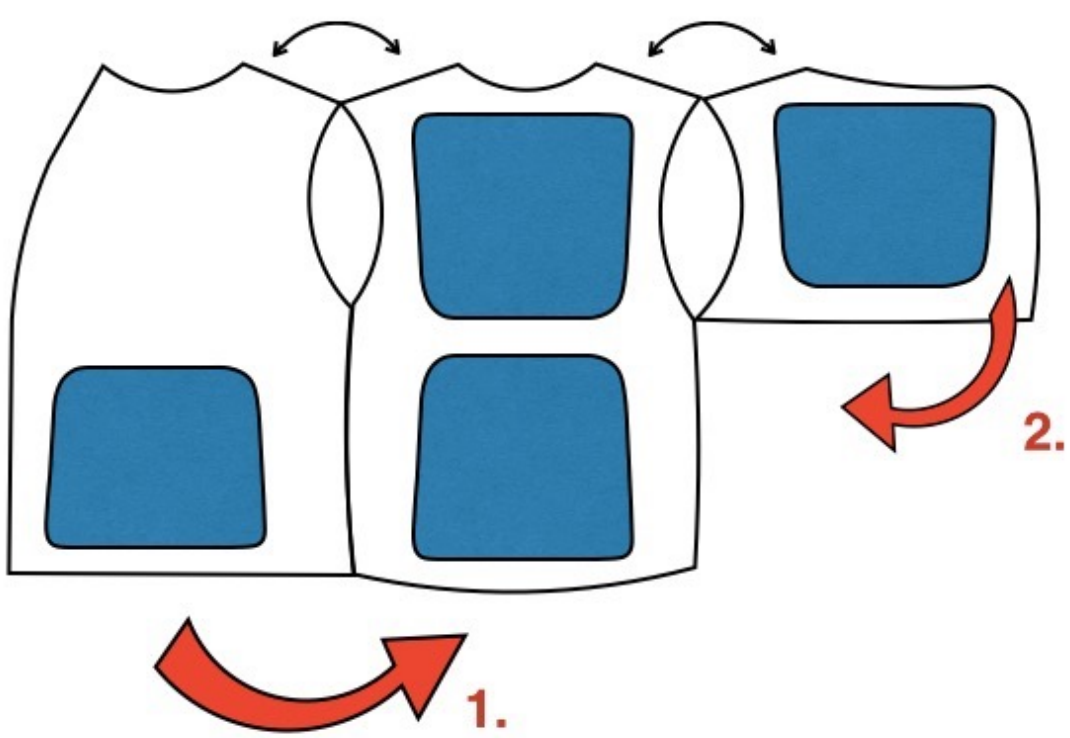
THE PROPOSED SOLUTION

→ a **sleeveless garment** with **pouches** to accomodate a system of **4 water containers** of chosen thickness **interconnected** via pipes, allowing the containers to be placed at **appropriate positions on the astronaut's body** and the **amount of water to be split to mitigate hazard**

