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SVET-2 SPACE GREENHOUSE LIGHT UNIT

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Abstract

The technical and physical problems and the method of their resolution in the development of the Light Unit (LU) - a part of the SVET-2 Space Greenhouse (SG) working onboard the MIR Orbital Complex since 1996 are described. Brief description of the LU, the luminescent lamps, and the technical requirements to a space research equipment presented from the Russian accepting institution (IBMP, Moscow) are given. The priorities of the new LU for the second modification of SVET-2 SG are described over the shortcomings of the old LU for SVET SG launched onboard MIR OS in 1990 under a Bulgarian-Russian project. Due mainly to the optimized parameters of the new LU, in the period 1996-99 in the SVET-2 SG were grown normally developed "space" plants and were obtained unique results in the field of Fundamental Gravitational Biology.

1. Introduction

The SVET Space Greenhouse was created in the Space Research Institute, Bulgarian Academy of Sciences (SRI-BAS) in the 80's with the purpose of conducting biological experiments with higher plants under weightlessness. It was launched onboard the MIR Orbital Station (OS) in 1990 when the first successful two month vegetable plant experiments were carried out in order to provide vitaminic addition to the astronaut food [1]. After the old Light Unit (LU1) had been in outage under extreme space conditions during the last several years, three of the six lamp power supplies failed while trying to use the SVET SG again on the MIR-SHUTTLE program in 1995. A new modification, SVET-2 SG, with optimized parameters of all units and systems (including a new LU2 unit) was developed in 1994-96 (financed by NASA) and launched onboard the MIR OS by Russian cargo modules and American space shuttles [2].

A number of successful plant experiments aimed at carrying out a full life cycle (normal plant growing and seed production from seeds planted onboard) were conducted by the flight SVET-2 equipment 1996-99 [3]. Synchronous earth experiments were carried out by the ground-based

SVET-2 units (in Bulgaria, USA and Russia), such as the three-month wheat plant experiment in a hermetically sealed cabin in IBMP, Moscow. Unique scientific results in the field of gravitational biology were obtained in these experiments. They proved that there were no "show-stoppers" for plant growth and development in weightlessness if the necessary environmental conditions were available.

Light, or rather its parameters such as spectrum, intensity, daylight duration etc. has been one of the main factors of vital importance for normal plant growth. Plants consume light energy mostly in two spectral bands - blue and red (λ=450 and 650 nm) to carry out their fundamental biological processes, such as photosynthesis (producing of biomass and air clearing) and phototropism (orientation towards the light in weightlessness). That is why, precise spectral analysis of 12 different kinds of fluorescent lamps was made in order to choose the optimal one with nearly identical other parameters [4]. The new LU2 with improved parameters has been in normal operation onboard during the next experiments providing 23 hour light per day with better intensity and thus contributing to plant biomass production.

2. Short description of LU2

LU2 can be moved vertically in the Plant Growth Unit (PGU) of SVET-1,2 SG and adjusted at three different levels - 20, 30 and 40 cm from the Vegetation Module surface (on the photo of Fig.1 it is fixed at the highest level) in order to provide best light intensity without overheating,

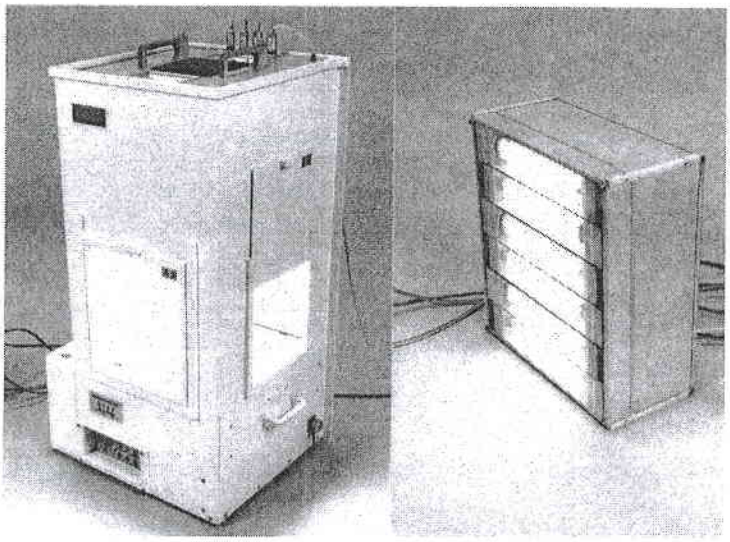

Fig. 1 A photo of the SVET-2 SG Plant Growth Unit with LU2 unit, fixed at the highest level (left) and a photo of the LU2 unit from the bottom (right).

