PROJECT "GREENHOUSE - MARS" - PLANT GROWTH STUDY WITH DIFFERENT SPECTRA LEDs LIGHT UNITS

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Abstract

Bulgarian scientists will take part in the Russian "500 days" Program on the preparation of a human spaceflight to Mars. A Contract "Greenhouse-Mars" for scientific cooperation with the Institute of Biomedical Problems (IBMP), Moscow, was signed in the framework of an agreement between the Bulgarian and the Russian Academy of Sciences in the field of Fundamental Space Research for the period 2006-2010. According to this Contract a part of the Greenhouse equipment, modules of Light Units with different spectra (combinations of light-emitting diodes - LEDs) necessary to carry out plant scientific experiments, will be developed. The experiment Program plans a crew of 6 volunteers to be confined to a ground-based "space craft" for 500 days to investigate the human organism reaction in conditions near to Mars spaceflight. The experiment is scheduled to start at the end of 2007 and a crew of volunteers will be confined to a specially-built training module in the IBMP – a mock of a future Mars Station, imitating all the Life Support Systems for a long-duration spaceflight. A Greenhouse with large plant area will be mounted "onboard" together with the necessary water and food supplies in order to ensure fresh vitamin addition to the "cosmonaut" food.

Mars-500 experiment

A manned mission to Mars in the near future is realistic, funding is adequate and will provide support for the ambitious plans to send a six-man crew to visit the planet within the next decades. The discussed budget of $3-5 billion for the mission reflected plans to use already developed spacecraft, and predicted it would happen not earlier than 2020. It would be very difficult for one country to carry out such a program - the project should be international and the Russian Space Agency has discussed manned Moon and Mars projects with NASA and ESA.

The Mars-500 experiment is under development by the Russian State Scientific Center - Institute of Biomedical Problems (IBMP), Moscow. During the experiment six volunteers (35-55 years old) will be locked for 500 days in a metal tube, a mock-up of a space station module to Mars, in an effort to mimic the stresses and challenges of a long manned mission and how they affect the human crew. An imitation of a manned flight to Mars with the help of volunteers is planned to start in the late 2007 or early 2008. During the 500 day study, the life of the six men will depend on a preset limit of supplies, including about 5 tons of food and oxygen and 3 tons of water. A doctor will accompany volunteers inside the module to treat illnesses and injuries. Volunteers will only be allowed to quit the experiment if they develop a severe ailment of psychological stress.

Mars-500 experiment participation is not solely reserved for Russian volunteers; it is opened for international participation. NASA has been invited by Russian scientists to join in the Mars mock mission. NASA astronauts currently serve six-month missions onboard the International Space Station (ISS), though Russian flight controllers have lobbied to increase joint U.S.-Russian missions up to one-year in duration. Veteran Russian cosmonaut Valery Polyakov, a medical doctor, set the current world record for the longest continuous spaceflight when he spent about 438 days aboard Russia's MIR Orbital Station (OS) between 1994 and 1995. Any medical and biological experiments made onboard the MIR OS and ISS aim at long-distance space flights of the future.

Bulgarian scientists from the Space Research Institute (SRI) will take part in the Russian “500 days” Program on the preparation of a human spaceflight to Mars. A Greenhouse with large plant area will be mounted “onboard” together with the necessary water and food supplies in order to ensure fresh vitamin addition to the “cosmonaut” food. A Contract for scientific cooperation on the “Greenhouse-Mars” Project between the SRI and IBMP was signed in the framework of an agreement between the Bulgarian and the Russian Academy of Sciences in the field of Fundamental Space Research for the period 2006-2010. According to this Contract a part of the Greenhouse equipment, modules of Light Units with different spectra (combinations of light-emitting diodes - LEDs) necessary to carry out plant scientific experiments during the Mars-500, will be developed.

