INTERNATIONAL SCIENCE AND TECHNOLOGY CENTER

I S T C
М Н Т Ц

AEROSPACE RESEARCH

ISTC FUNDED PROJECTS

1994–2011

SPACE

VOLUME 2

Edited by

Tatiana Ryzhova (ISTC)
Sergey Frolov (N.N. Semenov Institute
of Chemical Physics)

Moscow
2011

Aerospace Research: ISTC Funded Projects 1994–2011. Volume 2. Space / Edited by T. Ryzhova, S. Frolov. — 408 p.: 340 ill.

The book contains the synopses of 60 projects related to Space research and funded by ISTC Funding Parties — the European Union, Japan, the United States of America and Canada — during 17 years (1994–2011).

Project description gives a brief overview of its background, objectives, scope of work and results — expected for ongoing projects and obtained for completed projects. Some administrative information including tech code/area/field, status and technology development phase according to ISTC taxonomy also are given, as well as information about funding parties, allocated funding, project duration, and commencement date.

The names of foreign organizations expressed interest in the project and participated in the project as Foreign Collaborators are presented in the synopses and provide an overview of the international cooperation in Space strengthened through ISTC projects.

The book also includes information on core and supplemental ISTC programs, including Partner program and main ISTC partners in Space.

In addition, brief information on institutes — ISTC recipients in Space and a list of project proposals, which obtained good recommendation by ISTC scientific experts, but have not received funding yet, provide readers with an opportunity to meet their R&D needs through development cooperation/partnership with Russia/CIS.

The International Science and Technology Center (ISTC) is an international organization, created to promote international scientific cooperation. The European Union, Japan, the Russian Federation, and the United States of America started work on the basis of an international agreement established in 1992. Canada, Norway, and the Republic of Korea later became signatories to the ISTC Agreement, with Canada becoming a full Governing Board Member in 2004. The ISTC has also Armenia, Belarus, Georgia, Kazahstan, Kyrgyzstan, and Tajikistan as its members.

Subsequently, ISTC started its work in 1994 based on the Decree of the President of Russian Federation and since then ISTC has funded and managed more than 2750 projects with a total value of 860 million USD. About 30 million USD has been used to fund aerospace and aircraft research, with many other projects completed or developed in related fields.

ISTC has today 39 member states and offers a wide spectrum of programs, services, and activities. The ISTC Secretariat, based in Moscow, has about 125 staff members, among whom there are researchers, commercialization specialists, financial experts, and administrative staff.

Currently, the ISTC funds Collaborative research projects in a wide range of scientific disciplines and technology areas. Future strategic priorities of ISTC are those that make the world safer and more secure — environment, renewable and environmental friendly energy, nuclear safety and human health are at the first place. Obviously, many of these areas directly relate to the development of the aviation and aerospace industry and ISTC is proud of its record in developing projects and international relationships in this area.

ISTC has established strategic partnership with many Russian and other research institutes, innovation foundations and organizations, governmental organizations and agencies and investors that work to further strengthen to diversify their national economies.

ISTC is also a matchmaking organization that assists private industry in technology search, connecting international industry with high quality institutes in Russia and beyond. ISTC has over 400 commercial and governmental agency partners from around the globe, many of whom are engaged in R&D projects with experts from Russia and other countries of the CIS.

This book profiles many of the success stories resulting from the efforts of the Center and its many Partners, from breakthrough research in physics, gas- and thermodynamics to further extraterrestrial exploration.

Where better to find justification for this view than in ISTC's work with the industries of the international aerospace sector and the many Russian and CIS experts in this field, I consider that ISTC has delivered research results to the benefit of a modern and safer aerospace sector.

I trust you find this book interesting,

Adriaan van der Meer

Executive Director

Activity in Space

Since 1994, the ISTC contributes into space exploration progress through funding research projects and encouragement of international cooperation in this area. Already the first projects supported by ISTC in 1994 concerned to the priority problems of space exploration — propulsion systems, namely, to the feed system for nuclear propulsion (Mars mission) and rocket engine with a microwave pumping.

Now, the ISTC research projects portfolio in Space is a good example of scientific and technological capabilities of Russian/CIS research centers in many priority of space fields, such as advanced propulsion systems (nuclear, electric, laser), safety (radiation, microbiological, environmental), key technologies for interplanetary missions, spacecraft protection (thermo, antimeteoroids, and space debris), energy delivery over long distance, and others.

ISTC taxonomy places 60 funded by ISTC Parties projects among eight sections: (i) Astronomy; (ii) Extraterrestrial Exploration; (iii) Manned Space Station; (iv) Space Safety; (v) Space Vehicles and Support Equipment; (vi) Spacecraft Trajectories and Mechanics; (vii) Unmanned Spacecraft; and (viii) Other. Total number of projects related to Space much more if take into account the projects funded in such tech areas as Materials, Physics, Environment, Chemistry, and others, but intended for space application.

More than 160 organizations, research centers, and universities from Armenia, Georgia, Kazakhstan, Russia, and Tajikistan are ISTC recipients involved in aerospace projects. Joint work on ISTC projects contributes to renew cooperation between CIS scientists and encourage partnership between CIS R&D and leading space centers and industry in EU, USA, Canada, and Japan.

ISTC beneficiary institutes in Russia and the CIS working for aerospace application are ready to provide services to various companies in many priority problems, partly mentioned above.

Companies and other organizations working through ISTC receive transparent project fund management, direct tax-free grant payments to scientists, tax- and duty-free purchases of project equipment.

ISTC supports institutes from Russia/CIS not only by funding projects, but also through finding international partners for long-term R&D cooperation, supporting conversions in compliance with the international standards, improving communication systems in the institutes, personnel business training, and providing international travel grants for scientists to attend conferences and meetings.

Several important aerospace events were organized by ISTC on relevant problems of space exploration and international cooperation development on initiative of ISTC Parties, partners, and CIS scientists.

This book aims to assist potential customers in searching of talented scientific teams able on the high level to meet their needs in innovations.

For more information on the ISTC activities: **http://www.istc.ru**

Tatiana Ryzhova

Senior Project Manager,

Aerospace Research Coordinator

ISTC Programs

The core ISTC programs are Science and Partner Project Programs.

Science Project Program

Funded through the ISTC budget (contribution of Funding Parties: European Union, United States of America, Japan, Canada).

Foreign organizations participate as collaborators.

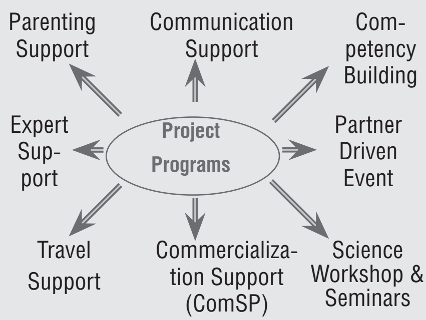
Co-funding is possible for foreign collaborators.

Partner Project Program

Foreign Partner funds through ISTC 100% of the Project expenses getting advantage of ISTC special status: tax and customs exemptions.

SUPPORTING PROGRAMS

Several programs were created at ISTC to improve projects performance and build sustainable capabilities and durable partnership.



Research Projects in Space

Total funded projects related to Space:
67 projects

Total allocated fund: more than $19M

Funded by ISTC Funding Parties (EU, USA, Japan, Canada): 60 projects

Funded by Partners: 7 projects

Main Research Areas of Projects

Astronomy

High Energy Physics (superhigh-energy cosmic ray: Cherenkov water detectors for extensive air showers (EAS) generated by cosmic ray particles; study of high-energy local gamma-quanta sources by mirror telescopes of Cherenkov radiation; cosmogenic evolution: instrumentation development for analysis of data on Comet Galilee' dust high-speed impact obtained by VEGA-1 and VEGA-2).

Astrophysics (cosmic objects origin — physical features of meteoroids and their parent bodies (i. e., Near-Earth Objects), Near-Earth Asteroids (NEAs), comets; creation of fireball network for observation and study of asteroidal-meteoroid situation).

