Belgorod State Technological University named after V.G. Shoukhov

25th Workshops on Radiation Monitoring for the International Space Station

Study of the Radiation Shielding Properties of the Composite Material in the ISS Service Module Crew Cabin

Natalia Cherkashina[1], Vyacheslav Pavlenko[1],
Andrew Kuritsyn[2], Elena Popova[2], Lyudmila Umnova[2],
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[1]Belgorod State Technological University named after V.G. Shoukhov
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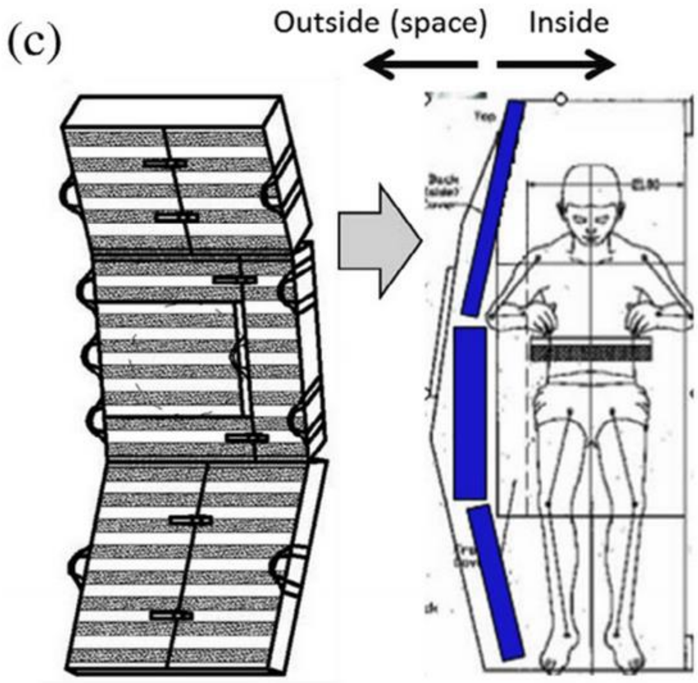
September 6-8, 2022
Mons, Belgium

RADIATION ON THE EARTH AND IN SPACE

Location and period of exposure	Dose, mSv
Background dose on the Earth's surface per day / per year	**~0.003 / ~1**
Dose aboard the space station per day / per year	**0.7 / 250**
Dose per chest x-ray	**0.1**
Dose from a powerful solar proton event in low Earth orbit/outside the magnetosphere	**6 / >100**
Dose for extravehicular activities (6 hours)	**~ 0.6**
Dose limit for an astronaut ~1 day / 1 month / 1 year	**150 / 250 / 500**
Dose limit for 1 year for group A personnel on Earth (on average for 5 years) in Russia	**20**
Occupational dose limit for cosmonaut / group A personnel (according to Russian standards)	**1000**

Δ(Life Time) **≤ 3 years**

EXPERIMENT ON SHIELDING AGAINST SPACE RADIATION (NEUTRONS INCLUDED) IN THE COSMONAUT'S CABIN ON THE RUSSIAN SEGMENT OF THE ISS



"Matryoshka-R" space experiment

PROPOSED POLYMER COMPOSITE (PC)

PC Composition: - 38,5 wt% polymer matrix $(C_2F_4)_n$ - fluoroplast-4 (PTFE);
- 58,5 wt% modified filler - bismuth oxide (Bi_2O_3)
- 3 wt% nanodispersed filler - tungsten carbide (WC)

Atomic composition of PC

Content of atoms, wt %				
C	**F**	**O**	**Bi**	**W**
9,42	**29,26**	**6,03**	**52,47**	**2,82**


РОССИЙСКАЯ ФЕДЕРАЦИЯ

ПАТЕНТ
НА ИЗОБРЕТЕНИЕ
№ 2748157

ПОЛИМЕРНЫЙ НАНОКОМПОЗИТ ДЛЯ ЗАЩИТЫ ОТ КОСМИЧЕСКОГО ВОЗДЕЙСТВИЯ И СПОСОБ ЕГО ПОЛУЧЕНИЯ

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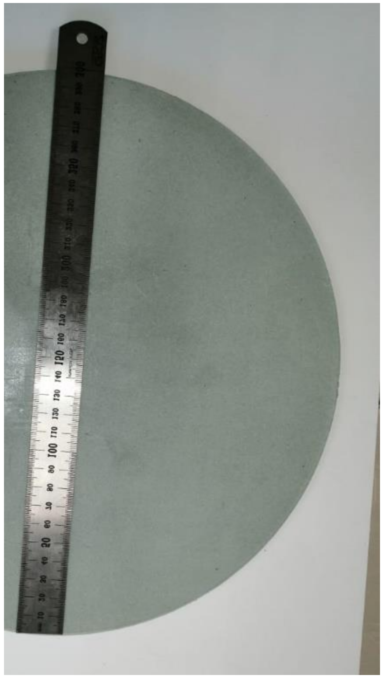
Заявка № **2020134472**
Приоритет изобретения **20 октября 2020 г.**
Дата государственной регистрации в Государственном реестре изобретений Российской Федерации **20 мая 2021 г.**
Срок действия исключительного права на изобретение истекает **20 октября 2040 г.**

