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- Biotechnology
- Protein Crystallization
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- Fluid Physics
- Fundamental Physics
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- Freezer/Cooler
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Astrium’s flight proven hardware and designs are offered at hardware component level or as a build-to-print capability.

With new approaches of commercial access to space, Astrium’s Payload Center provides the full range of microgravity platform services.
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## Quick Look-up Reference Table

This table provides an overview for the suitability of all experiment facilities mentioned in this catalog and their appropriate specimen for quick look-up.

<table>
<thead>
<tr>
<th>Hardware Section</th>
<th>Suitable Specimen</th>
<th>Contracted by</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIORACK Standard Experiment Container Type I and II</td>
<td>Plants x Aquatic x Insects x Tissues Cultures x Cell Cultures x Protein Crystals x Small Animals x</td>
<td>ESA</td>
</tr>
<tr>
<td>BIORACK Modified Experiment Container</td>
<td>Plants x Aquatic x Insects x Tissues Cultures x Cell Cultures x Protein Crystals x Small Animals x</td>
<td>ESA</td>
</tr>
<tr>
<td>BIORACK Modified Experiment Container (liquid)</td>
<td>Plants x Aquatic x Insects x Tissues Cultures x Cell Cultures x Protein Crystals x Small Animals x</td>
<td>ESA</td>
</tr>
<tr>
<td>BIOMAX</td>
<td>Plants x Aquatic x Insects x Tissues Cultures x Cell Cultures x Protein Crystals x Small Animals x</td>
<td>ESA</td>
</tr>
<tr>
<td>BIORACK Standard Experiment Container Type I and II</td>
<td>Plants x Aquatic x Insects x Tissues Cultures x Cell Cultures x Protein Crystals x Small Animals x</td>
<td>ESA</td>
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<td>ESA</td>
</tr>
</tbody>
</table>

**All the space you need**
1. Introduction to Space Biology
by Dr. Enno Brinckmann

Space and Biology—this combination of terms is not very common in science despite the fact that biological phenomena in the unique environment of weightlessness have been analyzed already since the early days of Space flight up to now. The exploration of Space requested investigations in an area, which was beyond the experience of man living on Earth: the border between the long established environment of gravity had to be crossed, and as in the rising era of steam trains, when people were questioning the survival in these high speed vessels, one could not imagine the impact of zero gravity and Space radiation on any organism during space flight.

After more than 50 years of Space research we now have a better understanding about life in weightlessness. In a recent publication (Brinckmann 2007), the authors summarize the unique results in plant root physiology and in cells of the immune system collected in their experiments over a period of 12 to 30 years. This wide timeframe indicates a typical fact of Space research: the frequency of experiments was very low, not days or weeks as in typical ground investigations, but rather months or years due to the rare flight opportunities, the complex preparation, and the many controls, all of them having also an impact on the costs for experimentation in Space. The transfer of an experimental idea from the common ground-based laboratory to the Space environment was usually combined with a large number of tests to prove that the situation in orbit is comparable to ground.

Nowadays, with standard hardware from NanoRacks, the integration time for an experiment on the ISS might be reduced from a few years to less than one year after contract signature. This approach is not intended to replace the present practice of a peer review experiment selection process followed by an adequate hardware development phase under guidance of the Space Agency. New scientific ideas should not be primarily driven by the availability of existing equipment, and complex investigations often need dedicated new hardware solutions for maximum output, especially with the given other restraints of space experimentation. A product driven approach, however, can add other qualities, like reduced cost, schedules, and comparability of results. In the end it will be the responsibility of the sponsoring organizations or the private commercial users to decide which path to go.

It is right now that the experiments in Space biology are stepping into the new era of the International Space Station (ISS) after the Space Shuttle has retired as the main carrier for numerous experiment facilities. Most experiment platforms are accumulated now on the ISS, a few others on satellites. The logistics and the experiment protocols are different on the ISS, more complex on the one hand, but larger exposure to weightlessness and Space radiation is possible on the other hand. It is our aim to demonstrate that experiments in Space are not a solitary research field but bound into a wide spectrum from ground-based fundamental research to application-oriented medical research.

For example, the mechanisms affecting the orientation of plants in the gravitational environment have been investigated since the early days of plant research. The progress achieved in this part of plant physiology was not possible without the experiments under reduced gravity in low Earth orbits. The reaction chain between the gravity stimulus and the cell-internal response can be described much better now with recent discoveries achieved in Space experiments: many pieces of the mosaic were collected and implemented, either by falsifying a previous hypothesis or by adding new evidence, which was previously unknown due to the permanent interference of gravity in ground-based experiments.

Human health research has also gained by space flight: investigations in the field of connective tissues, bone metabolism, and immune system were analyzed. The widely spread bone loss (by ageing, osteopenia, or by disease, osteoporosis) is accelerated tremendously in weightlessness and is therefore a research objective. This research is performed not only in astronauts but also in cellular models, in which the primary reactions and the potential cure of bone loss can be investigated. The removal of the gravitational force is a perfect way for short-term experimentation with cell cultures allowing deep insight in the primary processes of tissue formation, bone formation, and immune cell response in vitro. Whilst it seems obvious that the reduction of mechanical loading leads to bone loss (as on Earth during prolonged bed rest), it is not at all evident that cells of our immune system respond to such stimulation in the same way on Earth.
respond to gravity because it was present during their entire evolution on Earth. This mysterious phenomenon was already observed on astronauts from the very beginning of space flight.

Another important feature of Space flight is Space radiation and its impact on organisms and isolated cellular systems. Besides the technological approach for radiation research in Space and on ground, focusing on radiation damage of the DNA in single cells, general questions ranging from evolution to habitability of Mars have been studied.

For a better understanding of the specific situation of experiment conditions in Low Earth Orbit, we would like to shortly introduce some typical mission scenarios and ESA’s experiment platforms for biological research in Space. In this catalog, additional facilities and instruments built for other agencies are also described.

1.1 Flight mission scenarios

In general, there are four kinds of flight opportunities:

1. parabolic flights in an aircraft with multiple periods of 20 s of weightlessness;
2. sounding rockets with 5 to 15 minutes experiment time;
3. manned space flight missions with 7 to 16 days or more in orbit;
4. robotic missions in unmanned capsules for 12 to 15 days in orbit.

The mission data and a selected list of experiments flown on the missions are summarized in Table 1-1, Table 1-2, and Table 1-3. Each mission is identified by its flight number and the contained payloads. The experiments are given with their dedicated name, sometimes in connection with an identification number, and their Principle Investigator (PI) or team leader. The mission scenarios on the different carriers are not only distinguished by the duration of their free-fall (or microgravity) conditions, but also by the required ground logistics before (= late access) and after the flight (= early retrieval); this is an important factor when fresh samples with limited lifetime have to be transported into Space, and when the returning samples cannot be preserved in a stable condition or need immediate treatment after landing, for example behavioral studies on live animals.

### Table 1-1: Sounding rocket missions with payloads relevant to some experiments described in this catalog. TEM: Texas experiment module; CIS: cell-in-space module; BIM: biology in microgravity.

<table>
<thead>
<tr>
<th>Flight</th>
<th>Date</th>
<th>Payload</th>
<th>Investigator (country)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maser-1B</td>
<td>8 NOV 1992</td>
<td>TEM 06-5MZ</td>
<td>Cogoli (CH)</td>
</tr>
<tr>
<td>Maser 2</td>
<td>28 NOV 1995</td>
<td></td>
<td>Cogoli (CH)</td>
</tr>
<tr>
<td>Maser-3</td>
<td>10 APR 1989</td>
<td>CIS-1</td>
<td>Cogoli (CH)</td>
</tr>
<tr>
<td>Maser-4</td>
<td>29 MAR 1990</td>
<td>CIS-2</td>
<td>Cogoli (CH)</td>
</tr>
<tr>
<td>Maser-5</td>
<td>9 APR 1992</td>
<td>CIS-3</td>
<td>Cogoli (CH)</td>
</tr>
<tr>
<td>Maser-6</td>
<td>5 NOV 1993</td>
<td>CIS-4</td>
<td>Cogoli (CH)</td>
</tr>
<tr>
<td>Maser-7</td>
<td>3 MAY 1996</td>
<td>CIS-5, EMEC</td>
<td>Cogoli (CH)</td>
</tr>
<tr>
<td>Maser-9</td>
<td>16 MAR 2002</td>
<td>CIS-6</td>
<td>Cogoli (CH)</td>
</tr>
<tr>
<td>Maser-10</td>
<td>2 MAY 2005</td>
<td>BIM-1</td>
<td>Cogoli (CH)</td>
</tr>
<tr>
<td>Texus 18</td>
<td>6 MAY 1988</td>
<td>TEM-KT</td>
<td>Volkman (D)</td>
</tr>
<tr>
<td>Texus 19</td>
<td>28 NOV 1988</td>
<td>TEM-KT</td>
<td>Volkman (D)</td>
</tr>
</tbody>
</table>

### Table 1-2: Space flight missions with Crew support in the Space Shuttle (Space Transportation System, STS). Flights 61-A, 42 and 65 were research missions with Spacelab (D-1, German Spacelab Mission; IML-1 and IML-2, International Microgravity Laboratory #1 and #2), whereas flights 76, 81 and 84 were dedicated to activities on the Russian Mir Station with Spacehab in the Shuttle’s cargo bay (Shuttle-to-Mir Mission, S/MM-03, 05 and 06). The experiment list is reduced to those described in the book edited by Brinckmann, 2007.

<table>
<thead>
<tr>
<th>Flight</th>
<th>Date</th>
<th>Payload</th>
<th>Experiment (Investigator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS-9</td>
<td>28 NOV-8 DEC 1983</td>
<td>Biostack, Portable Incubator</td>
<td>Biostack (Bücker) ESS29 (Horneck) AOS/17/LS/CH (Cogoli)</td>
</tr>
<tr>
<td>STS-61-A (22)</td>
<td>30 OCT-5 NOV 1985</td>
<td>Biorack</td>
<td>19-D DOSIMETR (Bücker) 32-CH BLOOD (Cogoli) 33-CH LYMPHO (Cogoli)</td>
</tr>
<tr>
<td>STS-40</td>
<td>5 JUN-14 JUN 1991</td>
<td></td>
<td>781240 (Cogoli)</td>
</tr>
<tr>
<td>STS-42</td>
<td>22 JAN-30 JAN 1992</td>
<td>Biorack, LSLE freezer, Photobox</td>
<td>02-NL BONES (Veldhuizen) 10-D MOROSUS (Bücker) 12-D DOSIMETR (Reitz) 14-1-CH FRIEND (Cogoli) 14-2-CH HYBRID (Cogoli) 14-3-CH CULTURE (Cogoli) 20-F ROOTS (Perbal)</td>
</tr>
<tr>
<td>STS-55</td>
<td>24 APR-6 MAY 1993</td>
<td>RD-BIOS (Reitz) RD-UVRAD (Horneck)</td>
<td></td>
</tr>
<tr>
<td>STS-65</td>
<td>8 JUL-23 JUL 1994</td>
<td>Biorack, LSLE freezer, NIZEMI, Biostack</td>
<td>01-1-1 ADHESION (Cogoli) 01-1-1 MOTION (Cogoli) 08-NL BONES (Veldhuizen) 12-1-D KINETICS (Horneck) 12-2-D REPAIR (Horneck) 19-D DOSIMETR (Reitz) 32-1-F LENTIL (Perbal) CRESS (Veldhuizen) Biostack (Reitz)</td>
</tr>
<tr>
<td>STS-76</td>
<td>22 MAR-31 MAR 1996</td>
<td>Biorack, LSLE freezer</td>
<td>19-D DOSIMETR (Reitz) 32-2-F STATOCYTE (Driss-Ecole) 401-D STATOCYTE (Volkman) 486-D X-RAY (Kiefer)</td>
</tr>
<tr>
<td>STS-81</td>
<td>12 JAN-22 JAN 1997</td>
<td>Biorack, LSLE freezer, Photobox</td>
<td>19-D DOSIMETR (Reitz) 23-D CRESS (Volkman) 89-F GRAVITY (Perbal) 27-D CHARA (Bücher)</td>
</tr>
<tr>
<td>STS-84</td>
<td>15 MAY-24 MAY 1997</td>
<td>Biorack, LSLE freezer</td>
<td>22-D BETARAY (Kiefer) 33-D DOSIMETR (Reitz) 89-F ACTIN (Driss-Ecole)</td>
</tr>
<tr>
<td>STS-95</td>
<td>29 OCT-7 NOV 1998</td>
<td>Biobox-4</td>
<td>HUDEREM (LaPière) MARROW-4 (Bouillont)</td>
</tr>
</tbody>
</table>
Table 1‑3: Space flight missions in unmanned satellites. The European Retrievable Carrier (EURECA) was a satellite with automated experiments, launched and retrieved by the Space Shuttle [Innocenti & Mesland 1997]. Bion and Foton satellites were launched with Russian carriers.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Space Shuttle (Middeck)</th>
<th>Soyuz Flight to ISS</th>
<th>Bion/Foton</th>
<th>Texus, Maser, Maxus</th>
<th>SPACE X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late access before launch</td>
<td>17-24 hours</td>
<td>8-12 hours</td>
<td>48 hours</td>
<td>1 hour</td>
<td>24 hours</td>
</tr>
<tr>
<td>Launch site</td>
<td>Kennedy Space Center (USA)</td>
<td>Baikonur (Kazakhstan)</td>
<td>Plesepol (Russia)</td>
<td>Kiruna (Sweden)</td>
<td>Kennedy Space Center (USA)</td>
</tr>
<tr>
<td>Experiment preparation at the launch site</td>
<td>Full laboratory facility</td>
<td>Limited laboratory facility</td>
<td>No laboratory facility</td>
<td>Full laboratory facility</td>
<td>Full laboratory facility</td>
</tr>
<tr>
<td>Experiment start time in orbit</td>
<td>Launch + 4 hours (2-3 days)</td>
<td>Launch + 9 min (Maxus: 96 sec)</td>
<td>Launch +70 sec (Maxus: 96 sec)</td>
<td>Launch + 2 days (Maxus: 96 sec)</td>
<td>Launch + 2 days (Maxus: 96 sec)</td>
</tr>
<tr>
<td>Experiment duration (maximum)</td>
<td>16 days</td>
<td>10 days</td>
<td>12-15 days</td>
<td>weeks to month</td>
<td>weeks to month</td>
</tr>
<tr>
<td>Temperature control at descent</td>
<td>Ambient, cooler, freezer</td>
<td>Ambient, cooler, freezer</td>
<td>Cooler (Bioxbox)</td>
<td>Experiment provided</td>
<td>Experiment provided</td>
</tr>
<tr>
<td>Early retrieval at landing site</td>
<td>Landing + 6-8 hours</td>
<td>Landing + 2 hours</td>
<td>Landing + 1-2 hours</td>
<td>Landing + 1 hour</td>
<td>Landing + 48-60 hours</td>
</tr>
</tbody>
</table>

Table 1‑4: General conditions for experiment preparation, start, duration and return for manned and robotic space missions. Experiments on the Space Shuttle and on Soyuz flights to the International Space Station (ISS) could use Crew interface for operations; experiments in the Foton capsule and in Sounding Rockets (Texus, Maser, Maxus) were performed autonomously.

The situation is better for the Soyuz missions to the International Space Station (ISS), in which a late integration of payloads not heavier than 10 kg is still possible a few hours before the Crew is climbing into the seats. Due to the past Soyuz missions and Foton-11, however, all items had to be transported to the launch site via Moscow to allow for customs inspection and required additional time for the subsequent transport to the launch site, which extended the late access time for live samples considerably. Only recently, some experiment preparations were possible at the launch site in Baikonur (Kazakhstan). During the two days flight period to the ISS, the experiments in Soyuz were either inactive or limited to automatic functions: specific interaction by the Crew was only possible after docking to the ISS, which added for most samples two more days to the storage period after handover. During descent, the Space Shuttle was usually equipped with ambient and cold stowage compartments, whilst the temperature for samples returning from ISS in the Soyuz capsule was not actively controlled, resulting in temperature peaks up to 31 °C. In the future, the Dragon capsule of SpaceX could be equipped with temperature controlled stowage space during return to ground.

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1.3 Biobox on Foton and in the Space Shuttle

The Biobox facility was designed in 1990-1991 for biological experiments on unmanned recoverable capsules of the Bion and Foton type. It was operated in a fully automatic mode, without Crew intervention or even telecommanding. After one mission on Bion (Biobox-1) and two on Foton (Biobox-2 and -3), the project was transferred to the US Space Shuttle. After one successful flight on STS-95 (Biobox-4) the career of Biobox on the Shuttle came to a premature end with the STS-107 disaster in 2003 (Biobox-5). A completely re-designed Biobox was constructed and flew in 2007 on Foton-M3 (Biobox-6). The following information applies to Biobox-1 through Biobox-4.

Biobox was configured as a programmable single incubator. Experiments sharing that incubator were selected for compatible temperature requirements. On each flight the biological samples consisted of mammalian cell cultures (Table 1-3), which were accommodated in 30 automatic experiment units, dimensioned to a standard size of 20x40x80 mm³ (Biorack Type I container and CIS unit). In each unit, one or two 1 ml cultures could be grown. Culture media, biochemical stimulants and fixatives were contained within these units and could be supplied automatically according to a timeline pre-selected before flight.

From the 30 experiment units, six were placed on a centrifuge which generated 1-g acceleration during flight. As an additional reference, a duplicate model of Biobox was operated on ground almost synchronously with the flight unit. After flight, the results obtained in microgravity were compared with those obtained at 1-g (both from the on-board centrifuge and from ground) to identify biological effects that were specifically linked to weightlessness.

Before launch, the temperature in Biobox was maintained at +20 °C to suppress the growth and development of the cell cultures before entrance into microgravity. The cells were automatically awakened from their dormancy at 9 min after lift-off, when the in-built micro-accelerometer acknowledged the presence of microgravity. At this moment, the centrifuge was kicked into action and the incubator temperature was switched to +37 °C, the optimal value for culturing mammalian cells. Later during flight, when all cultures had been stopped by adding fixatives, the centrifuge was switched off and the temperature was lowered to prevent the fixed material from decaying. All these events occurred automatically, controlled by internal timers. The full automation was retained on the Space Shuttle (Biobox-4), with the Crew operations restricted to the occasional cleaning of the Biobox cooling fans’ inlet grid.

Nevertheless, the streamlined simplicity of the automated flight operations was off-set by the complexity and ever-changing demands of the mission operations. Note that Biobox-1 was the very first facility of the European Space Agency (ESA) on any Russian carrier [Demets et al. 2002].

With an inconveniently long late access period of 48 h (Table 1-4), the decision was made to prepare the experiments, as well as the three Biobox1 and Biobox-2 facilities (flight, flight spare and ground), in Moscow. For this purpose a pre-fabricated laboratory (called Moslab) was set-up in the Netherlands and, after road transport, re-assembled in Moscow [Demets et al. 2002]. Loaded with experiments, the flight model of Biobox was ferried by aircraft from Moscow to the launch site Plesetsk three days before launch. The ground model was retained and operated in Moslab.

Due to a changing financial and political climate, Moslab could no longer be maintained for Biobox-3. An alternative ground operations plan had to be invented. All pre-flight operations, including the experiment preparations, were transferred to the ESA facility (ESTEC) in the Netherlands. In order to send Biobox as late as possible to the launch site Plesetsk, a special aircraft was chartered. After landing in Moscow for customs clearance and refueling, Biobox was left on the plane while the ESA personnel debarked for passport and visa clearance. Six hours later the aircraft was back in the air, destination Plesetsk, leading to a complete transportation time (from experiment handover until launch) of 72 hours. The Biobox ground model was retained at ESTEC for ground reference experiments.

