EXECUTIVE SUMMARY REPORT

From: CREATHES

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To: THE EUROPEAN SPACE AGENCY (ESA)

The European Space Research and Technology Centre (ESTEC),
Keplerlaan 1,
2201 AZ Noordwijk,
The Netherlands,

Subject: ITT AO/1-8252/15/NL/PA
Title: Evaluation Study of Micro and Nano-Encapsulation Technologies for Crew Health, Wellbeing and Life Support

Category: ESA Express Procurement – EXPRO/EXPRO+
Our ref.: ESA contract N.4000115456

CONTEXT

Funded by the European Space Agency (ESA) through its General Studies Programme (GSP) (www.esa.int/gsp), this activity aimed to provide more insights on the possible space applications of micro- and nanoencapsulation (MNE) techniques and technologies. NASA performed some early studies[3,4] in the international space station (ISS) with aim to assess whether new drugs could be produced under a microgravity environment. However, the study of MNE in the space context remained primarily limited to these few experiments.

While high-level needs are well identified in terms of astronaut's health (e.g. countermeasures, drug delivery) and life support (e.g. food taste, cleanliness, odours management, bio-active component protection), yet micro and nanoencapsulation-based technologies have not been assessed to bring a solution to some of the needs specified above.

The overall objective of this GSP study was therefore to assess the potentials of MNE for this targeted subset of space applications namely "Astronaut's Health, Wellbeing and Life Support" and detect promising routes for future related activities.

Three main tasks were carried out during this 10-month project, with the following main objectives:
- To review the state of the art of MNE for the possible applications identified,
- To define requirements and use cases,
- To update these requirements after consultation of experts during the technical workshop,
- To produce a roadmap and define strategy to reach the objectives on different time scale,
- To select 2 promising applications and propose R&D projects grounds for these concepts.

The project was carried out by a consortium led by CREATHES (FR), with MEDES (FR) as a subcontractor.

[3] NASA webpage:
http://www.nasa.gov/mission_pages/station/research/experiments/277.html, 2017
[4] NASA webpage:
http://www.nasa.gov/mission_pages/station/research/benefits/cancer_treatment.html, 2012

SUMMARY OF THE STUDY

Following ESA's statement of work, the project was divided into 3 main work packages.

The literature review about Astronaut's Health, Wellbeing and Life Support on both MNE and space aspects, allowed to identify a very large State-of-the-Art (SoA) as several potential work areas and products exists on Earth.

Based on this review work, a Technical Meeting was organized with a number of selected experts representing all the identified work areas. The aims of this technical meeting were:

- to define if the topic/use case presents real interest for ESA,
- to identify terrestrial constraints regarding to current state-of-the-art and compare them to space constraints,
- to evaluate the development and the work still to be done to extrapolate existing solutions to space.

This meeting was conducted as a fully interactive brainstorming and discussion session between ESA, the selected experts and the consortium in charge of the project. It allowed the identification and prioritization of 10 potential topics of interests for ESA as well as possible technological concepts.

Preliminary roadmaps were built for each of them and 2 projects were selected:

- **MNE of microorganisms for bioregenerative LSS**
- **Optimization of protein assimilation after intake**

Based on the outcomes and previous tasks, CREATHES prepared the ground for these 2 dedicated R&D projects involving MNE.

MAIN RESULTS

WP1 – BACKGROUND ANALYSIS

During WP1, the literature review allowed to identify several potential work areas and existing SoA on Earth, regarding the following topics:

- Side effect limitations of pharmaceutical countermeasure by dose reduction or by administration way change,
- Assimilation improvement of nutritional compounds against muscle loss for example,
- Reduce skin diseases or skin sensibility due to dehydration, or improve wound healing process,
- Reduction of intestinal disorders due to space conditions,
- Improved control of the biocontamination with benefit to personal hygiene or surface cleaning,
- Food preservation,
- Food taste and food cooking in space

Concerning the benefit of MNE, some terrestrial concepts could be extrapolated to the space context. CREATHES asked experts' opinion and further discussion were hold with ESA:

- to define if the topic/use case offers a real interest for ESA,
- to identify terrestrial constraints regarding to current state-of-the-art and compare them to space constraints,
- to evaluate the development and the work still to be done to extrapolate existing solutions to space.

WP2 – TECHNICAL MEETING WITH EXPERT

During WP1, 6 domains were identified with potential space applications involving added value of MNE:

- Drugs and pharmaceutical applications,
- Nutrition,
- Skin, health and dare
- Microorganisms,
- Life support,
- Food.

A technical meeting with experts coming from all these identified domains was organized with the objectives to eliminate non-possible solutions / areas of interest, and to select the best potential trio « technology / interest / benefit for ESA ».

The meeting was divided into 6 sessions, regarding to the 6 domains for which topics were pointed out during the SoA. For each thematic, a board composed of both major experts (specialists in the concerned area) and complementary experts (specialist in related areas) were involved.