Space Safety

Radiation Safety (solar radiation — space patrol complex for permanent measurements of ultraviolet and X-ray fluxes in range from 0.14 to 125 nm; X-Ray spectrometer for patrol complex, high-energy neutron spectrometer (PHENS) for real-time measurements aboard spacecraft).

Spacecraft Protection (antimeteoroids and space debris shielding: multilayered spacecraft shield protection (modeling), spacecraft survivability in debris environment on Earth orbits; light shielding with required survivability level; unified shielding construction with high ballistic limit characteristics (BLC); study of microparticles impact on spacecraft and solar arrays using "MIR" and "Salyut" data).

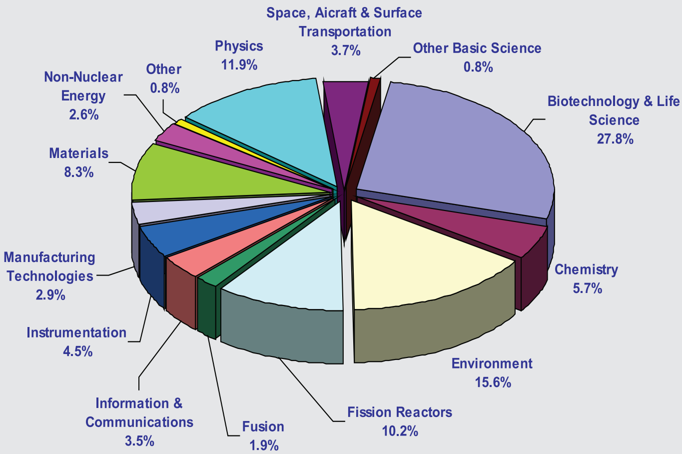
Microbiological Safety (methods for prolonged protection of space constructions from microbial colonization, biodegradation and bio-corrosion).

Environmental Safety (utilization of toxic component of rocket fuel; analysis of environmental objects contaminated with rocket fuel residuals and their toxic metabolites and creation of biosensor module for mutagens detection).

ISTC Projects by Tech Areas

Total ISTC Projects: 2746

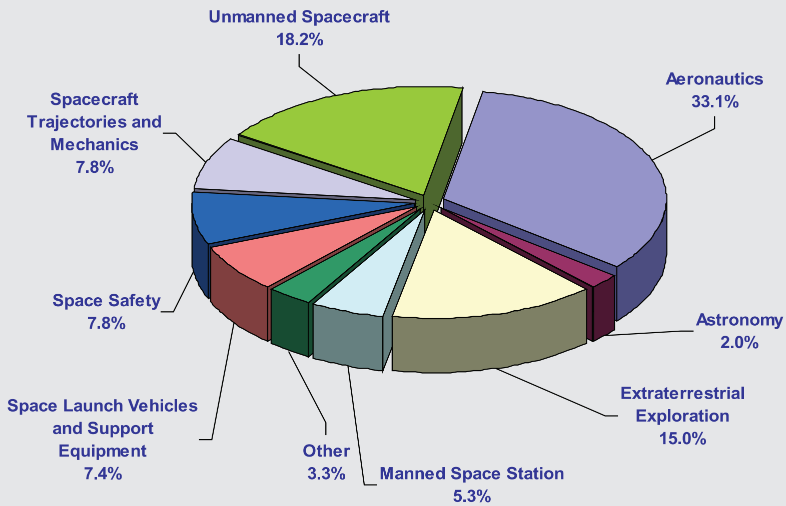
Total Fund: more than $857 M



Aerospace Projects by Tech Fields

Total Projects: 104

Total Fund: more than $29 M



Manned Space Station

Spacecraft Crew Safety (study of so called "cosmic adaptation syndrome" (CAS), infrared telemeasuring complex of cosmonaut medical control; cultivation of microorganisms under conditions of an orbital space flight, complex of oxygen supply for extreme/space conditions).

Spacecraft Thermoregulation (advanced loop heat pipes and their components for thermoregulating spacecraft; experimental-computational system based on technique of inverse heat transfer problems for thermal state estimation).

Interplanetary Missions (key technologies for Mars mission: expedition architecture studies, power-propulsion systems and power plants for operation on the Martian surface, environmentally friendly propulsion systems, spacecraft and launching vehicles (LV) for space transportation, ascent–descent planetary module, medical-biological technologies, on-board and planetary equipment providing efficient exploration of planets).

Unmanned Spacecraft

Planetary Missions ("Small Mars Mission with a Lander" — key tasks of mission: a possibility of a piggyback launch on "Arian-5" and "Rockot" LV, Mars Surface Element (MSE) descent from approach trajectory and Martian orbit; descent module (DM) configuration, interfaces between DM and orbiter, configuration of the Martian surface station (surface element), deployment mechanism, and interfaces with Entry, Descent, and Landing System; mission schedule).

Advanced Technologies (demonstration of inflatable reentry and descent technology and inflatable and rigidizable technology for Solar Array, recoverable vehicle with scientific and technological equipment for production of high-effective materials and preparations under zero-g conditions, derived from warheads and to be launched by RSM-40, RSM-50 rockets).

Propulsion Systems (advanced electric propulsion systems (EPS) — Hall thrusters).

Extraterrestrial Exploration

Propulsion Systems (nuclear thermal power propulsion system (NTPP) — conceptual project for Mars mission; Solar-powered rocket engine using hydrogen and oxygen fuel for shifting satellites from Low Earth Orbit to Stationary Orbit).

Thermal Protection (aerothermoballistics, radiation gasdynamics, heat and mass transfer for return missions; thermal protection systems for interplanetary flight; radiation and physical-chemical processes for space objects in Mars or Venus Atmosphere).

Instruments & Systems (superconducting direct detector arrays for telescope radiometers based on ground and space missions; soft landing system for planet probe spacecraft; ultrahigh-sensitive terahertz frequency band hot-electron S-LN-S microbolometer; satellite observations for seismoelectromagnetic phenomena study).

Space Vehicles and Support Equipment

Propulsion Systems (creation of laser rocket engine; laser ignition in jet engines; adaptation of laser ignition for combustion chamber of rocket engine; microwave pumped rocket engine; testing of feed system for nuclear propulsion).

Support Systems (optical automatic system for control of rendezvous parameters of manned and unmanned space vehicles, Earth and Sun location CCD-sensors).

Spacecraft Trajectories and Mechanics

Space Mechanism & Components (review of space mechanisms and components; long-life lubricating technology for mechanisms; loop heat pipes and capillary pumps for thermal control system; flanged connection with static spherical bearing for space launchers; heat transfer intensification in air–hydrogen heat exchanger).

Propulsion Systems (electric propulsion based on accelerator with closed electron drift; study of hydrogen jet burning in supersonic air flow for supersonic combustion ramjet).

Spacecraft Trajectories (flight tests preparation of EXPERT reentry demonstrator).

Partnership in Space through ISTC

In total, 7 projects were funded by Partners:

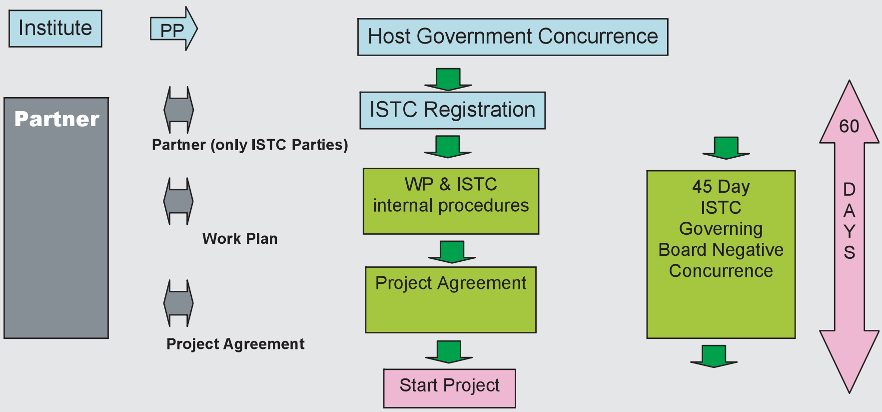
EU Partners:
EADS Space Transportation, Les Mureaux, France
EADS Space Transportation (EADS ST GmbH), Bremen, Germany

U.S. Partners:
European Office of Aerospace Research Development (EOARD)

Main Russia/CIS Recipients

- Keldysh Research Center, Russia
- Lavochkin Association, Russia
- Institute of Biomedical Problems RAS, Russia
- Chemical Automatics Engineering Design Corp., Russia
- NPO "ENERGIA"
- Central Research Institute of Machine Building (TsNIIMash), Russia Institute of Astrophysics, Tajikistan

Procedure of Partner Project approval



Contents

Astronomy

List of Projects

In total, 5 projects were funded by the ISTC Parties and 1 project by a Partner.

