AMER

Executive Summary

REFERENCE : AMER-ES

ISSUE : B

REVISION : 0

DATE : 06.12.2012

PAGE NUMBER : 7

APPROVAL

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A	0	12.11.2012	X. HUTSEBAUT	ALL	INITIAL

1 INTRODUCTION

Radiation poses one of the biggest potential problems for deep space exploration by humans and reliably quantifying risks for future human missions to deep space locations is at present extremely challenging. Deep space radiation, and especially high mass and energy (HZE) which is the most damageable one for living matter, cannot be reproduced on earth. To address this topic living matter, and preferably human cells, must be sent into deep space and their interaction with radiation and repair mechanisms understood.

In order to prepare future human deep space missions, ESA decided to dedicate payloads on deep space missions to study living cells interactions and repair to HZE radiation. In this framework, the AMERE study has established the feasibility of such an experiment. The goal of this experiment is to expose living cells, physiologically as close as possible to human cells, to deep space radiation during a long time. HZE radiation would then produce damage in the DNA of the hit cells. The AMERE experiment would be provided with a fluorescence microscope in order to inspect damage due to radiation, and consecutive damage-repair mechanisms triggered by the cells.

2 REQUIREMENTS REVIEW AND ADAPTATION

Starting from scientific requirements, the consortium has broken down these requirements to a list of engineering requirements while identifying the technological challenges posed by the mission. During this step, all of the requirements provided by ESA have been reconsidered, their implications on the payload design have been estimated and finally, the consortium has modified the requirements when it revealed necessary. In addition, requirements have been broken down relative to the part of the AMERE experiment it addresses. This allows the consortium to better define and select the different components, even though we are at an early stage of the experiment.

After that, the consortium started to elaborate a concept of the experiment, and identify the potential scenario of the experiment. This concept is illustrated on the Figure 2-1. Relationship between the different components is shown on Figure 2-2.