The experiments were accommodated on circular platforms in experiment-specific modules: Texas Experiment Modules (TEM) were flying on Texus rockets and CIS (cell-in-space) modules on the Maser missions (Table 1-1). Each module was autonomous; it had its own power supply and electronics unit (Figure 1-1). An identical module was often used for biological ground reference experiments. The useful diameter of the experiment deck was 403 mm, the length varied between 160 and 1155 mm, with a mass range of 22-116 kg. These modules provided the desired temperatures for the samples and automated features like video observation, experiment activation and fixation, control runs on an onboard 1-g centrifuge, and data storage or transmission to ground.
After Biobox-3 a new flight opportunity was offered on the US Space Shuttle. Once more, a brand-new ground operations scenario had to be devised. This time, the experiments were prepared at ESTEC in the Netherlands, while Biobox-4 was simultaneously readied at the Spacehab Payload Processing Facility (SPPF) in Florida. Three days before launch, the fully prepared experiments, were being flown from ESTEC to Florida in thermal boxes at +20 °C, for installation in Biobox, which happened 36 h before launch. Despite the better late-access conditions (36 h for Spacehab, 48 h for Bion/Foton), the lead time for the sample preparations was not improved due to the unintentional high carbon dioxide level to save absorber materials. In Table 1-5, it is obvious from Table 1-5, that the environment was similar to ground lab conditions, except for the slightly higher temperature and fluctuating temperatures (22.6 – 27.2 °C) and the intentionally elevated carbon dioxide level to save absorber materials.

1.4 Biorack in Spacelab and Spacehab

Biorack was the first multi-user facility of the European Space Agency (ESA), designed for biological experiments in Spacelab, the European part of NASA’s Space Transportation System (STS), better known as the Space Shuttle. It flew three times in Spacelab and three times in Spacehab. Spacelab was the European part of NASA’s Space Transportation System (STS), better known as the Space Shuttle. In addition to Spacelab and Spacehab, the Shuttle’s middeck can also be used for experiment facilities and stowage with the same environmental conditions. The middeck stowage lockers were the latest accessible units before lift-off. This late access time was also supported by the very late preparation of the samples in fully equipped laboratories in Hangar-L at Kennedy Space Center close to the launch site.

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All the space you need

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<th>Dev Point Temperature</th>
<th>Relative Humidity</th>
<th>Cabin Pressure</th>
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Table 1-5: Spacehab environmental data during the Shuttle-to-Mir Mission #6 (S/MM-06). The data points are 12-hourly mean values from the Payload Operations Control Center (POCC) readings and were used for a simulation of the environmental conditions in Spacehab on the ground. Parameters are given in various dimensions for convenience. MET: mission elapsed time; r.h.: relative humidity.
The entire Biorack facility was a combination of three incubators, a cooler/freezer, a glove-box and stowage racks (Figure 1-3). Each incubator contained two centrifuges and static rack positions for the experiment containers, the latter exposing the samples to microgravity conditions. Incubator temperatures were set before flight in the range of 22 °C to 37 °C. There was no temperature control required in Biorack during launch and landing, since the incubators and cold storage racks were empty. The centrifuges provided 1-g acceleration (center of EC) for eight Type I containers but had to be stopped for container transfer, leading to accumulated stationary periods of about 0.1 % to 1.7 % of the entire running time. When the centrifuge was shared, these stops affected shortly also other experiments. A post-flight evaluation of 22 Biorack experiments revealed, that the on-board 1-g reference centrifuge gave in 50 % of the experiments the same results as the controls in the identical Biorack ground model [Perry 1999]. This could be interpreted as an influence of other spaceflight conditions, like radiation, or as an effect of a delayed and in several cases interrupted exposure to the 1-g conditions in orbit. On the Shuttle-to-Mir missions, the centrifuge was also adjustable in-flight to pre-set accelerations of 0.1, 0.2, 0.3 and 0.4-g.

To protect the Crew from potential contamination with toxic materials, Biorack was equipped with a sealed glove-box, which had in addition an under-pressure of 7 hPa. Thus, two levels of containment were achieved by the mechanical isolation and the under-pressure in case a leak would occur in the gloves or in the box itself. By this safety precaution, the Crew was able to open the Experiment Containers and to perform experimental manipulations, mainly activation or fixation of the samples, with dedicated tools or simple lab equipment, like syringes or multi-injectors. A video camcorder or a photo camera above the glove-box window allowed ground controllers to observe the glove-box operations and to document experimental results (Figure 1-4).

The cooler/freezer unit was flown twice with 4 °C/-15 °C, respectively, but these units were not active during launch and landing. Active cooling during two missions was provided by NASA’s LSLE-freezer (Life Sciences Laboratory Equipment, LSLE), set at -22 °C. As an alternative to these power-consuming cooling units ESA used the Passive Thermal Conditioning Units (PTCU) consisting of a large container with a wax, which was solidified before flight at low temperatures, surrounded by a double-walled evacuated Dewar vessel (∅ 21x50 cm) with high insulation capacity. Several kinds of wax served as phase change material and kept its temperature constant for about 20 days until the wax started melting. This way it was possible to store for example up to 20 Type I containers refrigerated or frozen, especially during launch and landing, when power supply was limited. Even loading of the PTCU with “warm” containers did not affect the performance of the PTCU considerably. During the last two Shuttle-to-Mir missions (S/MM-05, S/MM-06), Biorack had to rely on the +5 °C PTCU as the only source of refrigeration capacity.

The stowage racks next to the Biorack facility were used to store Experiment Containers at ambient temperature. Also a microscope and a photo camera, tools, film rolls, video tapes, and spare parts were stored in these lockers. A special storage item was the Photobox developed by the French Space Agency (CNES) for experiments with plant roots. The Photobox had a size of 40x17x15 cm and was battery driven. It allowed time lapse flash photography of root curvature in microgravity. The Crew placed up to six mini-containers into the holder of the Photobox, which had mirrors to reflect the twelve surfaces with plant seedlings into the camera. After Crew activation, the Photobox captured automatically the root development on the 35-mm camera during several hours. For the S/MM-06 mission, the Photobox was equipped with a battery driven mini-centrifuge. In this way the root curvature after a gravity stimulus could be followed without Crew intervention or any other disturbance of the microgravity environment.
After the retirement of Biorack in 1997, which happened after six successful flights with 89 experiments performed, a new facility was developed by ESA for biological experiments in the Space Shuttle. It was called Biopack and had the size of two Middeck Lockers. Biopack consisted of an incubator with static racks and three small centrifuges, accommodating the standard Type I and Type II containers. A small built-in refrigerator and freezer as well as a portable glove-box completed the Biopack facility [van Loon 2004]. The experiments could be monitored with telemetry and controlled by telecommanding from ground. However, its maiden flight on STS-107 in 2003 ended with the Columbia disaster.

Since ESA had lost the Biobox flight unit during the failed Foton-M1 launch (2002) and the spare flight model on STS-107 together with Biopack, no facility for biological experiments was left. An immediate alternative was found in the Aquarius incubator, which had been used by the French Space Agency for the Soyuz mission “Odyssee” in 2002 and the Spanish Soyuz mission “Cervantes” in 2003. For the Dutch Soyuz mission “DELTA” in 2004, a new concept of this – now called Kubik- incubator was developed by ESA: besides a wider temperature range, including refrigeration capacity, an insert with a reference centrifuge for eight Type I containers was added. In the meantime, a new Kubik design supports experiments on the ISS with a variety of Biorack containers. Since sufficient stowage room is not available during the return of the Soyuz spacecraft, the incubators would stay on board of the ISS and could be used for future experiments, whereas the returning samples were carried in smaller foam insulated containers to ground. As many experiments are demanding a fully controlled environment, ESA has also developed two sophisticated incubator systems for research projects on the ISS [Brinckmann 2003]: the European Modular Cultivation System (EMCS) already performing well in orbit and Biolab, which resembles a complete small biological laboratory that has been launched 2007 in the European Columbus Module.

ESA decided to rebuild the BIOBOX facility with improved performance for a mission on Foton-M4 in 2007. The same facility was flown as SIMBOX on the Shenzhou 8 mission in a contract to DLR. SIMBOX was the first international payload in the Chinese manned spaceflight program.

Presently, NanoRacks and Astrium jointly bring together the advantages of 30 years of science-driven hardware development with a commercially-driven utilization approach in order to achieve:

- shortened payload integration schedule and cost efficient access via NanoRacks
- access to artificial gravity centrifuge by use of Astrium’s Biorack Type 1 EC form-factor
- access to large Biorack portfolio of already existing experiment hardware
- compatibility to other ISS and non-ISS facilities.

We hope that the readers will get in this catalog a good overview about the achievements of biological research in Space, in addition to the information about facilities, experiment hardware and their projects.

References: Introduction


Longdon, N., David, V. (Eds.), Biorack on Spacelab D1, ESA SP-1091, ESA Publications Division, ESTEC, Noordwijk, 1987.


Perry, M. (Ed.), Biorack on Spacehab: Experiments on Shuttle to Mir Missions 03, 05 & 06, ESA SP-1222, ESA Publications Division, ESTEC, Noordwijk, 1999.


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2. Astrium Development, Operation, Support, and Services

2.1 Astrium Operation Services

The Payload Center of Astrium Space Transportation has equipped a quarter of the micro-gravity experiment facilities aboard the International Space Station (ISS). The Payload Center covers all areas of microgravity research: physical science, material science, life science. Besides, the center also includes the department of energy and life support systems, which is crucial for manned spaceflight, but also terrestrial applications such as life-support systems of submarines, regenerative fuel cell systems for on- and off-grid energy storage applications.

With new approaches of commercial access to space, Astrium’s Payload Center provides the full range of micro-gravity platform services.

How the Astrium Payload Center can be of assistance:

- Science Consulting: How to best reach the researcher’s goals
- Provision of test hardware to start early experiment validation
- Development and adaptation of hardware, if needed
- Pre-flight preparation
- Access to micro-gravity platforms: ISS, parabola flights (global), sounding rockets, drop towers, and in the future: space plane, satellite-based research platforms
- Post-flight analysis

2.2 Experiment Development and Flight Qualification

In support of experimenters/principal investigators (PIs), Astrium offers an array of services ranging from experiment hardware selection to mission integration in order to realize your on-orbit science goals. Support services can include the following:

- Astrium has the knowledgeable, long-term experiment hardware experts to assist in the selection of science hardware to match experiment criteria.
- Experiment hardware integration capabilities – Astrium has the history and capability to provide space flight hardware components or fully integrated experiment packages based on customer requirements.
- Laboratory support facilities and testing support – Astrium can provide integration laboratory space and support personnel for experiment build up and test, inclusive of flight qualification and integrated system testing.
- Comprehensive mission integration capabilities and efficiencies in:
  - Cargo manifest and payload configuration control
  - Requirements definition and efficient closure approach – intimate knowledge and experience with NASA and ESA verification processes
- Safety and reliability at payload level
  - Certification of Flight Readiness at payload level
• Sustaining Engineering
  – Maintain engineering and expertise for Astrium owned and managed ISS systems and components
  – Provide technical support in support of ISS operations effecting Astrium responsible hardware and systems
• Astrium has the proven capability to provide hands-on training for flight hardware and simulators, extravehicular activity (EVA), weightless environment as well as tailored classroom training for astronauts, flight controllers and technical personnel.
• Astrium has highly trained and experienced personnel to conduct real-time flight operations at the NASA JSC Mission Control Center (MCC)
• Our unique relationship with all ISS agency counterparts in the US, Europe, and Japan provide customers with direct access to the various control centers for experiment ground control and commanding.
• Extensive knowledge in the Department of State International Traffic In Arms Regulations (ITAR) and Department of Commerce Export Administration Regulations (EAR).

### 2.3 Payload Integration

Astrum’s long-term involvement in the operation of BIOLAB, EMCS, and MSL ensures that the gained knowledge is carried from increment to increment with respect to facility technical details and/or peculiarities. This is a major asset in case of on-orbit troubleshooting for failure recovery. At the same time, new experiments benefit from Astrium’s previous experience.

Astrium has also the experience of successfully integrating experiments into payload facilities provided by third parties, i.e. MSG experiments and FSL experiments.

Once the facility is on-orbit and permanently installed (rack or sub-rack level payload), Astrum’s focus is on operations preparation, facility maintenance, and integration of experiments for the facility. This part is far more challenging than the pure launch of a payload since the facility must be maintained and prepared to receive an experiment while the experiment mission preparation work is carried out on ground.

### 2.4 Utilization of Astrium Operated ISS Science Facilities

Astrum has the capability to provide a full range of services to support an experimenter with in-flight utilization of Astrum operated facilities on the ISS.

Astrum can provide the full range of interface services with the ISS management team to allow the experimenter to focus on science. The services and required interfaces which Astrum can provide as a representative of an experiment/PI to the ISS Payload and experiment entities are described below.

![Figure 2-1: Astrium Integration Support Services](image-url)
3. Facility BIOLAB

3.1 BIOLAB Facility overview

BIOLAB is a modular system integrated into an International Standard Payload Rack (ISPR) and is divided into two sections:

- The automatic section for automatic in-orbit operations, where experiments, once loaded by the Crew, are performed automatically
- The manual section dedicated to samples handled by the Crew and storage

Main Features:

- Automated multi-user facility with exchangeable experiment containers to perform experiments in the field of biology
- Designed for biological experiments to study the effect of microgravity and space radiation on cell cultures, tissues, micro-organisms, small plants and small animals
- Execution of experiments in controlled environment according to pre-programmed time-lined protocol

![Figure 3-1: BIOLAB Facility](image)
### Automatic Ambient Temperature Stowage (AAS)
- Stowage of empty syringes, HM tools, and liquid waste reservoirs at ambient temperature

### Automatic Temperature Controlled Stowage (ATCS)
- -20 ° to +8 °C samples, chemicals stowage (+/- 1 °C accuracy)
- Cool down capability: 5 x 1 ml from 37 °C to -20 °C in 30 min (saline solution)
- Accessed via Handling Mechanism

### Temperature Controlled Units (TCU)
- +10 °C to -20 °C storage
- Cool down capability: 250 g of Al from 37 °C to -20 °C in 60 min
- Accommodation of ATCS inserts and experiment containers. 23 l internal volume

### Incubator incl. 2 centrifuges
- Temperature control: 18 to 40 °C
- 2x centrifuge rotors:
  - 600 mm in diameter
  - controlled speed: 10-3 to 2 g
- 6 experiment container on each rotor:
  - 4 x EC Positions 2 x AEC
- observation and illumination
- Life Support System (LSS)
- Gas composition control (N₂, O₂, CO₂)
- Humidity control
- Pressure control

---

**Figure 3-2: BIOLAB Facility Elements**

All the space you need
Handling Mechanism
- Automatic transfer of fluids using syringes among:
  - Experiment containers located on the centrifuges
  - Analyses instruments
  - AAS
  - 2 x ATCs
  - Automatic manipulation of experiment HW using the push-pull-rotate tool

BioGloveBox
- Provides a closed environment for manual experiment manipulation
- Temperature controlled between 21 °C and 28 °C, +/- 2 °C
- 32 l internal work volume, under-pressurized
- 300 l/min air ventilation and filtering
- Slide-in / slide-out capability inside rack
- 2 interfaces for experiment container accommodation
- External and internal control panels
- Ozone generation for Biolab sterilization

Analysis Instrument Microscope (AI-MS)
- 4 planar semi-apochromatic universal objectives from OLYMPUS
- Observation area is at least 4x4 mm
- Observation techniques:
  - Bright field
  - Dark field
  - Phase contrast
- Objective magnification: 4x, 10x, 20x, 40x
- Accessed via Handling Mechanism

Analysis Instrument Spectrophotometer (AI-SP)
- Derived from a compact ZEISS instrument (MMS1)
- UV-visible range between 220 nm and 450 nm (effective 190÷730 nm)
- Visible range between 400 and 900 nm (effective 300÷1150 nm)
- Accessed via Handling Mechanism
3.3.1 Standard Experiment Container (EC.S)

Main Features:
- Internal dimensions: 60x60x100 mm³ (X x Y x Z) (volume, useable for experiments)
- Internal volume: 360 ml
- External illumination and video observation through transparent cover

EC.S Structure:
Provides all interfaces to BIOLAB centrifuge rotor

EC.S Handling Mechanism Plate:
Provides all Interfaces to BIOLAB Handling Mechanism

EC.S Cover Locking Mechanism
Allows Crew to open the cover

Figure 3-3: Standard Experiment Container (EC.S)

EC.S Cover Type 1
Is made for transparent material of optical quality to allow observation inside the Experiment Container by means of the Incubator Observation System. The transparent material of optical quality allows illumination of the Experiment Container interior by means of the Incubator Illumination System. Besides visible light, the illumination of the biological sample with IR light with a wavelength between 900 and 1100 nm is possible.

EC.S Cover Type 2
This cover is made of Makrolon which is a dark material, avoiding light to enter the Experiment Container internal volume

All the space you need

3.3.2 Experiment Container Double Sealed (EC.DS)

Main Features:
- Internal dimensions: 60x60x100 mm³ (X x Y x Z) (volume, useable for experiments)
- Internal volume: 360 ml
- External illumination and video observation through transparent cover.
- The Experiment Container Double Sealed provides two levels of containment.

EC.DS Structure:
Provides all interfaces to BIOLAB centrifuge

EC.DS Cover Locking Mechanism
Allows Crew to open the cover

EC.DS Cover Locking Mechanism Plate:
Provides all Interfaces to BIOLAB Handling Mechanism

Figure 3-4: Experiment Container Double Sealed (EC.DS)

Qualification Status: ☑ Qualified for use on ISS
3.3.3 Advanced Experiment Container (AEC)

**Main Features**
- Internal dimensions: 106x133x154 mm³ (X x Y x Z) (volume, useable for experiments)
- Internal volume: 2185 ml
- AEC Mass: Empty AEC ≤1500 grams (including EC-electronics and sensors). The experiment-specific Handling Mechanism Plate (HMP) has to be added. By using of a blind HMP w/o any HM-I/F’s, the empty AEC weighs 1700 gr.
- The maximum mass of the EUE in an AEC is limited to 1600 grams.
- The total integrated mass is specified with 3300 grams limited by the rotor specified speed up performance and maximum torque.

The AEC is equipped with an internal electronics and a harness, coming from internal AEC PCB, which provides the electrical interface to the experiment.

3.3.4 Standard Automatic Ambient Stowage (AAS)

**Gravitational environment:** No control of the acceleration is provided in the storage compartment.

**Thermal environment:** No temperature control is provided for the AAS. The temperature of the inserts is the same as of the Handling Mechanism drawer.

**Insert exchange:** The AAS door can be opened to extract the inserts.

The BIOLAB automatic Handling Mechanism has access to all insert locations.

**Main Components:**

The standard AAS insert contains up to:
- 96 syringes of 1 ml needed for the experiment run. Each syringe’s position is separated by means of a µ-pore filter to avoid cross contamination between used and unused syringes.
- 2 double containment syringes
- 1 EC tool
- 2 liquid bags can also be installed in that insert and used by the Handling Mechanism

**Qualification Status:**
- Advanced Experiment Container (AEC): Qualified for use on ISS
- Standard Automatic Ambient Stowage (AAS): Qualified for use on ISS
### 3.3.5 WAICO Automatic Ambient Stowage (AAS)

Gravitational environment: No control of the acceleration is provided in the storage compartment.

Thermal environment: No temperature control is provided for the AAS. The temperature of the inserts is the same as of the Handling Mechanism drawer.

Insert exchange: The AAS door can be opened to extract the inserts.

The BIOLAB automatic Handling Mechanism has access to all insert locations.