Руководитель Федеральной службы по интеллектуальной собственности

Г.П. Ивлиев



Experimental PC


XXII Московский международный Салон изобретений и инновационных технологий

«АРХИМЕД-2019»

ДИПЛОМ

Решением Международного Жюри награждается

ЗОЛОТОЙ МЕДАЛЬЮ

Федеральное государственное бюджетное образовательное учреждение высшего образования «Белгородский государственный технологический университет им. В.Г. Шухова за разработку «Полимерный композит для защиты от космической радиации и способ его получения» (Павленко В.И., Лончаков Ю.В., Дерябин Ю.А., Черкашина Н.И., Ястребинский Р.Н., Дерябин А.Ю., Павленко А.В., Манаев В.А.)

Председатель Международного Жюри, академик, член президиума РАН

Президент Салона

Руководитель Федеральной службы по интеллектуальной собственности


Diploma of Excellence

MEDAL INVENTICA 2020

Offered to

PAVLENKO V.I., KURITSYN A.A., POPOVA E.V., GLAGOLEV S.N., CHERKASHINA N.I.

Belgorod State Technological University named after V.G. Shukhov

MULTI-LAYERED CARBON-POLYMER COMPOSITE FOR THE PROTECTION AGAINST SPACE IMPACT AND METHOD FOR THE PRODUCTION OF THEREOF

in recognition of high scientific contribution and loyalty to the XXIV-th INTERNATIONAL EXHIBITION OF INVENTICS

INVENTICA 2020

Iasi, Romania

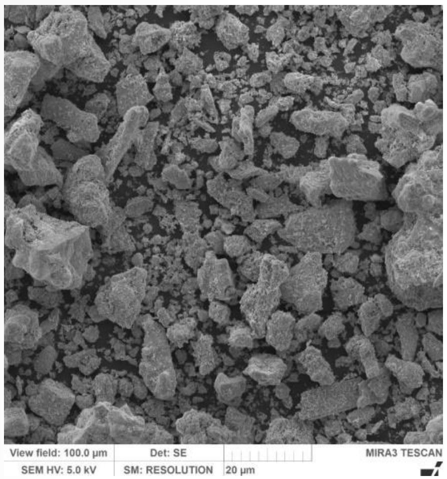
29-31 July 2020

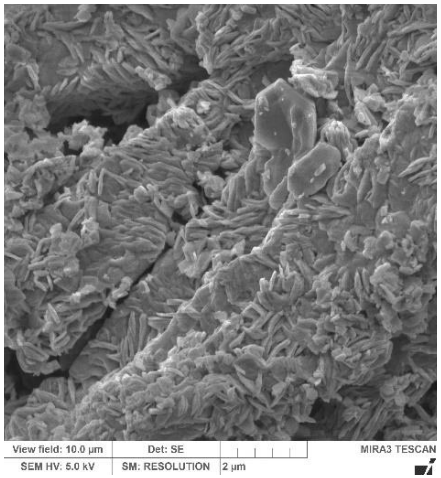
GENERAL MANAGER
NATIONAL INSTITUTE OF INVENTICS
Prof. Neculai SEGHEDIN PhD

By the decision of the International Jury, the development was awarded the GOLD MEDAL of the XXII Moscow International Salon of Inventions and Innovative Technologies "Archimedes-2019".

BISMUTH OXIDE FILLER CHARACTERISTICS

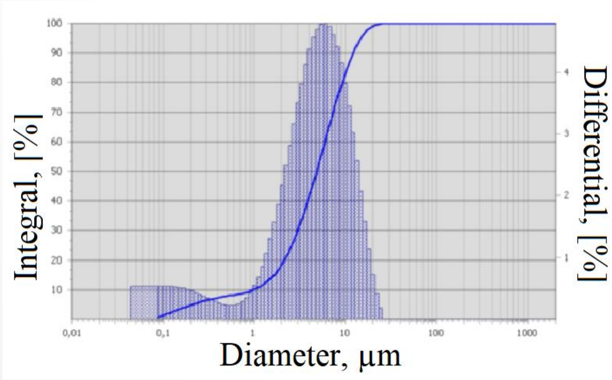
Bismuth oxide (α-Bi_2O_3)
(manufactured by Plant of Rare Metals LLC, Novosibirsk, Russia).