4.1. The illuminance (E) created by LU2 is measured at a distance of 15 cm from the center of the lamp area. There are strong requirements to this parameter. It should not fall down under a fixed minimal value during the equipment warranty period (2 years). The lamp spectrum should meet plant requirements (for photosynthesis, phototropism). The LU2 unit should provide and maintain steady light parameters even in case of lamp replacement onboard without additional tuning. Such replacement is made by the astronauts in case of lamp failure or lifetime expiration. LU2 should provide optimal operating conditions and maximal life of the lamps. The lamp intensity and operating state have been checked onboard during the MIR-NASA program by the American astronauts using two luxmeters built in the SVET-2 SG and the information has been transmitted to Earth by the Telemetry System.

4.2. The LU2 input power consumption (P_{in}) should be minimal in the whole range of the onboard power supplies (±27 V, +7,- 4 V) and when maintaining an optimal proportion lx/W and maximal life of the lamps. The LU1 input power consumption (243 W when the input voltage is 27 V and 306 W when it is 34 V) can be taken as a basis for comparison. Such consumption allows only 16 hour lighting period per day. LU is the biggest energy consumer. All the rest units such as CU, the system for water and air supply, sensors and measuring systems, consume relatively low power (about 10 W) per day.

4.3. The total lamp and LU2 heat losses (P_0) should be as low as possible because the unit is located just above the plants. A heat sensor monitoring air temperature near the plants is mounted in the LU2 input to avoid plant overheating. The sensor information is transmitted to the SVET-2 CU and to Earth by the Telemetry System. If the temperature registered by the sensor exceeds an admissible value, CU switches off LU2 and switches on the fan for lamp cooling.

4.4. Technical and structural LU2 reliability is required in order to ensure optimal light characteristics in case of accidents onboard during a several month experiment. The failure of some functional units of LU2 should not cause a failure of the other units. Unit interchangeability is also required (for example in case of failure in the second supply unit and the third light body, it should be possible to use the second light body and the third supply unit). In case of replacing the light body or a failure in it no-load and short circuit protections should be provided.

4.5. The parameter repetition and stability in the separate units of LU2 is an important condition for conducting simultaneous experiments onboard and on Earth. LU2 should provide identical conditions (average luminous energy, spectrum and temperature) for plant growth during several month simultaneous experiments. High parameter stability in the separate LU2 units would provide a possibility for earth optimization of the rest SVET-2 parameters - substrate moisture, nutrient solution composition, composition of the gases released during vegetation etc.

4.6. The starting parameters should meet the General Technical Requirements - 87 (GTR-87) placed by the Institute of Biomedical Problems, Moscow, Russia. This paper contains the general requirements towards the scientific equipment working onboard the MIR OS. The amplitude of the unit starting current should not exceed the fivefold value of the maximal consumed current in operating mode. The requirement for independent operation in manual mode was set forth after a CU failure that occurred during the 1995 SVET-2 experiment. Then, the automatic control fell off and the astronauts could not switch over to manual control for lack of autonomous power supply since, in LU1, only an external power supply (±12V from CU) was used [6].

4.7. LU2 should meet the GTR-87 requirements for electromagnetic compatibility (EMC) with all the rest equipment units [7] in order to be admitted onboard of the MIR OS. For that purpose, due constructional and electrical measures (filters etc.) should be taken when developing LU2 unit.

5. Functional diagram and parameters of the SVET LU1 unit

The LU1 functional diagram is shown in Fig. 2.

The following abbreviations have been used in this diagram:

CU - Control unit, LPS - lamp power supply; LBU - lamp body unit; LVR - linear voltage regulator; LC - filter for EMC; BO - blocking oscillator; L - lamp; C - output choke; T - ouput transformer; FPS - fan power supply; F - fan; TS - temperature sensor; SWB - two position switch for board power supply; SWL - three position switch for switching the light modes and SWF - three position switch for switching the fan modes.