**Main Components:**

The WAICO AAS insert contains up to:
- 6 double or triple containment syringes (inter-changeable)
- 2 liquid containments with a storage capacity of 240 ml each (2 x 240 ml)

### 3.3.6 TRIPLELUX Automatic Ambient Stowage (AAS)

Gravitational environment: No control of the acceleration is provided in the storage compartment.

Thermal environment: No temperature control is provided for the AAS. The temperature of the inserts is the same as of the Handling Mechanism drawer.

Insert exchange: The AAS door can be opened to extract the inserts.

The BIOLAB automatic Handling Mechanism has access to all insert locations.

**Main Components:**

The TRIPLELUX AAS Insert contains up to:
- 50 standard 1ml syringes
- 6 positions for Triplelux Reservoirs

---

**Figure 3-7: WAICO Automatic Ambient Stowage (AAS)**

**Qualification Status:** ☑ Qualified for use on ISS

**Figure 3-8: TRIPLELUX Automatic Ambient Stowage (AAS)**

**Qualification Status:** ☑ Qualified for use on ISS
3.3.7 Automatic Temperature Control Stowage (ATCS)

Gravitational environment: No control of the acceleration is provided in the storage compartment.

Thermal environment: Each ATCS can be independently controlled between -20 °C and +10 °C.

Insert exchange: The ATCS doors can be opened to extract the inserts.

The BIOLAB automatic Handling Mechanism has access to all insert locations.

The vials are made of silicone rubber (Cohrastic 9235) and are closed by double septa of the same material.

Main Components:
Since many different applications can be considered, different layouts of these inserts can be designed. The Standard ATCS inserts consist of hermetically sealed aluminum boxes with vertical plates mounted inside to separate the sample bags.

The ATCS is available in two models: Standard and WAICO ATCS.

3.3.7.1 Standard ATCS

The standard ATCS insert provides storage for liquid samples in sample bags with 2 ml internal volume. There are 48 sample bags, 44 to be accessed by 1ml syringes and 4 to be accessed by double containment syringes.

Figure 3-9: Standard ATCS Insert

Qualification Status: ⬤ Qualified for use on ISS

3.3.7.2 WAICO ATCS

The WAICO ATCS provides three compartments, each with 120 ml for samples or chemistry. The compartments can be accessed by double or triple containment syringes.

Figure 3-10: WAICO ATCS

Qualification Status: ⬤ Qualified for use on ISS
3.3.8 BIOLAB Tools

The Biolab tools in general are used by the Handling Mechanism to transfer liquid.

**1ml Syringe**

Syringe volume 1 ml
Liquid transfers are possible from and to:
- Experiment Container
  - AAS
  - ATCS
only to:
- Microscope
- Spectrophotometer

**Double Containment Syringes**

Liquid transfers are possible from and to:
- Experiment Container
  - AAS
  - ATCS

**Triple Containment Syringes**

Liquid transfers are possible from and to:
- Experiment Container
  - AAS
  - ATCS

Pipetting accuracy better than 1 % of the volume of 4 ml, and +/- 10 % at 40 µl.

**Qualification Status:** Qualified for use on ISS

3.4 BIOLAB Ground, Test and Laboratory Equipment

3.4.1 FTGSE

The fully representative Engineering Model of BIOLAB is available at the Microgravity User Support Center MUSC in Cologne. Astrium provides interface kits to users and experiment developers for functional testing at their facilities. Further details on this Functional Test Ground Support Equipment FTGSE are available upon request.

3.5 BIOLAB Experiments

3.5.1 BIOLAB Experiment WAICO

Waving and coiling of Arabidopsis roots at different g-levels (WAICO) studies the interaction of circumnutation (the successive bowing or bending in different directions of the growing tip of the stems and roots) and gravitropism (a tendency to grow toward or away from the gravity vector) of Arabidopsis thaliana in microgravity and 1-g.

**Principal Investigator**

Günter Scherer, Ph.D., Leibniz University of Hanover, Germany

**Research Summary**

- Waving and coiling of Arabidopsis roots at different g-levels (WAICO) compares the waiving and coiling growth of Arabidopsis thaliana at different g-levels between 0-g and 1-g by time lapse imaging of the root growth over an approximate 2 week period on the ISS.
- WAICO also compares the response of gravitropic wild type Arabidopsis thaliana with the agravitropic (growth without a gravitational response) AtPLA1 knockout, A. thaliana mutant, and observes root structure (post-flight fixed samples), in particular microtubule orientation, to understand how the root structure contributes to the waving and coiling process.

**Description**

Waving and coiling of Arabidopsis roots at different g-levels (WAICO) shall help understand the interaction of circumnutation (the successive bowing or bending in different directions of the growing tip of the stems and roots) and gravitropism (a tendency to grow toward or away from gravity), by observing the waving and coiling of Arabidopsis thaliana wild type and an agravitropic mutant (Atpla1-1 knockout). Specifically, verify that circumnutation of Arabidopsis roots is driven by an endogenous mechanism that is independent of gravity as a cue.
Biological Samples
Arabidopsis thaliana, wild type (ecotype Wassilewskija) and strain (knockout line for gene At1g61850)

Experiment protocol summary
- Seeds launched dry and separated from agar, maintained at ambient temperature during upload.
- Reagents stored on orbit at +4 °C prior to the activation of the experiment for up to 7 months from time of hand-over.
- Seeds stored on orbit at +4 °C prior to the activation of the experiment for up to 7 months from time of hand-over. Alternative storage is ambient, but in this case the seeds should be exposed to +4 °C for at least 7 days (vernalisation) & vernalisation should occur within 1 month of the experiment activation.
- Cultivation for nominally 12 days at 22 °C in ethylene free air with high humidity (80% or above) and continuous illumination (prefer 5000-10000lux).
- Minimum 30 seeds per g-level and plant type (wild type and mutant).
- 1 cultivation bowl with 15 seeds each in each Experiment Container (EC).
- All seeds germinated at 1-g, with g-vector acting perpendicular to agar surface for approximately 3 days.
- Growing seedlings observed by video every day, samples briefly re-orientated to permit perpendicular view of agar surface with growing seedlings.
- Samples re-orientated at 45 degrees to g-vector and cultivated for approximately 9 days.
- Samples photographed with high resolution stills camera at end of experiment run prior to fixation.
- Samples fixed, then washed twice at end of run.
- Refrigerated stowage of fixed samples after end of experiment run for up to 3 months (prefer download within 4-6 weeks after end of experiment run).
- Fixed samples downloaded in refrigerated stowage.

General Experiment Procedure

Parameters measured:
- Inflight parameters measured:
  - Daily video observation of root position
  - High resolution photography of seedling at end of experiment run (before fixation)
- Post-flight analysis
  - Root structure (post-flight analysis on fixed samples)

Figure 3-12: WAICO Hardware Layout and Main Features
3.5.2 BIOLAB Experiment TRIPLELUX (TPLX)

The risk assessment for human health in space - especially for long duration missions - requires the disentanglement of a complex interplay of parameters in order to understand the mechanisms that cause the reported physiological responses. The aim of the TRIPLELUX experiment is to gain a better understanding of the cellular mechanisms underlying the following biological phenomena observed during spaceflight:

- Aggravation of radiation responses in microgravity
- Impairment of the immune functions under spaceflight conditions

**Experiment Parts A & B:**
Observation of the rate of phagocytosis in vertebrate (A) and invertebrate (B) immune cells to investigate the effects of microgravity and LEO cosmic radiation on this basic immune function.

**Experiment Part C:**
Observation of gene activation following DNA damage, caused by LEO cosmic radiation and UV irradiation, to investigate the induction of DNA repair under spaceflight conditions.

**Figure 3-13: BIOLAB Experiment TRIPLELUX (TPLX)**

The cellular responses are translated into chemical- or bioluminescence signals as a rapid optical reporter system
Main hardware item:
- Stock Culture Bag (SCB), storable down to -96 °C
- Integrated Advanced Experiment Container (I-AEC) containing luminescence detector systems and electronics
- Specific protocol for the utilization in space and in Biolab of the luminescence detectors developed by Astrium
- HM Plate Unit (HMPU) prepared with nutrient mixture, storable down to -20 °C
- Viability Test Experiment Container (VT-EC): cell viability test preparation for microscope, and liquid storage

In-orbit Crew-performed hardware assembly:

**Figure 3-14: TRIPLELUX In-Orbit Hardware Assembly**

Main Features:
- Cell cultivation between +18 and +37 °C, at µg or 1-g
- Luminescence measurement (photon counting) at 350 to 550 nm for several hours
- Data downlink
- 1 or 2 cultivation cuvettes
- 4x measurement cuvettes
- 1 or 2 liquid reservoirs for automatic injection
- Gas supply via gas permeable material
- Biocompatible
- Irradiation of cell culture by integrated UV-LED (Part C, optional)
- Density measurement (optional)
- Magnetic stirrer to avoid sedimentation on the 1-g centrifuge
- Automatic liquid distribution inside the experiment container
- Return of biological samples at low temperature possible

- Modular design for multiple future usage

Liquid volumes (per reservoir):
- Stock culture bag: 1 to 5 ml
- Cultivation cuvette: 4 to 10 ml
- Measurement cuvette: 4 to 5 ml
- Liquid reservoirs: 1 to 5 ml
- Sample Return: 0.1 to 2 ml

- I-AEC:
- HMPU:
- MD-EC
- VT-EC:
- SCB:
- I-AEC incl. HMPU:

**Table 3-4: TRIPLELUX Experiment Unique Equipment**

Qualification Status: ☑ Qualified for use on ISS
### 3.5.3 BIOLAB Experiment CERASP / CELLRAD

**Experiment Scientific Objectives:**
During spaceflight the Crew is exposed to a unique environment providing µg-conditions and an increased radiation level with different composition. The impact on humans has to be studied in more detail to be able to derive clear requirements to protect crews during long-term missions on the ISS or in future missions to Moon and Mars.

The experiment CELLRAD, formerly CERASP, focuses on the "Cellular Response to Radiation in Space" and studies the effects of radiation combined with microgravity. To get a sound understanding, there will be a control experiment in space running in parallel without radiation. The experiments will be executed under µg and 1-g conditions.

It is planned to use one of the three different sub-clones of human embryonic kidney cells (HEK/293), which provide specific characteristic capabilities:

<table>
<thead>
<tr>
<th>Cell type</th>
<th>Special characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEK-pCMV-EGFP</td>
<td>DNA repair proficient, Viability reporter strain</td>
</tr>
<tr>
<td>HEK-pNFκB-d2EGFP/Neo</td>
<td>DNA repair proficient, NFκB reporter strain (damage induction)</td>
</tr>
<tr>
<td>HEK-pNFκB-EGFP/Neo</td>
<td>DNA repair proficient, NFκB reporter strain (damage accumulation)</td>
</tr>
</tbody>
</table>

Table 3-5: CELLRAD (formerly CERASP) Experiment Cell Types

The use of A549 cells (a lung carcinoma cell line) is to be considered as a backup.

These are all mammalian cells, which have to be cultured as attached cells for the experiment phase.

The cultures are exposed in-flight to artificial radiation doses, "imitating" the space radiation. After the radiation the cultures are incubated for different durations to start or to perform the DNA repair process. Then they are fixed with formaldehyde, and stored until the analysis on ground. There is no in-flight analysis required.

**The biological objectives are:**
- Gene activation of mammalian cells by space flight conditions, based on a fluorescent promoter reporter system using green fluorescent protein
- Radiation-induced apoptotic cell death
- DNA damage and repair in mammalian cells, using a micro-scale adapted method of DNA unwinding (microFADU)
- Chromosome damage represented by chromosome aberrations, sister chromatid exchange and micronuclei induced by radiation applied directly under space conditions.

**Hardware Description**
- The CELLRAD Experiment will be performed in an ECDS (Experiment Container Double Sealed).
- All liquid contacting parts can be sterilized.
- The biological material is pre-seeded by the scientist in cut-outs of standard 96 multi-well plates.
- The MPU (Multi-well Plate Unit) contains a selected multi-well plate and a system to provide liquid exchange to all 18 wells (6x3). Per ECDS 2 MPUs as the experiments heart are mounted.
- The tanks contain approx. 12 ml of culture medium for the medium exchange and approx. 12 ml of fixative for the termination of the experiment. The waste liquid compartment has a capacity of approx. 24ml.
- The irradiation of the cell culture is provided by Pm-147, a beta-radiation source. In this experiment a dose between 0 and 15 Gray can be achieved, in 3 Gray steps. The irradiation is switched on and off by a shielding mechanism.
- Pumps provide a fully automatic liquid flow through all 36 culture chambers (each with approx. 100µl volume, 2 MPUs). The pump speed is about 1ml/min (adjustable).

**Experiment sequence:**
- The radiation source is mounted in the ECDS. This is performed by qualified personnel only.
- The pre-seeded multi-well plate assembly is mounted in the ECDS. This task can be performed by the PI.
- The tanks are filled with the necessary liquids. This task can be performed by the PI.
- The ECDS will be closed. This task can be performed by the PI.
- The ECDS will be placed on its experiment platform or Ground Support Equipment (µg or 1-g). This task can be performed by the PI.
- The experiment will be started (These tasks can be performed by the PI):
  1. Pressing a button will open the shield of the shielding mechanism unit.
  2. The cells will be irradiated for a given time span.
  3. After this time span the shield will be closed, either by automatic control or by pressing a button.
  4. After a given time span the culture medium will be exchanged by activating the pumps either by automatic control or by pressing a button.
  5. After a given time span the fixative will replace the culture medium by activating the pumps and valves either by automatic control or by pressing a button.
  6. The experiment is terminated. The scientist can remove the biological samples or the entire ECDS can be stored for any time span in a given temperature.
The above described experiment steps and their sequence can be arranged and adapted in multiple ways. Several liquid exchanges can be performed, e.g. by adding tanks. The hardware is designed to give maximum freedom to the scientist, once the radiation source installed. When the ECDS is closed, it can be handled safely. The design is compliant to NASA safety rules.

Thanks to the specific design of CELLRAD, Astrium is able to maximize the usage of COTS Multiwell plates that are normally used in Biological laboratories on ground, so that the heritage and successful history of compatibility with standard biological samples is granted and applied to the specific experiment objectives of investigating radiation effects on Biological samples in microgravity.

Figure 3-15: BIOLAB Experiment CELLRAD Drawing

Figure 3-16: BIOLAB Experiment CELLRAD

Figure 3-17: CELLRAD Multi-well Plate Unit: Exploded View

Qualification Status: Under Development for use on ISS

All the space you need
4. European Modular Cultivation System (EMCS) Facility

4.1 EMCS Facility Overview

The European Modular Cultivation System (EMCS) is an ESA experiment facility that is dedicated to studying biology in a reduced gravity environment on the ISS. It supports the cultivation, stimulation, and Crew-assisted operation of biological experiments under controlled conditions (e.g., temperature, atmospheric composition, water supply, illumination, observation, and gravity). Up to now the facility has performed seven experiments and processed more than 300 culture cells in 200 days of science operation, investigating the effects of gravity and light on the early development and growth, signal perception, and transduction in plant tropisms. Experiments with insects, amphibians, and invertebrates as well as studies with cell and tissue cultures are also foreseen in EMCS.

EMCS was launched in July 2006. It is installed in an EXPRESS-Rack on-board the European Columbus Module as part of the International Space Station (ISS). It is operated by the Norwegian User Support Center (N-USOC) in Trondheim with engineering support from Astrium/Germany. Astrium is also responsible for the regular maintenance of the facility to provide full service to experiments.

4.2 Scientific Objectives

The main research focus of the EMCS facility is plant biology. EMCS supports experimental investigation of:

- Long term growth stability in plants including multi-generation studies (seed-to-seed)
- Early development in plants
- Gravity influence on early development and growth (g-level threshold research)
- Influence of light in plant phototropism
- Perception and signal transduction in plant tropisms
- Possibility for research on small animals, tissues and cell cultures, also on radiation effects.

4.3 Facility Description

The EMCS facility contains an incubator with two slowly rotating rotors. Each rotor can accommodate up to four Experiment Containers (ECs), which house the so called Experiment Unique Equipment (EUE), dedicated to the specific investigation. Through the rotors, life support (temperature, humidity, O2 and CO2, trace gas removal) and water is supplied to the ECs, as well as illumination (white and infrared) and observation capabilities.

EMCS operates autonomously with regards to its facility-provided services. Crew involvement is needed for experiment set-up (EC installation into incubator) and exchange of consumables such as gas and water. After finishing the experiment set-up, the facility can be controlled by commanding either from the ground or by the Crew via the on-board EXPRESS Laptop.

The EMCS modular design allows for the implementation of alternative rotors, which could be designed and built in the future to accommodate experiments with larger plants and invertebrates, aquatic species, or for confocal microscopic observations. Such specific rotors are currently not available and would have to be developed for specific experiments.
4.3.1 EMCS Facility Main Features

- Slots for up to 8 Experiment Containers (ECs) on 2 rotors inside the incubator
- Micropore filters (0.2 μm pore size) in all air- and water systems
- Artificial gravity: 0.001-g to 2-g (independently controlled on both rotors)
- Incubator temperature: +18 °C to +40 °C
- Incubator atmosphere: O₂: 15% to 22%, CO₂*: 0.2 to 5.5 % (rest: N₂)
  *) CO₂ concentration equivalent or higher than concentration in Columbus Lab
- Incubator flushing with N₂ for atmosphere set-up
- Ethylene removal from experiment
- Filtered (0.2 μm) air flow through EC (rel. humidity: 30%, 50% to 90%, flow rate: 0.2 to 0.4 l/min)
- Filtered (0.2 μm) water supply to and removal from EC: 0.4 to 0.8 ml/min
- Power supply to EC: +/-12V, +5V
- Data channels per EC: 2 analog out, 4 digital in/out, 1 serial (RS485), 1 NTSC video
- LED illumination of experiment along g-vector:
  - Full/reduced white illumination: >75 W/m² (reduced: about 50 W/m²) in the range 400-700 nm with a peak at 468 nm and increased red light
  - Infrared illumination: 935 nm
  - Camera infrared illumination along the optical axis (perpendicular to g-vector)
- Video observation of experiment through transparent cover: analog color NTSC video and digital still images. Field of view: wide range: complete EC, resolution 0.3 mm; max zoom: 30 x 22 mm, 0.1 mm resolution
- Housekeeping and science data sampling rate: 1 Hz
- Video recording: analog Hi-8 NTSC video tape recorder
- Downlink of analog video and digital still images

Figure 4-1: EMCS installed in EXPRESS Rack 3 in Columbus on ISS
**Figure 4-2: EMCS Facility including subsystems (view into incubator with open main door)**

- SPLC
- Holding Structure
- Rotor E-Box
- Video Camera
- ACS Sensor + Gas Removal Module
- VES-GN2 Module
- EC mounted on Centrifuge
- RBLSS Module
- Centrifuge Motor
- Centrifuge Rotor
- ACS Gas Modules

**Figure 4-3: EMCS Incubator Front View**

- EMCS Connector
- EC Exchange Doors
- EC Door Locking Lever
- GN2 and VES I/F Module
- CO₂ Supply Module
- Air-Mix Supply Module
- Rotor E-Box
- Main Door
- Seat-track portions
- Thermal Control System (TCS)
- EMCS
- Connector

All the space you need
4.3.2 Modular Design

The modular design of EMCS allows exchanging all experiment related, life-limited components on-orbit. As required by experiment resources and duration, a number of modules are designed to be replaceable on orbit as part of standard Crew activities:

- Water Reservoirs
- RBLSS Modules
- Gas Removal Modules
- Sensor Modules
- Airmix and CO₂ Supply Modules

4.3.2.1 Water Reservoirs

Filled with 230 ml pure, sterile water, it is used by the humidity control and for experiment specific water supply (e.g. hydration). In addition it collects waste water from the experiment and the dehumidifier. One water reservoir serves 4 Experiment Containers on one rotor.