#0493

“The Physics of High-Speed Impact in Methods of Solar System’s Exploration”

(High-Speed Impact)

– Russian Academy of Sciences / Space Research Institute, Moscow, Russia

– VNIITF, Snezhinsk, Chelyabinsk reg., Russia

#0643

“Cherenkov Water Detector of Extensive Air Showers Generated by High-Energy Particles”

(Cherenkov Water Detector)

– MEPhI, Moscow, Russia

– Scientific Engineering Center SNIIP, Moscow, Russia

#1106

“Research of Very High Energy Local Gamma-Quanta Sources by Mirror Telescopes of Cherenkov Radiation and Development of Scintillation Methods for Gamma-Quanta Sources — Observation with Energy > 100 TEV”

(Cosmic Gamma-Quanta (>100 TeV) Observation)

– FIAN Lebedev, Moscow, Russia

#T-1086

“Meteor Showers as Indicators of Cometary Nature of Near Earth Asteroids (NEAs) and Physical Properties of Meteoroids”

(Meteor Showers)

– Institute of Astrophysics, Dushanbe, Tajikistan

#T-1629

“Fireball Network in Tajikistan and Search for Near-Earth Objects Associated with Fireball Showers”

(Fireball Network in Tajikistan)

– Institute of Astrophysics, Dushanbe, Tajikistan

Project Number:	#0493
Full and Short Title:	The Physics of High-Speed Impact in Methods of Solar System's Exploration **High-Speed Impact**
Tech Code / Area / Field:	SAT-AST / Space, Aircraft and Surface Transportation / Astronomy PHY-NGD / Physics / Fluid Mechanics and Gas Dynamics
Status:	Project completed
Technology Development Phase:	Basic research
Allocated Funding :	$200,000 (EU: $100,000, US: $100,000)
Commencement date:	February 1, 1997
Duration:	24 months, extended by 5 months
Leading Institute:	Russian Academy of Sciences / Space Research Institute, Moscow, Russia
Contact Information:	Phone: +7 (495) 333 52 12 Fax: +7 (495) 913 30 40 E-mail: iki@cosmos.ru Website: http://www.iki.rssi.ru
Supporting Institutes:	VNIITF, Snezhinsk, Chelyabinsk Region, Russia
Collaborators:	Los-Alamos National Laboratory, Los-Alamos, NM, USA Max-Planck-Institut for Astronomie, Katienburg-Lindau, Germany (Ip W-H) NASA / Ames Research Center, Moffett Field, CA, USA NASA / Jet Propulsion Laboratory, Pasadena, CA, USA Southwest Research Institute / Division of Geophysical, Astrophysical and Planetary Sciences, Boulder, CO, USA
Project Manager:	EVLANOV Evgenii Nikolaevich
Contact Information:	Phone: +7 (495) 333 11 67 Fax: +7 (495) 333 21 77 E-mail: rodionov@iki.rssi.ru
ISTC Senior Project Manager:	ZYKOV Sergey Anantol'evich
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (499) 978 01 10 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

Space experiments on exploration of Halley comet were conducted in 1986. The chemical composition of the comet dust was studied by space vehicles Vega-1 and Vega-2 (Fig.1) equipped with DIMA (dust-impact mass analyzers) apparatus and traveled through the comet tail. In DIMA devices, a space dust particle impacted a screen made of high-purity silver at a relative velocity of about 80 km/s and incidence angle of 30^o or 55^o. The material of the dust particle and screen evaporated and was ionized. The expanding plasma cloud passed through a set of electrodes that withdrew its ion component and directed it to a time-of-flight mass spectrometer.

Measurements furnished unique experimental information contained in more than 5 thousand mass-spectra produced by impacts of individual particles. Qualitative interpretation of the spectra provided very important results concerning understanding the cosmogonical evolution of the Solar system (e. g., a non-volatile organic component was detected in dust particles).

Project Objectives

Objective of the Project was to develop physical and mathematical models, numerical techniques and software for the analysis and interpretation of the data on high-speed impacts collected by space vehicles Vega-1 and Vega 2 in the course of exploring the Solar system.

The first task was mathematical interpretation of the direct mass-spectral measurements of space dust from comets that evaporated after fast impact onto the screen in the space vehicle.

The objective of the second task was the analysis of the interaction of fast operating probes carried by the space vehicles with the atmosphere and surface of planets.

Description of the Works

The relative velocity of Solar system objects was of the order of few tens of kilometers per second. Their collisions resulted in material preheating to few hundreds of degrees, pressure rise to few tens of millions of atmospheres, and several-fold change of the density of colliding bodies.

Within the Project, it was suggested to develop reliable physical and mathematical models, numerical techniques and software to be applied for analyzing and interpreting the results of two experimental techniques of fast impact in exploration of the Solar system.

The first technique was direct mass-spectral measurements of the comet dust composition by DIMA apparatus (DIMA-1 and DIMA-2) onboard of space vehicles Vega-2 and Vega-1 (Fig. 2).

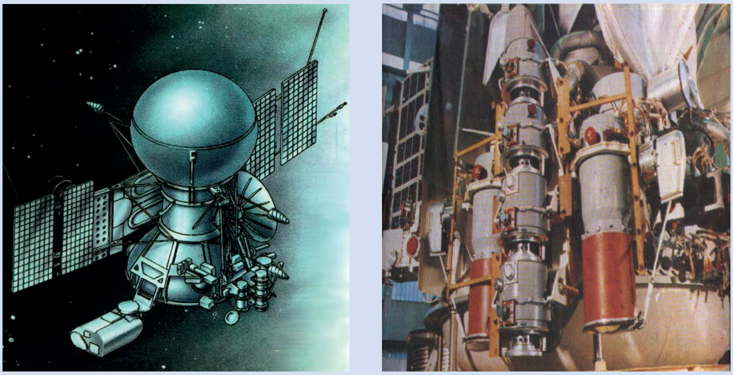


Figure 1: Automated interplanetary probes VEGA: astrotrackers Vega-1 and Vega-2

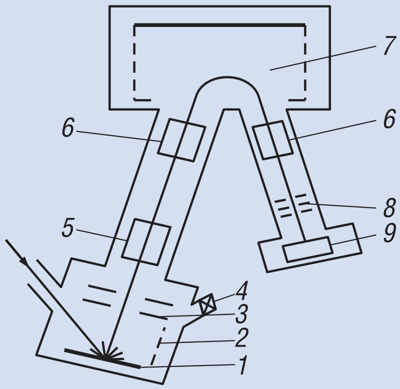


Figure 2: General schematic of the DIMA apparatus: 1 — screen; 2 — trapping grid; 3 — accelerating grid at a 1-kilovolt potential located 1 cm away from the screen; 4 — photomultiplier; 5 — control grid; 6 — electrostatic lenses; 7 — electrostatic reflector; 8 — delaying grid, 9 — detector of ions

The high-speed impact (79 km/s) was attended by evaporation and ionization of both the dust particle and target. The ion components were analyzed by time-of-flight techniques.

Based on the analysis performed and on photometric observations, the comet dust parameters and probable chemical particle compositions were assessed (Table 1). The composition of the dust particle material is seen to vary from carbon C to iron Fe with intermediate values which are close to those of Al for the most probable compositions. The comet particle masses vary from 10^{-17} to 10^{-11} g; the density of solid particles ranges from 0.954 to 3.64 g/cm^3. Small particles (10^{-17}–10^{-15} g) are solid. Most of the coarser particles have a complicated porous structure. Their volume porosity can reach 95%.