SEM image of particles α-Bi_2O_3

a



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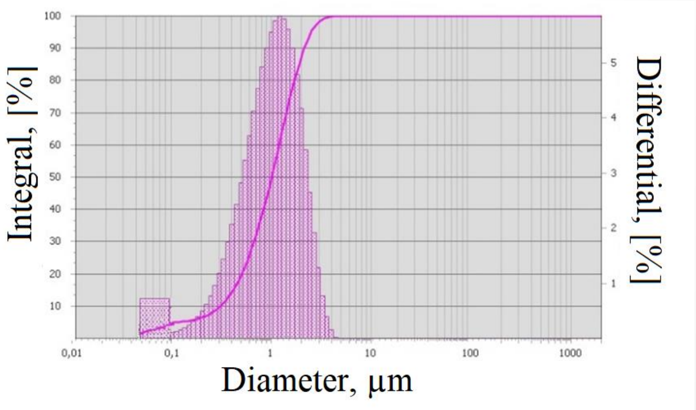


Fractional compositions of the filler before (a) and after (b) physical-mechanical treatment
(wet grinding 6 h and ultrasonic treatment 30 min)

COMPOSITE MANUFACTURING TECHNOLOGY

Static Testing Machine 300LX-B1-C3-J1C (Instron)

The technology includes cryogenic grinding, heating, pressing and hardening.

PHYSICAL AND MECHANICAL PROPERTIES OF THE COMPOSITE

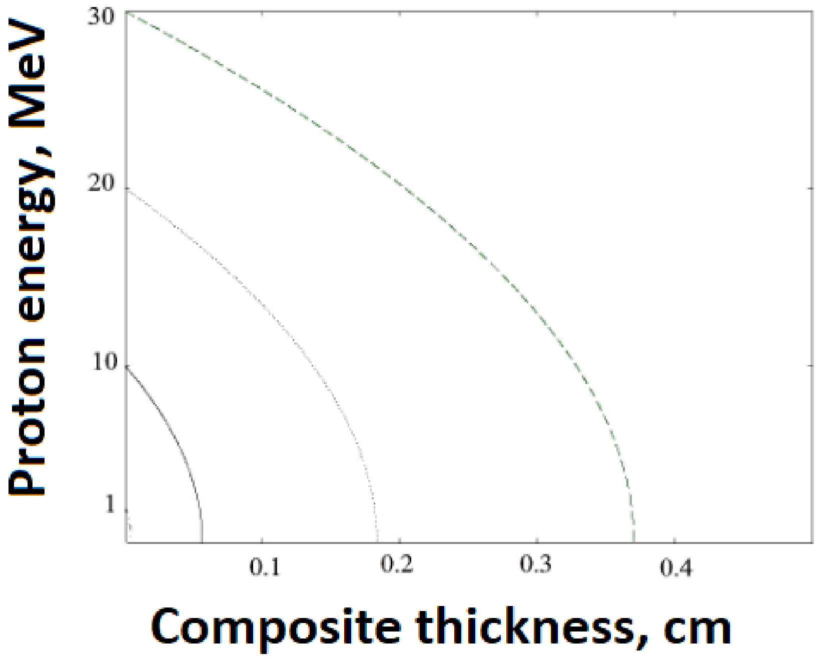
Density, g/cm3	4,0
Bending strength, MPa	12
Compressive strength, MPa	17
Tensile modulus, GPa	0.38
Elongation at break, %	4.5
Microhardness (according to Brinell), HV	27
Operating temperature, °C: - on air - in vacuum ($P=1.4\cdot10^{-5}$ Pa)	 от -170 до 250 от -170 до 320
Thermal cycling -170….+150 °C, cycles	> 50
Electrical strength, kV/mm	17
Dielectric constant (10^3 Hz)	3.3
Specific electrical resistance, Ohm·m	10^{17}
Thermal conductivity, W/(m·K)	0.24
Radiation resistance, MGy	5