4.3.2.2 Rotor Based Life Support System (RBLSS) Module

This module provides the air flow, humidity control, and water supply to, and removal from, Experiment Containers. One RBLSS Module serves 2 Experiment Containers.
4.3.2.3 Gas Removal Module

This module contains absorber material to remove ethylene from the incubator atmosphere produced by the experiments.

Figure 4-6: Gas Removal Module

4.3.2.4 Airmix and CO₂ Supply Module

Compressed gas bottles for oxygen-enriched air (30% O₂, 70% N₂) and for CO₂, used by the atmosphere control system.

Figure 4-7: Airmix and CO₂ Supply Module

4.3.2.5 Sensor Module

Contains sensors for oxygen and carbon dioxide used by the atmosphere control system and for safety supervision.

Figure 4-8: Sensor Module

4.4 EMCS Experiment Container

Up to this day more than 120 Experiment Containers with a standardized design were built for experiments in EMCS. Experiment Containers interface with the rotors of EMCS and are used to integrate experiment specific hardware mechanically and electrically.

4.4.1 Experiment Container Main Features

- Available experiment volume per EC: 160 x 60 x 60 mm³ (g-vector along long side)
- Maximum experiment mass: 1000 grams
- Micropore filters (0.2 μm pore size) in air- and water systems
- Single shot valves to seal ECs hermetically (e.g. after fixation)
- Closed EC provides one level of safety containment; additional levels have to be realized by the experiment inside the EC
- Power: +12V DC, -12V DC, +5V DC; max. continuous power per EC: 1W
- 2 analog out lines to EMCS
- 4 digital in/out lines from/to EMCS
- Serial interface from/to EMCS
- NTSC video interface to EMCS
- Pressure sensor
- Humidity/temperature sensor
- Transparent cover allowing illumination and observation

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4.4.2 Experiment Container Design

Experiment Containers (EC) provide the mechanical, fluid, and electrical interface between the experiment and the EMCS. They allow experiment developers to design and integrate their experiment hardware for operation in EMCS. Experiment Containers are produced by Astrium as ordered by the experiment developer.

An Experiment Container consists of a baseplate and a transparent cover which, when mounted, provides an enclosed, air-tight volume (60 x 60 x 160 mm³) for the experiment, fixed mechanically to the baseplate and connected to gas, water, power and data.

The transparent cover allows illumination and observation of the experiment in the closed EC.

An electrical connection is available to provide electrical power, data acquisition, and command or housekeeping signals for the experiment.

The baseplate is equipped with a differential pressure sensor, which monitors the pressure difference between the closed EC volume and the EMCS incubator. A relative humidity/temperature sensor is provided on request. This allows the sensor to be implemented in the most suitable location within the EC volume, depending on the experiment design.

All containers have labels on both, the baseplate and the cover for visual identification. The electronics in the baseplate also contain an ID chip which allows for electronic identification and linking of each individual container to its own unique data and command files.

The EC temperature control inside the EMCS facility is based on a temperature sensor in contact with the bottom side of the baseplate. This sensor is installed at the EC interface on rotor side. For usage of EC internal power sources a proper heat rejection towards the EC baseplate has to be ensured by the experiment developer. Heat rejection shall be realized by conduction to the baseplate metallic surface.

4.4.3 Level of Containment

The EC provides a single level of containment for liquids, gases, vapors, solids, and biological contamination when in the stand-alone configuration (not attached to the EMCS centrifuge). The EC is able to maintain this level of containment up to a differential pressure of 1 bar.

Levels of Containment for different mission phases

<table>
<thead>
<tr>
<th>Mission Phase</th>
<th>Gases</th>
<th>Liquids</th>
<th>Solids/Biological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch/Landing</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>On-orbit Stowage</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Installed on EMCS Rotor</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Installed on EMCS Rotor after</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Single-Shot-Valve Activation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(non-reversible closure of EC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>air and water interface)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4-1: EMCS EC Levels of Containment

All the space you need
Figure 4-11: External dimensions, top view (Camera view)

Figure 4-12: External dimensions, long side view

Figure 4-13: Internal dimensions available for experiment, illumination side view

Figure 4-14: Internal dimensions available for experiment, long side view

Qualification Status: ☑ Qualified for use on ISS

All the space you need
4.5 EMCS Ground, Test and Laboratory Equipment

4.5.1 Experiment Reference Model (ERM)

The fully representative Engineering Model (EM) of EMCS is available at the Norwegian User Support Center N-USOC in Trondheim.

Two additional Experiment Reference Models ERM1 and ERM2 are available at N-USOC and at NASA Ames Research Center in Moffett Field, CA.

The ERMs offer all functional interfaces to perform a complete experiment inside the EMCS Experiment Containers with a gravitational orientation like on the EMCS centrifuge.

Both ERMs have been built by Astrium and are presently maintained by the N-USOC with technical support of Astrium.

4.5.2 Experiment Container Development Kits (ECDK)

Astrium provides interface kits to users and experiment developers for functional testing of their experiment hardware. Further details on these Experiment Container Development Kits are available upon request.

4.6 EMCS Experiments

4.6.1 EMCS Experiment Multigen-1

(Molecular and Plant Physiological Analyses of the Microgravity Effects on Multigenerational Studies of Arabidopsis thaliana)

Figure 4-15: Multigen-1 Experiment accommodated in EMCS EC
(Developed by Prototech under subcontract to Astrium)

Investigators
Tor-Henning Iversen, PhD., Norwegian University of Science and Technology, Trondheim, Norway

Biological Material/Specimen
Arabidopsis thaliana

Experiment Scope
Molecular and Plant Physiological Analyses of the Microgravity Effects on Multi-generation Studies of Arabidopsis thaliana (Multigen) studied the full life cycle of Arabidopsis thaliana, a small flowering plant related to cabbage and mustard, in microgravity. The experiment had the following goals:

- To achieve successful long duration space exploration a renewable food source for the astronauts must be available.
- To examine the possibility of sustainable plant growth for long-duration space exploration by growing several generations of the plants in orbit.
- To study seed production and viability of Arabidopsis thaliana in microgravity.

The results of this investigation will support future plans to grow plants on the long-duration transit to Mars.
Experiment Protocol
The seeds were launched in a dry state inside the dedicated Multigen hardware in an EMCS experiment container, maintained at 22 °C. Prior to experiment execution, the plant cultivation chambers were placed inside EMCS by the Crew. Hydration was performed autonomously by EMCS, inducing germination. The growth process was closely followed using the EMCS provided time-lapse video system. After a maximum growth period of 90 days, and with mature plants, EMCS initiated a dehydration process. The plant cultivation chambers were then removed from EMCS and stowed for return to Earth. Following their return to Earth, the dehydrated plants, as well as images captured during flight, were used for ground-based morphological studies.

Mission
Multigen-1 was performed on the ISS during Increment 16 in 2007.

4.6.1.1 Hardware Description
The Multigen-1 experiment was accommodated inside an EMCS Experiment Container (EC) using dedicated hardware, the Plant Cultivation Chamber PCC, as shown in Figure 4-16. The PCC has an exchangeable “flower pot” that can support growth of different types of plants, and was optimized for the Multigen-1 experiment and the cultivation of Arabidopsis thaliana. It is capable of supplying nutrients and EMCS-delivered water supply and air circulation to the plant accommodated in the EC, and it is permanently mounted for the duration of the experiment.

Figure 4-16: Multigen-1 Experiment Container (EC)

Figure 4-17: Multigen-1 Experiment Schematic

The PCC is composed of the following components: a cover, locking cover, growth substrate container, sealing cover, PCC block, and bottom lid. Towards the EC base plate a cover (made of anodized aluminum) with two separate grooves is mounted and fixed with four M3-screws. (Absent in next generation of PCC due to rearrangement of the water inlets). One groove is for the water supply tube and the other is for the flying leads connected to the switch/connector board. This cover protects and hides the wires and the tube from the EC baseplate. The locking cover (made of anodized aluminum) is locking the growth substrate container and covering the water supply tube. It also prevents eventually condensed water to drain down to the switch/connector board. This cover is fixed with four screws (one at each corner) through the sealing cover into threads in the PCC block.

The growth substrate container (made of stainless steel with lid made of black acryl PMMA) is only coupled to the inlet water supply tube and is easily removable when the locking cover is dismounted and the water tube disconnected. The sealing cover (made of anodized aluminum) is protecting the components and electronics installed inside the PCC block. The PCC block is connected directly to the gas inlet and outlet, and it fixes the EC baseplate fixation threads with two M3 setscrews and nuts. The bottom lid covers the cavities below the PCC consisting of an air duct and the volume containing water absorbent borosilicate fibers (for water trapping). The PCC assembly is shown in Figure 4-18, and the PCC components and interfaces are shown in Figure 4-19 and Figure 4-20.
Figure 4-18: Assembly of the Multigen-1 PCC

Figure 4-19: Components of the Multigen-1 PCC

The following EMCS EC services were used by the Multigen-1 hardware:

- Temperature sensor inside Experiment Container
- Humidity sensor inside the Experiment Container
- Water supply from EMCS System (6-8 ml per EC/PCC for germination, 0.25-1 ml per day during growth period)
- Water removal in the event of over-watering of the PCC
- Air circulation (supply and removal); O₂ = 21% ± 1%, ethylene < 0.01 ppm, relative humidity 50-90%
- Thermal control (+18 to +25 °C)
- 2 analog lines (telemetry)
- 3 digital lines (commanding capabilities)
- +5V power supply
- Illumination at maximum level for day-night cycle
- Video frame-grabbing of still pictures (1 picture/min for the first 3 days, 1 picture/10min for 10 days when leaves have developed)
- 1 picture/30min for the rest of the experiment period
- Schedules for automated control of the Multigen experiment in EMCS.

Qualification Status: ✔ Qualified for use on ISS
4.6.2 EMCS Experiment GRAVI-1

4.6.2.1 Experiment Description

Investigator
Dr. Dominique Driss-Ecole, Université P. et M. Curie, Paris, France

Biological Material/Specimen
Green Lentils (Lens culinaris)

Experiment Scope
It was the scientific goal of the GRAVI-1 experiment to investigate three parameters of the gravitropic response for better understanding of the perception and the transduction of the gravistimulus during initial plant growth:

- the first one is the presentation dose (minimum quantity of stimulation to provoke a significant curvature),
- the second one is the threshold acceleration for gravisensing (minimum acceleration which can be perceived),
- the last one is the minimum deviation from the gravity vector, which leads to a re-orientation of the root.

The experiment was performed with lentil seedling roots exposed to centrifugal acceleration levels from $10^{-2}$-g to $10^{-3}$-g after microgravity in order to determine the threshold of acceleration the roots respond to.

Experiment Protocol
The lentil seeds were launched in a dry state inside the culture chambers. They started to germinate in microgravity after hydration with distilled water. The seedling roots were stimulated by means of the EMCS centrifuge for 30 hours, while the gravitropic response (root curvature) is recorded by time-lapse video observation. Thus, it was possible to determine precisely the threshold acceleration at which the root responds to the gravity stimulus.

Two experiment runs were performed. After termination of each experiment run the Culture Chambers with the plants were photographed by the Crew.

Mission
The GRAVI-1 experiment hardware was launched on 10 December 2006 with Space Shuttle flight STS-116. The experiment was performed in EMCS on 15 - 18 January 2007, the return of the hardware was in August 2007 with STS-118.

All the space you need
4.6.2.2 Hardware Description

The experiment accommodation inside the EMCS EC is shown in Figure 4-24. The GRAVI-1 experiment uses a Handler as support structure, and two Culture Chambers, located on both sides of the Handler. The Culture Chambers are fixed to the Handler via a bracket system. This system allows an easy operation and can also be handled in a glovebox if required.

The Handler is bolted to the EC Base plate and it is not removable in orbit.

The GRAVI-1 experiment did not apply toxic chemicals. Pure water is used to hydrate the seeds.

Figure 4-24: Accommodation of GRAVI-1 experiment inside the EMCS Experiment Container

Handler

The Handler is a small box bolted to the EC base plate. It provides air to the Culture Chambers and electrical power to their transparent heaters. Air and electrical power are provided by the EMCS system. The Culture Chambers are exchangeable and manually attached to the Handler by Crew.

Culture Chamber

Each GRAVI-1 experiment container is equipped with two Culture Chambers manually attached to the Handler by the Crew. The design of the Culture Chamber is shown in Figure 4-25.

Figure 4-25: GRAVI-1 Culture Chamber components

The Culture Chamber has two nested housings:

- Inner chamber containing the seeds (on top and bottom side of the Culture Chamber)
- Outer chamber for air supply

The inner chamber of the Culture Chamber housing has a special shape which was optimized for an equal hydration of the spongy substrate using the test results from parabolic flights.

The lentils are kept in position by three so called capture elements in each of the two inner chambers of the Culture Chamber. Each capture element can hold four lentils.

The windows sides towards the Biofoil are equipped with a transparent heater. The heater consists of a micro-thin wire laid in a pattern between optical grade polyester sheets. The heaters prevent fogging of the Biofoil, which would restrict the observation of the seeds in the inner chamber. The Biofoil allows gas exchange, but retains water.

Qualification Status: ☑ Qualified for use on ISS
4.6.3 EMCS Experiment GRAVI-2

4.6.3.1 Experiment Description

Investigator
Dr. Valérie Legué, Université Henri Poincaré, Nancy, France

Biological Material/Specimen
Green Lentils (Lens culinaris)

Experiment Scope
The GRAVI-2 experiment is the second part of an overall experiment GRAVI, which is split into two different experiment phases that are carried out in two different missions aboard the ISS.

The scientific goal is to investigate the parameters of the gravitropic response of lentil seedling roots for better understanding of the perception and the transduction of the gravistimulus during initial plant growth.

The aim of this experiment is to study the implication of amyloplasts displacement and calcium signalling in root gravitensing, and thus to understand cellular signalling mechanisms involved during the threshold acceleration.

Specific goals:
1. To subject lentil seedling roots to centrifugal acceleration levels from 10^{-1}-g to 2-g and in microgravity
2. To determine the movement of amyloplasts under the influence of the stimulation.
3. To analyse free calcium distribution and calcium binding- and targeted-proteins.

All the space you need

Experiment Protocol
The lentil seeds are launched in a dry state and start to germinate after hydration with distilled water. The seedling roots will be stimulated by means of a centrifuge for several hours and the gravitropic response (root curvature) will be followed by time-lapse photography during this centrifugation. Thus, it will be possible to determine precisely the threshold acceleration at which the root responds to the gravity stimulus. After the stimulation period, the roots will be observed again to cover all visually detectable results. The samples will be available after the mission. The samples will be automatically chemically fixed after the experiment execution and analyzed on ground. The Fixatives were classified as Toxic Hazard Level 2 and Toxic Hazard Level 1 and require 3 and 2 levels of containment, respectively.

Block Diagram
Showing:
- the air flow through the Handler and the Culture Chambers
- the fixative flow from the Fixative Unit to the Culture Chambers

Mission
The GRAVI-2 experiment is presently scheduled to be launched and returned with the SpaceX Flight 1 of NASA’s Commercial Resupply Services, planned for the year 2012.
4.6.3.2 Hardware Description

The experiment accommodation inside the EMCS EC is shown in Figure 4-28, while Figure 4-27 presents the corresponding block diagram. The EUE of GRAVI-2 consists of a support structure (Handler) which provides interfaces for two Culture Chambers (CC) and one Fixative Unit (FU). The Chambers are connected to the Handler via a bracket system. This system allows an easy one-handed operation that can also be performed in a glovebox. The same design of brackets / latch was already successfully used during GRAVI-1.

The Handler, CC, and FU provide 2 levels of containment each.

While the two kinds of chambers have to be replaced by the Crew for performing two separate runs of the experiment, the Handler is bolted to the EC Base plate and it is not removable in orbit.

The GRAVI-2 experiment is using chemical fixatives that are toxic liquids. Otherwise, pure water is used to hydrate the seeds. The water is added manually by the Crew before installing the Culture Chambers into the Experiment Container.

This hardware allows the flexible handling of liquids between the positions of the handler and therefore serves a wide range of plant experiment protocols.

Culture Chamber

Each GRAVI-2 experiment houses two Culture Chambers (CC), attached to the Handler. The design of the GRAVI-2 CC is shown in Figure 4-29.

The CC has two nested compartments:
- Inner chamber containing the seeds (on top and bottom side of the CC)
- Outer chamber for air supply

As for GRAVI-1, the Culture Chamber the inner chamber of the Culture Chamber housing has a special shape optimized for a uniform hydration of the spongy substrate. The lentils are kept in position by three capture elements, and the windows sides towards the Biofoil are equipped with a transparent heater.
**Fixative Unit**

The biological material of GRAVI-2 will be automatically fixed after 30 hours of germination. Therefore a Fixative Unit (Figure 4-30) is placed on the Handler beneath one of the Culture Chambers. The Fixative Unit has similar septa interfaces as the CC. It can be connected to the Handler via the same latch, interfaces and Penetration Units. Inside the Fixative Unit a flexible membrane divides the fixative bag and the waste air volume.

**Handler**

The Handler is mounted to the EC base plate and serves as interface between the CCs, FUs and the EC base plate. It provides mechanical, gas, fixative liquid, thermal and electrical interfaces.

All air and fixative interfaces to the CC are established via Penetration Units. These Units are controlled via the EMCS SPLC computer and a dedicated control board of the Handler.

The same EC with integrated Handler can be used for several experiment runs.

Figure 4-31 shows the Handler integrated into the EC, Figure 4-31 only the Handler.

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**Figure 4-30: GRAVI-2 Fixative Unit**

**Figure 4-31: GRAVI-2 Handler on EC Base Plate**

**Figure 4-32: GRAVI-2 Handler**
Fixative Unit (FU) Container and Culture Chamber (CC) Container

The Fixative Units provide two levels of containment. For stowage and transportation of the Fixative Units, containing the toxic chemical THL2, dedicated metallic containers, the Fixative Unit Containers as shown in Figure 4-34 (left), will be used. They provide the required, third additional level of containment. Two Fixative Units find place in one FU Container.

Also, the Culture Chambers are providing two levels of containment. After fixation of the experiment material with the fixative THL2, the additional third level of containment can be provided by the Culture Chamber Containers, see Figure 4-34 (right). Four Culture Chambers can be placed into the CC Container for stowage and transport.

Figure 4-34: GRAVI-2 Fixative Unit Container (left) and Culture Chamber Container (right)

Qualification Status: ☑ Qualified for use on ISS

Transport Boxes

For launch and on-orbit stowage of the ECs and syringes Transport Foams are available. The Syringe Pouch can stow ten syringes that will be used by the Crew for manual watering of the GRAVI-2 experiment. The EC Transport Box contains four ECs (see Figure 4-36).
4.6.4 EMCS Experiment GENARA-A

4.6.4.1 Experiment Description

Investigator
E. Carrero-Diaz, Université Pierre et Marie Curie, Paris, France

Biological Material/Specimen
Arabidopsis thaliana

Figure 4-35: GRAVI-2 Syringe Pouch

Figure 4-36: GRAVI-2 EC Transport Box

Qualification Status: ❑ Qualified for use on ISS

All the space you need
Experiment Scope

Previous space experiments have shown that plant growth was disturbed in microgravity although the seed-to-seed cycle could be completed by *Arabidopsis thaliana*. It has been postulated that the microgravity environment itself has a negative influence on basic physiological processes of the plants. Due to the culture conditions and the lack of 1-g reference controls in space, the impact of stress conditions on the measured effects/results could not be solved or measured.