The analysis has shown that during impact and subsequent expansion, the particle and screen materials transferred to a state of a dense nonideal plasma at any assumed parameters of comet dust particles.

The analysis has also indicated that simulation of the whole variety of processes attending mass-spectrometric measurements could be split into 3 stages:

(1) dynamic processes of impact and material expansion;

(2) expansion of and ionization kinetics in the plasma cloud; and

(3) passage of the plasma cloud through the measuring device of DIMA apparatus.

The stages differed significantly in the processes taking place during them, their time, and spatial characteristics. Information gained at one of the stages served as initial conditions for the subsequent stage. This approach permitted to most efficiently use, at each stage, the models, methods, and computer codes elaborated.

Computational and theoretical analysis of the physical processes occurring in the course of impact and appraisal of their effect on the expansion dynamics and gasdynamic parameters of the plasma cloud suggested the following:

Table 1: Probable compositions of comet dust particles

#	Composition, %(wt.)	ρ, g/cm^3	$\bar{A}$, g/mole
1	1 of organics (CH_2)	0.954	10.4
2	40% MgO, 60% SiO_2	2.96	21.4
3	30% MgO, 45% SiO_2 , 25% Fe_2O_3	3.33	27.0
4	100% FeS	3.64	44
5	50% of organics (CH_2), 15% MgO, 25% SiO_2, 10% Fe_2O_3	1.45	18.2

– elastic-plastic and strength properties of the colliding materials exerted no effect on the plasma cloud properties; and

– electron thermal conductivity was important at the initial stage when the physical states of interacting materials were formed.

The materials were preheated ahead of the shock wave front, heat fluxes arose at the contact surface because temperatures of the interacting materials differed. However, the contribution of the aforesaid effects faded away as ever increasing masses of the materials were involved in the collision process and showed up only when the smallest particles collided at the highest impact velocities (M = 10^{-17} g; V_0 = 80 km/s).

Thus, a model of nonsteady adiabatic gasdynamics could be used in majority of cases of interest to depict the collision process and material expansion. To refine the prediction results, a three-temperature model of radiation gas dynamics was applied. Here, a multicomponent single-velocity approximation of the model was used for solid material consisting of electrons, photons, and ions. Every component had its own temperature which was governed by material motion, heat diffusion, and energetic potentials. The energy equation for photons was written in the diffusion approximation.

To simulate the processes occurring at the first stage, finite-difference techniques and computer codes MECH, MAKH, MAKH-3, and TIGR-3T were used.

Codes MECH and MAKH made it possible to simulate in two-dimensional (2D) approximation a wide class of unsteady adiabatic (with no heat conduction and tensor material properties) flows of multicomponent materials of complex geometry, the MAKH-3 code was three-dimensional (3D). In particular, the codes allowed computing vortex flows with large deformations of contact boundaries, their destruction, and intermixing of the materials, which was pertinent to the high-speed impact problems.

The technique and TIGR-3T code allowed the processes of radiation gasdynamics with photon, ion, and electron heat conduction to be modeled in 2D formulation.

The methods suggested to simulate high-speed impact and subsequent material expansion were adapted and verified, to this end numerical solutions of some problems were compared with available analytical solutions. In addition, based on solutions to the problems of comet dust particle impact on a screen and expansion of the evaporated material into vacuum, the effects of various computational parameters and numerical procedures on the results were assessed by comparing the results yielded by the different techniques applied.

To model the processes attending expansion of the plasma cloud at the first stage, the TARAN code was properly adapted and used and a new code TIGRAN was elaborated.

TARAN was capable of computing ion composition and radiation characteristics of an inhomogeneous nonequilibrium and unsteady plasma (in the one-dimensional (1D) case). All the radiation-collisional processes, spontaneous radiative decays, excitation and de-excitation of ions by electron impact, three-body, photo-, and dielectron-recombination, appropriate ionization processes, and radiation transport effects pertinent to plasma were taken into account.

The rates of processes taking place in a plasma were calculated assuming that the distribution of free electrons over velocities was Maxwellian. The processes of reemission in lines were treated in the escape factor approximation. Calculations took into account the dynamic Doppler-effect and Voigt line profiles. In the problems considered, populations of ion states had to be calculated both in a highly compressed and highly rarified plasma. Therefore, two approximations were used, namely, description of the distribution of populations based on the equilibrium Saha–Boltzmann relationships and based on the solution of kinetic equations. The criteria for transition from one approximation to the other were derived empirically.

The model and technique of self-consistent 2D description of ionization kinetics and nonequilibrium plasma radiation spectra were realized in the TIGRAN code. The code was created by combining the TIGR-3 and TARAN codes. Spectral intensities of plasma radiation in the continuum and lines and mean degree of ionization computed within the TARAN code at each time step were transferred to TIGR-3T. The TIGR-3T code, in turn, provided temperature and density distributions in space and time for Lagrangian particles to be used in kinetic calculations by TARAN.

Expansion of the plasma cloud and ionization kinetics in it were modeled using two approaches. In the first approach, the plasma ionization kinetics was calculated by code TARAN based on the information provided by calculations at the fist stage for Lagrangian particles flying in the selected direction in the plasma cloud. A set of calculations yielded an ion composition of the plasma cloud at various time instants.

In the second approach, computations performed at the first simulation stage were continued with the use of the TIGRAN code with allowance for nonequilibrium ionization kinetics and noneqilibrium radiation spectra.

The analysis has demonstrated that in the majority of cases, numerical investigations could be conducted using the TARAN code, while the TIGRAN code was used to refine the calculation results.

There were two factors which restricted detection of ions in DIMA apparatus:

(1) ion-optical system of the apparatus operated as a single-channel energy analyzer (the energy channel width for ions equaled 100 and 10 V, respectively); and

(2) the detector could record only ions that fell into a limited solid angle $|\theta| < \theta_{max}$, where θ_{max} equals to few degrees and θ is the angle between the ion velocity vector and axis of the measurement channel.

A model of collisionless motion of charged particles in the drawing field induced by electrodes was applied to describe interaction of an expanding plasma cloud with the drawing electric field between the apparatus screen and accelerating grid. Numerical simulation was performed by the "particle–grid" method. It was assumed that the plasma with a compensated charge of electrons and ions was

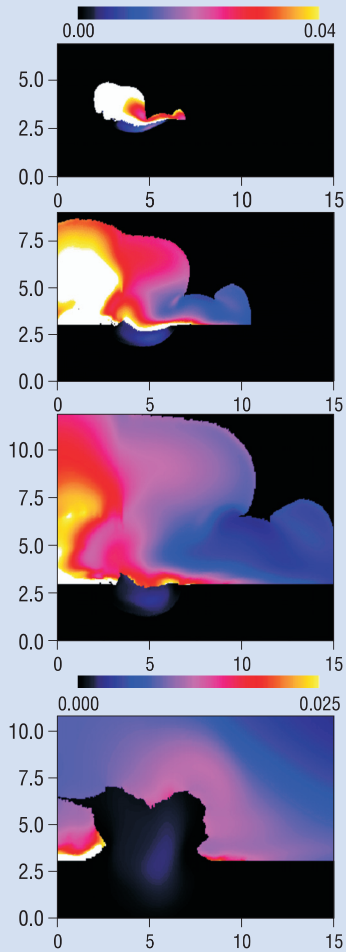


Figure 3: Calculated fields of the specific internal energy of the plasma cloud produced by a solid dust particle $3 \cdot 10^{-12}$ in mass of composition #2 at time instants t = 0.03, 0.06, 0.1, and 0.4 ns. Internal energy and sizes are given in 10^7 J/g and μm, respectively

separated from the ion cloud with a sharp boundary. The electric field in the ion cloud was found by solving the field equation; the calculated field was used to solve the equations of particle motion.

Numerical experiments allowed the evolution of the characteristics of various particles in an expanding plasma cloud to be studied (Fig. 3). Dependences of the mean charges (C_e) of silver, comet dust particle materials, and individual chemical elements entering into their composition on various parameters of dust particles and conditions of their impact onto the screen were investigated at the ionization freezing stage (Fig. 4). The major attention in calculations was given to those Lagrangian plasma particles the ion composition of which most likely could be detected with allowance for the restrictions imposed by the construction of DIMA apparatus.