• *Preliminary conception scheme*



container system with circuitry

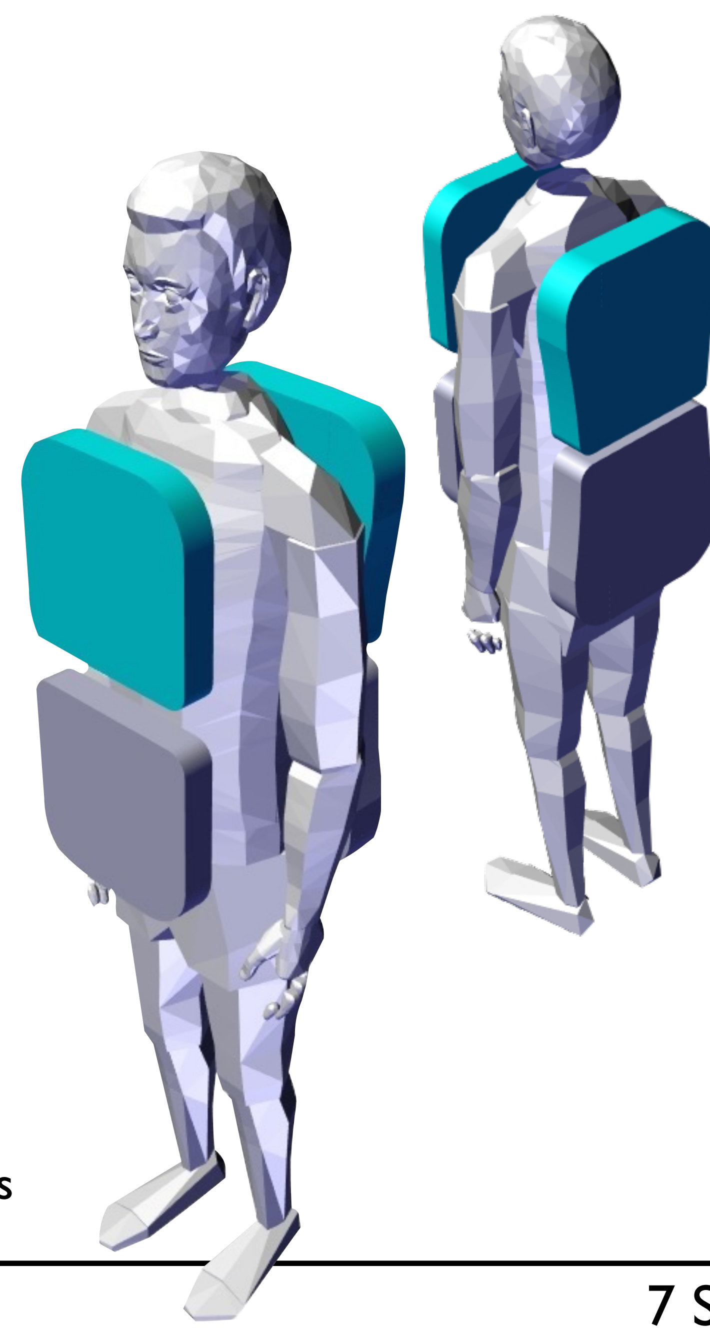


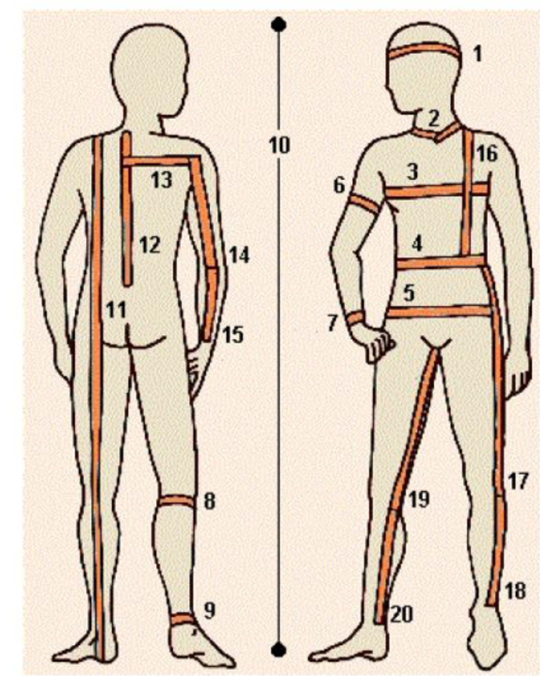
sketch of the garment with positioning of the containers

Desired thickness of 5 to 7 cm

Lateral dimensions

tailored on *anthropometric measurements* taken in a dedicated baseline data collection during a meeting with P. Nespoli

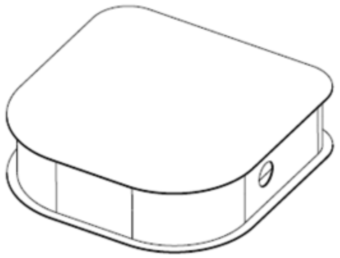




• *Selection of materials and suppliers for the manufacturing*

- **ARESCOSMO** manufactured **water containers**, CORETECH®
  ~ 26 x 26 cm frontal ones (~ 3.9 liters), 36 x 36 cm back ones (~ 7.5 liters), thickness ~ 7 cm
  3 of them with a single interface for connection to the "*COLLECTOR*" bag,
  collector bag (→|←PWD), with three interfaces to connect the 3

tested with safety margins applied to the PWD MDP, up to 24 psig (~1.6 barg) without showing rupture or collapse



drawing of the single bag
and system of the 4 interconnected bags
under vacuum

- Commercially available **pipes and valves** to interconnect the bags and isolate the water amount in each when valves are closed
- Max water allowance of the system: **22.8 liters**
- The system bags + interconnecting pipes has been designed so that the **garment** can be **folded at launch** to shape its volume and adapt it to stowage in the carrier
- Test of **material compatibility** with **iodinated water (SMAT)**
- Verification of standards on **cleanliness** for water after use for filling (**TAS-I**)

• *Selection of materials and suppliers for the manufacturing*

- **AVIOTEC** manufactured the **garment**, NOMEX®, pouches for water containers, closed with velcro straps to allow for container inspection, pockets for pipes, valves and QD, velcro straps to be adjusted for wearing

Garment with embedded containers, view of the inside (top) and outside (bottom)

Pouch opened uncovering a bag

Donning of the garment

• *Configuration for launch*

- **containers vacuumed**, **garment folded** and inserted in a *ad-hoc* manufactured **NOMEX transport bag**

final dimensions of the payload ~ 60 x 50 x 25 cm, ~ 75 liters, ~ 5 kg

• *The flexible water container - a parallel experiment by TAS-I*

- the transport bag also contains a dedicated pocket for a **flexible water container** that is **launched filled with potable water**. At return, **water analysis** will confirm if the material the container is made of is able to keep water potable.
  The material is undergoing patenting by TAS-I.

