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Equipment for the Greenhouse SVET'95 project and some optimisations for future experiments on board the MIR orbital complex

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Introduction

Higher plants are a basic link in a future Biological Life Support System intended to provide space crews with food and clear the air in spacecrafts as well. SVET Space Greenhouse (SG) which is the first and the only one for the present automatic equipment for higher plant growth was designed under a Russian-Bulgarian project within the INTERCOSMOS programme and launched onboard the CRYSTAL module, docked to the MIR Orbital Complex (OC) even in June 1990. The technical and technological methods and means used in the process of development gave an opportunity to carry out the first two–month experiments with plants of radishes and Chinese cabbage.

The experiments with SVET SG were resumed in 1995 and an American Gas Exchange Measurement System (GEMS) was supplemented to the existing Bulgarian plant life support systems. A three–month experiment with wheat, named "GREENHOUSE SVET" was started on August 10, 1995 by the 19th Russian crew (Nikolai Budarin), and continued by the 20th ESA international crew up to November 9. Plant samples of different development stages and units of SVET SG were sent back to Earth by Shuttle STS–74.

A set of SVET–2 equipment (a greenhouse of new generation) was developed and launched on board the MIR OC to conduct experiments in 1996–1997. Successful earth three–month experiments with wheat were carried out with SVET-2 SG by a three–member crew within a sealed cabin in IBMP, Moscow (from 25 Oct. 1995 to 22 Jan. 1996).

Description of the equipment for GREENHOUSE SVET'95 project

The GREENHOUSE SVET equipment used in the 1995 experiment included the Bulgarian–Russian developed SVET SG and the new supplemented Russian–American SVET Instrumentation System (SIS) [1]. The block diagram is shown in Fig.1. The Vegetation Module (VM) full of substrate is mounted on rails in the Plant Growth Unit (PGU) of SVET. The Illumination Unit (IU) can be vertically moved and fixed at different positions. A ventilator ensures lamp cooling and air circulation within PGU. A hydro–air system (HAS) is located on the bottom of PGU. Two of the PGU walls can be removed for easy operation, and one of them is transparent. The sensors for measurement and control of the environmental parameters in PGU are mounted. The Control Unit (CU) receives and processes the data obtained by the sensors during all the vegetation cycle and automatically controls the executive mechanisms. Special microprocessor programs ensure automation of all processes and give signals if failure has occurred. Visual control and manual guidance are also possible.