Comparative 2D and 3D calculations of comet particle impact on the screen and of plasma cloud expansion have revealed that although the density and temperature in 3D calculations dropped more intensely, this led solely to an earlier occurrence of the ionization freezing stage. The ionization degree values were virtually identical.

The plasma cloud exhibited significant inhomogeneity of its properties irrespective of the supposed chemical particle composition and

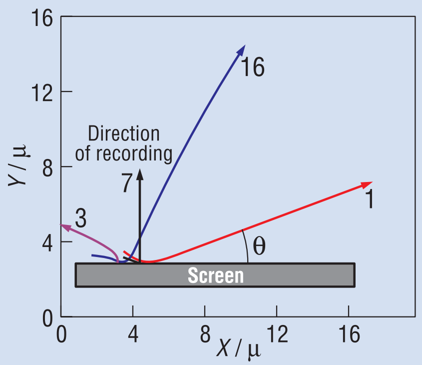


Figure 4: Trajectories of some selected Lagrangian particles separating after impact

porosity (temperature in the particle, its velocity, and mean charge ranged between 4 and 80 eV, 2 and 140 km/s; 0.005 and 3.5, respectively). When dust particle porosity was great, flow inhomogeneity and vorticity persisted longer time than they did in the case of solid particles. The ionization freezing stage came later.

Obtained Results

The following results were gained within the Project:

• A decrease in the dust particle mass by a factor of 10^3 was shown to entail an about 1.5- or 3-fold increase in the average charge, while an increase in porosity of all chemical compositions increased the maximum average charges of dust particles and decreased that of silver particles.

• Average charges of particles moving along the direction of the recording channel of DIMA-1 (impact angle of 55°) were lower than charges recorded by DIMA-2 (30°).

• Particle density was the most significant parameter of various chemical compositions of dust particles affecting the properties of the plasma cloud. As the initial density of particles increased by a factor of ~ 2, the average charges in the major mass of the plasma cloud increased 1.5- or 2-fold irrespective of particle porosity.

• The average charge of Lagrangian plasma particles flying along the recording channels of DIMA was less than unity (C_e < 1) for both solid and porous comet dust particles of various chemical composition, i. e., these plasma areas were mixtures of neutral and single-charged ions, which was consistent with experimental data.

• The mathematical simulation facilities developed can be used, in combination or separately, when solving some other problems related to high-speed impacts as well as in investigations of such plasma phenomena as corona of LTS-targets, Z-pinch medium of X-ray lasers, etc.

Project Number:	#0643 Project Development Grant (PDG)
Full and Short Title:	Cherenkov Water Detector of Extensive Air Showers Generated by High-Energy Particles **Cherenkov Water Detector**
Tech Code / Area / Field:	SAT-AST / Space, Aircraft and Surface Transportation / Astronomy PHY-PFA / Physics / Particles, Fields and Accelerator Physics
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding :	$30,000 (EU: $15,000, US: $15,000)
Commencement date:	December 1, 1997
Duration:	6 months
Leading Institute:	Moscow State Engineering Physics Institute (MEPhI), Moscow, Russia
Contact Information:	Phone: +7 (495) 324 84 00, 324 87 66 Fax: +7 (495) 324 83 56 Website: http://www.mephi.ru
Supporting Institutes:	No
Collaborators:	CNRS/ Université de Paris VI ET VII / Laboratorie de Physique Nucléaire et de Hautes Energies, Paris, France (Boratav M) Universita Degli Studi di Torino / Instituto di Fisica, Torino, Italy (Saaverora O) University of Chicago, Chicago, IL, USA (Cronin J)
Project Manager:	PETRUKHIN Anatoly Afanas'evich AYNUTDINOV Vladimir
Contact Information:	Phone: +7 (495) 333 11 67 Fax: +7 (495) 324 87 80 E-mail: av11786@comtv.ru, rodionov@iki.rssi.ru
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 31 57 Fax: +7 (499) 978 46 37 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

Cherenkov water detector technique is rather promising for the creation of setups for superhigh energy cosmic ray investigations. Increasing scales and costs of such setups require a careful and optimal choice of technical solutions, taking into account the expenditures necessary for their implementation. Development of an efficient precision measuring electronic system; selection of an optimal water conservation method which could provide the stable optical properties of the water during long experimental measurements; elaboration of the system for monitoring the parameters of all basic units of Cherenkov water detectors were among important tasks of the problem.

The Project Proposal #0643 "Cherenkov water detector of extensive air showers generated by high-energy particles" was submitted to the ISTC and was aimed to study the above listed tasks. It got recommendation to be modified to sufficiently satisfy the needs of the unique international project of Pierre Auger Observatory (PAO) for the detection of extremely high energy cosmic ray particles, which will include several thousands of Cherenkov water detectors.

Project Objectives

The main objective of the Project Development Grant was preparation of the revised version of the Project #0643 "Cherenkov water detector of extensive air showers generated by high-energy particles" and its work plan, aimed at creation of detecting system for PAO surface station and of test facilities for thorough experimental study of this system.

Description of the Works

All necessary parameters of detecting system for PAO have been agreed with representatives of "Pierre Auger."

A specialized size-reduced prototype of PAO surface station was constructed for studies of detection system parameters in the conditions closed to real experiment (Fig. 1).

Test facilities for PMT (photomultiplier) and front-end electronics checkup were constructed.

Front-end electronics for PAO surface station was designed. Studies of phototubes and front-end electronics operation with test facilities were performed.

Obtained Results

The following main results were obtained during the PDG:

1. The size-reduced prototype of the PAO surface station was designed and constructed (see Fig. 1). The setup included:

– water tank with fiducial volume 1.2 m^3, which was viewed by a cluster of six phototubes;

– external triggering system on the basis of scintillation counters; and

– data acquisition system.

2. Specialized test facility was created for measurements of single-photoelectron pa-

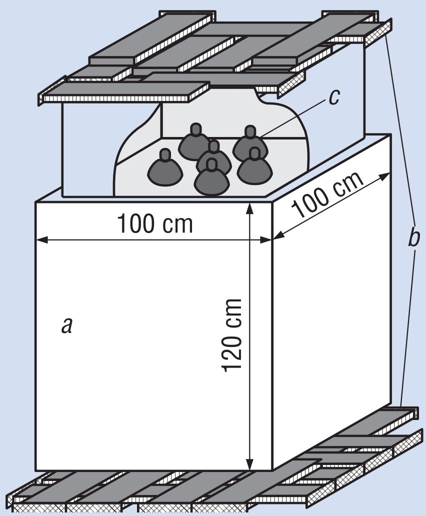


Figure1: Prototype of the PAO surface detector: a — tank with water; b — scintillation counters; and c — cluster of six FEU-173

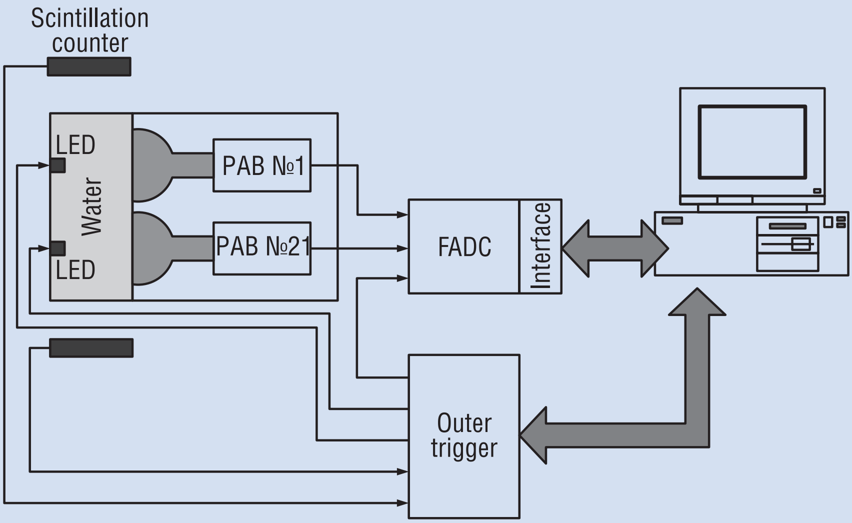


Figure 2: Test facility for PhAB operation studies

rameters of the PMT, which allowed checking four phototubes simultaneously.