• *Summary of on-board operations*

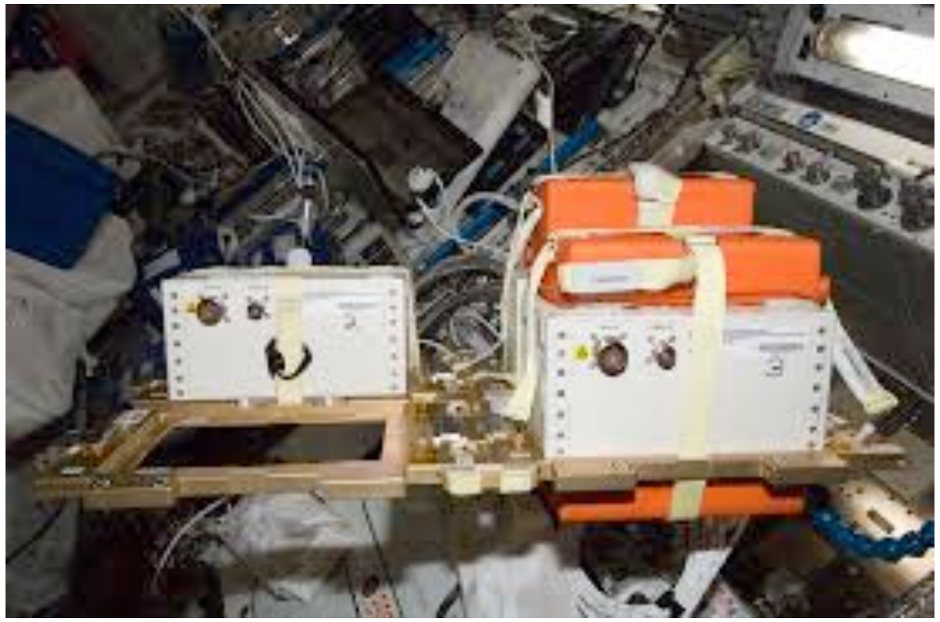
Operations will take place in the US Lab

- retrieve the transport bag and unpack the garment
- inspect the payload for go/no-go (e.g. check vacuum condition of the bag)
- connect to PWD
- fill with ~22L of water (telemetry controls the quantity, crew monitors fill)
  *expected fill time of ~ **30 minutes***
- disconnect after filling
- inspect for any leaks
- don garment - video recording and picture
  *garment is worn **for about 30 minutes***
- complete a questionnaire with feedback on the session
- perform nominal tasks within the area
- doff garment
- connect to WPA Waste Water Tank for draining
- verify bags are empty and stow back in the bag

• *Experimental validation of the shielding strategy*

A coupled **PERSEO / ALTEA-LIDAL** (**Uni Roma Tor Vergata**) experimental session is foreseen to evaluate the **efficacy of the shielding** offered by the PERSEO garment

Measurement setup and conditions still TBD



• *PERSEO - perspectives for deep-space exploration missions*

A successful outcome of the experimental session and a positive feedback from P. Nespoli will:

- validate the **strategy of personal shielding against SPE** using **wearable water-filled devices**
- open the way for **refining the design** of the garment, based on feedbacks and optimization thus e.g. achieving a more ergonomic water distribution
- open the way for **designing new devices** (e.g. sleeping bags, water walls for crew quarter…), based on the same principles, also exploring the use of other shielding materials

A successful outcome of water analysis at the return of the flexible container will:

- open the way for adoption of the same material for **shielding devices able to stow water keeping it potable**

From the movie DUNE - D. Lynch, 1984, based on the book by F. Herbert, 1965

• *PERSEO - perspectives for deep-space exploration missions*

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- open the way for adoption of the same material for **shielding devices able to stow water keeping it potable**

Dragon carrying the PERSEO payload and flying over Italy while approaching ISS…

…stay tuned

for the experimental session on board!

PERSEO Collaboration

the PERSEO patch
is designed by
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http://radbiophys.unipv.eu/

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