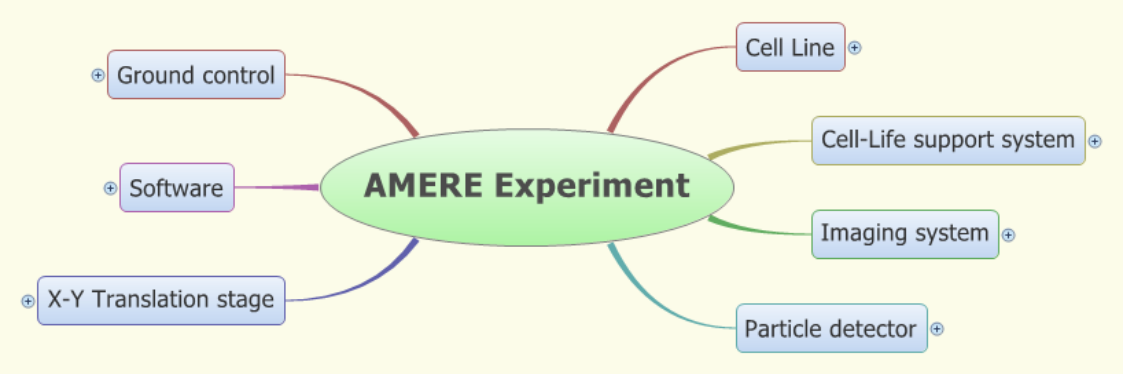

Figure 2-1: AMERE Experiment concept

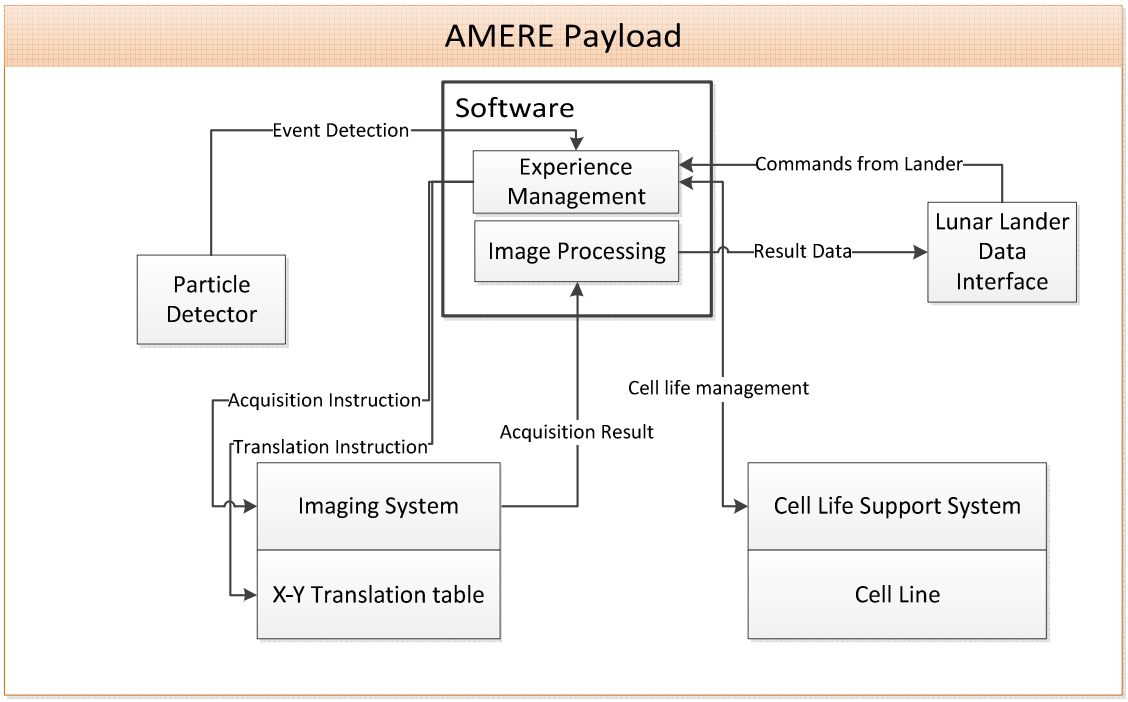

Figure 2-2: Relationship between elements of the experiment

The experiment shall actually be driven by the particle detector; as a radiation event is detected and its trajectory hits the cell layer, the experiment management shall move the microscope to the appropriate location. Fluorescence acquisition can then be started and the corresponding data is downloaded to earth on the course of the different measurements. In the same time, cell life support system shall permanently monitor cell condition and make decision of replacing the cells or modifying its environmental conditions.

Having those requirements and the concept of the experiment, the team started to elaborate the design of the main parts of the payload. The very first step of this design phase identifies the main challenges and potential pitfalls of each component of the experiment. Then potential design or technological solutions to meet the requirements have been identified for each component of the experiment.

3 TECHNOLOGICAL TRADE OFFS

Due to mission scenario, the only method to keep human cells alive during the complete journey to the moon, three months, is to freeze the cells at a T° below -80°C. This way, metabolism of the cell is blocked and can be resumed when heating the cell up to human body temperature. This constraint actually impacts the complete design of the payload in order to keep the cold part of the payload at the right temperature without spending too much energy.

For the main components of the experiment, technological trade-offs have been done and solutions have been proposed for solving most challenges. This trade-off step also includes selection of different candidate human cell lines. The consortium has arrested technological choices for the main components of the payload. Particle detector shall be a telescope of position sensitive devices, namely double sided silicon micro-strip wafers. The optical microscope shall be a structured light microscope including 2 fluorescence excitation channels, an autofocus system, dark field imaging. As regards cell-life support system, the most appropriate solution is to dispatch cells on several samples. Each sample will embed the necessary nutriments for the cells to survive during one week. Nutriments shall be delivered to the cells using microfluidic chip device as it allows for passive and accurate control fluxes or pressure.

In addition, some preliminary testing activities have been established based on the mission requirements and scenario. Those testing activities have been executed in the same time as the design of the payload. Three candidate cell lines have been selected and have undergone the same testing sequence; this provides a more complete basis for making the final selection of the most appropriate cell line.

4 CELL LINE TESTINGS

Given the specificities of the AMERE experiment, dedicated test protocols have been established for the cell lines. Cell performance in the framework of the AMERE mission has been assessed for the 3 selected candidate cell line. This way, we have at the end of the study, one candidate cell line and at the minimum one backup line.

The three selected cell lines are HBEC3, U2OS and HT1080, all in combination with 53BP1 fluorescent marker. Different tests have been carried on; ability to stop and resume cell metabolism by freezing and heating the cells has been estimated. Survival and growth rate have been measured after freezing considering different sets of environmental parameters. Also, a preliminary vibration test has been done in order to check the cell attachment resistance to vibration, in function of different cell filling factors.

From these tests, it appeared that the most appropriate cell configuration is the U2OS as it showed the most radiation response, other features of the 3 cell lines being comparable. The two other cell lines are not eliminated at this point of the activities.

5 PAYLOAD DESIGN

In the same time as the above-mentioned activities, design of the payload has been initiated. Few initial requirements were considered; the payload is supposed to stay on the top of the satellite, the mechanical interface is supposed to be a thermally isolating plate. The global architecture of the payload is shown on the figure below; all the elements are mounted on a main chassis plate.