During the workshop, different elements were collected:

- Experts' opinions about both SoA and possible solutions/interests for space,
- Specification of needs and space scenario for which MNE could possibly be of added value,
- Identification of areas for possible improvements.

Collected data exploited by CREATHES allowed to identify several potential ideas, which were classified in different topics and according to trade-off criteria (table 1):

Level	Area	Potential project	Topics
Research	**Drugs and pharmaceutics**	Understand metabolic changes due to microgravity	1
		Identify added value of MNE on model molecules	
Application	**Nutrition**	MNE to increase protein assimilation in supplementation	2.1
	Skin	Encapsulation of active compounds for skin treatment through smart-textiles	5
	Life support	H2O2 encapsulation and microcapsules deposition on dry wipes	4.1
	Microorganisms	Postpone microorganisms "growth" by putting them in stand-by with MNE	4.2
	Food	Enhance shelf-life of products	3.1
		Enhance taste and pleasure during meals	3.2
	Nutrition	MNE of vitamin D, EPA and DHA *– for food supplementation*	2.2
		MNE of vitamin D, EPA and DHA *– for nutraceutics*	

Table 1: Potential projects and associated topics

Topic 1 - PHARMA.

- **T1. Potential use of MNE to optimize medication use and efficiency**
  This use case aims at using MNE for drugs to optimize medication use. Experts have acknowledged the potential of MNE in particular to optimize the administration

routes, to limit the side effects and more generally to optimize the dose-efficiency. However, they have highlighted the current gaps regarding drug metabolism, pharmacokinetics and pharmacodynamics in the field of space physiology and medicine, which currently prevent to potentially evaluate in the short term the added value of MNE in that context. It was concluded that further microgravity human pharmacokinetics and pharmacodynamics research work is thus first required.

Topic 2 - NUTRITION

- **T2.1 Protein supplementation –** This use case consists in using protein MNE for food supplementation as a potential optimized nutritional countermeasure against muscle loss.
- **T2.2 MNE for food supplementation or nutraceutics for lipophilic vitamins, EPA and DHA –** The use case aims at using MNE to optimize nutraceutics and food supplementations, especially with MNE of vitamin D, EPA and DHA.

Topic 3 – FOOD

- **T3.1. Shelf life extension**. This use case focuses on the potential benefit of MNE to extend the shelf life of food;
- **T3.2. Taste**. This use case aims at using MNE to improve the taste of food (for instance with aroma encapsulation) and more generally the pleasure associated to the food.

Topic 4 – ENVIRONMENT CONTROL & LIFE SUPPORT SYSTEMS (ECLSS)

- **T4.1. Disinfection wipe shelf-life extension –** The identified use case would consist in using MNE to encapsulate H_2O_2 in order to significantly extend the shelf life of the disinfection wipes used to limit microbial contamination.
- **T4.2. MNE of microorganisms for better control of future bioregenerative life support systems –** This use case would consist in using MNE to encapsulate microorganisms to put them in a kind of stand-by state to better control them and preserve or even increase their shelf life. This MNE could potentially significantly contribute to a better control of bioregenerative life support systems such as MELISSA. More generally, MNE encapsulation of microorganisms could also support plant growth on-board.

Topic 5 – SKIN

- **T5. Smart clothing with MNE –** This use case aims at using MNE to encapsulate active compounds within clothes especially to improve skin health. Such encapsulation could also support the development of long term clothing by improving the hygiene and limiting the needs for odors.

WP2 and especially workshop organized with experts, permits to discard and validate potential interests for ESA and possible technological concepts regarding to their opinion. 10 potential projects were identified and preliminary roadmaps were built for each of them.

WP3 – RESEARCH AND TECHNOLOGY ROADMAP AND CONCEPTS

Among the 10 potential projects identified in WP2, 2 were selected:

- **T4.2. MNE of microorganisms for bioregenerative LSS**
- **T2.1. Optimization of protein assimilation after intake**

Trade-off analysis was mainly based on criteria from the space-specific perspective, ESA's role in technology gap filler and potential of MNE businesses. Priority levels were attributed to each project, then sorted regarding the obtained score.

Based on the outcomes and previous tasks, CREATHES prepared the ground for these 2 dedicated R&D projects involving MNE:

MNE of microorganisms for bioregenerative LSS

Duration	3 years (taking into account several viability studies)
Estimated budget	300 - 450 kEUR

Optimization of protein assimilation after intake

- **Phase 1: Preliminary study: from requirements to concept and designs**

Duration	12 months
Estimated budget	100-150 kEUR

- **Phase 2: Development project of MNE solutions and validation studies**

Duration	1-3 year + evaluations
Estimated budget (MNE)	400 - 500 kEUR (to confirm after phase 1)
Estimated budget (evaluation)	To be defined after phase 1