NEAR-EARTH SIMULATION FACILITIES
OUTER SPACE

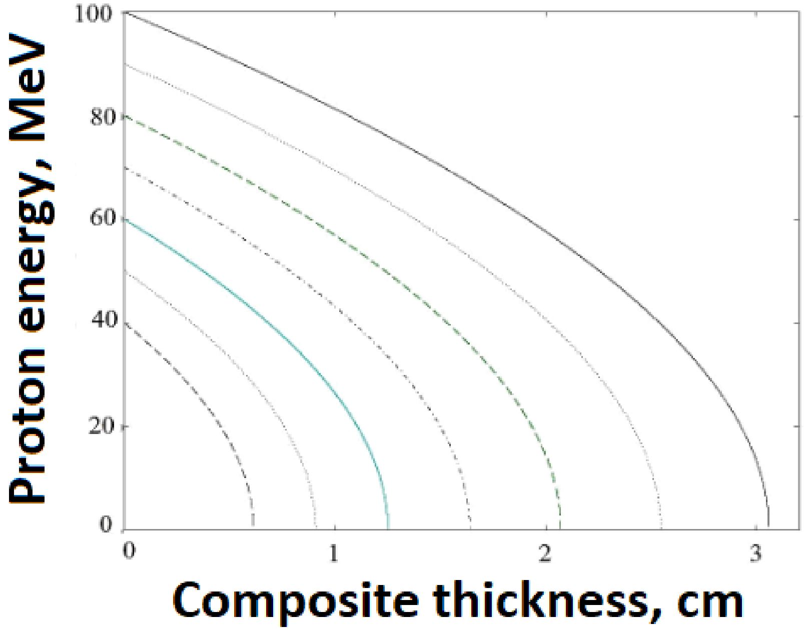
Vacuum Ultraviolet (VUV) Testing
Machine for PC
in conditions close to near-Earth space

Installation for Irradiation of PC with
Fast Electrons under Conditions
Approximate to Near-Earth Space

PHYSICAL AND MATHEMATICAL MODELING OF THE PASSAGE OF PROTON RADIATION THROUGH A PC



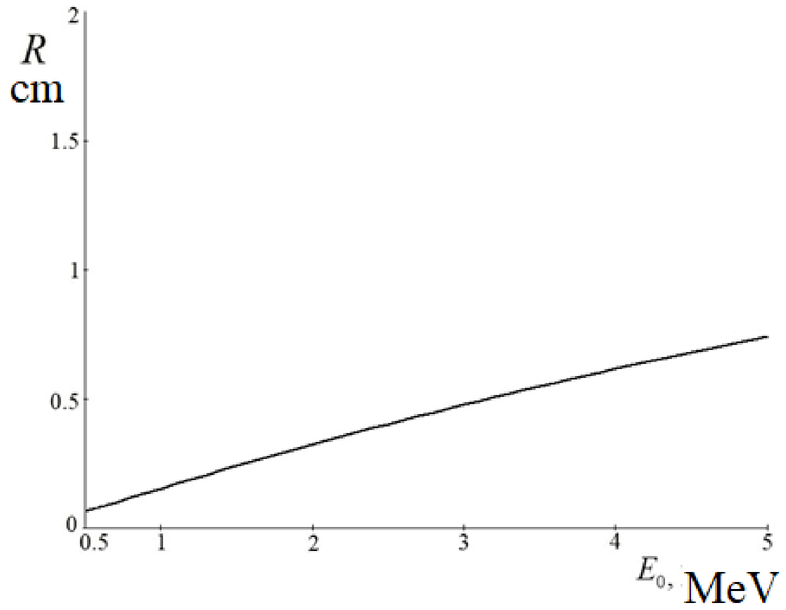
Proton energy change
(10 - 30 MeV), passed in the PC
path x (cm)