The goal of the initially planned GENARA experiment was to address the existence of genes regulated by gravity, whose expression depends (at least) upon the mechanism of gravisensing and the redistribution of hormones (especially the plant hormones IAA (auxin, Indole-3-Acetic Acid) and ABA (Abscisic Acid)). The growth of *Arabidopsis* was followed by video observation, and models of plant architecture were provided for 1g controls and samples grown under µg. Transgenic plants, harboring either IAA or ABA responsive elements, were used. These elements drive specifically the expression of a reporter gene. These local bio-monitors reported the local (re)distribution of IAA and ABA at the plant’s tissue level when cultivated under µg and in parallel under 1-g reference conditions.

In the long run it is expected that the understanding of altered molecular activities induced by space flight will help to design plant systems that compensate the negative impact on plant growth in space. This aspect is of special importance for the application of plant based systems as part of biological life support systems or as food source for long-term missions.

Experiment Protocol

The experiment consisted of three parts, each addressing a specific aspect and lasting 14 days (for part 1 and part 3) and 10 days (for part 2):

- Part 1 focused on the changes of the plant hormone IAA
- Part 2 had the focus on the gravity regulated genes (GRG)
- Part 3 was dedicated on the induction of the plant hormone ABA.

Gene differentially expressed under µg versus 1-g controls were analyzed on ground by DNA array technology and protein profiles. For these analyses, specially processed/preserved or frozen sample material was used.

Mission

The GENARA experiment hardware was launched on May 14, 2010 with Space Shuttle flight STS-132. The experiment was performed in EMCS on July 09 – 23, 2010; the return of the samples was in March 2011 with STS-133.
Culture Chamber

Each GENARA-A Experiment Container houses four Culture Chambers attached to the Handler. For the experiment performance, chromatography paper, white tissue sewed with white thread, and two rows of seeds are added.

The Culture Chamber is shown in Figure 4-41 and Figure 4-42.

Hardware Description

The experiment accommodation inside the EMCS EC is shown in Figure 4-40. GENARA-A used a Handler as support structure, and four Culture Chambers, located on the inner side of the rotor, pointing to the LED panel of the EMCS facility. In addition two heater foils are bonded to the inner side of the EC cover. The Culture Chambers are fixed to the Handler via a lever system. This system allows an easy, one handed operation by the astronaut and can also be handled in a glovebox if required.

The Handler is bolted to the EC Base plate and it is not removable in orbit.

The GENARA-A experiment did not use toxic chemicals. Pure water is used to hydrate the seeds automatically inside the EC for starting the experiment run on the EMCS Rotor.

Figure 4-40: Accommodation of GENARA-A experiment inside EMCS Experiment Container

Figure 4-41: Design of the GENARA-A Culture Chamber

Figure 4-42: Frame with Biofoil (left) and Culture Chamber Bottom (right)
Handler

The Handler (see Figure 4-43) serves as holding structure for the four Culture Chambers. It provides the gas interface and the water distribution via four valves that are triggered by the built-in electronic.

Figure 4‑43: GENARA-A Handler

Figure 4‑44: Handler Mounted on EMCS Experiment Container

Qualification Status: ☑ Qualified for use on ISS
5. Type I Experiment Facilities

5.1 BIORACK Heritage

The ESA/BIORACK facility, originally developed for the Spacelab and first flown on the D1 mission, has proven to be the most versatile facility ever built for life science experimentation in space. It was used during a time span of 12 years and served on the 6 missions: D1, IML1, IML2, SMM3, SMM5, SMM6.

In the course of these missions a complete infrastructure was developed, consisting of:

- Incubators (22 °C & 37 °C)
- Centrifuges (1-g and variable-g)
- Coolers
- Freezers
- Passive Thermal Conditioning Units
- Glovebox
- Photo & Video Equipment
- Microscope
- Ambient Stowage Provisions

Figure 5-1: BIORACK Heritage
89 individual experiments were realized according to two standard experiment containers, which were especially developed for BIORACK (Type I/O, I/E & Type II from left to right).

**Figure 5-2: BIORACK Experiment Containers Type I/O, Type I/E & Type II**

The flight model of BIORACK is now integrated in the Spacelab module, on display in the "Bremen-Halle" at Bremen airport, Germany. The large inventory of support hardware, however, is still available for further utilization in other programs, and the standard BIORACK experiment container has been used as baseline for numerous other facilities.

**Figure 5-3: Various BIORACK Facility & Experiment Hardware**

5.1.1 Centrifuge

The original BIORACK 1-g centrifuges were developed as a pure 1-g reference to distinguish between µg and other spaceflight effects (radiation, stress...). These centrifuges were used during 3 Spacelab flights: D-1, IML-1 & IML-2. For 3 more missions (SMM3, 5 & 6) they underwent a modification process, adding the feature to change the speed set-point for a resulting g-level between 0.1 and 1.5-g for threshold studies.

The standard centrifuges were equipped with sliprings for power and data transfer to the experiments on the centrifuge (2 positions). Some were equipped with supply of 4 positions.

**Qualification Status:**
- ☑ Qualified for STS
- ☑ Qualified for unmanned capsule missions (BION/FOTON)
- ☑ Under development for use on ISS
5.1.2 PTCUs

A special transport system with a passive thermal control based on phase-change materials was developed for the BIORACK experiments. These PTCUs (Passive Thermal Control Units) can provide controlled temperature levels of –10 °C, +5 °C and +10 °C for a maximum of 20 ECIs per PTCU and a maximum standing time of 16-20 days. The PTCUs were fitted in Middeck locker inserts which housed additionally a set of ECIs at ambient temperatures.

Figure 5-4: PTCUs and PTCU rack

Sectional Drawing of PTCU

Qualification Status: ☑ Qualified for STS

5.1.3 NIZEMI

DLR’s NIZEMI (German acronym for “Niedergeschwindigkeits-Zentrifugen-Mikroskop” = slow rotating centrifuge microscope), has been developed as a facility for threshold studies under observation (micro- and macroscopic) in a thermally controlled environment. The NIZEMI experiments were developed compatible to the BIORACK experiment container system. The BIORACK facility was used for the incubation and manual processing of the experiments, while the NIZEMI facility was used for the subsequent sample analysis. Astrium is currently in the development of the next space microscope generation for on-orbit in-situ and in-vivo analysis. This generation shall represent the first convocal fluorescence microscope facility for a TEXUS application (called FLUMIAS) and is considered for capsule applications at a later stage.

Figure 5-5: NIZEMI (Slow Rotating Centrifuge Microscope)
5.1.4 Standard Experiment Container Type I and Type II

The original BIORACK Experiment Containers consisted of four types:

- EC I/O
- EC I/E
- EC II/O
- EC II/E

The Type I has 68 ml internal volume, the Type II 350 ml. During the development of the BIOBOX 6 facility under ESA contract, the standard type I containers have been modified to a new bigger thickness which results into 114 ml internal volume. These containers are called IBEX. E stands for electrical interface. The EC II containers do not fit on a BIORACK centrifuge.

5.1.5 Modified Experiment Container

In the course of the use of the BIORACK experiment container system, a variety of non-standard types were developed, according to individual experiment applications. Examples are from left to right:

- EC I/O standard type
- EC I/O for gas exchange via Teflon foil (retaining vapor)
- EC I/E w. piggy bag for CO₂ supply, compatible with BIOBOX centrifuge
- EC I/O w. windows for illumination and observation
- EC I/O w. Gore-Tex membrane for increased gas exchange
- EC I/E standard type

For the DornierMinisystem (internal Dornier R&D project) a special experiment container type with liquid interface was developed. The interfaces shall enable experiments which require larger volumes than the standard EC I to be fitted on a standard BIORACK centrifuge. The interfaces can be mated/ demated in flight without leakage, keeping the system compatible with the BIORACK infrastructure (e.g. PTUAs).

Qualification Status:
- 🌴 Qualified for use on ISS
- 🌴 Qualified for use on STS
- 🌴 Qualified for use unmanned capsules

Figure 5-6: BIORACK Containers (Type I/O, Type I/E and Type II/O)

Qualification Status:
- 🌴 Qualified for use on ISS
- 🌴 Qualified for use on STS
- 🌴 Qualified for use unmanned capsules (BION/FOTON)

Figure 5-7: Modified BIORACK Experiment Containers

Qualification Status:
- 🌴 Qualified for use on ISS
- 🌴 Designed for use on unmanned capsule missions

Figure 5-8: Modified BIORACK Experiment Containers
5.1.6 BIORACK Standard in other facilities

Based on the BIORACK standard a series of facilities has been developed following the same experiment containers standard, as shown in the following figure. The experiment standard delivered since 1985 in more than 25 missions the impressive record of more than 120 experiments and of more than 300 publications in peer reviewed journals. It is today still continued with ESA's KUBIK and BIOBOX facility and will be soon available through Nanoracks for US National Lab users.

Fig. 3-9: Facilities following BIORACK Experiment Container Standard.

5.2 BIOBOX

The BIOBOX facility is composed of two incubators, an interface box for capsule missions (FOTON, Shenzhou) and a harness in between see following Figure 5-9 and Figure 5-10.

Figure 5-9: BIOBOX Overall Facility Configuration

Figure 5-10: BIOBOX in Flight Configuration for FOTON (left) & Front Doors Removed (right)
For an EXPRESS rack accommodation of BIOBOX on the ISS, the interface box is not required and can be connected directly via its internal serial interface.

To grow biological samples (typically cell cultures) in space, the incubators of BIOBOX-6 provide the required environment for the experiments. Before starting the experiments the temperature inside the incubators is around +20 °C. When the experiments are started the temperature is steadily increased to +36.5 °C, the optimum living and working temperature for mammalian cells. (Other temperatures e.g. +22 °C for plant experiments are also possible). At the same time in each incubator the reference centrifuge, located on an extractable Experiment Platform, is started. Once the experiments are finished the cells are chemically fixed, the centrifuges are stopped, and the temperature is lowered to +4 °C. This temperature shall be maintained until the end of the mission.

5.2.1 Technical DATA

A summary of the technical data is given in the following:

- 2 Middeck-Locker size incubators, each with variable-g centrifuge
- Experiment platform for variable experiment accommodation, standard platform for 32 EC (ratio 1-g : µg, 1:1)
- Temperature range +4 to +40 °C
- Interfaces compatible for FOTON, shuttle and ISS accommodation
- Manual or fully automated processing of experiment units
- Telemetry and on-board data storage
- Incubator Mass incl. Experiment Platform: approx. 32 kg
- Standard Experiment Interface: Experiment Containers (EC) TYPE I and I/X
  - Centrifuge: 16 EC
  - Static rack: max. 28 EC
- Power Consumption
  - Run Mode 36 °C: 40 W
  - Cool Mode 6 °C: 50 W
  - Transients 5K/h: 80 W
  - Peak: 130 W
  - Sleep: 20 W
- Internal data storage capacity: 512 MB

**Qualification Status:**
- ☑ Qualified for use on ISS
- ☑ Qualified for use unmanned capsule missions

5.3 NanoRacks

Astrium and NanoRacks offer a platform for microgravity investigations with a centrifuge for gravitational research. The centrifuge system, based on a standard experiment container system, was developed by Astrium for ESA and has been used for more than 120 experiments for various topics, mainly in biology and life sciences.

The joint facility allows a continuation of this research and is operated under NanoRacks’ Space Act Agreement with NASA as part of NASA’s National Laboratory on the International Space Station. The gravitational facility allows for a first time access for commercial users to an in-orbit centrifuge for 1-g reference and threshold studies.
6. Type I Experiment Containers

The BIORACK type experimentation is based on the accommodation of various Experiment Unique Equipments (EUEs) into Experiment Containers which provide the interface to facilities and support infrastructure.

The infrastructure is standardized for a variety of experimental facilities assuring that Experiment Containers and the Experiment Unique Equipment that had been developed for one facility can also be used within one of the others by following the same standard.

EC interfaces and capabilities were continuously upgraded. SIMBOX for Shenzhou 8 offers now continuous power for internal LEDs and pumps. An EC based camera for video observation will be realized for the NanoRacks Centrifuge.

Figure 6-1: BIORACK Type I Experiment Containers and new EUE design concepts

Qualification Status:
- ☑ Qualified for use on ISS and unmanned capsule missions
- ☑ Qualified for use on unmanned capsule missions
7. Type I Experiment Inserts

7.1 Unit 28 D/1

This experiment unit is suitable to perform liquid cell culture experiments with a dedicated initiation and final preservation.

The experiment unit 28 D/1 was developed by Astrium (former DASA/Dornier) for Prof. Mennigmann at the University of Frankfurt. It flew with bacteria cultures during 3 Spacelab missions:
- D-1
- IML-1
- D-2

Figure 7-1: Unit 28 D/1

The basic functions are shown below:

Figure 7-2: Unit 28 D/1 Basic Functions

Qualification Status: ☑ Qualified for use on STS

Unit specifications:
- Culture volume: 12.6 ml
- Volume for adding of liquids: 2x1.1 ml
- Sample volume: 0.5 ml
- Vol. for sample fixative: 0.063 ml
- Gas exchange via Teflon membrane (area: 15 cm²)
- Mass: 180 g (including EC I)
- The experiment activation/fixation is performed manually with a tool
7.2 BIOLABOR – FLUC

The experiment unit FLUC was developed by Astrium (former DASA/Dornier) for Prof. Mennigmann at the University of Frankfurt. It served for the investigation on the genetic stability of growing microorganisms. It flew during the Spacelab mission D-2.

Specifications:
- 82 culture compartments
- Volume of compartments: 0.1 ml each
- Compartment sealed individually with rubber pistons
- Material: Polysulfon (autoclavable)
- No manipulation during mission

Qualification Status: ☑ Qualified for use on STS

Figure 7‑3: BIOLABOR‑FLUC

All the space you need

7.3 BIOLABOR – CULT/GROW 2/1

The experiment units CULT/GROW were developed by Astrium (former DASA/Dornier) for Prof. Reske at the University of Mainz. It served for the investigation on the growth behavior of lymphocyte cells. The units were used during the Spacelab mission D-2.

Specifications:
- 2 culture compartments
- Volume of compartments: 10 ml each
- Compartment sealed with septa
- Material: Polysulfon blocs & gas permeable foil (both autoclavable)

Manipulation during mission: Injection & removal of samples via septum with syringe. The units are complemented by a dosing aid, filter units, syringes and sample/culture units with 4 bags each.

Qualification Status: ☑ Qualified for use on STS

Figure 7‑4: BIOLABOR‑CULT/GROW 2/1
7.4 BIOLABOR – CULT/GROW 4/1

The CULT/GROW sample unit was developed by Astrium (former DASA/Dornier) for Prof. Reske at the University of Mainz. It served for the fixation of lymphocytes and flew during the Spacelab mission D-2.

Specifications like CULT/GROW unit but:

- 4 compartments
- Volume of compartments: 4.5 ml each
- 2nd sealing level for containment of fixative (glutaraldehyde)

Figure 7-5: BIOLABOR – CULT/GROW 4/2

Qualification Status: ☑ Qualified for use on STS

7.5 BIOLABOR – META

The META experiment unit was developed by Astrium (former DASA/Dornier) for Prof. Mueller at the Medical University of Lübeck. It served for the investigation of metabolic activity & biosynthesis of connective tissue cells. It flew during the Spacelab mission D-2.

Unit specifications:

- 5 culture compartments
- Culture volume: 2.6 ml each
- Marker volume: 0.26 ml each
- Cell plate area: 185 mm²
- Material: Stainless steel & Titanium
- Mass: 283 g incl. Container
- Blocs can be disconnected and processed individually

Launch Configuration:
Axle position 1
Cell plate exposed to culture volume
Radioactive marker (proline) contained separately

Experiment Initiation:
Axle position 2
Turn of axle connects the radioactive marker compartment with the culture volume

Experiment Stop:
Axle position 3
Turn of axle separates cell plate from the culture volume.
A compensation volume in the axle allows freezing of the unit

Qualification Status: ☑ Qualified for use on STS
7.6 BIORACK– CHARA

The CHARA hardware was developed by Astrium (former DASA/Dornier) for Dr. Buchen at the University of Bonn. It served for the investigation of the growth of CHARA rhizoids. The cuvette can be fitted on the NIZEMI for macro- & microscopic observation during application of g-level profiles. The unit has two compartments for liquid exchange (e.g. fixative, washing liquids). The exchange is performed with a special tool. It flew during the Spacelab missions IML-2 and the Shuttle-to-Mir Mission-05 (SMM5).

Figure 7-7: BIORACK– CHARA

7.7 NIZEMI - CRESS

The CRESS cuvettes were developed by Astrium (former DASA/Dornier) for Prof. Volkmann at the University of Bonn. It served for the investigation of the behavior of cress roots under µ-g and g-level profiles (NIZEMI). It flew during

- IML-2
- SSMM3
- SSMM5

During SMM5 a special tray was developed, allowing the CRESS cuvettes to be photographed with time lapse on the BIORACK/PHOTOBOX (CNES/COMAT).

Notice also that the seeds are grown in perpendicular direction to the picture above.

Figure 7-8: CRESS Tray

Qualification Status: ☑ Qualified for use on STS
The operation of the CRESS cuvettes included:
- Activation, manual watering with syringe (0.4 ml), above
- Growth period (4 cuvettes per EC I, 1-g, μ-g, g-levels)
- Fixation, manual addition of fixative with special tool for slow, bubble-free filling and waste bag

Specifications:
- Cuvette volume: 4 ml
- Seed holders for different growing directions (8-12 seeds)
- Water volume: 0.4 ml
- Fixation volume: 4 ml (polycarbonate blocs with piston)

**Qualification Status:** ☑ Qualified for use on STS

### 7.8 FUNGI

The experiment FUNGI of Prof. Hock and Dr. Hahn (Technical University of Munich) investigated the chromosome crossing of fungi under space conditions. The experiment flew on SMMS.

The technical configuration of FUNGI is as follows: BIORACK EC I containers were prepared with air holes. Each container held four small petri dishes with nutrient medium. BIOSTACK particle detector foils were mounted to each polystyrene petri dish stack to measure the absorbed radiation dose.

The fungal cultures and nutrient medium were stored at +4 °C before experiment initiation in orbit by transfer to a +22 °C incubator.

During the mission video images were transferred to the ground before the cultures were stored again at +4 °C for landing.

**Qualification Status:** ☑ Qualified for use on STS

All the space you need
7.9 EC I as Hermetically Sealed Storage

For the BIORACK D1-experiment LYMPHO (Dr. A Cogoli, Technical University of Zurich) a special syringe storage container was developed. BIORACK EC I (and II) containers have been used to hermetically seal a variety of materials and liquids.

Syringes storage containers have been flying in support of many experiments.

7.10 Mamba (Motorized Ampoule Breaker Assembly)

**Principle:**
The MAMBA Unit has been designed for biological experiments in which the biological specimen is contained in sealed flexible bags. One or more capillary glass ampoules are stored also inside the bags (typically with stimulus and fixative for successively activation and fixation of the experiment). The position of the ampoules is fixed with rods, which can be rotated by means of a DC motor, thus breaking the ampoules in order to release the contained fluid. The timing of the experiment can be programmed using Windows software, the unit identification and timing parameters are stored in the MAMBA. During the experiment, temperatures and timing events are stored in the MAMBA internal flash memory to allow evaluation of the experiment after download of the data.

The MAMBAs are accommodated in a standard type I/E container and require a 8-13 V experiment start trigger. When used in an environment in which batteries are allowed, batteries can be integrated to provide temperature measurements and absolute timing during the whole mission (without batteries this will be limited to the time the external power is on).