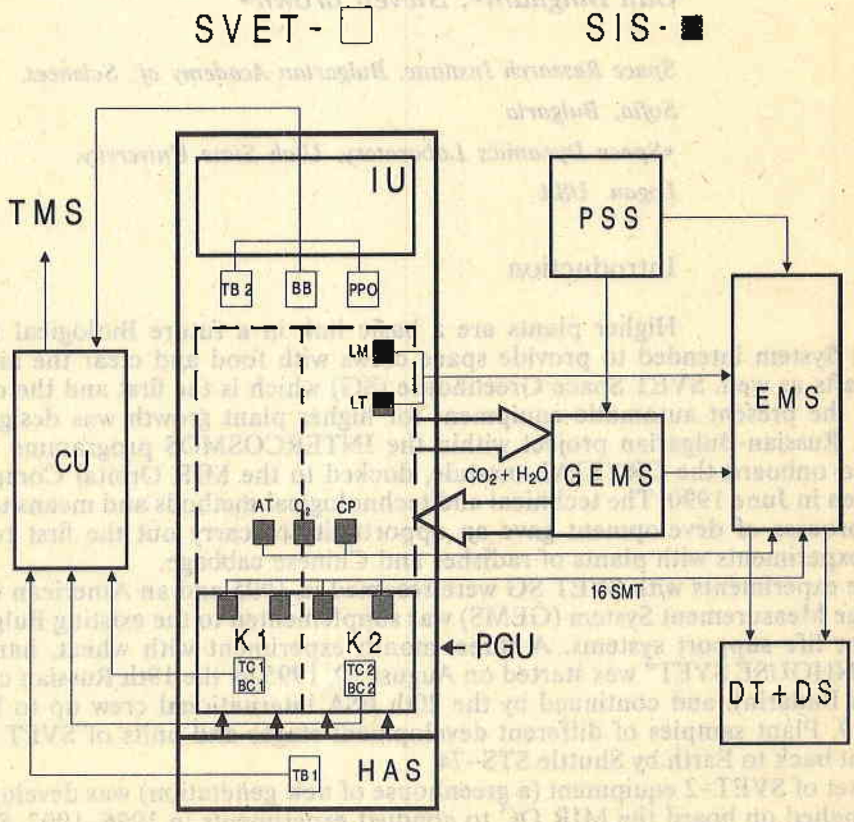

Fig. 1. Block diagram of the integrated system SVET - SIS and location of the sensors

The parameters controlled by CU are as follows:

- air temperature entering PGU-TB1;
- air temperature within PGU-TB2;
- substrate temperature in cell K1 of VM-TC1;
- substrate temperature in cell K2 of VM-TC2;
- relative air humidity within PGU-BB;
- substrate moisture in K1-BC1;
- substrate moisture in K2-BC2;
- duration of the lighting period -PPO.

The sensors measuring TB2, BB and PPO mounted on a unit fastened to IU will drop out of the GREENHOUSE SVET–2 equipment for the 1996 experiment. Only TB2 will stay (on the top of IU) to control switching off of the light in case of exceeding the admissible temperature in PGU. CU measures the parameters of the vegetation process every 4 hours and records a telemetric frame which is transmitted to Earth by the Telemetric System (TMS).

SIS encloses two separate transparent bags, called leaf chambers which cover the plants growing in each vegetation module (VM) of SVET SG. It allows local gas exchange and leaf environment measurement [2].

SIS consists of four primary modules: a gas exchange monitoring system (GEMS), an environmental monitoring system (EMS), a power supply system (PSS), and a data collection and display system (DT+DS) [3].

The gas exchange system has for an object to provide accurate measurement of absolute and differential CO_2 and H_2O levels in the air entering and exiting the PGU as well as absolute and differential pressures in the measured gases. It is necessary to evaluate some prime indicators of plant health as photosynthesis, respiration, and transpiration.

The environmental measurement system provides the capability to measure the air and soil conditions in which plants are growing.

The leaf area measurement system is a modified version of a commercial leaf area scanner. In flight, leaves will be attached to the leaf board and scanned using a hand-held scanner.

SIS supplements SVET SG with additional sensors which will give the possibility to take more information about the air and soil conditions for growing up of the plants.

The additional variables to be measured are:

- plant air temperature (AT);
- plant light monitor (LM);
- plant leaf temperature (LT);
- soil temperature and moisture (SMT);
- cabin pressure (CP);
- cabin O_2;
- cabin H_2O (air humidity);
- cabin CO_2.

The PGU environmental variables are measured by an instrument cluster with sensors located on the upper end of a rod in one corner of each leaf chamber.

The SVET system provides one substrate moisture sensor per module (BC1(2)) which measures and controls the substrate moisture level by means of the CU and hydrosystem. 16 additional sensors SMT (8 per module) will be supplemented by SIS to monitor the water distribution. They are designed to be integrated in the existing VM on flight.

Equipment problems during the GREENHOUSE SVET'95 experiment and results

During the GREENHOUSE'95 experiment there were several failures of the SVET hardware sent to MIR in 1990 [4]. They were caused by problems arisen in compatibility between the Bulgarian and American equipment.

After a brief functioning period, three of the six and subsequently the forth lamp shut down. It was concluded that an overheating had occurred because of the leaf bags restricting the flow of cooling air. Later the leaf bags were removed but the Control Unit microprocessor system of SVET failed because of an overloaded power supply caused by the non–functioning lamps. It was reach a decision to pass to manual mode. 18 days later CU completely failed (the supply of 12V letting the equipment to operate in manual mode dropped off) as a result of long operation in abnormal mode. A way was devised to provide 12V from the American power supply and SVET continued its work.