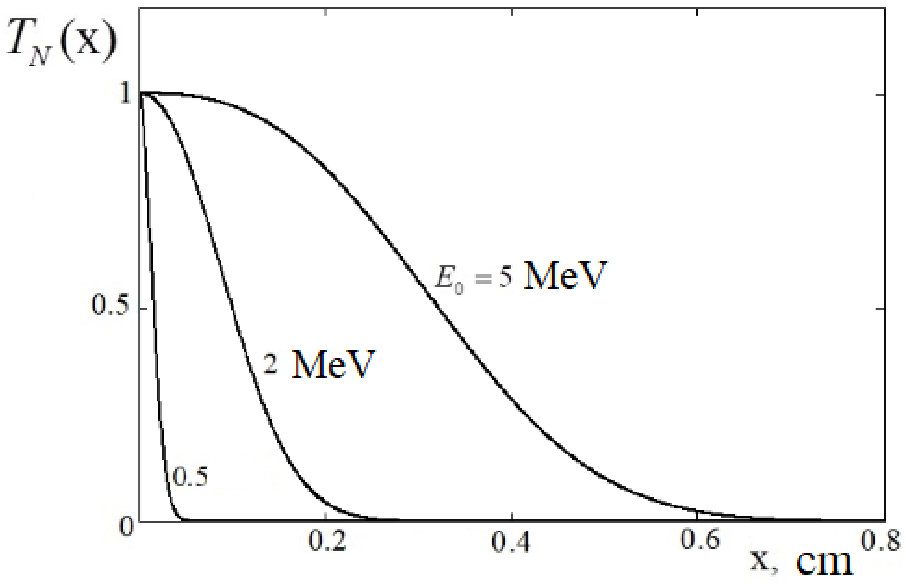


Proton energy change
(40 -100 MeV), passed in the PC path
x (cm)

Effective range (L) of protons with E = 100 MeV L=3.0 cm in PC (in Al - 3.6 cm); at E = 40 MeV L=0.63 cm in PC (in Al - 0.70 cm)

PHYSICAL AND MATHEMATICAL SIMULATION OF THE PASSAGE OF FAST ELECTRONS THROUGH A PC





Effective electron range in PC
versus electron energy

Effective range of electrons
(E=5 MeV) in PC - 0.58 cm (in Al - 0.95 cm)

Electron Transmittance for normal fall
(90 deg.) on PC versus electron energy

EXPERIMENTAL RESULTS ON γ-IRRADIATION OF PC

Comparative characteristics of radiation-protective properties at E_γ = 0,66 MeV (^{137}Cs)

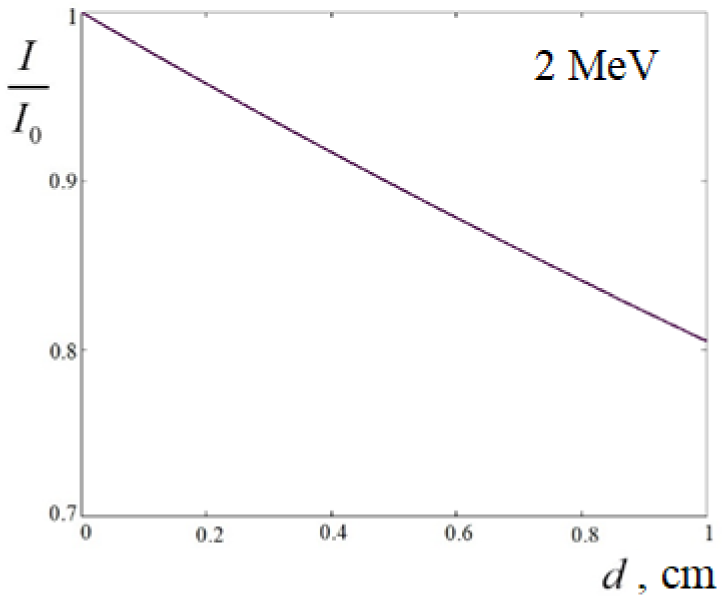
Parameter	PC	Al
Linear attenuation coefficient of γ -radiation, μ, cm^{-1}	0.79	0.20
Mass factor attenuation of γ-radiation, μ_m, cm^2 /g	3.39	0.56

Comparative characteristics of radiation-protective properties at E_γ = 1,25 MeV (^{60}Co)

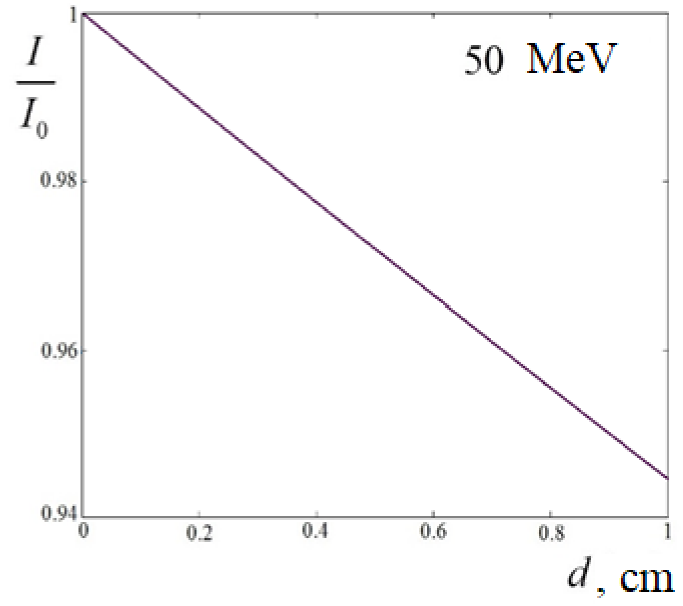
Parameter	PC	Al
Linear attenuation coefficient of γ -radiation, μ, cm^{-1}	0.40	0.15
Mass factor attenuation of γ-radiation, μm, cm^2 /g	1.72	0.42