3. Pilot samples of analog part of front-end electronics units for PAO surface station with dynamic range 105 were designed and manufactured.

4. Testing of FEU-173 phototubes with PAO Surface Station prototype has shown that this PMT was capable of detecting single muons with good efficiency.

5. Pilot samples of the basic measuring unit for the Cherenkov water detector which included Phototube, Amplifiers and Base (PhAB) were developed and tested (Fig. 2).

6. Results of front-end electronics and PhAB tests were presented at the IV Auger Collaboration Meeting and were approved by all foreign collaborators.

7. The Work Plan was prepared and agreed with all foreign collaborators of Project #0643.

Project Number:	#1106
Full and Short Title:	Research of Very High Energy Local Gamma-Quanta Sources by Mirror Telescopes of Cherenkov Radiation and Development of Scintillation Methods for Gamma-Quanta Sources Observation with Energy > 100 TeV **Cosmic Gamma-Quanta (> 100 TeV) Observation**
Tech Code / Area / Field:	SAT-AST / Space, Aircraft and Surface Transportation / Astronomy
Status:	Project completed
Technology Development Phase:	Basic research
Allocated Funding :	136,127 € (EU)
Commencement date:	April 1, 1999
Duration:	24 months
Leading Institute:	FIAN Lebedev, Moscow, Russia
Contact Information:	Phone: +7 (495) 135 42 64 Fax: +7 (495) 938 22 51, (499) 135 78 80 E-mail: postmaster@lebedev.ru Website: http://www.lebedev.ru
Supporting Institutes:	No
Collaborators:	CNRS / Ecole Polytechnique, Palaiseau, France (Fleury Patrick)
Project Manager:	SINITSYNA Vera Georgievna
Contact Information:	Phone: +7 (495) 135 50 11 Fax: +7 (495) 132 66 20
ISTC Senior Project Manager:	HAMADA Shozo
Contact Information:	Phone: +7 (495) 982 31 67 Fax: +7 (495) 978 36 03 E-mail: hamada@istc.ru
ISTC Website:	http://www.istc.ru

Background

The Project was aimed at the development of very high energy gamma-astronomy methods and observation of local sources of gamma-quanta with energy of 1012–1014 eV. With SHALON-1 gamma-telescope, which feature is an imaging unit including a 144-pixel camera with the quite large field of view > 8o, installed on Tien-Shan high-mountainous station (3338 m), the observations of five extragalactic and four galactic sources of gamma-quanta were carried out (1992–2000). During these

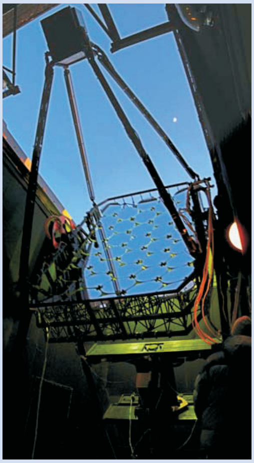


Figure1: SHALON-2 telescope

observations, the extragalactic sources NGC 1275, 3c454.3, and 1739+522 were detected for the first time in the world. The fluxes of metagalactic and galactic sources observed by both SHALON and other world experiments were approximately equal, but the difference of distance was 104. It means that radiating power of extragalactic sources was 108 times higher. Taking into account a limited number of sources in our Galaxy in comparison with Metagalaxy, one can expect that cosmic rays with energy more 1 TeV are mainly of extragalactic origin. The other important objective of the project was the installation of new

SHALON-2 telescope (Fig. 1) at the same observatory at a distance of 260 m from SHALON-1. In accordance with Work Plan, manufacturing, transportation, and assembling of metallic basis construction and optic system for the new telescope was completed.

Project Objectives

The Project objective was a contribution into a number of fundamental problems:

(1) the power of supermassive black holes in the Active Galactic Nuclei, quasars, blasars at the very high energies;

(2) the search and investigation of Supernova Remnants (TNR) and supernova explosions in the astrophysics of very high energies and neutrino physics;

(3) new particles and processes beyond the Standard Model;

(4) Extragalactic and Galactic sources of very high energy;

(5) the origin of very high energy gamma-rays in the cosmic objects;

(6) the astrophysical origin of cosmic rays;

(7) astrophysics of very high energy neutrino; and

(8) cosmological problems: Extragalactic Background Light.

Description of the Works

The gamma-ray and neutrino sources at the energy range 1–100 TeV were searched and investigated using Extensive Air Showers (EAS). The observation of showers was based on wide Cherenkov light distribution of the electron cascade generated by the primary particles in Earth's atmosphere. So, the observations were carried out only at moonless nights. The experiments were performed in SHALON observatories at Tien-Shan High Mountain Station. This place has the climatic weather and atmosphere condition satisfied in the best way to the requirements of Cherenkov Experiment. Due to the extremely low flux (10^{-12} cm^{-2} s^{-1}) of the gamma-rays at the energies above ~ 1 TeV, it was impossible to investigate the sources of very high energy gamma-quanta with the space experiments as their sensitivity was strongly limited by calorimeter size. This sensitivity limitation to the gamma-ray flux at energy > 1 TeV of space experiment had forced to develop a new observation method with the effective registration size exceeding 0.1 km^2 and with higher angular resolution (less than 0.1^o), but with huge background of EAS of cosmic rays. The Cherenkov radiation of EAS born in the mountain slope was observed along the direction of neutrino by gamma-telescope placed on the distance about 7 km from a mountain slope in area exceeding $7{\cdot}10^5$ m^2. Thus, the main difficulty of observation of EAS generated by neutrino in conditions of high mountainous observations, connected with the small cross section of neutrino–nuclei inelastic collisions, was supposed to be overcome this way.

The Cherenkov gamma-telescope SHALON located at 3338 m above sea level, at the Tien Shan high-mountain observatory of Lebedev Physical Institute, has been designed for gamma-astronomical observation in the energy range 800 GeV – 100 TeV. The SHALON mirror telescopic system, each one, consists of a composed mirror with area of 11.2 m^2. Each of the telescope is equipped with 144 photomultipliers receiver with the field of view of pixel exceeding 8^o. Note that the gamma-astronomical research is being carried out with SHALON-1 since 1992 and with SHALON-2 since 2002.

During the period 1992–2010, SHALON has been used for observations of galactic sources: Crab Nebula, Tycho's SNR*, Cas A, Geminga*, Cygnus X-3, 2129+47XR and extragalactic sources NGC 1275** (z = 0.0179); SN 2006gy (z = 0.019); Mkn421 (z =0.031); Mkn501 (z = 0.034); Mkn 180 (z = 0.046); 3c382 (z = 0.0578), OJ 287* (z = 0.306); 3c454.3* (z = 0.859); and 1739+522 (z = 1.375).

Obtained Results

Supernova Remnants viewed in very high energy gamma-rays

During the period 1992–2010, SHALON has been used for observations of galactic sources; among them are Crab Nebula (Pulsar Wind Nebula), Cygnus X-3 (High Mass X-ray Binary), Tycho's SNR (shell-type Supernova remnant), Geminga (radio-weak pulsar), and 2129+47XR (low-mass X-ray binary).

Tycho's SNR

Tycho's SNR has long been considered as a candidate to cosmic-ray hadrons source in Northern Hemisphere, although the sensitivity of the present generation of Imaging Atmospheric Cherenkov System's seemed to be too small for Tycho's detection. Tycho's SNR has been discovered by SHALON at TeV energies at the range 0.8–80 TeV [1, 2]. The obtained flux and spectral energy distribution have confirmed the predictions of nonlinear kinetic model [3], that is, the effective acceleration of the cosmic rays in the supernova remnants up to ultrahigh energies (~ 10^{15} eV) has been confirmed experimentally.