Thus enough of the problems were overcome to keep the plants growing during the 90–day interval from seed planting to harvest. Plants about 8 cm tall (in consequence of the insufficient irradiance), but appearing quite healthy with a normal green colour that reached the 3–leaf stage were grown in this experiment. Unfortunately they grew in all directions but not directly towards the lamps, because SVET was lined with the American mirror Mylar so light had came from all directions.

After the experiment accomplished CU, IU and VM were returned back to Earth by Shuttle STS–74 and sent to Bulgaria to have their defect analysis made. IU was restored and sent to Russia for a synchronous earth experiment to be conducted (in conditions repeating the onboard ones). For that purpose a possibility to switch on and off different number of lamps was brought in it to imitate the situation arisen on board. The goal of this experiment was to estimate the impact of microgravity on plant growth by re–creating on Earth all the rest conditions.

As a result of the experience gained in the GREENHOUSE SVET'95 experiment a space greenhouse SVET–2 of new generation was to be developed for the planned seed–to–seed experiment in 1996 as well as some experiments on board the MIR OC in 1997.

Some optimisations of the SVET hardware for future experiments

A new, optimised Illumination Unit within the SVET–2 equipment with considerably improved technical and biotechnical characteristics has been designed to meet the requirements of the plants.

The plants need light with determined quantity and quality. A photo–physiological inquiry shows that the plants consume energy mostly in two spectral bands–blue and red. The activity of some physiological processes depending on the effect of light of different wave length is shown in Fig. 2 (curve *1* – phototropism and curve *2* – photosynthesis). Till the experiment in 1990 fluorescent lamps LB 8-6 (12 pieces) were used. The spectral–response characteristic of IU using these kinds 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.

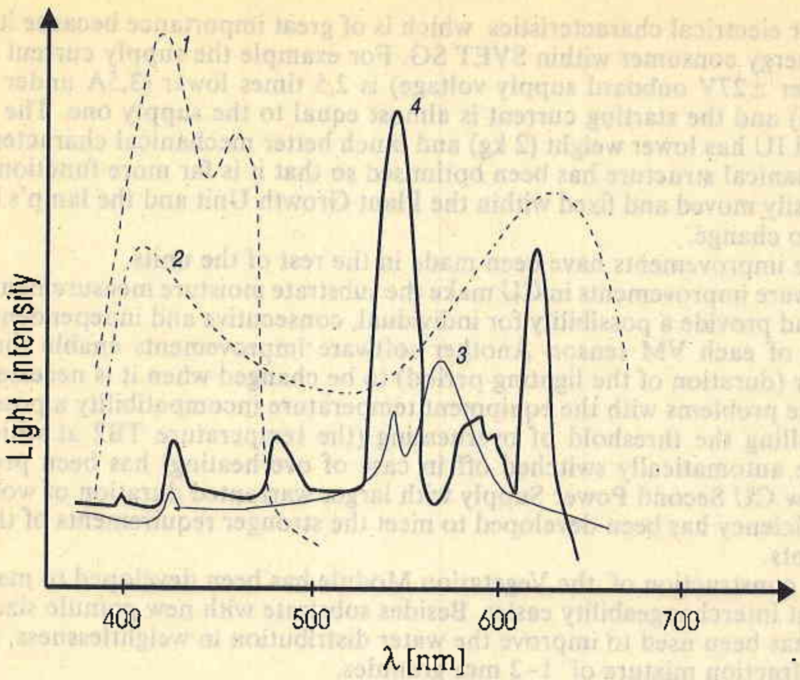

Fig. 2. Light wave length necessary for plant's: *1* – phototropism, and *2* – photosynthesis; Spectral response characteristics of the lamps used in *3* – SVET (LB 6-8) and *4* – SVET–2 (DS 11–21)

The increased supply of fluorescent lamps in the last years gave a possibility to conduct an extensive researches on the characteristics of the supplied kinds of lamps. The spectral–response characteristics of 12 kind of lamps in the band 400–600 nm have been taken with the help of the Faculty of Physics at Sofia University. For some of them the measuring range in the blue and red region respectively has been enlarged. The energy characteristics which are of particular importance when put to use the onboard power supplies have been analysed. The geometrical dimensions of IU narrow the range of the used lamps too. The fluorescent lamp DS 11/21 of OSRAM (6 pieces) as a most suitable for our aim was chosen. 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* of Fig. 2).