THEORETICAL RESULTS ON NEUTRON EXPOSURE

a



b

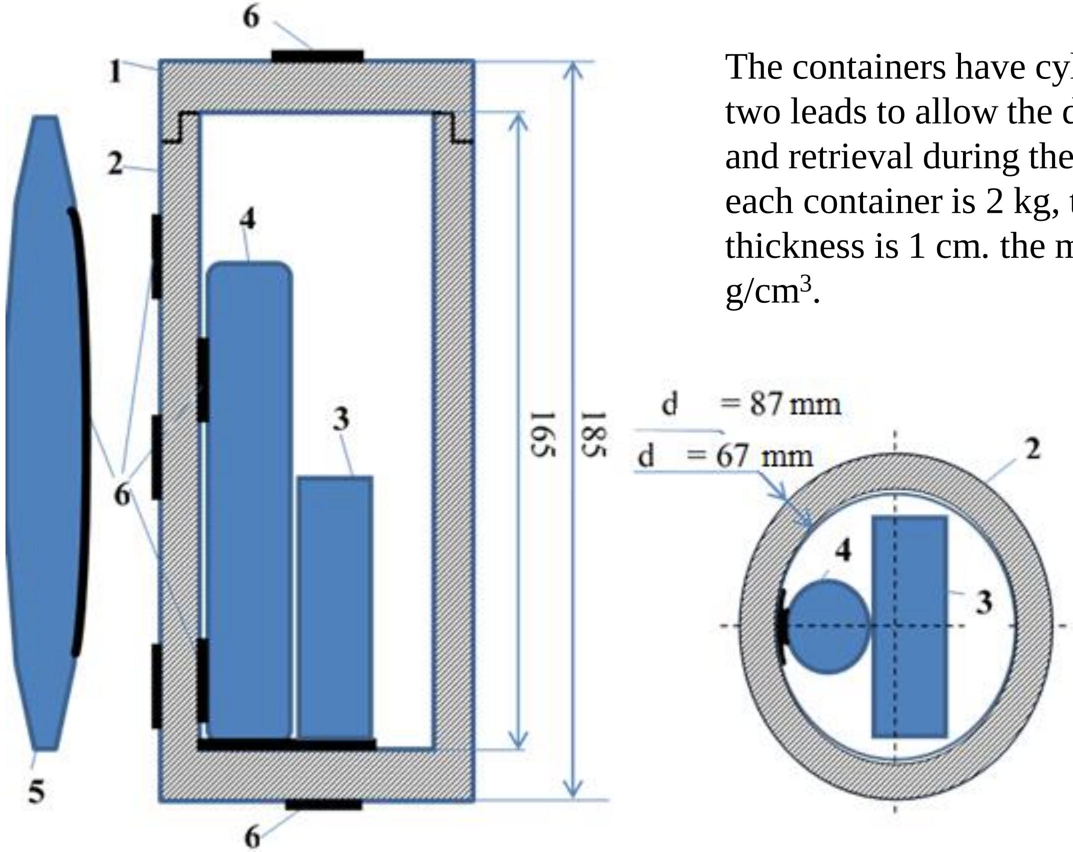


Attenuation of neutron flux when passing through a protective composite at energy of:
a – 2 MeV; b – 50 MeV

When passing through the developed protective composite 1 cm thick, the neutron flux decreases by 19.0 and 5.5% at neutron energies of 2 and 50 MeV, respectively.