**Flight History:**
The MAMBAs (without internal timer) were flown during the Biopack STS-107 mission and the Soyuz mission Cervantes. The MAMBAs as described here were flown in the Kubik facility during ISS Increment 12 and 13 mission (March/April 2006) carrying the Myocyte experiment.

**Specifications:**
- **Size:** ........................................... 20x40x80 mm³ (Type I/E container compatible)
- **Experiment bag size:** ............ 76x33 mm (2x) / 76x16 mm (4x)
- **Materials:** .............................. PEEK Stainless Steel
- **Electrical I/F:** .......................... 8-13 V Input
- **Power:** .................................... 5 mA during acquisition/timing
  - 100 mA during activation/fixation (duration 2.5 s)
- **Memory:** ............................... 512 kb (>30000 temperature/log events)
- **Timeline using batteries:** ........ 20 days max.
- **Temperature sensor accuracy:** ... 0-70 °C
- **Temperature accuracy:** ............. 0.5 °C

**Qualification Status:**
☑️ Qualified for use on ISS
☑️ Qualified for use on STS
7.11 Biorack Tadpoles & Oreochromis

A Mini Aquarium was developed for Prof. Horn at the University of Ulm for the investigation of the behavior and development of tadpoles and tilapia fish (Oreochromis).

A special gas permeable / water impermeable foil is used for primary containment, allowing observation through the foil. The container has increased gas permeability (Gore-Tex) for a sufficient air supply.

Figure 7-13: Mini Aquarium

Specifications:
- Aquatic volume: 45 ml
- Material: PSU & Biofoil exposed
- Gas permeability through foil

Additional aquarium types exist for smaller sizes (e.g. 8 per EC) as well as types with additional septum ports for manual operations.

Qualification Status:
☑ Qualified for use on ISS
☑ Qualified for use on STS

7.12 Feeding & Recycling Unit

Aquatic experiments with adult fish and prolonged experiment times require feeding capabilities and water quality management. A distributed system with fluid connection between several dedicated functional units allows the experiment within the BIORACK system including access to a 1-g reference centrifuge.

Qualification Status: ☑ Designed for use on ISS
7.13 SIMBOX TYPE V

The fully automated Type V experiment insert was developed for the SIMBOX mission under contract of DLR. It shall serve agar-based experiments which shall either be preserved with fixative or enriched with nutrients in liquid form. It can be equipped with holding structures for e.g. callus cultures, with single or stacked slides, with self-made customized inserts or without any insert at all. Furthermore it can change its functionality by replacing the membrane window with an illumination window.

It has been proven to be optimized for cell callus or small plants experimentation requiring automatic fixation without any disturbance by Crew interaction.

Figure 7‑15: Plant Cultivation Unit (SIMBOX Type V)

7.13.1 Hardware Description

Main Features:
The EUE of Type V consists of a support structure (housing made of PEEK) which includes two Culture Chambers (CCs), the pump support structure, a Fixative Unit (Tank) and a canal system. The chambers can be closed with different windows made of Polycarbonate or Polysulfone (PSU). A Fixative/Waste Unit is connected to the Culture Chambers via tubing and tube connectors. It is mounted to the housing with four screws. A pump is integrated into the housing. It is fixed by two cylinder head screws. The container lid of the Type I-Container is mounted to the housing to provide an easy assembly for the PI.

Figure 7‑16: Type V, without Tray System and without illumination

Hardware Specifications:
- The EUE (with EC support) does not exceed the interior envelope of the closed EC SIBX-DE-X. Dimensions EUE (LxWxH): 84,5 x 40 x 30 mm
- The Experiment consists of 2 Culture Chambers, each has the following size (radii not included): CC (LxWxH): 31,7 x 24 x 14,3 mm ± 0,15 mm
- The mini-pump has a flow rate of ≥2,43 ml/min
- The mini-pump has a power consumption of ≤ 70 mA
- One support structure per culture chamber
- The tank has a volume of 20,3 ml ± 0,5 ml

Function:
The two chambers are filled with biological cells, plants, or other material. The Fixative Unit is completely filled with a nutrient liquid or a fixative. The flexible membrane in between allows the liquid to expand and fill the whole tank volume (in the drawings the tank membrane is symbolized for a simpler illustration). The pump will be activated after a certain time to pump the stored liquid into the chambers. The waste tank will compensate the pressure. Liquids or air from the Culture Chambers (CC) will be pushed into the waste tank.
Suitable for Life Sciences

**1st Step: Initial Status**

- **CC1**
- **CC2**
- **Pump**
- **Tank, Liquid**
- **Tank, Waste**

**2nd Step: Activation**

- **CC1**
- **CC2**
- **Pump**
- **Tank, Liquid**

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**Extra:**

- **Windows**

There are different variations available for the windows. The standard window is the solid one, made of Makrolon. There are also several different shapes with cut-outs. These are covered by a gas permeable membrane (so-called 'Biofoil') which is glued on the window frame with a special adhesive. These windows allow that oxygen can enter the chambers. The Biofoil windows are made of PSU and are bio-compatible.

![Figure 7-18: Different Windows for Experiment Unit Type V](image)

Additionally, an LED window is available. It is made of the transparent material Makrolon and has an LED panel to simulate a day/night cycle. Different LEDs can be used for the illumination.

All windows are mutually compatible.

- **Slides**

The CCs (Culture Chambers) can be filled with biological material of any kind. To simplify the insertion and to fix the cells there is the possibility to use specimen slides.

The Agar Tray has spikes to allow a better grip for the Agar or cells. A normal tray made of Makrolon allows inserting the cells after they have been taken in culture. The tray system accommodates up to two slides on top of each other.

All slides can be used inside a slide holder to take the cells in culture - before the insertion.

![Figure 7-19: Different Substrate Holders (slides) for Experiment Unit Type V](image)
One-Chamber-Housing

The Type V housing has two CCs. They are connected with two bore holes through the wall in between. There is also the possibility to have them not connected. That means one chamber could have no connection to the pump or the tank.

Example

In general there are two Type V experiment possibilities. The housing contains either two connected chambers connected to the tank or one chamber without connection that cannot be flushed with liquids.

Every housing can be equipped with different windows (below: windows with LEDs, windows with Biofoil, solid windows) and slides (below: one slide, tray system). Otherwise they will be assembled the same way.

Figure 7-20: Housing for Experiment Unit Type V

In that case the pump activation will only pump the fixation or nutrition liquid into the first CC. From there the waste material will directly flow into the waste side of the tank.

In the block diagram the flow direction of the liquids are shown, and the activation of the pump is symbolized.

Figure 7-21: Block Diagram for Experiment Unit Type V

Step 1: initial status

Step 2: activation

Figure 7-22: Main Housing Options for Experiment Unit Type V

The normal Type V model has tank assembled at the bottom to have the possibility to supply the biological material with liquid (fixation/nutrition). To use the Type V experiment for an aquatic system with only liquids, there is a way to only have the housing with the pump without the tank. In that case one chamber is filled with the material and the other with a fixative (only example). The two bore holes connecting the CCs are used for two valves. This way an early exchange will be avoided. After activation of the pump a pressure is building up and the valves open to mix the two liquids. Also for the version the different windows can be used (here: window with LED and solid window).

Figure 7-23: Experiment Unit Type V (without tank)

Qualification Status:
- Qualified for unmanned capsule mission
- Designed for use on ISS
7.13.2 Experiment Descriptions

Functional genomic analysis of plant signal transduction and secondary metabolism under microgravity (Oryza sativa)

Investigator
Weiming Cai, Institute of Plant Physiology and Ecology, CAS, Shanghai

Biological Material/Specimen
Rice Callus Cultures

Experiment Scope
Comparative transcriptomic analysis of rice cells, in response to microgravity, 1-g centrifuge and the ground gravity. Analysis of transcript profile in rice cells under microgravity, to identify the genes that are involved in microgravity sensing, signaling, and metabolism adjustment, and to expand our understanding of the molecular mechanism of microgravity response.

Molecular biology basis of cytoskeleton responding to microgravity in plant cells

Investigator
Prof. ZhengHuiqiong, Institute of Plant Physiology and Ecology, CAS, Shanghai

Biological Material/Specimen
Arabidopsis cell cultures

Experiment Scope
The cytoskeleton is fundamentally involved in most cell biological processes, such as proliferation, cell wall formation, auxin transport, and may play an important part in gravisensation and gravitropism, ranging from translation to signaling. Proteomics has also been considered as the most promising technique for identification of proteins that are induced, repressed, and post-translationally modified during gravity response in plant cells. Despite the apparent involvement of the cytoskeleton in plant cell gravity responses, the underlying molecular mechanisms still remain largely unknown. In our previous study, a proteomic analysis of responses of the Arabidopsis callus cells to clinostat rotation showed that clinostat rotation had a significant impact on the expression of proteins. Using the BIOBOX incubator, we plan to extend this data to the microgravity-regulated cytoskeleton proteins that function in the microgravity response mechanisms using Arabidopsis callus cells.

Investigation of rice proteomic change in response to microgravity

Investigator
Prof. SunWeining, Institute of Plant Physiology and Ecology, CAS, Shanghai

Biological Material/Specimen
Rice Callus Cultures

Experiment Scope
The goal of the experiment is to study the microgravity response of plant cells at the proteomic level. Therefore the plant material namely rice callus will be carried into the space by the space ship Shenzhou-8. The plant material will be fixed in space, and calli will be collected after recovery of the space ship and used for proteomic analysis. The proteome change will be compared with the material cultivated in the in-flight 1-g centrifuge and on the ground.

The study of animal behavior and development (C. elegans)

Investigator
Prof. Wang Gaohon, Institute of Hydrobiology, CAS, Wuhan

Biological Material/Specimen
Caenorhabditis elegans

Studies on development and physiological response of algae in space

Investigator
Prof. Hu Chunxiang, Institute of Hydrobiology, CAS, Wuhan

Biological Material/Specimen
Haematococcus pluvialis

Gene expressions analyses for plants stimulated by space microgravity condition (Arabidopsis thaliana)

Investigator
Prof. Liu Min, Institute of Genetics and Developmental Biology, CAS, Beijing

Biological Material/Specimen
Arabidopsis thaliana seedlings
Molecular adaptation of *Euglena gracilis* to microgravity

**Investigator**
Prof. Lebert, University Erlangen, Germany

**Biological Material/Specimen**
*Euglena gracilis*

Expression of plant genes and proteins under microgravity (*Arabidopsis* callus culture)

**Investigator**
Prof. Hampp, University Tübingen, Germany

**Biological Material/Specimen**
*Arabidopsis thaliana* callus

Experiment Scope

Cell cultures offer a homogenous population of cells with identical properties. They are thus ideally suited to assay plant responses to a changing environment. In our experiment we use callus cells from *Arabidopsis thaliana* (cv. Columbia), derived from stems. This material has been shown to exhibit rapid responses on the molecular level to biotic and abiotic stress. While exposure to e.g. altered gravitational fields yield transient adaptations in the range of hours, exposure to more than 24hrs, appear to establish new physiological steady states. With the SIMBOX experiment, we like to investigate what kind of physiological steady states are established under prolonged periods of microgravity. These will be assayed by the determination of the state of gene and protein expression at given periods of exposure.

For the purpose of conservation of a given physiological state, the cell cultures will be metabolically stopped (quenched) by the addition of a quenching agent such as RNA later. Proper sample/agent mixing ratios given, this method has been shown to yield intact RNA up to 21 days at bench temperature (24 °C; own experiments, unpublished).

For transfer from the capsule back to the laboratory in Tübingen for analysis, samples should be kept closely above freezing point by cold packs, contained in styrofoam boxes.

Analysis of microgravity modulated gene networks

**Investigator**
Prof. Palme, University Freiburg, Germany

**Biological Material/Specimen**
*Arabidopsis thaliana* seedlings (wild type and gravity insensitive mutant)

Experiment Scope

Aim of this experiment is to analyze changes in gene network organization (genome-wide analysis of RNA expression) upon microgravity effect. We aim to compare 5-days old etiolated Arabidopsis seedlings of wild type (Columbia-0) and of a mutant affected in gravireponse and related to auxin signalling pathway. Gene expression pattern and reconstructed on its base signalling networks will be analysed for photosynthetic (hypocotyl) and non-photosynthetic (root apical meristem -RAM-, elongation zone, mature root) gravisensing organs of Arabidopsis seedlings. Sterile seeds will be incorporated on a carrier, supplemented with dried growth medium, and will germinate after hydration using sterile water. Control seedlings (centrifuge 1-g) and seedlings continuously exposed to microgravity (µg) for both, wild type and the mutant line, will be chemically fixed using RNA later (Ambion) after 120 hours. RNA will be isolated from different seedlings areas, linearly amplified and used for microarray gene expression profiling. Ground controls (1-g) and additional experiments will be performed in parallel at laboratory environment.
7.14 SIMBOX Type IV

The fully automated type IV experiment insert was developed for the SIMBOX mission under contract of DLR.

It shall serve experiments with cell cultures which need to be in a medium and require enrichment of the media with fresh nutrients as well as a sample fixation. Contents of two tanks which can be filled with any liquid can be automatically pumped into the experiment volume. It can be equipped with single slides as well as with self-made customized inserts or without any at all.

It has been proven to be optimal for non-adherent cells in media experimentation requiring automated liquid injection without any disturbing Crew interaction.

7.14.1 Hardware Description

Main Features

The Type IV EUE consists also of a support structure. The housing is made of PEEK, but has, different from the Type V, only one chamber. Moreover there is also a pump but two smaller tanks. That means there is the possibility of two liquid changes. Since this is an aquatic system with liquid inside the window is a solid Makrolon window. The flowing directions are managed by a tubing system with valves. This pump is able to pump in two directions.

Hardware specification:

- The EUE does not exceed the interior envelope of the closed EC SIBX-DE-X. Dimensions EUE (LxWxH): 84.5 x 40 x 30 mm
- The Culture Chamber has the following volume: 13.5 ml ± 0.3 ml
- The mini-pump has a flow rate of ≥ 2.43 ml/min
- The mini-pump has a power consumption of ≤ 70 mA
- The Window has the size of 77.26 x 37.26 mm
- The tanks have a volume each of 11.5 ml ± 0.3 ml

Function:

The biological material is inside the CC stored in a liquid. The pump will be activated to start the first fluid exchange. The fluid exchange (in order to feed alternatively to fix the biological material) within Type IV experiments is an automated process. Therefore two Fixative Units (A and B), each containing about 12.3 ml of fluid, are placed beneath the Culture Chamber (V=12.9 ml). Each Fixative Unit consists of three main parts: an upper shell, a membrane and a lower shell. The membrane made of Elastosil M4600 is glued-in strain-relieved and serves as a barrier between fresh and waste medium, which means between liquid stowed in the unit before experiment start and liquid which will be replaced within the chamber and therefore be pressed into the unit.

Each unit has two septa ports used for filling before experiment start and withdrawal of waste fluid after experiment run. Furthermore, each Fixative Unit has one tube cup with an integrated non-return valve. The flow direction of the non-return valve in Fixative Unit B is opposite of the flow direction in Fixative Unit A. As the pump is running forward and reverses, one port of the Culture Chamber is used as outlet and inlet port as well.
Figure 7-26: Type IV EUE bottom view

For the first fluid exchange the fluid is pumped from Fixative Unit B top part
- through Needle Cup with non-return valve to inlet port 1 (with Filter System big) into Culture Chamber
- through Filter System small of outlet/inlet port 2
- to Pump
- to Cannula Support
- through Tube Cup with integrated non-return valve into Fixative Unit B bottom part

For the second fluid exchange the fluid is pumped from Fixative Unit A
- through Tube Cup with integrated non-return valve of Fixative Unit A
- to Cannula Support
- to Pump
- through Filter System small of outlet/inlet port 2 into Culture Chamber
- through Filter System big of outlet port 3
- through Needle Cup with integrated non-return valve into Fixative Unit A

Figure 7-27: Flow System

Block Diagramm

1. Step

2. Step: First Activation
3. Step: Second Activation

![Figure 7-28: SIMBOX Experiment Unit Type IV Block Diagram](image)

**Qualification Status:**
- ☑ Qualified for unmanned capsule mission
- ☑ Designed for use on ISS

### 7.14.2 Experiment Description

**Impact of microgravity on human thyroid carcinoma cells.**

**Investigator**
Prof. Daniela Grimm, Charite Berlin, Germany

**Biological Material/Specimen**
Human Thyroid Cancer Cells

**Experiment Scope**
The principle aim of this Shenzhou spaceflight is to investigate how thyroid carcinoma cells react, when they are exposed to real microgravity. These experiments will confirm and/or extend the knowledge, which we gained when we characterized the thyroid cancer cells after exposure to simulated microgravity. The expected information may help to improve in vitro cancer studies such as antitumor drug or trans-endothelial migration tests. Therefore, we want to culture single cancer cells of the ML-1 cell line during a two-week Shenzhou spaceflight. During the flight, the cells are expected to form three-dimensional multicellular tumor spheroids (MCTS), which clearly resemble the respective originating tumor. Under conditions of microgravity cells keep floating without stirring so that initial cell-cell interactions required for spheroid formation are induced by forces only due to biochemical components actually expressed on surfaces of cells, but gravity related push and shear events do not influence MCTS formation in Space. Hence naturally directed cell-cell attachment processes are anticipated, as long as cells are exposed to microgravity.

**Differentiation of human neuroglioma cells in microgravity**

**Investigator**
Prof. Wolfgang Hanke, University Hohenheim, Germany

**Biological Material/Specimen**
Human Neuroglioma Cells (SH-SY5Y)

**Experiment Scope**
The goal of the experiment is to study long-term changes in the development and activity of human neuronal cells under microgravity. The emphasis lies on electrophysiological properties.

For this purpose a human neuroblastoma cell line (SH-SY5Y) will be used in the experiments. This cell line has several advantages:

- No GMO (genetically modified organism), thus requiring no special safety means
- well characterized
- relevant repertoire of ion channels (sodium and potassium)
- easy cultivation
- sturdy (e.g. temperature range, tested at 22 °C)
- differentiation can be controlled artificially by chemical compounds in the medium

The experiment itself is relatively simple. Several samples of SH-SY5Y will be transferred in suitable containers in the Shenzhou 8 capsule.

(I) On 3rd day in space (resting phase),

(II) the differentiation of the cells will be started by changing the culture medium with an adjusted medium. The cells should incubate in the medium for 5 days. In this time the cells multiply and start to become real neurons.

(III) Afterwards the medium will be changed to a 4% PFA fixation medium
7.15 SIMBOX Mini Aquarium

The Astrium Mini Aquarium was manufactured for many μ-gravity research experiments on fishes and tadpoles for ESA. The family of the passive Mini Aquarium systems in different configurations was driven to serve other experiments by the Simbox mission contracted by DLR.

The units mainly differ in size and arrangements in order to have optimized conditions for nematodes, fungi experiments, Drosophila experiments and much more. It is the space application of a typical Petri dish equipment with a gas-permeable membrane, guaranteeing gas exchange but preventing the loss of humidity.

Hardware Description

The EUE of the passive aquarium consists of a support structure (housing) which is covered by a gas permeable membrane (Biofoil) and closed with a metal frame. One of the housings is divided into 4 Chambers, 2 large ones and 2 small ones with a ratio of 2:1. The frame is mounted with screws and corner stones.

The second passive housing consists of a support structure (housing) which is covered on both sides by a gas permeable membrane (Biofoil) and closed with a metal frame. The housing is divided into two times 4 CCs, where two are bigger than the others.

The systems allow an easy access for preparation.

The housings of the Mini Aquariums provide a safe containment of the specimen. The specimen is mounted on a polycarbonate slide. For easier handling the slide is equipped with a placement aiding screw system. A sealing tightens the Culture Chamber and prevents leakage. A gas permeable membrane (Biofoil) provides the required gas exchange of the Culture Chambers with the environment.