Light Units of the SVET Space Greenhouse on fluorescent lamps

The scientific cooperation between the SRI and the IBMP on the bilateral “Greenhouse” Project is traditional and useful for more than 2 decades. The first SVET Space Greenhouse (SG) was created in the 80’s on a Joint scientific project in the framework of the “Intercosmos” Program, aiming to study the ways and methods for the use of higher plants in the space Biological Life Support Systems (BLSS). The subject of the project was to develop biotechnology for higher plants growing in microgravity with the prospects to use it in the future long-term manned mission to Mars. SVET SG was launched onboard the MIR OS in 1990, when the first two-month vegetable plant experiments were carried out in order to provide vitamin addition to the astronaut food [1]. Artificial lighting was provided by fluorescent lamps mounted in the Light Unit (LU). A new modification SVET-2 SG with optimized parameters of all units and systems (including new LU-2) was developed and launched onboard the MIR OS in 1996, financed by NASA [2].

Plants need light with determined quantity and quality. They consume light energy mostly in two spectral bands - blue and red (around 450 and 650 nm) to carry out their fundamental biological processes such as photosynthesis (production of biomass and air clearing) and phototropism (orientation towards the light in weightlessness). The intensity of this physiological processes in light of different wave length is shown in Fig.1 (curve 1 - phototropism and curve 2 - photosynthesis). To provide experimentally defined light conditions of irradiance, spectral quality, and duration is one of the major engineering requirements of any controlled environment plant chamber [3].

The Bulgarian developed LU with dimensions 336/330/200 mm can be moved vertically in the Plant Chamber of SVET SG and adjusted at three different levels – 20, 30 and 40 cm from the plant seedling surface in order to provide best light intensity without overheating, depending on the plant development stage. A ventilator cooling the lamps and the air in the shoot zone is mounted on the upper bearing plate together with a panel for LU control (manual or automatic).

Russian fluorescent lamps LB 8-6 (12 pieces), especially developed for the MIR OS board were used in the 1990 experiment. The spectral-response characteristic of LU using these kind of lamps is shown by curve 3. It is seen that almost the whole luminous energy is concentrated in minimum sensibility zone of the plants. That considerable discrepancy between the light source and plant needs was due to the lack of special lamps (during the period of development) with appropriate characteristics and save enough for the crew in case of breaking a lamp. The fluorescent lamp DS 11/21 of OSRAM (6 pieces) as a most suitable for our aim was chosen for the LU-2 [4]. At that the lamp spectrum is suitable for intensive photosynthesis as well as for providing phototropism of the plants, so important in conditions of a space flight (curve 4).

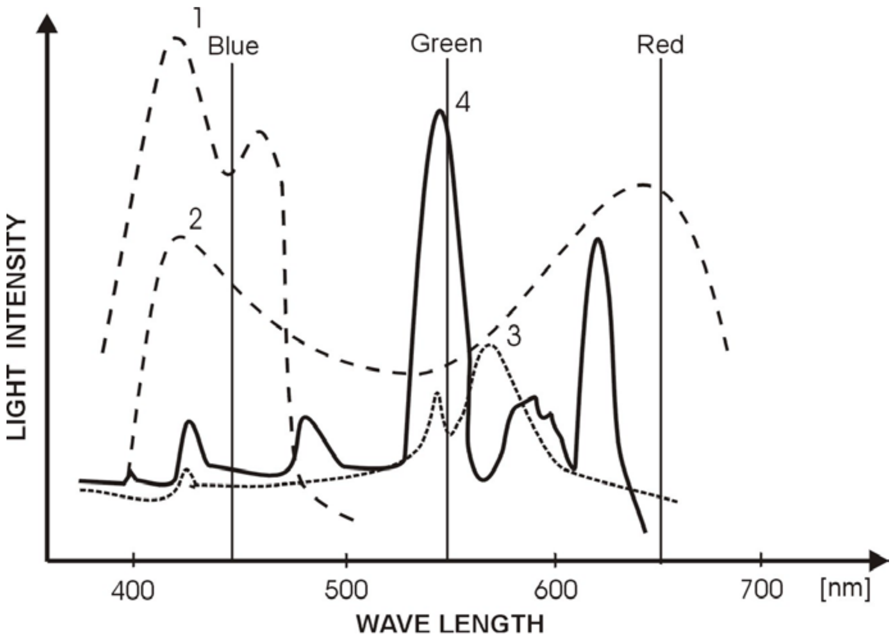

Fig.1. Light wave length necessary for plant's: 1 - phototropism and 2 – photosynthesis; Spectral characteristics of the fluorescent lamps used in 3 - SVET SG (LB 6-8) and 4 – SVET-2 SG (DS 11/21) and of the new blue, green and red LEDs.