SCIENTIFIC EQUIPMENT USED in "PROTECTIVE COMPOSITE" SPACE EXPERIMENT

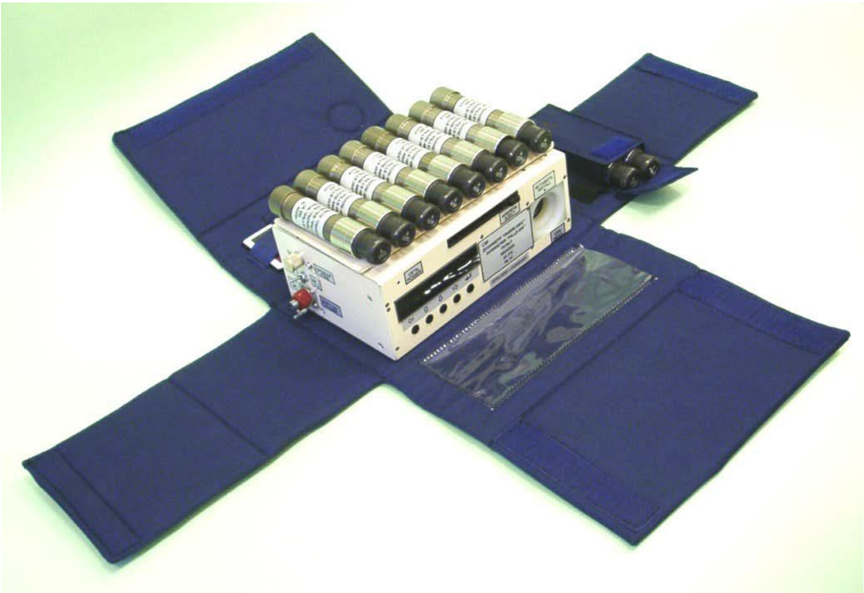
On February 17, 2022 two containers from the composite material together with passive detectors were delivered to ISS by Progress-MC-19 cargo spacecraft.



The containers have cylindrical form with two leads to allow the detectors placement and retrieval during the flight; the mass of each container is 2 kg, the container wall thickness is 1 cm. the material density is 4 g/cm^3.

Design model of a radiation shield in the form of a container: 1 – container cover; 2 – container body; 3 - DI-MTS detector, 4 - Pille-ISS detector; 5 - Bubble dosimeter in a case; 6 - Velcro fastener

DOSIMETER "PILLE-ISS"



Developed by the Magyar Tudományos Akadémia Energiatudományi Kutatóközpont (Hungarian Academy of Sciences Energy Science Research Center, Hungary) and the Institute of Biomedical Problems Russian Academy of Sciences (Russia).

It was delivered as a regular dosimeter in 2003. Currently in use.

Main functions:

- measurement of the absorbed dose at various points in the compartments of the Russian segment of the ISS;
- dose measurement during out-of-ship activities;
- automatic measurements of doses by a sensor inside the console;
- individual dosimetric control.

CHARACTERISTICS OF THE "PILLE-ISS" DOSIMETER

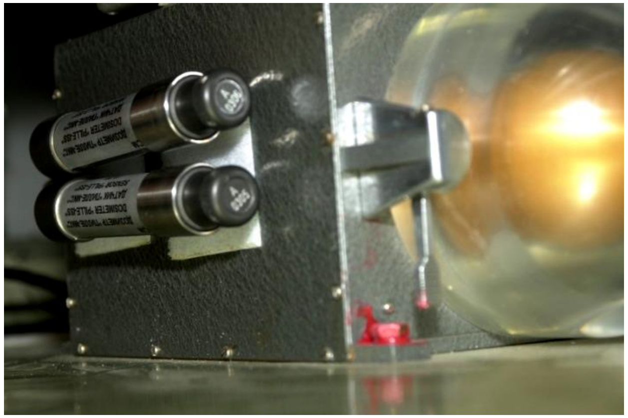
It consists of a set of sensors and a remote control in which the accumulated information is read and written to the memory card.

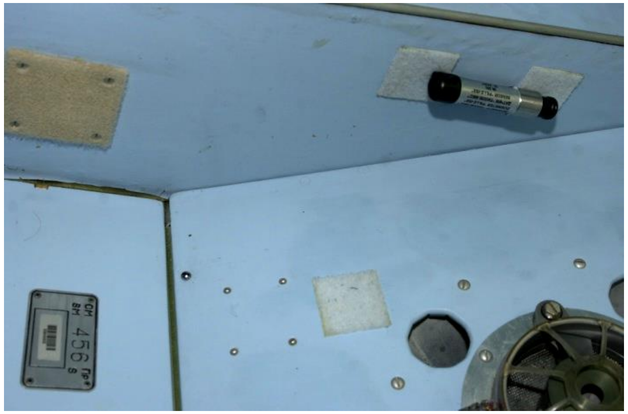
Detectors – thermoluminescent (material $CaSO_4$: Dy)

	Dimensions, mm	Weight, kg	Power consumption, W
Control pane	**213x126x70**	**1.5**	**10**
Detector	**Ø 23x120**	**0.08**	**-**