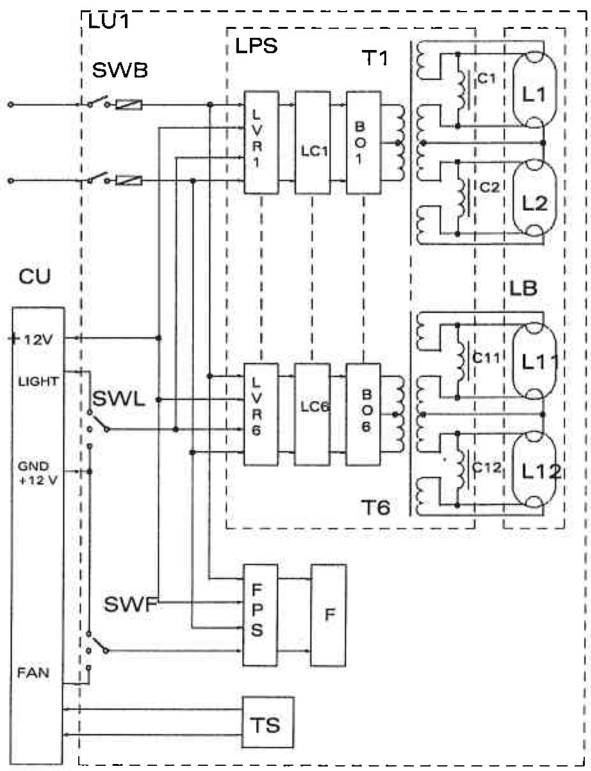

Fig. 2 Functional diagram of the SVET LU1 unit.

LVR converts the unstable board power supply (24-34 V) into 20 VPC stable voltage. The chosen linear voltage regulator has low efficiency (η_{LVR} = 0.7) under an average board supply of 29 VPC.

BO converts the stabilized constant voltage on its input into stabilized alternating square output voltage. The chosen push-pull blocking oscillator on the basis of bipolar transistors and saturation of the transformer has high commutation loss, frequency instability and efficiency $\eta_{BS} = 0.9$.

T provides stabilized preheating voltage and sets lamp current by C. The chosen fluorescent lamp LS 8-6 has a low lm/W ratio. That is why, a higher heating voltage is used in order to obtain the necessary light intensity. This makes plant environment temperature conditions worse and shortens lamp heating life. The chosen saw-tooth alternating current in the plasma and non-stop heating mode shortens lamp life. In long operation, the lamp phosphor around the cathode becomes black and this makes light radiation worse.

In this circuit solution for the lamp power supply unit, light radiation stability depends on the following parameters: voltage regulator output, voltage stability, blocking oscillator frequency, choke inductance temperature stability and lamp voltage temperature stability. In permanent heating conditions, lamp efficiency $\eta_L = 0.8$. The ratio of power supplied to the lamp plasma (P_p) and the input onboard power supply (P_{in}) is:

$$P_p/P_{in} = \eta_{LVR} x \eta_{BO} x \eta_T x \eta_C x \eta_L = 0.7x0.9x0.99x0.99x0.8 = 0.494$$

The conclusion can be drawn that half of the onboard power is lost before it has been supplied to the lamp plasma, i.e. the efficiency of the secondary lamp power supply is low.

6. Operational diagram and parameters of the SVET-2 LU2 unit

The operational diagram of the new LU2 unit is shown in Fig. 3. Here, the used abbreviations mean: F1-F6 - breakdown fuses; 1 - EMC filter; 2 - soft start circuit; 3 - DC/DC converter; 4 - DC/AC converter; 5 - lamp current sensor; 6 - negative voltage feedback; 7 - enable and control circuit for the starting process; 8 - DC/DC converter control circuit; 9 - error amplifier; 10 - comparison circuit; 11 - 12 V voltage regulator; 12 - circuit for step lamp switch-on; 13 - EMC input filter; C1 - C6 - start lamp capacitors; Ka - switch for manual guidance of the lighting in case of failure, SW1 - SW6 - switches for inhibition of damaged LU2 channels; V1-V6 - enable voltage for the respective LU2 channels.

The unit's functions and operation are as follows:

♦ Filter /1/ rejects onboard power-supply noise and the current noise of the DC/DC converter.

♦ Filter /13/ is common for all channels. It rejects the aerial currents flown through the DC/DC and DC/AC converters as a result of electromagnetic radiation. Filters /1/ and /13/ ensure the desired LU2 electromagnetic compatibility with the onboard systems.

♦ Circuit /2/ limits the charging current of the capacitors in circuits /1/ and /3/ when switching off the SWB switch. When V1 enable voltage appears the V_{32} voltage increases slowly and circuit /2/ passes to state ON.

♦ The DC/DC converter increases the input constant voltage and separates the lamp from the onboard power supply in a galvanic way.