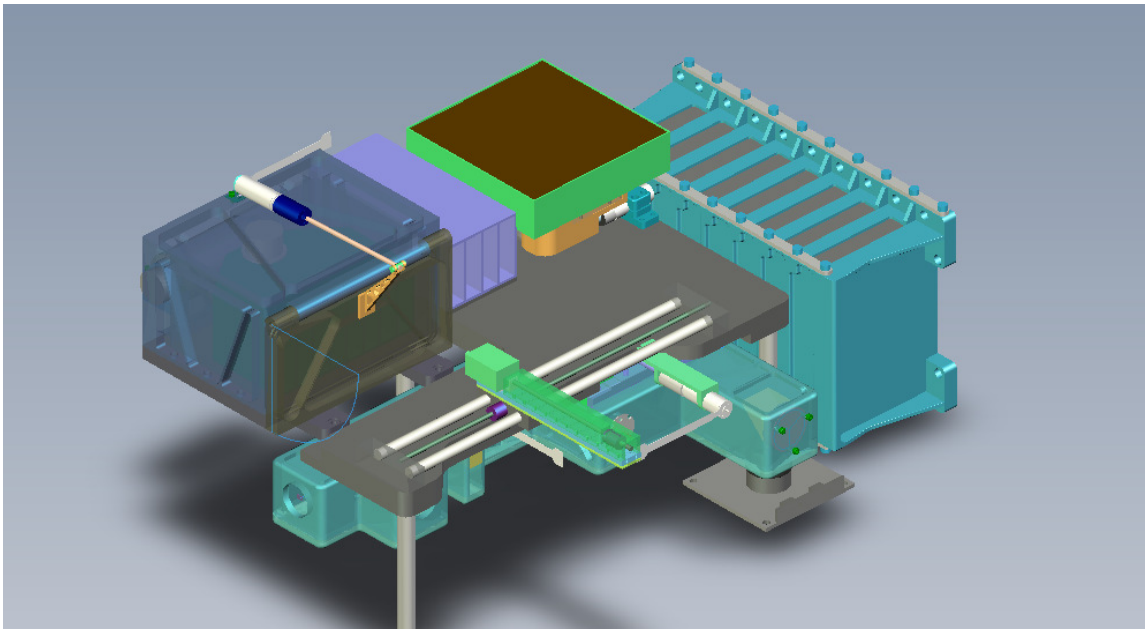

Figure 5-1: Global view of the AMERE payload

The blue box on the left side of the payload is the cold chamber, where the cells are stored during pre-launch and travel to the moon. Cell samples shall be moved out of this chamber to the experiment site using the 3-axis robot at the foreground. The experiment

side is the orange part located at the background of the above figure; it is partially covered with the particle detectors (brown square). The optical microscope is located under the main chassis and the electronics box is located in the box at the bottom of the above view; exactly at the opposite side of the cold chamber. Finally, the purple part in the middle of the payload is a container to dispose cell samples once they have been used for the experiment.

Once the satellite has landed and the payloads have been deployed, the robot shall take a cell sample in the cold chamber and put it in the experiment site where the sample shall be heated to 37°C. Once in the experiment site, cells are exposed to space radiation, the experiment starts as soon as the cells are in good condition. When incident radiation is detected on the cell layer, the microscope shall be moved to the impact location so that it can take images of the irradiated cell & DNA. Images shall be downloaded to earth on the course of the experiment.

Having designed most important arts of the payload, the consortium is able to provide with the following engineering budgets estimations.

Table 5-1: Engineering budgets of the experiment

Feature	Budget [Units]
Width	470 mm
Length	470 mm
Height	250 mm
Mass	25 kg including 15% margin for all
Electrical power (average)	15 W
Electrical power (peak)	55 W
Data	1,15 GB to be downloaded per day of activity

Thermal analysis of the behavior of the payload has also been done by the consortium. This is a quite delicate point as one part of the experiment stays cold whatever the environmental conditions; the cold chamber temperature cannot overcome -80°C while in the same time, all other components must stay in their temperature range (storage or working depending on the mission phase). Thermal control system has been figured out to meet those requirements while sparing as much power as possible. It has been split into two independent systems, one for the cold chamber, one for the other elements. Thermal items remains to be developed in order to make this concept real. Namely, short spatial footprint heat pipes with variable conductance are required for the present thermal concept to be developed.

6 CONCLUSIONS & FURTHER WORK

Finally, the consortium has to provide ESA with development perspectives and priority developments to be carried on in the next phases. To this point of view, the consortium has identified microfluidic device to be the most urgent development. Although microfluidics is nowadays broadly used for manipulating and growing living cells on so-called Lab-on-Chip experiment, such devices have never been sent to space. To this end, technological maturity of these devices must be increased and their resistance to demanding space environmental conditions evaluated. However, thermal concept of the payload requires specific devices to be developed as stated in the design report of the experiment; Low spatial footprint variable conductance heat pipes do not exist so far. Also, embedded software and electronics have to be developed. That task includes all the autonomous decision systems and automated cell condition estimation etc. For this sake, reference images have to be produced in order to develop and test the software. And this cannot be achieved otherwise than building a breadboard of the optical microscope.

To summarize, further development activities of this experiment are three folded, microfluidic device, thermal aspects of the payload and breadboard of the optical microscope.

Considering the present advancement state of the project, the items remaining with low technological maturity and the remaining development to bring the elaborated concept to a flying experiment, we do not find it realistic to be ready for a mission in 2018. Nevertheless, the present study remains relevant in the framework of other future spatial missions, even though it would require some adaptation.