The measurement error from 10 µGy is less than 5%

PHOTO OF THE «PILLE-ISS» DOSIMETER ON THE RUSSIAN SEGMENT OF THE ISS



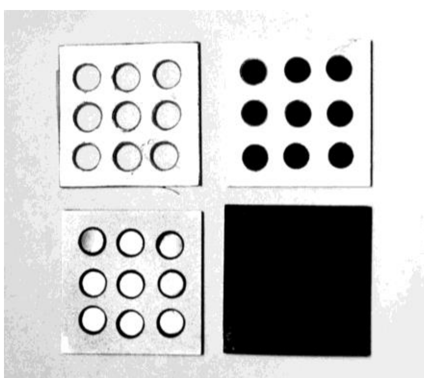


DOSIMETER INDIVIDUAL FOR A MANNED TRANSPORT SHIP (DI-MTS)

The dosimeter provides:

- registration of the integral absorbed dose from the flow of charged particles of solar cosmic radiation, galactic cosmic radiation, radiation belts of the Earth in the range from $1 \cdot 10^{-4}$ to 5 Gy;
- measurement of the linear energy transfer spectrum of charged particles in the range from 5 to 700 keV/μm;
- determination of the radiation quality factor (by calculation after ground processing);
- determination of the equivalent dose in the range from $1 \cdot 10^{-4}$ to 10 Sv.

The dosimeter consists of:
- holder with 9 thermoluminescent detectors (TLD), 2 pieces maximum
- solid state track detector (SSTD), 2 pieces maximum.



Holder for TLD

Appearance of the detector

Overall dimensions of the detector: 80x65x20 mm.

SSTD

SCIENTIFIC EQUIPMENT USED IN "PROTECTIVE COMPOSITE" SPACE EXPERIMENT ON THE RUSSIAN SEGMENT OF THE ISS

Photo of a container from radiation-protective composite

Photo of scientific equipment

Photo of scientific equipment on the ISS

CARRYING OUT "PROTECTIVE COMPOSITE" SPACE EXPERIMENT ABOARD THE ISS

Russian cosmonaut Sergei Korsakov conducts the "Protective composite" space experiment on the Russian Segment of the ISS

Scientific equipment of "Protective composite" space experiment in hands of the hero of Russia, cosmonaut Anton Shkaplerov on the Russian segment of the ISS

DATA OF «PILLE-ISS» DOSIMETER INSIDE AND OUTSIDE CONTAINERS

Date of data transfer to Earth	Dose, µGy			
	First container		Second container	
	inside the container	in the styling pocket	inside the container	in the styling pocket
03/21/2022	$1.04\cdot10^4$	$1.5\cdot10^4$	$7.31\cdot10^3$	$1.59\cdot10^4$
04/19/2022	$9.68\cdot10^3$	$1.31\cdot10^4$	$6.97\cdot10^3$	$1.54\cdot10^4$
05/26/2022	$1.22\cdot10^4$	$1.69\cdot10^4$	$9.31\cdot10^3$	$2.07\cdot10^4$
06/29/2022	$1.09\cdot10^4$	$1.54\cdot10^4$	$8.04\cdot10^3$	$1.78\cdot10^4$
07/22/2022	$7.6\cdot10^3$	$1.05\cdot10^4$	$5.81\cdot10^3$	$1.21\cdot10^4$
08/25/2022	$1.08\cdot10^4$	$1.49\cdot10^4$	$8.11\cdot10^3$	$1.73\cdot10^3$

The results obtained in recent sessions demonstrate high shielding properties of the composite material as the absorbed dose inside the containers is from 30 to 60 % lower than that outside on the crew cabin wall.

CONCLUSION

1. A unique polymer composite material was developed and patented in Russia to protect crewmembers and sensitive electronic components from space radiation in-flight.

2. On ground studies demonstrated high shielding properties of the composite materials for low energy electron and proton fluxes. The on ground studies were followed by the space experiment in the ISS Russian Segment.

3. The results obtained in recent sessions demonstrate high shielding properties of the composite material as the absorbed dose inside the containers is from 30 to 60 % lower than that outside on the crew cabin wall.

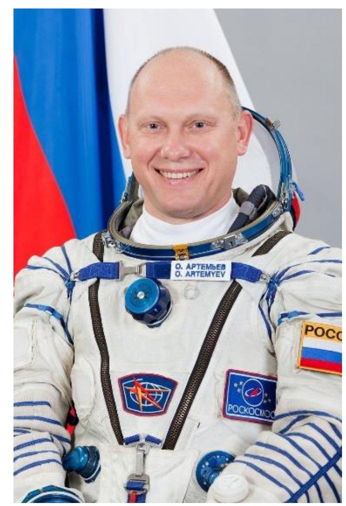
4. The study will be continued in 2023.

Gratitude to the cosmonauts for research in the Russian segment of the ISS:

Sergei Korsakov

Petr Dubrov

Anton Shkaplerov



Oleg Artemiev

Denis Matveev