♦ The DC/AC converter generates the necessary ignition voltage in lamp burning mode as well as the chosen working voltage for the lamp in current regulation mode.

♦ Sensor /5/ consisting of a current transformer and a low-pass filter produces a voltage V_{rms} proportional to the lamp current.

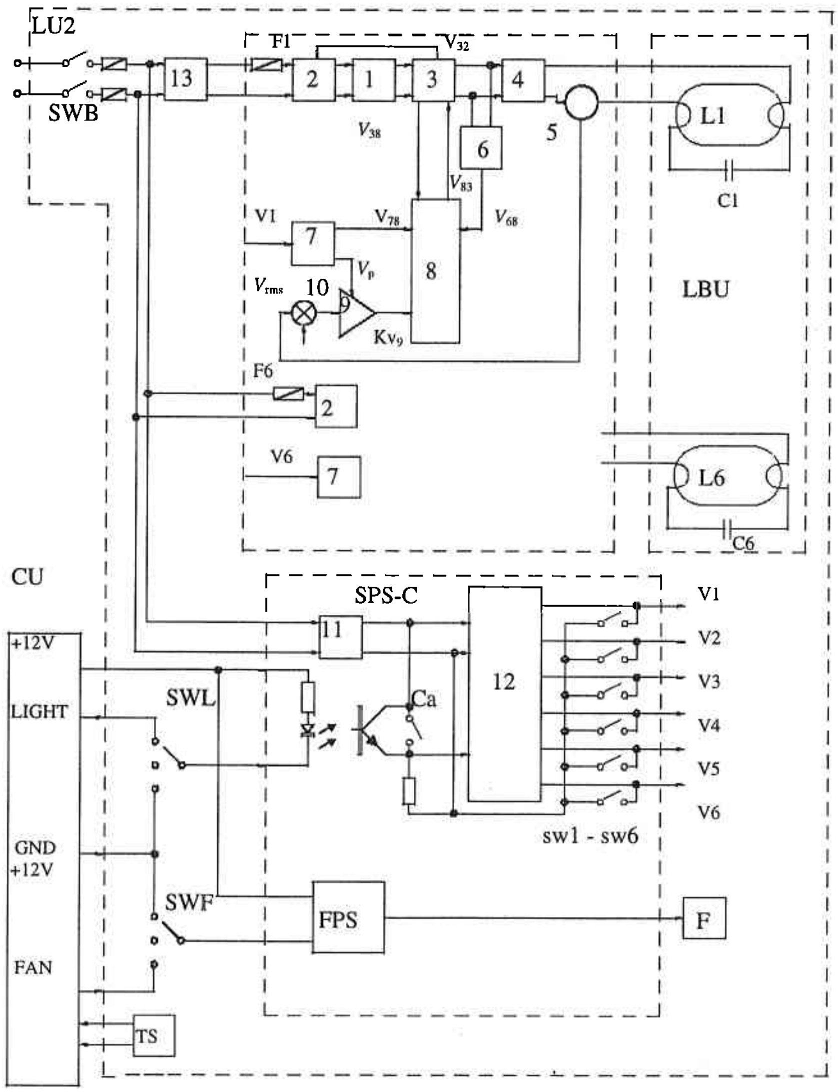

Fig 3. Operational diagram of the SVET LU2 unit.

♦ The negative voltage feedback circuit /6/ has protective functions. It is activated at the end of the starting process even in case of breakdown of a lamp or a starting capacitor, i.e. it provides no-load protection of LU2.

♦ After receiving V1 enable voltage the circuit /7/ generates V_{nc} voltage for soft start of units /3/, /4/ and /8/. Upon lamp burning this circuit supplies enable voltage V_{79} to the circuit for current lamp regulation - units /5/, /9/ and /10/.

♦ Comparison circuit /10/ compares the current V_{rms} with the set V_{10} value. The V_{10} voltage is generated using precise reference voltage.

♦ Circuit /8/ converts the constant V_{68}, V_{78} and kV_1 voltages into square controlling voltage V_{83} whose duty factor is directly proportional to their values. The V_{38} voltage is proportional to the instantaneous value of the current in switch transistor /3/ and it activates the LU2 protection in case of a short circuit in the output.

♦ Circuit /11/ regulates the supply voltage for /12/.

♦ When switching on the SWB switch circuit /12/ generates consecutively enable voltages V1 to V6. This circuit improves the LU2 starting parameters in conformity with the GTR-87 requirements [7].