The evidences of hadron origin of the hard gamma-rays in the Tycho's SNR are presented in Fig. 2*a*. The additional information about parameters of Tycho's SNR can be obtained in frame of nonlinear kinetic model if the TeV gamma-quantum spectrum of SHALON telescope is taken into account, namely, a source distance and an ambient density (Fig. 2*b*). The unique information about the Galactic objects like Supernova Remnants and the possibility of examining the models of cosmic-ray acceleration in SNR shocks (Figs. 3*a* and 3*b*) comes from the Cherenkov telescopes.

In fact, HEGRA did not detect Tycho's SNR, but established a very low upper limit at energies exceeding 1 TeV. This value is consistent with that previously published by Whipple collaboration, being a factor of 4 lower (the spectral index of –1.1 for this comparison).

The ϖ^0-decay gamma-quantum flux turns out to be somewhat greater than inverse Compton flux at 1 TeV and becomes strongly dominating at 10 TeV [3]. The predicted gamma-quanta flux is consistent with upper limits published by Whipple and HEGRA. The expected flux of gamma-quanta from ϖ^0-decay, $F_\nu \sim E_\nu - 1$, extends up to ~ 30 TeV while the flux of gamma-rays originated from the Inverse Compton scattering has a sharp cutoff above the few TeV; so, the detection of gamma-rays with energies of 10 to 80 TeV by SHALON is an evidence of their hadronic origin (see Fig. 2). The Tycho's SNR has been recently (2010)

*The source discovered by SHALON telescope in 2000 and confirmed by VERITAS Cherenkov telescope (UaSA) in 2010.

**The sources discovered by SHALON telescope and then confirmed by Fermi LAT space experiment at the high energies.

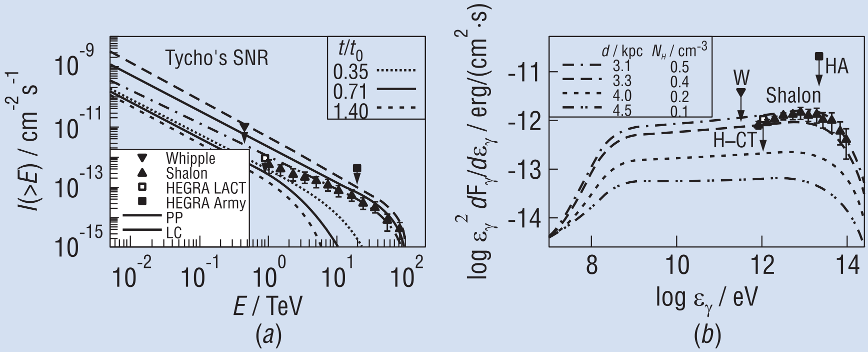


Figure 2: The Tycho's SNR gamma-quantum integral spectrum by SHALON in comparison with other experiments: the observed upper limits Whipple, HEGRA IACT system, HEGRA AIROBICC and calculations: IC emission (thin lines), ϖ0- decay (thick lines) [3] (a), and spectral energy distribution of the gamma-ray emission from Tycho's SNR [3] (b). All cases have dominant hadronic gamma-ray flux

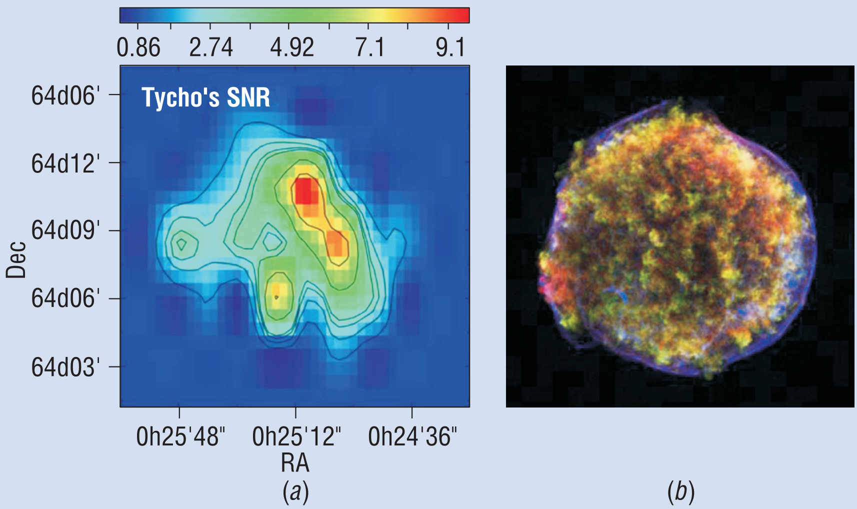


Figure 3: The SHALON image of Y-ray emission from Tycho's SNR (a) and Chandra X-ray image of Tycho's SNR (b)

detected by VERITAS telescope as a source of very high-energy gamma rays. Figure 2*b* presents spectral energy distribution of the gamma-ray emission from Tychos SNR as a function of gamma-ray energy ε_γ for a mechanical SN explosion energy of $E_{SN} = 1.2 \cdot 10^{51}$ erg and four different distances *d* and corresponding values of the interstellar medium number densities NH. All cases have dominant hadronic gamma-ray flux.

Thus, the shell-type SNRs at Northern Hemisphere should be detected at the TeV energy range in gamma-rays of predominantly hadronic origin and the expected flux of gamma-quanta from ϖ^0-decay (2–5)·10^{-13} erg/(cm^{2}s) extends up to 100 TeV if the distance is within the range 3.1–3.3 kpc (see Fig. 2).

Supermassive black holes in Active Galactic Nuclei, quasars, blasars viewed at very high energy gamma rays

The radio-loud Active Galactic Nuclei (AGNi) have the radio emission arising primarily from a core region rather than from lobes. There are many variations of the models for the explanation of specific features of AGNi and quasars which are the objects with high luminosity, nonthermal spectrum and jets. One of them is the accretion black hole model. Also, in a number of models, the emission from AGNi is believed to arise from relativistic jets oriented at small angles to our line of sight.

The new metagalactic sources have been detected by SHALON at TeV energies. That are Seyfert galaxy NGC 1275 which has been observed with the Tibet Array (about 5 TeV) and recently detected by Fermi as a source of high-energy gamma rays (from 100 MeV up to 100 GeV) and distant AGNi 3c454.3 ($z = 0.859$) and 1739+522 ($z = 1.375$) [4]. The gamma-ray fluxes, spectral energy distributions (SED), integral spectra, and images of distant AGNi at TeV energies were obtained. Also, the distant quasar 3c454.3 has been recently detected by Fermi as a source of high-energy gamma rays.

Galaxy clusters have been considered as sources of TeV gamma rays emitted by high-energy protons and electrons accelerated by large-scale structure-formation shocks, galactic winds, or AGNi. The Perseus cluster of galaxies is one of the best studied clusters due to its proximity (~ 100 Mpc or $z = 0.0179$) and its brightness. Galaxy NGC 1275 is the central dominant galaxy of the Perseus Cluster of Galaxies and is of Seyfert galaxy class. It is known as a powerful X-ray and radio source.

In 1996, a new metagalactic source was detected by SHALON at TeV energies. This object was identified with Seyfert galaxy NGC 1275 (with redshift $z = 0.0179$); its image is shown in Fig. 4. The maxima of the TeV gamma-ray, X-ray (Fabian *et al.*, 2000) and radio emission coincide with the active nucleus of NGC 1275. In contrast, the X-ray and TeV emission disappears almost completely in the vicinity of the radio lobes. Thus, the correlation between TeV and X-ray emitting regions was found to exist. The integral gamma-ray flux for this source was found to be (0.78 ± 0.13)·10^{-12} cm^{-2}s^{-1}

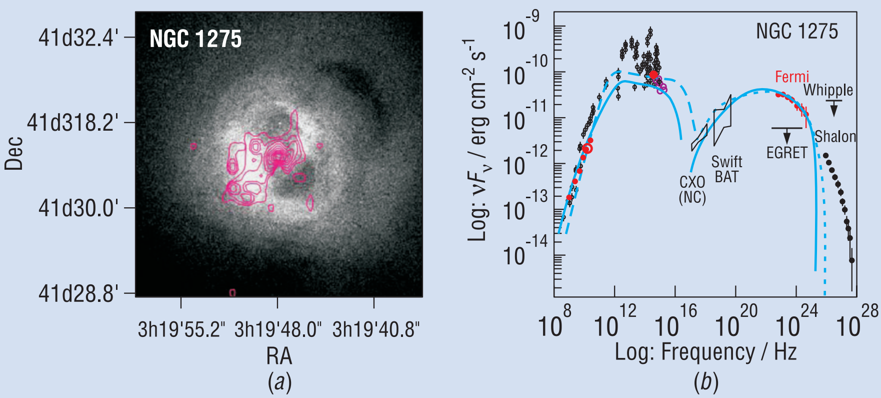


Figure 4: (a) Chandra X-ray image of NGC 1275 together with SHALON data. The contour lines show the TeV-structure by SHALON observations; and (b) Overall SED of NGC 1275. The low-energy data from Abdo et al., 2009. The SED is fitted with a one-zone synchrotron/SSC model (blue dashed curve) and a decelerating flow model (blue solid curves)

at energies exceeding 0.8 TeV. The energy spectrum of NGC 1275 at 0.8 to 30 TeV can be approximated by the power law with index $\gamma = -2.25 \pm 0.1$.