Considerably (2,5 times) improved brightness characteristics of LU-2 were obtained at a distance of 15 cm from the illuminants, the intensity was 27 000 lx (under 12 000 lx in SVET SG in 1990). In the circumstance we could expect considerable increase of the plant productivity (quantity of biomass) in the future experiments. The larger warranted duration of work of the lamps DS 11/21 (8000 hours) ensure 5 times better reliability of the equipment. Besides the new LU-2 has considerably better electrical characteristics which is of great importance because it was the biggest energy consumer within SVET SG. For example the supply current of the unit (under 27V onboard supply voltage) is 2,5 times lower (3,5A under 9A in SVET SG) and the starting current is almost equal to the supply one [5].

A number of successful plant experiments and research were carried out under the fluorescent lamps lighting of the SVET-2 SG equipment in 1996-2000. Due to the improved LU-2 characteristics (along with the substrate moistening) “space” plants looking like the “earth” ones were grown during the experiments and had almost the same biomass and vegetation cycle. The unique scientific results obtained in the field of the gravitational plant biology proved that there were no “show-stoppers” for plant growth and development in microgravity [6,7].

Unfortunately the lighting systems, based on white fluorescent lamps, used in plant growing facilities have been developed more for human and not plant lighting purposes - the well lighted green plants have very positive psychological effect on the space crew. Nevertheless such lighting systems have found extensive use in terrestrial controlled environment facilities.

Regarding the use of such lamps in space-based plant chambers there are serious limitations relative to both power utilization and meetint safety requirements of the space hardware. The mercury contained in the fluorescent lamps represents a serious safety hazard if a lamp is broken so that the mercury is released into the atmosphere of the space vehicle. The LU-2 OSRAM lamps were hermetically sealed in special developed light bodies that ensure maximum light characteristics. The safety concern requirements are adequately addressed but the irradiance of these light systems is significantly decreased and the volume required by the light system is difficult to accommodate in the very limited LU place.

Light Units on light-emitting diodes (LEDs)

The plant will be an important component of future BLSS for the long-term space mission to Mars as a source of food and air purification. Lighting systems for long-term plant growing should be lightweight, reliable, and durable, and light-emitting diodes (LEDs) have such characteristics. The development of LU based on the LEDs for the space greenhouse facilities started in USA in the 90's for the Space Shuttle missions [8].

Major advances have been achieved in semiconductor technology and this has led to the availability of LEDs having photon output and electrical efficiencies that make them an excellent light system for plant growing facilities. Another significant improvement of the LED technology that essentially converts these devices to an effective radiant energy source involves mounting the LED chip on a highly thermally conductive ceramic substrate that is bonded to a metal heat sink. Mounting the semiconductor material in this way allows for operating the device at high forward drive current with the consequent high photon output while maintaining the temperature of the LED at or near ambient temperature of the environment. Such LED operating temperatures results in a high quantum efficiency of the LED plus prolonging the life and maintaining the photon output during the life of the LED.

Since LEDs emit photons over a specific spectral region, in contrast to other lamps, they should be carefully selected so that the levels of photosynthetically active, photomorphogenic, and phototropic radiation provided to meet the plant requirements. Photons in the red region of the spectrum are most efficient as a source of photosynthetically active radiation (Fig.1). Thus, LEDs having a peak emission around 650 nm serve as a most efficient source providing the photons used in photosynthesis which coincides with the red absorption peak of chlorophyll. Irradiance levels of 0-500 $\mu mol.m^{-2}.s^{-1}$ in the red spectral region can be achieved with an LED plant lighting unit. Light in the blue region of the spectrum (400 to 500 nm) and with low levels of irradiance (0-80 $\mu mol.m^{-2}.s^{-1}$) is generally considered to be involved in the photomorphogenic and phototropic responses. Likewise, the light requirements involved in the phytochrome responses can be easily met with low levels of light at wavelengths of 630 and 680 nm. Supplementation of the red photon emitting LEDs with LEDs that emit in the blue (450 nm) and infrared (735 nm) region of the spectrum would meet light requirements of plants in a controlled environment facility [9].