7. LU2 analysis

After a long inquiry, the OSRAM DS 11/21 lamp was chosen. Its luminous flux is 900 lm in normal mode (11 W) that corresponds to the luminous flux of a 75W-filament lamp. 8000-hour work is warranted when maintaining 0.150 A alternate current of 50 Hz frequency within ±10 % accuracy as well as ambient temperature within the range of +5° C to +50° C. The spectrum of the DS11/21 lamp was studied in laboratory conditions to evaluate its dependence on the frequency and the value of the lamp working current and the temperature of the lamp glass bulb. Two power-supplies were used for the purpose - the first one was from 220 V (50 Hz) line power supply through a choke and starter and the second one was realized in conformity with Fig. 3 with regulation of the lamp current frequency and value. It was found out that the spectrum depends mostly on the lamp phosphor characteristics. Some Hg whose leakage could cause crew poisoning was also detected. That is why, strict precautions were taken to seal hermetically the lamp bodies, so that they could work even when flooded with water or under increased pressure.

The dependence of the illuminance (E) on the lamp working current (I_L) and air temperature within the lamp body in real working conditions was also studied in SRI - BAS. The American digital photometer SPECTRA-CANDELA-II, 2010 model was used in these studies. On Table 2 are shown the results obtained for one DS 11/21 OSRAM lamp housed within a hermetically sealed lamp body working in a steady-state regime at t_a=20 ° C, and supplied by the SVET-2 Secondary Power Supply (SPS) (index "rms" is used

T a b l e 2. Parameters of fluorescent lamp depending on lamp current

Regime	Lamp current (I_L)		Lamp voltage (V_L)		Lamp power (P_L)		Illuminance (E) at the distance of 15 cm		Lamp efficiency (E/P_L)	
	A_{rms}	%	V_{rms}	%	W_{rms}	%	lx	%	lx/W	%
1	0.104	83.2	87.60	114.5	9.11	95.3	4192	93.1	460.1	97.7
2	0.125	100.0	76.48	100.0	9.56	100.0	4500	100.0	470.7	100.0
3	0.152	121.6	69.60	91.0	10.58	110.7	4705	104.5	444.7	94.5

to mark the root-mean-square value of the respective parameter).

The measurements were made after two-hour work when the fan was off. In Regime 3, the rated power recommended by the producer (11 W) was supplied to the lamp and the heat losses were maximal. They resulted in heating of the lamp body whereas temperatures in the middle point of the brass reflector reached +53 °C while in the middle of the transparent plexiglass it reached +41° C. It can be assumed that air temperature within the lamp body is about +50 °C and the lamp works in bad temperature conditions (see Table 1 - when t_a=50 °C).

When the lamp current value is lower than 0.104 /A_{rms}/ the lamp goes out sharply. After a number of tests, the optimal working lamp current was found (Regime 2) in which the lamp efficiency is maximal and the percentage of the heat loss in the lamp body is minimal. In Regime 2 I_L is about the arithmetical-mean of both values - the minimal and the rated one.

The other two regimes have the following disadvantages: in Regime 1, 2.3 % of the lamp efficiency gets lost, lamp ignition is unsteady at low temperature, and the phosphor around lamp cathodes goes black upon continuous work (10 % of effective phosphor radiation area gets lost); in Regime 3, when the lamp current has a rated value lamp efficiency is 5.5 % lower and heat losses in the lamp body are maximal.

The measurements from Table 2 prove that the lamp has a negative resistance (R_L) within the range from minimal to the rated lamp current [8]:

$$R_L = (V_3 - V_1)/(I_3 - I_1) = (69.60 - 87.60)/(0.152 - 0.104) = - 375\ \Omega .$$

As an SPS load the negative resistance causes difficulties in the control process. That is why, it has to be compensated by a high enough positive resistance (active or reactive) additionally limiting the lamp current.

The relative change of E depends mainly on the relative change of P_L. The comparison between Regime 2 and Regime 3 reveals the following: when increasing I_L by 21.6 %, V_L becomes 9 % lower, P_L is on 10.7 % increase, but the growth of E is 4.5 % only. Comparing these regimes it can also be seen that when decreasing I_L by 16.8 %, V_L increases by 14.5 %, P_L falls by 4.7 %, but this leads to a 6.9 % decrease of E. That is why, I_L current regulation was chosen as the most effective way to stabilize lamp intensity E. High precision of ±1 % was achieved when maintaining a constant I_L current within a wide range of ambient temperature t_a and onboard power-supply (from 20 V to 40 V). The main parameters of one LU2 channel working in steady-state regime at t_a=20 °C and 27 V onboard power supply are given on Table 3.