In connection with building of lamp's bodies two more important investigations have been conducted – on a white reflecting paint, made to order, suiting very special requirements, and on a transparency coefficient of the plexiglass for proofing the separate illuminants. As a result of the investigations considerably (2,5 times) improved brightness characteristics of IU have been received – at a distance of 15 cm from the illuminants the intensity is 27 000 lx (under 12 000 lx in SVET SG in 1990). In the circumstance we can 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 IU has considerably better electrical characteristics which is of great importance because it is 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. The newly developed IU has lower weight (2 kg) and much better mechanical characteristics. The mechanical structure has been optimised so that it is far more functional: IU can be easily moved and fixed within the Plant Growth Unit and the lamp's bodies are easy to change.

Some improvements have been made in the rest of the units.

Software improvements in CU make the substrate moisture measurement more precise and provide a possibility for individual, consecutive and independent measurement of each VM sensor. Another software improvements enable the PPO parameter (duration of the lighting period) to be changed when it is necessary. To resolve the problems with the equipment temperature incompatibility a possibility of controlling the threshold of overheating (the temperature TB2 at which the lamps are automatically switched off in case of overheating) has been provided too. A new CU Second Power Supply with larger warranted duration of work and higher efficiency has been developed to meet the stronger requirements of the new experiments.

New construction of the Vegetation Module has been developed to make the equipment interchangeability easier. Besides substrate with new granule size composition has been used to improve the water distribution in weightlessness. It represents a fraction mixture of 1–2 mm granules.

Secondary Pump Power Supply with higher efficiency and higher starting current has been upgraded to replace the SPPS unit standing on MIR within PGU.

Conclusion

The new developed upgraded units (IU, CU, VM and Secondary Pump Power Supply – SPPS) were produced, sent to Moscow in January 1996 and launched on board the MIR OC (VM on Shuttle in March and all the rest on the Progress module in April 1996). New fundamental biological research for growing a crop of wheat "from seed to seed" during the six-month flight (from July to December 1996) of an American astronaut will be carried out with this equipment. Three new experiments with plants that have a shorter vegetation cycle (peas for example) have been planned for 1997. Perfect results have been obtained in preliminary earth experiments with vegetable plants (onions, peas, lettuces and dill) carried out on the space greenhouse of new generation SVET–2 in the Space Research Institute, Sofia.

All the 1996–1997 experiments will be conduced on the program MIR–NASA and financed by NASA. To provide the equipment for these experiments bilateral agreements between Bulgaria, Russia and USA have been concluded. Thereby another step towards creating a steady onboard Biological Life Support System for the future long-term manned space missions (initially to Mars) has been made.

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Апаратура за проекта "ОРАНЖЕРИЯ СВЕТ" през 1995 г. и някои оптимизации за бъдещи експерименти на борда на орбитална станция МИР

Таня Иванова, Пламен Костов, Светлана Сапунова, Гейл Бингхам, Стивън Браун

(Резюме)

В статията е описана апаратурната част на експеримента, проведен от 10 август до 9 ноември 1995 г. на борда на орбиталния комплекс (ОК) МИР по проект "ОРАНЖЕРИЯ СВЕТ". Разгледани са някои проблеми, възникнали в хода на експеримента, както и научните резултати от него – база на предстоящите експерименти с пшеница "от семе до семе" и с други растения на борда на ОК МИР по програма МИР–НАСА през 1996–1997. Описани са оптимизациите, въведени в хардуера на оранжерия СВЕТ-2 – оранжерия от нова генерация, разработена за провеждането на новите експерименти.