A Light Unit with 90% red and 10% blue LEDs was used as a lighting system of the American Greenhouse ASTROCULTURE™ flight unit during three Space Shuttle missions, STS-57, STS-63, and STS-73, as well as of the commercial ADVASC flight unit on ISS [10]. The video from the board showing the dark-violet colored plants was terrible, but fortunately it was not visible for the crew in the closed chamber. The performance of the LED unit, in terms of photon output, was the same while in a space environment as the performance was while being tested on the ground. In addition to being used as a lighting source in plant growth chambers, the LED lamps can be a very effective photon source for photosynthetic research to study electron transport, carbon metabolism and trace gas emission.

Ground-based research with Light Units on LEDs of different spectra

Previous studies demonstrated that the combination of red and blue light was an effective light source for several crops. Yet the appearance of plants under red and blue lighting is purplish gray making visual assessment of any problems difficult. The addition of green light would make the plant leave appear green and normal similar to a natural setting under white light and may also offer a psychological benefit to the crew – very important for long-term living in closed system with only technical equipment surrounding [11].

Green supplemental lighting could also offer benefits, since green light can better penetrate the plant canopy and potentially increase plant growth by increasing photosynthesis from the leaves in the lower canopy. The American experimental study proved that plants treated with red and blue LEDs, and with additional green fluorescent lamps, produced more biomass than the plants grown under white fluorescent lamps [12]. Now it is not clear enough what the optimal spectra of the future LEDs LU should be so as to achieve maximum plant productivity and to provide nourishing food for the crew.

A Greenhouse with a large growing area (up to 3 m^2) is decided to be included in the ground-based Mars-500 experiment equipment. Two big laboratory facilities with growing area of 1600x800 mm could be used to conduct scientific plant experiments. A part of the Greenhouse equipment - modules of LU with different spectra (combinations of light-emitting diodes - LEDs) - will be developed in Bulgaria on the "Greenhouse-Mars" Project. The requirements to the spectra of the LEDs to be used in the LU modules from biological point of view are with different percent of blue, green and red color (see Fig.1):

1. 50% blue (450nm), 20% green (550nm), 30% red (650nm)
2. 30% blue (450nm), 20% green (550nm), 50% red (650nm)
3. 10% blue (450nm), 20% green (550nm), 70% red (650nm)
4. 10% blue (450nm), 90% red (650nm)

Recently white LEDs with different viewing angles and light intensity came into the market. Maybe the presence of 10% white light in the Light Unit composition is necessary for psychological effect. The white LEDs will be probably mounted on side panels, like in the stadium lighting, and will be used when photos are taken or the plants are observed by the operator. The most important task in both the ground and space experiments is to find the optimal LED composition so as to achieve plant growth as good as under fluorescent lamp lighting.

A universal small light module, 40 x 40mm in size and with separate pulse power supply of 220V should be developed during the first project stage. Such a module is easy multipliable in the presence of funds. LEDs with high power dissipation, high luminous intensity and appropriate cooling could provide photosynthetic photon flux of 350-400 $\mu mol.m^{-2}.s^{-1}$ on the whole plant area at a distance of 500 mm.

At least two universal modules (a double module) will be produced during the second project stage to investigate the influence of two different light spectra on plant growth and development. Other four double modules, 800 x 400 mm in size, providing the above mentioned spectra will be produced during the third stage. They could be easy transported to Moscow by plain to be used for biological and technical tests within the ready-built structure of the experimental model in IBMP.

Different plant species, mostly lettuce crops, will be grown under different light spectra provided by LEDs with a small viewing angle and maximum light intensity on the plant surface during the experiment. Samples will be taken at different plant development stages to be analyzed in order to investigate the influence of light spectrum on the plant physiological parameters. The psychological effect on the crew emotional frame (the dependence “plant - operator”) will also be studied in this long-term experiment.