Figure 7-29: SIMBOX Mini Aquarium

Figure 7-30: SIMBOX Mini Aquarium (Passive Housing Types)
Hardware Specifications
- The EUE shall not exceed the interior envelope of the closed EC SIBX-DE-HP 80.3 x 42.6 x 32.4 mm or the envelope of the closed EC SIBX-DE-X-HP 80.3 x 42.6 x 31.6 mm
- There are 4 Culture Chambers, they shall have the following sizes: 2 x Small: 5.83 ml, 2 x Large: 11.66 ml or for the second passive EUE. The Experiment has got 2 sides (bottom and top), each consists of 4 Culture Chambers with the following sizes: 2 x Small: 6.59 ml, 2 x Large: 6.62 ml
- One Biofoil sheet with one metal cover frame, Biofoil surface: 2 x Large: 720 mm², 2 x Small: 360 mm²

Function
The samples will be enclosed in the housing. Throughout the whole mission there will be gas exchange through the gas permeable membrane with the outer environment. The only difference between the two passive experiments is the size of the CCs, and the second passive housing has chambers on both sides. No electrical connection is required, because there is no need for activation.

Block Diagram:

Figure 7-31: SIMBOX Mini Aquarium (Passive Housing Configuration)

Figure 7-32: Block Diagram Mini Aquarium (Passive)

Qualification Status:
☑ Qualified for unmanned capsule mission
☑ Designed for use on ISS
7.15.1 Experiment Descriptions

First Passive EUE

- Synergistic effects of space radiation and microgravity on Drosophila and C. elegans

Investigator

Prof. Sun Yeqing, Dalian Maritime University, Dalian

Biological Material/Specimen

Drosophila and C. elegans

Experiment Scope

Samples of Drosophila in egg stage (2 strains) and C. elegans in Dauer stage (2 strains) are chosen in this experiment. They will be divided into two groups, one group in aquarium with 4 chambers container (in µg environment), while another group in 1-g rotational aquarium with 4 chambers container. The samples will be cultured in containers throughout the flight. They will be collected when the mission ended for further research.

Ground-based research including simulated irradiation and microgravity treatment on the same samples will be conducted at the same time.

All these samples will be collected for genetic and epigenetic research on systemic level to reveal the biological synergistic effects of space radiation and microgravity.

Second passive EUE

- Spaceflight effects on microbial growth and metabolism

Investigator

Prof. Huang Ying, Institute of Microbiology, CAS, Beijing

Biological Material/Specimen

Bacillus subtilis, Streptomyces sp.

Experiment Scope

Microbes have the ability to sense and respond quickly to environmental changes. This property, as well as the convenience of handling and short life cycle of microorganisms, makes microbes excellent research materials for spaceflight. Although spaceflight conditions are known to have profound effects on numerous microbial parameters, the mechanisms by which these occur are unknown. This experiment is designed to investigate the effects of spaceflight on the growth and metabolism of spore-forming prokaryotic microorganisms, and to probe into the molecular mechanisms of the effects. Cells will be inoculated on agar or in broth in the cultivation chambers of EC, which will be loaded into SIMBOX on ShenZhou-8. The cells will go through their life cycle in space. Cells will be recovered alive for morphological, physiological and genetic analyses.

7.16 SIMBOX Green House

The Green House experiment insert was developed for the SIMBOX mission under contract of DLR.

It shall serve the growth of higher plants under µg-conditions in solid media (agar or soil). It has a dedicated illumination which is homogeneous over the height of the chamber in order to avoid an inhomogeneous growth of the plant. Especially during the first stage of the growth special housing shapes allows a sufficient illumination (light spot) on the surface of the agar. Gas-permeable membranes ensure the gas exchange with low loss of humidity.

Figure 7-33: SIMBOX Green House

Hardware Description

The experiment consists of housing with two sides of Biofoil to ensure gas exchange. On top a LED panel is mounted to provide light for the plants.

Figure 7-34: Design for Green House
The bottom part of the green house provides the safe containment of the specimen. The specimen is located in the bottom, which is attached to the cover with a latch mechanism and screws. A sealing tightens the Culture Chamber and prevents leakage. A gas permeable membrane (Biofoil) on both sides of the cover provides the required gas exchange of the Culture Chambers with the environment.

**Hardware Specification:**
- The EUE does not exceed the interior envelope of the closed KIC-SLB-HP 80,3 x 42,6 x 21,6 mm
- The Experiment has got glued-on Biofoil at 2 sides with the following size on each side: Biofoil surface: 2110 mm²

**Function**
The green house can be used to grow plants. The seedlings are planted on Agar in the Agar Container. The Biofoil walls allow a steady gas exchange, and with the LED panel a day/night cycle can be performed. The only electrical activation for this EUE is the light function.

**7.16.1 Experiment Descriptions**

**Metabolism of higher plant in space (Oryza sativa)**

**Investigator**
Prof. Wen Xiaogang, Institute of Botany, CAS, Beijing

**Biological Material/Specimen**
Oryza sativa L. (rice) seed

**Experiment Scope**
Plant photosynthesis is the basis and the indispensable component of a controlled ecological life support system. Understanding the development of the photosynthetic apparatus and its functioning under microgravity is an important role in space research. Our purpose is to further understand how the photosynthetic and other metabolic functions of higher plants are affected under spaceflight conditions.

Rice seeds are planted in agar medium 1 day before the space ship launches. Seeds germinate and grow in the space.
7.17 SIMBOX Closed Ecosystem

The closed ecological system was developed for the SIMBOX mission under contract of DLR. It composes of two aquatic chambers which are separated by a micro-membrane. The membrane can be chosen depending on the material which shall be exchanged between the compartments. It is equipped with fully automated sensors to monitor the number of species and their vitality to get information about the stability of the system. It contains a stirrer to distribute the specimens homogenously in the chamber before the measurements to avoid an inadequate measurement of aggregates.

Figure 7-37: SIMBOX Closed Ecosystem

Hardware Description

The EUE consists of a support structure (housing and cover window made of PSU), which includes an upper chamber with a glued-on gas permeable membrane (Biofoil) and a lower chamber with an integrated stirring unit and an optical density measuring system. The ratio between the volumes of the upper and the lower chamber is 70:30.

The upper chamber is closed by a transparent window and a metal frame. The lower chamber is directly illuminated by LED’s while the upper chamber will also be illuminated but indirectly through the transparent membrane between the two chambers. For filling purposes there is one plug for each chamber (2 x M6) inserted in the front side and also in the cover window.

Figure 7-38: SIMBOX Closed Ecosystem - 3D Schematic

Hardware Specifications

- The EUE shall not exceed the interior envelope of the closed KIC-SLB-E1 Container. Dimensions EUE (LxWxH): 80 x 40 x 35 mm
- There are 2 Culture Chambers, they shall have the following volumes: Top: 14.5 ml, Bottom: 40.27 ml
- The experiment has got illumination with the following number of LEDs and color: 6 low intensity LEDs for night illumination (643nm), 6 high-intensity LEDs for day illumination (645nm).
- Biofoil shall enable gas exchange: Biofoil is modified according PI’s needs. Biofoil surface: 2280 mm²
- The stirrer shall have the following stirring speed: 130 min⁻¹
- Detector shall detect changes in optical density of the specimen suspension
Function
The Joint experiment uses a closed aquatic system. 3-4 different species are housed in 2 compartments, divided by a gas-permeable membrane to ensure gas exchange. The lower compartment with Euglena is equipped with illumination, a stirrer for circulation and a measuring device for optical density measurements.

The Density Measurement Unit (DMU) is a small one-channel absorbance reader. Its purpose is to determine the microbe density in a biological sample within the specified volume of the Joint Experiment Chamber by measuring the light absorbed by the sample.

A microcontroller controls all the functions of the device. A high power LED is used as the excitation light source and a very sensitive photodiode serves as the detecting unit. The detector and the LED are placed across the sample being attached to the experiment chamber walls. The LED emits light of a certain wavelength and intensity which then is partially absorbed by the sample. The transmitted light is measured by the detector. An amplifier converts the photocurrent into a voltage, which finally is converted by the microcontroller into a digital readout value and stored in the non-volatile memory. From the transmitted light intensity, the microbe density can be inferred mathematically.

For ground use contactless oxygen measurement is possible with this device.

Block Diagram
First picture, the "Joint" Experiment Chamber is shown from the side. One can see the top and the bottom chamber with the gas permeable membrane in between. The gas exchange between both chambers is possible throughout the whole experiment.

Joint EUE shown without any electrical functions

In the following Joint EUE only the bottom chamber is shown from the top to make the illustration simpler. The day/night illumination functions independently from the other activations. There are six (night) LEDs which illuminate the whole time and six (day) LEDs which turn off and on in a cycle. To measure the density inside the liquid the DMU is switched on. The LED gives a signal to the receiving part. Just before the density measurement activation the liquid inside the bottom chamber will be swirled by activation of the stirrer.

Figure 7-39: SIMBOX Experiment Unit Type "Joint" Block Diagram

Qualification Status:
☑ Qualified for unmanned capsule mission
☑ Designed for use on ISS
7.17.1 Experiment Descriptions

Study on closed aquatic ecological systems

Investigator
Dr. Michael Lebert, University Erlangen, Germany
Prof. Liu Yongding, Institute of Hydrobiology, CAS, Wuhan China

Biological Material/Specimen
Euglena gracilis, Gobiocypris rarus

Experiment Scope
For the Joint experiment it is planned to use a closed aquatic system. It is intended to have 3-4 different species in two compartments, which are divided by a gas-permeable membrane to ensure the gas exchange. The lower compartment with Euglena is equipped with illumination, a stirrer for circulation and a measuring device for optical density measurements.

7.18 SIMBOX Plunger

The plunger experiment insert was developed for the SIMBOX mission under contract of DLR.

It shall serve adherent cell culture experiments which are cultivated in a medium and require enrichment of the media with fresh nutrients as well as a sample fixation. Two plungers which can be filled with any liquid can be automatically activated to inject the liquid into the experiment volume. It is equipped with single slides which are optically clear for microscope observation. It has been proven to be optimal for adhesive cells in media experimentation requiring automated liquid injection without any disturbance by Crew interaction.

Hardware Description
The EUE of Exp. 15 Ullrich consists of a support structure (housing made of PEEK) which includes three Culture Chambers (CCs) and six Supply Units (SU). Each CC has two Supply Units and represents an independent loop. The CCs are closed on the top of the housing by Specimen Slides (made of PC), where the biological material is attached. The housing is tightened by a silicon sealing and covered by an aluminum plate (cover), which is fixed by screws. The container lid of the Type I-Container is mounted to the housing to provide an easy assembly for the PI.

Figure 7-40: SIMBOX Plunger
Qualification Status:
- ☑ Qualified for unmanned capsule mission
- ☑ Designed for use on ISS

Hardware Specifications
- The EUE shall not exceed the interior envelope of the closed EC SIBX-DE Dimensions EUE (LxWxH): 80 x 40 x 20 mm
- The Bellows shall contain the volume: 620 µl
- The specimen slide shall contain a minimum surface (for cell cultivation) of: 28.1 x 19 mm
- The Plungers shall be able to be activated by the electrical characteristics: U = 5V, I = 310 mA, min. t = 2.5 s
- The inner volume of the Culture Compartment shall be about: 213 µl
- The EUE shall contain 6 supply units (plungers), two for one culture compartment each.

Function
The Plunger Unit has three CCs in which the slides hold the cells. The chamber (covered by the window slide) contains the medium. With the first activation the medium will be exchanged by emptying the first plunger. The waste medium will be pushed behind the empty plunger. This way all plungers are emptied.

For a better comparison between the three CCs always the first plunger per chamber is activated. That means the first, the third and the fifth plunger will be activated first to have the first media exchange for all three chambers. Later the other three plungers will be emptied to change the medium again. The waste material always flows behind the activated plunger.
7.18.1 Experiment Descriptions

Effect of microgravity on activation and function of monocytic/macrophageal cells

- Innate Immunity in microgravity

Investigator
Prof. Dr. med. Dr. rer. nat. Oliver Ullrich, Otto-von-Guericke-University Magdeburg, Magdeburg, Germany

Biological Material/Specimen
Human monocytic cells

Experiment Scope
The proposed project aims to investigate the long-term effect of microgravity on key functions of monocytic/macrophageal cells, the antigen-presenting, phagocytosing immune effector cells of the immune system. For instance, differentiation of monocytic cells into macrophages and the expression of adhesion molecules, which enable close contact to T cells and endothelial cell surface, are crucial and indispensable processes in immune response.
8. Protein Crystallization Facilities

8.1 Protein Crystallization & Diagnostics Facility (PCDF)

Dedicated to Basic Research: To understand the crystal growth process

PCDF was operated aboard the ISS from 03/2009 through 07/2009. PCDF is a multi-user experiment facility mainly dedicated to the in-depth investigation of the protein crystal growth process under microgravity (µg) conditions in the European Columbus module of the International Space Station (ISS). It was built by an industrial team led by ASTRIUM Space Transportation, under a contract with the European Space Agency (ESA).

The PCDF flight model is designed and qualified for a ten years lifetime and a total of 15 ISS mission increments each lasting 3 to 6 months. The facility is composed of two units:

- Process Unit Locker (lower part) containing the process chamber with the protein experiments and the diagnostic instruments
- Electronics Unit Drawer with the computer to control the entire facility autonomously and for tele-science operation

PCDF is equipped with sophisticated diagnostics tools to investigate the protein growth process from the nucleation of first molecules to the full growth of a large crystal. The diagnostics and experiment processing tools are:

- Accommodation of 4 experiment boxes
- Reactors with 50 µl to 3.4 ml protein volume and with composition control accuracy of +/- 5 µl
- Stabilization and control of the experiment temperature with +/- 0.1 °C in a range from +4 to +40 °C
- Black & white high resolution digital camera with 60 dB S/N on 3 axes drive
- Microscope and wide field of view optics
- Interferometers with piezo-controlled phase shift capability and λ/100 resolution.
- Dynamic light scattering in backscattering mode on 3 axes drive
- Telescience capability

PCDF consists of two major units which are the process unit (PU) and the electronic unit (EU). The purpose of the PU is twofold: It is used for up and down transportation of the experiment material and for the performance of the protein crystallization investigations in orbit. This is the reason why the sub-units of the PU have to include all items for the crystallization experiments and the dedicated diagnostics, but also have to include the sub-systems to ensure the appropriate transport and storage of the temperature- and degradation-sensitive protein material.

The process chamber is separated in four sections for either Batch or Dialysis Protein Growth Method supplied with individual temperature and composition control devices. The process chamber includes also the complete wide field of view, microscope, and Mach-Zehnder interferometer optics, as well as the digital CCD camera and the light scattering devices to perform the dedicated diagnostics tasks.

For the proper preparation of the experiments a science reference model is available to the principal investigators.
Summary of PCDF Technical Data:

Process Unit

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of Process Unit (Locker)</td>
<td>516 x 440 x 253 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>26.7 kg</td>
</tr>
<tr>
<td>Max. Power Consumption</td>
<td>&lt; 280 W</td>
</tr>
<tr>
<td>Process Chamber Temperature</td>
<td>selectable out of the following range:</td>
</tr>
<tr>
<td></td>
<td>- +6 °C to +30 °C (during launch and transfer)</td>
</tr>
<tr>
<td></td>
<td>- +14 °C to +30 °C (during in-orbit operation)</td>
</tr>
<tr>
<td>Cooling Medium</td>
<td>Avionics Air (during transfer phase)</td>
</tr>
<tr>
<td></td>
<td>Moderate Water Cooling Loop (in-orbit operation)</td>
</tr>
<tr>
<td>Experiment Temperature Stability</td>
<td>± 0.1 °C</td>
</tr>
<tr>
<td>Performance of Temperature Ramps</td>
<td>yes</td>
</tr>
<tr>
<td>Number of Experiment Boxes</td>
<td>4</td>
</tr>
<tr>
<td>Individual Experiment Box Temperature</td>
<td>± 10 °C with regard to process chamber</td>
</tr>
<tr>
<td>Protein Crystallization Methods</td>
<td>Batch and Dialysis</td>
</tr>
<tr>
<td>Protein Volumes of Reactors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Dialysis: 50, 130, 300 µl</td>
</tr>
<tr>
<td></td>
<td>- Batch: 3 ml (initial)</td>
</tr>
<tr>
<td></td>
<td>- Extended Length (XL): 1.1 ml</td>
</tr>
<tr>
<td>Injection Volume of Reactors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Dialysis: 2 ml</td>
</tr>
<tr>
<td></td>
<td>- Batch: 3 ml</td>
</tr>
<tr>
<td></td>
<td>- XL: 2 ml</td>
</tr>
<tr>
<td>Stirring of Mixed Liquids</td>
<td>yes</td>
</tr>
<tr>
<td>Reactor Material</td>
<td>Quartz Glass</td>
</tr>
<tr>
<td>1000 x 1000 Pixel Digital Video System</td>
<td>black and white with 12 bit resolution and 60 dB S/N ratio</td>
</tr>
<tr>
<td>Wide Field of View Optics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Dialysis: Magnification: 1.2 / DoF 5.9 mm / FoV 10 x 10 mm</td>
</tr>
<tr>
<td></td>
<td>- Batch Magnification: 0.6 / DoF 37 mm / FoV 20.6 x 20.6 mm</td>
</tr>
<tr>
<td></td>
<td>- XL: Magnification: 0.6 / DoF 37 mm / FoV 20 x 8.35 mm</td>
</tr>
<tr>
<td>Microscope</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Dialysis: Magnification: 6.1 / DoF 0.245 mm / FoV 2.0 x 2.0 mm</td>
</tr>
<tr>
<td></td>
<td>- Batch Magnification: 3.0 / DoF 0.94 mm / FoV 4.12 x 4.12 mm</td>
</tr>
<tr>
<td></td>
<td>- XL: Magnification: 3.0 / DoF 0.94 mm / FoV 4.12 x 4.12 mm</td>
</tr>
<tr>
<td>Mach-Zehnder Interferometer</td>
<td>for Batch &amp; Dialysis</td>
</tr>
<tr>
<td>LED Illumination</td>
<td>592 nm for WFOV and 654 nm for Microscope</td>
</tr>
<tr>
<td>Laser Illumination</td>
<td>852 nm</td>
</tr>
<tr>
<td>Light Scattering Optics</td>
<td>Back-scattering Method</td>
</tr>
<tr>
<td>Temperature Controls during Transfer Phase</td>
<td>By 8 bit µ-p in PUE 1 (MHS80C32) 256 kByte RAM</td>
</tr>
<tr>
<td>Data Storage during Transfer Phases</td>
<td>in EEPROM</td>
</tr>
</tbody>
</table>

Electronics Unit

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of Electronics Unit (Drawer)</td>
<td>572 x 386 x 290 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>38 kg</td>
</tr>
<tr>
<td>Max. Power Consumption</td>
<td>&lt; 280 W</td>
</tr>
<tr>
<td>Power Interfaces to Rack</td>
<td>2 x 28 VDC / 10 Amps</td>
</tr>
<tr>
<td>Process Control</td>
<td>Standard Payload Computer (SPLC)</td>
</tr>
<tr>
<td></td>
<td>32 bit ERC chipset, 4 MByte EEPROM, 6 MB RAM</td>
</tr>
<tr>
<td>Data Interfaces to Rack</td>
<td>RS 422 and IEEE 1355 for video data</td>
</tr>
<tr>
<td>PCDF Operation Modes</td>
<td>- fully autonomous</td>
</tr>
<tr>
<td></td>
<td>- by ground control</td>
</tr>
<tr>
<td></td>
<td>- by Crew via EDR laptop</td>
</tr>
<tr>
<td>Intermediate Storage Capacity for Images</td>
<td>12 MByte</td>
</tr>
<tr>
<td>PCDF Accommodation Onboard ISS/COF</td>
<td>Inside European Drawer Rack (EDR)</td>
</tr>
<tr>
<td>Up- and Download Systems</td>
<td>NASA Space Shuttle Middeck (Process Unit)</td>
</tr>
<tr>
<td></td>
<td>EDR or EXPRESS Rack in APM or MPLM (Electronics Unit)</td>
</tr>
<tr>
<td>Typical Mission Time</td>
<td>- 3 - 6 months (Process Unit)</td>
</tr>
<tr>
<td></td>
<td>- up to 2 years (Electronics Unit)</td>
</tr>
</tbody>
</table>

Table 8-1: Summary of PCDF Technical Data

Qualification Status: ☑ Qualified for use on ISS

Figure 8-1: PCDF - Electronic Unit (top), Process Unit (bottom)
Figure 8-2: Box Open with Reactor

Figure 8-3: Batch Experiment Assembly

Figure 8-4: Dialysis Reactor

Figure 8-5: Extended Length Dialysis Reactor

All the space you need
8.2 Zeolite Solution Crystallization Diagnostics Facility (ZSCDF)

8.2.1 Facility Overview

ZSCDF (Zeolite Solution Crystallization Diagnostics Facility) shall allow the investigation of aggregation processes in liquids, especially the formation of porous silica from Ordered Liquid Phases (OLP). It is using dynamic light scattering (DLS) as principal technique, and a miniaturized viscosity sensor for the monitoring of structural changes in the liquid medium.