The measurements were made after two-hour work, without an SPS control board and with a fan off. Comparing Regime 1 with Regime 2 it can be seen that total SPS efficiency is highest when lamp current is minimal since in this case SPS efficiency is maximal. SPS losses are propotional to the square of I_L. Comparison between Regime 3 and Regime 2 proves that the LU2 parameters become worse with a rated I_L value: a 10.7 % increase of P_{in} leads to 8.3 % loss of total efficiency E/P_{in} while E is on 4.5 % increase only (see Table 2 and Table 3).

T a b l e 3 Parameters of each channel of LU2 of SVET-2

Regime	Lamp current (I_L)		Onboard power supply (P_L)		Losses in SPS (P_{in} - P_L)		SPS efficiency P_L/P_{in}	Intensity margin (E/E_{min})	Total SPS and lamp efficiency (E/P_{in})	
	A_{rms}	%	W_{rms}	%	W_{rms}	%	%	%	lx/W	%
1	0.104	83.2	10.91	88.4	1.80	64.7	83.5	209.6	384.2	105.3
2	0.125	100.0	12.34	100.0	2.78	100.0	77.5	225.0	364.7	100.0
3	0.152	121.6	14.07	110.7	3.49	125.5	75.2	235.2	334.4	91.7

In conclusion, the comparison between the efficiency of the old LU1 and the new LU2 with onboard power-supply of 27 V shows the following:

- in LU1 the efficiency is 49.38 lx/W;
- in LU2 the efficiency is 285.7 lx/W (5.78 times higher).

Assuming the total LU1 illuminance of 12 000 lx as a minimal one from the point of view of satisfying plant needs, each of the six LU2 channels should provide the desired minimal illuminance E_{min} = 2000 lx. In reality, it is two times higher. Table 2 shows that even with minimal I_L current the intensity margin is 209.6 %. This high intensity margin in LU2 provides minimal intensity in case of lamp aging or non-identity when replacing a lamp during operation. The high total efficiency E/P_{in} ensures stable LU2 operation with maximal daylight duration of 23 hours, thus prolonging the time necessary for biomass production and providing normal plant growth.

Due to the improved LU2 characteristics (along with the substrate moistening) "space" plants looking like the "earth" ones were grown during the experiments. One of the flight LU2 units worked normally onboard the MIR OS over 6000 hours in the period from 1996 to 1997 without any remarks. Six-month experiments with two consecutive crops of *Super-Dwarf* wheat were conducted on the MIR-NASA-3 program in 1996 with the participation of American astronauts. Irrespective of the optimal environmental conditions, no seeds were produced in these experiments probably because of the high concentration of the gas ethylene available in the MIR OS atmosphere. The experiment was repeated in 1998 - 1999 with another ethylene hardy wheat variety when seeds were produced and later planted in order to grow a second crop. The three consecutive crops of *Brassica rapa* plants grown in 1997 on the MIR-NASA-5 program (plants developed from seeds that were themselves produced on board) proved the possibility for plant reproduction in weightlessness. The unique scientific results received during the SVET-2 SG experiments will contribute to develop the future biological life support systems necessary to support crew life during long-lasting manned space missions - first to the Moon and Mars.

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БЛОК ОСВЕТЛЕНИЕ НА КОСМИЧЕСКАТА ОРАНЖЕРИЯ СВЕТ-2

Павлин Граматиков, Таня Иванова

Резюме

Представени са техническите и физическите проблеми, методите и средствата за решаването им, при разработката на нов Блок осветление (БО2) - част от Космическата оранжерия (КО) СВЕТ-2, работеща на Орбиталната станция (ОС) МИР от 1996 година. Накратко са описани луминисцентните лампи, използвани в БО2, както и техническите изисквания към научната апаратура за космически цели, зададени от руската приемаща страна - Института по медико-биологични проблеми, Москва. Описани са предимствата на новия БО2, разработен на втората модификация на КО СВЕТ-2 и параметрите му накратко са сравнени с тези на първоначалния вариант Блок осветление (БО1), летял на ОС МИР през 1900 г. по българо-руски проект. Благодарение на оптимизацията основно на параметрите на осветлението на втория вариант БО2, в КО СВЕТ-2 бяха отгледани нормално развити "космически" растения (предимно пшеница) през периода 1996-1999 година и бяха получени уникални резултати в областта на фундаменталната гравитационна биология.