The contracted time for the “Greenhouse – Mars” Project is 3 years (2006-2008). The terms for equipment development on the Project should be in conformity with the start of the Mars-500 experiment – the universal module should be developed by the end of 2006 at the latest and the double and fourfold module – in 2007.

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References

1. I v a n o v a T.N., Yu.A.B e r k o v i c h, A.L.M a s h i n s k i y and G.I.M e l e s h k o. The First "Space" Vegetables have been Grown in the "SVET" Greenhouse Using Controlled Environment. Conditions. *Acta Astronautica*, 29(8), 1993, 639-644.
2. I v a n o v a T.N., P.T.K o s t o v, S.M.S a p u n o v a, I.W.D a n d o l o v, F.B.Salisbury, G.E.Bingham, V. N.Sytchov, M.A.Levinskikh, I.G.Podolski, D.B.Bubenheim and G.Jahns. Six-Month Space Greenhouse Experiments - a Step to Creation of Future Biological Life Support Systems. *Acta Astronautica*, Vol. 42, Nos. 1-8, 1998, 11-23.
3. K o s t o v P.T., T.N. I v a n o v a and S.M. S a p u n o v a. Adequate Substrate Moistening System and Artificial Lighting for the Growth of Higher Plants in the "SVET" Space Greenhouse. *ACTA VET. BRNO*, Vol.65, 1, 1996, 19-25.
4. I v a n o v a T., P.K o s t o v, S.S a p u n o v a, G.B i n g h a m and S.B r o w n. Equipment for the Greenhouse SVET’95 Project and Some Optimisations for Future Experiments on board the MIR Orbital Complex. *Aerospace Research in Bulgaria*, 14, 1998, 71-77.
5. G r a m a t i c o v P. and T.I v a n o v a. SVET-2 Space Greenhouse Light Unit. *Aerospace Research in Bulgaria*, 16, 1999, 24-34.
6. I v a n o v a T., P. K o s t o v and S. S a p u n o v a. Renewing of the Greenhouse Biotechnological Experiments Onboard the MIR Space Complex. *46th International Astronautical Congress*, Oslo, Norway, 2-6 October 1995, Rep. IAF/IAA-95-G.4.01.
7. I v a n o v a T., P.K o s t o v, I.D a n d o l o v, S.S a p u n o v a. Results from Microgravity Experiments in the SVET Space Greenhouse Onboard the MIR Orbital Station, *51st International Astronautical Congress*, Rio de Janeiro, Brazil, 2-6 October 2000, Rep. IAF-00-J.3.10.
8. B u l a R.J., D.J. T e n n e s s e n, R.C. M o r r o w and T.W. T i b b i t s. Light Emitting Diodes as a Plant Lighting Source. *Proceedings of International Lighting in Controlled Environments Workshop*, NASA Conference Publication; Kennedy Space Center, Florida, USA, CP-3309, 1994, 255-268.
9. B u l a R.J. and R.W. I g n a t i u s. Providing Controlled Environments for Plant Growth in Space. *International Symposium on Plant Production in Closed Ecosystems*, Narita Japan, August 26-29,1996.
10. Z h o u W., R.J. B u l a and N.A. D u f f i e. Performance Evaluation on the Commercial Plant Biotechnology Facility. SAE Technical Paper Series #981666, *28th International Conference on Environmental Systems*, Danvers, Massachusetts, July 13-16, 1998.
11. F o l t a K.M., L.L.K o s s, R. Mc M o r r o w, H.H. K i m, D. K e n i t z, R.M. W h e e l e r and J.C.S a g e r. Design and Fabrication of Adjustable red-green-blue LED Light Arrays for Plant Research. *BMC Plant Biology* 2005, 5:17.
12. K i m H.H., G.D.G o i n s, R.M. W h e e l e r and J.C. S a g e r. Green-light Supplementation for Enhanced Lettuce Growth under Red- and Blue-light-emitting Diodes. *HortScience* 39(7):1617-1622, 2004.