ZSCDF consists of an Electronics Unit (EU) and a Process Unit (PU), accommodated in the European Drawer Rack (EDR). Both units are based on hardware of the Protein Crystallization Diagnostics Facility (PCDF), which returned from ISS after a successful mission in 2009. The modifications for ZSCDF include the experiment cells and a Light Scattering Electronics with Single Photon Detectors and fast correlators.

A design concept to combine the two units into one has also been developed.

8.2.2 Facility Design

The ZSCDF Electronics Unit comprises the Power and Data Electronics (PDE) and the Light Scattering Electronics (LSE).

The PDE controls the experiments via commands from ground, or autonomously by pre-defined scripts. All scientific and housekeeping data are sent to ground in real-time.

The LSE contains Avalanche Photo Diodes for detection of single photons, which are received from the experiment via optical fibers. The signals are routed to fast correlators, which calculate the auto-correlation functions (ACF). Three optical channels can be measured in parallel.

![Diagram of ZSCDF Electronics Unit](image)
The ZSCDF Process Unit houses the experiments with the diagnostics tools.

Two experiment cells are contained in the Experiment Unit, which provides 3 levels of containment. They have mechanisms for independent injection of two liquids into a reaction volume, a stirrer, and the sensor head (quartz crystal resonator) for viscosity measurements. The cells can be thermally controlled from 20 °C to 95 °C.

For light scattering measurements, each cell is equipped with a laser diode of 100 mW optical power at 660 nm, and collection optics at three scattering angles (45°, 90°, 170°).

In addition, photo diodes allow the measurement of the turbidity of the samples.

8.2.3 Main Experiment Features

### Experiment Cells
- 2 Zeolite Experiment Assemblies (ZEA) in a common housing, with 3 levels of containment

### Liquid Volumes
- Reaction Volume: ~1.5 ml
- Injection Volume 1: ~2.0 ml
- Injection Volume 2: ~1.5 ml

### Injection
- Measurement accuracy: 0.5%
- Minimum step size: 5%
- Injection rate: ~1 ml/min

### Stirring
- Frequency: ~2 Hz
- Total time: max. 500 min

### Internal Leak Rate
- Before activation: < 1 µl/10 days
- After activation: < 1 µl/day

### Thermal Control
- Range: +20 to +95 °C
- Stability: < 0.5 °C
- Gradient over cell: < 0.1 °C/cm
- Ramp: +10 °C/min for heating

### Optical Diagnostics
- Polarized DLS:
  - Simultaneously at 3 angles (45°, 90°, 170°)
  - 50 ns cross correlation for all angles simultaneously
  - Optical Laser power 100 mW at 660 nm
  - Detector: Avalanche Photo Diodes
- Turbidity measurements
  - Laser intensity measurements at cell entrance and exit

### Viscosity Measurement
- Miniatrized sensor head (Quartz Resonator)
  - Range: 1.2 - 20 cP
  - Precision: 0.1 cP

### Facility Control
- Remotely from ground, or by script

### Data Transfer
- Housekeeping Data
- Autocorrelation functions
- Scattering Intensity
- Viscosity Spectra

### Table 8-2: ZSCDF Technical Data

#### Qualification Status:
- 🌐 Designed for use on ISS
8.3 Advanced Protein Crystallization Facility (APCF)

APCF was designed to obtain better crystals and for a better understanding of the growth process.


APCF is a multi-user experiment facility for the crystal growth of proteins in the microgravity environment of space, developed under ESA contract. For the experiments, various types of experiment cells are available to perform protein crystal growth according to the most commonly used methods which are: vapor diffusion, free interface diffusion, and dialysis. A movable optical system allows the optical observation of some cells. Additionally, by means of an interferometer, the concentration profile within the experiment cells can be measured.

APCF was designed to be accommodated in a Shuttle Middeck Locker to be accommodated in the Shuttle middeck, in Spacelab, in the SpaceHab module, or in the Express Rack of the ISS. After the switching-on by the astronaut, APCF is operating fully automatically according to a pre-defined parameter set.

Forty Eight experiment cells can be accommodated in one APCF (two are available) and kept at a constant temperature. A movable optical system enables the direct observation of the protein chamber of 10 cells in sequence, 5 on each side. In 1996, a Mach-Zehnder interferometer was added to observe 5 of the 48 cells and to measure and visualize changes in the refractive index, due to concentration gradients, diffusion, or convection.

Three crystallization methods can be applied in the APCF:

- Dialysis (DIA)
- Liquid/liquid diffusion or free interface diffusion (FID)
- Vapor diffusion or hanging drop (HD)

The standard reactors for these methods are available for different volumes of the protein chamber. New reactors for the FID method have been developed for the STS-95 SpaceHab mission to allow more sophisticated experiments. One is the reactor with a long protein and salt chamber (FID-XL, size of three standard reactors), another with mirrors which allows the observation of the protein volume from two orthogonal directions (FID-Ortho). Both types have markings in the protein volume to allow the exact determination of the position of the grown crystals.

More than 426 experiments have been performed. After the mission the space grown crystals are analyzed using X-ray / synchrotron beams. The recorded video images and interferograms allow following the growth process in space. Many important results have been achieved and published in the scientific literature.
**Figure 8-12: Special Reactors: Extended Length and Ortho View**

Qualification Status:
- Qualified for use on ISS
- Qualified for use on STS

**Figure 8-13: Mach-Zehnder Interferograms & Video Observation: Reactor Places for Video and Interferometer (MZI) Observation**

**Summary of Main APCF Performance Data**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of experiment cells</td>
<td>48</td>
</tr>
</tbody>
</table>
| Crystallization methods | Dialysis (DIA)  
Free Interface Diffusion (FID)  
Vapor Diffusion (Hanging Drop, HD) |
| Modularity | exchangeability of types of experiment cells |
| Size of Protein Volume |  
FID: 20 - 470 µl, 1280 µl (FID)  
Dialysis: 15 - 450 µl, 1260 (Dialysis)  
Hanging Drop: 4 - 8 µl and 35 - 80 µl |
| Process Temperature (range, selectable) | +4 °C to +20 °C |
| Temperature Stability | < ± 0.3 °C |
| Video Observation |  
- black and white CCD camera with 582 lines and 500 pixels/line  
- LED illumination (λ = 850 nm)  
  - polarized light with adjustable analyzer  
  - field of view:  
    - WFOV: 8.5 mm x 6.3 mm (EM)  
      9.5 mm x 7.8 mm (FM 1)  
    - NFOV: 5.0 mm x 3.7 mm (all models)  
- Mach-Zehnder Interferometer (λ = 850 nm)  
  - field of view:  
    - 7.5 mm x 6.0 mm (EM)  
    - 7.5 mm x 7.5 mm (FM 1)  
    - 7.2 mm x 8.4 mm (FM 2) |
| 10 for video images | 5 for interferograms |
| Data Storage | Storage of images / interferograms |
| Housekeeping Data on Video Tape | 8 bit image digitization  
storage capacity of 15,000 images |
| Facility Volume | 408 x 240 x 500 mm |
| Facility Mass | 26.5 kg incl. installation foam (with 48 reactors) |
| Power Consumption | 65 W |

**Table 8-3: Main APCF Performance Data Summary**

All the space you need
8.4 Commercial Protein Crystallization Facility (CPCF)

CPCF was developed for commercial application of the protein crystal growth in space.

CPCF-1 was flown on the Shuttle mission STS-95 (10/1998), CPCF-2 was on the ISS between May and July in 2001 and again between March and May 2002.

CPCF-1 main characteristics:
- 1 flight module
- 20 APCF-type reactors
- Activation/deactivation as integrated part

CPCF-2 (adapted for ISS) main characteristics:
- 4 individual modules available
- 8 APCF-type reactors per module
- Activation/deactivation by separate activation mechanism

CPCF-1 consists of one module with 20 reactors (experiments), and CPCF-2 was flown with 4 identical, individual modules with eight reactors each. All standard growth methods, as also used in APCF, can be applied, i.e. vapor diffusion, free interface diffusion, and dialysis.

A variety of different volume combinations (protein, salt, buffer) are available. For CPCF-2, the experiments are activated/de-activated by a separate activation mechanism. For operation in space they are placed in a thermostat to ensure proper crystallization temperature.

Main Data

CPCF-1:
- 20 reactors (APCF-Type)
- "Double containment" of experiment materials
- Volume 400 x 100 x 96 mm
- Mass 4.0 kg
- Thermal control (e.g. thermostat) needed

CPCF-2:
- Experiment Module:
  - 8 reactors (APCF-Type) per module
  - Double containment of experiment materials
  - Volume 95 x 95 x 140 mm
  - Mass 1.6 kg
  - Thermal control (e.g. thermostat) needed

Activation Mechanism:
- Volume 95 x 95 x 106 mm
- Mass < 1 kg

Protein Crystallization Experiment in CPCF:

<table>
<thead>
<tr>
<th>Major Steps</th>
<th>months prior to mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>General pre-clarification</td>
<td>8-4</td>
</tr>
<tr>
<td>Identification of need to crystallize a protein under µg</td>
<td></td>
</tr>
<tr>
<td>Contact Astrium</td>
<td></td>
</tr>
<tr>
<td>Clarification of technical issues (crystal growth: method, volume, temperature, experiment specials, mission details)</td>
<td></td>
</tr>
<tr>
<td>When mission is defined</td>
<td>4</td>
</tr>
<tr>
<td>Selection of growth method and reactors</td>
<td></td>
</tr>
<tr>
<td>Familiarization with ground and flight hardware; hand-over of reactors for proper preparation of flight experiments*</td>
<td></td>
</tr>
<tr>
<td>First list of chemicals incl. proteins (confidential**) *</td>
<td></td>
</tr>
<tr>
<td>Final list of chemicals incl. proteins (confidential**) *</td>
<td></td>
</tr>
<tr>
<td>Filling of flight experiments*</td>
<td></td>
</tr>
<tr>
<td>Hand-over of flight experiments ready for mission</td>
<td></td>
</tr>
<tr>
<td>Mission</td>
<td></td>
</tr>
<tr>
<td>&lt; 10 days</td>
<td></td>
</tr>
<tr>
<td>&lt; 6 days</td>
<td></td>
</tr>
<tr>
<td>Post-Mission</td>
<td>&lt; 3 days after mission</td>
</tr>
<tr>
<td>Hand-over of experiments</td>
<td></td>
</tr>
</tbody>
</table>

*) support offered by Astrium, if needed
**) proprietary details are not needed

Table 8-4: CPCF Experiment Definition and Mission Integration Process
Figure 8-14: CPCF-1 Module  Figure 8-15: CPCF-2 Module with Activating Mechanism

Figure 8-16: CPCF-2 Module with Experiments

Figure 8-17: Reactor Types for CPCF Experiments

Figure 8-18: Accommodation of CPCF-2 Modules in CRIOGEM (ISS Compatible)

Qualification Status:
☑ Qualified for use on ISS
☑ Qualified for use on STS
9. Rodent Research

9.1 Rodent Life Support

Astrium developed in an ESA sponsored phase A/B study a dedicated life support system for a gravitational Mouse in Space facility (MIS) onboard a Russian FOTON capsule. Before completion of the study the planned FOTON mission was changed to a BION mission with a capsule-provided life support.

Astrium continued the completion of a functional breadboard followed by an extensive testing and verification program on partial company investment.

The proposed design concept is based on the related Astrium intellectual property, adapted to the specifications of commercial cargo carriers and the utilization needs of the Italian Space Agency’s Mouse Drawer System (MDS) facility (6-8 mice).

The objective of the proposed Life Support System (LSS) is the conditioning of the air to be circulated through the cages for gas composition, temperature and relative humidity. It consists of:

- Flow control system
- Photocatalytic VOC (volatile organic compounds) remover
- NH$_3$ remover incl. Cooler/condenser & NH$_3$ absorption by specific activated charcoal
- CO$_2$ remover (cCO$_2 < 500$ ppm; maximum concentration of CO$_2$ can be adjusted) based on KO$_2$ cartridges which release O$_2$ by chemical binding of CO$_2$ (O$_2$ is stoichiometrically released in excess)
- rH control or remover for metabolic, exhaled water
- Distributed sensors
- LSS-Controller
The potassium superoxide (KO₂) cartridge is the core element of the LSS. Its main task is to remove the carbon dioxide generated by mice and to provide the oxygen for mice.

Due to the use of the KO₂, the O₂ generated by the chemical reaction with H₂O and CO₂ leads to an excess of oxygen.

To maintain the required concentration of oxygen at the LSS output, a selective O₂ removal unit has been implemented.

The complete system has been successfully verified during > 500 hours of system testing.

**Qualification Status:** ☑️ Designed for unmanned capsule missions
10. Microgravity Science Glovebox (MSG)

Astrium’s MSG Glovebox Facility provides the following features:

- Allows for handling of critical substances in human space flight environment for experiments in the fields of
  - Material science
  - Fluid physics
  - Biology
- Tele-science capabilities

Figure 10-1: Microgravity Science Glovebox inside Destiny
(Astronaut Jeff Williams performing the PFMI Experiment inside MSG)
11. Minus Eighty Degree Freezer (MELFI)

Astrium’s MELFI Cooler/Freezer Facility provides the following features:

- Storage and preservation of life science and biological samples
- Refrigerated volume of 300 liters in 4 identical enclosures (dewars)
- Cold temperatures individually controlled for each dewar:
  - -80 °C, -26 °C, +4 °C
- Provides a variety of receiving boxes and (vial) cards for sample accommodation

Figure 11-1: Minus Eighty Degree Freezer (MELFI)
### 12. Qualification Status Summary

The following table summarizes the heritage and qualification status of the hardware contained in this catalog:

1=Qualified  2=Designed  3=Under Development

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Section</th>
<th>Flight History</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISS STS Capsule</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>BIOLAB Experiment Container (EC.S)</td>
<td>3.3.1</td>
<td>Since Increment 16</td>
<td>1</td>
</tr>
<tr>
<td>BIOLAB Experiment Container (EC.DS)</td>
<td>3.3.2</td>
<td>Since Increment 16</td>
<td>1</td>
</tr>
<tr>
<td>BIOLAB Advanced Experiment Container (AEC)</td>
<td>3.3.3</td>
<td>Since Increment 16</td>
<td>1</td>
</tr>
<tr>
<td>Standard Automatic Ambient Stowage (AAS)</td>
<td>3.3.4</td>
<td>Since Increment 16</td>
<td>1</td>
</tr>
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<td>WAICO Automatic Ambient Stowage (AAS)</td>
<td>3.3.5</td>
<td>Since Increment 16</td>
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<tr>
<td>TRIPLELUX Automatic Ambient Stowage (AAS)</td>
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<td>Since Increment 16</td>
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<tr>
<td>Standard Automatic Temperature Control Stowage (ATCS)</td>
<td>3.3.7.1</td>
<td>Since Increment 16</td>
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<td>WAICO Automatic Temperature Control Stowage (ATCS)</td>
<td>3.3.7.2</td>
<td>Since Increment 16</td>
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<td>BIOLAB Tools: 1 ml Syringe</td>
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<td>Since Increment 16</td>
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<tr>
<td>BIOLAB Tools: Double Containment Syringes</td>
<td>3.3.8</td>
<td>Since Increment 16</td>
<td>1</td>
</tr>
<tr>
<td>BIOLAB Tools: Triple Containment Syringes</td>
<td>3.3.8</td>
<td>Since Increment 16</td>
<td>1</td>
</tr>
<tr>
<td>BIOLAB Experiment WAICO</td>
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<td>Since Increment 16</td>
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<td>BIOLAB Experiment TRIPLELUX</td>
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<td>Since Increment 16</td>
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<tr>
<td>BIOLAB Experiment CERASP / CELLRAD</td>
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<td>EMCS Experiment Container</td>
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<td>Since Increment 13</td>
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<tr>
<td>EMCS Experiment Multigen-1</td>
<td>4.6.1</td>
<td>Since Increment 13</td>
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### Hardware Section

<table>
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<tr>
<th>Hardware</th>
<th>Section</th>
<th>Flight History</th>
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<th>STS</th>
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<tr>
<td>EMCS Experiment</td>
<td>4.6.2</td>
<td>Since Increment 13</td>
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<td></td>
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</tr>
<tr>
<td>GRAVI-2</td>
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</tr>
<tr>
<td>GRAVI-2 Fixative Unit and Culture Chamber Container</td>
<td>4.6.3.2</td>
<td>Since Increment 13</td>
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<td></td>
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<tr>
<td>GRAVI-2 Transport Boxes</td>
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<td>EMCS Experiment</td>
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### Hardware Section

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All the space you need
References to non-Astrium Payloads

Astrium can provide access to a large variety of European developed and flight-qualified hardware through its cooperation with most of the European industrial stakeholders in ISS utilization and μg experimentation.

A special arrangement is in place, which allows Astrium to offer hardware from Kayser Italia of Livorno, Italy.

Further agreements exist in the United States with NanoRacks and Intrinsyx, Mountain View, California, USA.

Acknowledgement

Astrium Space Transportation wants to thank all Crew members, who have helped us develop the equipment and eventually performed the operations onboard Space Shuttles, the MIR Station, and the International Space Station. We also thank the dedicated teams at the involved ground support centers around the world.

We also thank our valued and long-standing customers from ESA, DLR, CNES, ASI, JAXA, and NASA – for whom we had the opportunity to develop our equipment in the first place.

Furthermore, Astrium would like to recognize and thank all of our subcontractors and suppliers for their contributions to many of our products.

Last but not least, Astrium Space Transportation wants to thank the extra-ordinary biologists, chemists, physicists, and engineers as well as all other space experts and support team members connected with our life science department. The Friedrichshafen Astrium team successfully masters the challenges of building highly complex life science experiments for space and has been doing so for more than 30 years.

We are proud of our space heritage – and our team members seem to have found their life’s calling in extending the frontiers of space research for the benefits of humanity.

Some members of the Friedrichshafen-team have been with us from the beginnings of the Space business at the Lake Constance. We especially remember our dedicated team member and extraordinary designer Udo König. Thank you.