In autumn 2006, the flux increase was detected from the NGC 1275 region. The detailed analysis of gamma-shower direction turned out to be the detection of a metagalactic object. This object was identified with the supernova SN 2006gy detected in September 2006 by ROTSE IIIb McDonald (Fig. 5*a*) that is about 10 min away from NGC 1275. So, the explosion of extragalactic supernova was observed at TeV energies for the first time with SHALON Cherenkov telescope (Figs. 5*b* and 5*c*).

Extragalactic Background Light

The understanding of mechanism of AGNi requires the detection of a large sample of very high energy gamma-ray objects at varying redshifts. As the TeV gamma rays can be absorbed due to interaction of low-energy photons of Extragalactic Background Light

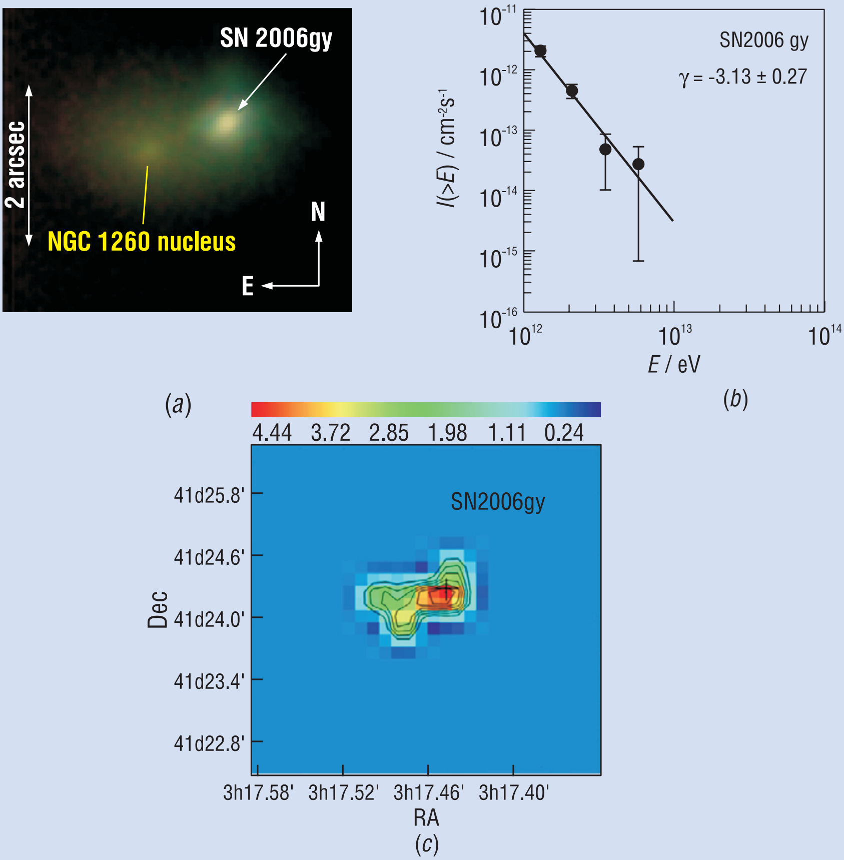


Figure 5: (a) The image of SN 2006gy (Chandra) and the nucleus of NGC 1260 at three wavebands: J band (1.25 m); H band (1.65 m), and Ks band (2.2 m); (b) the gamma-quantum integral spectrum of SN2006gy by SHALON; and (c) the SN2006gy image at TeV energy range

(EBL), the observations of AGNi can also be used for studying background light from UV to far infrared and even cosmic microwave background. The EBL spectrum is known to contain information about star and galaxy formation on early stages of Universe evolution. The redshifts of SHALON-detected very high-energy gamma-ray sources range from z = 0.0179 to 1.375 [5].

Spectral energy distribution of EBL obtained from observations of Mkn421, Mkn501, 3c454.3, and 1739+522 (with z from 0.031 to 1.375) together with models and measurements are presented in Figs. 6 and 7. Observations of distant metagalactic sources at TeV energy range have shown that the Universe is more transparent to very high energy gamma rays than previously believed.

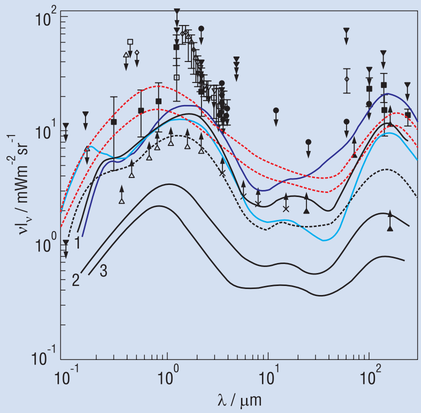


Figure 6: Spectral energy distribution of EBL: models (Stecker et al., 2006; Kneiske et al., 2002) and measurements (Kneiske et al., 2002): 1 — averaged EBL shape from best-fit model and Low-SFR model (Kneiske et al., 2002), 2 — EBL shape obtained from observations of 3c454.3 (z = 0.859); and 3 — EBL shape obtained from observations of 1739+522 (z = 1.375)

Searches for TeV to PeV neutrinos on Extensive Air Showers with the high mountain SHALON mirror Cherenkov Telescope

A neutrino telescope detects the Cherenkov radiation generated in water or ice by passage of relativistic charged particles produced by neutrino collisions with nucleons in the detector volume. Because of weakness of neutrino interaction, a very large detector volume is required. Some alternative approaches have been proposed. One of them is using the earth matter or mountain as a target volume for conversion neutrinos to leptons which then initiate Extensive Air Shower (EAS) in the atmosphere, and then the showers can be detected by Cherenkov telescope. Observations of neutrino-initiated EAS at the mountain shadow seems attractive because mountain valleys are screened from background showers of cosmic rays and the only particles that can survive are neutrinos with energies exceeding 1013 eV coming under the horizon.

During 350 h of observations at the large zenith angle 97º5', events were detected which have expected angular characteristics of a light burst of an electron–photon cascade developing within a telescope observation angle. These showers had energy in the range of about 6–17.5 TeV. These events may correspond to the decay of a new neutral, high-penetrating particle after it is produced in the atmosphere and has crossed 1000 km of rock. As a possible explanation, the scenario with an unstable neutrino of mass $m \approx 0.5$ GeV and $c\tau \approx 30$ m is discussed. Remarkably, one of these models has been recently proposed to explain an excess of electron-like neutrino events at MiniBooNE (FermiLab).

Publications:

1. Sinitsyna, V. G., S. S. Borisov, F. I. Musin, S. I. Nikolsky, and V. Y. Sinitsyna. 2009. A Synchrotron self-Compton emission model compared with VHE spectrum of Crab Nebula, Geminga energy spectra and hadronic gamma-rays in Tycho SNR. Nuclear Phys. B (Proc. Suppl.) 196:433–36.

2. Sinitsyna, V. G., and V. Y. Sinitsyna. 2009. TeV Gammas and Cosmic ray production in

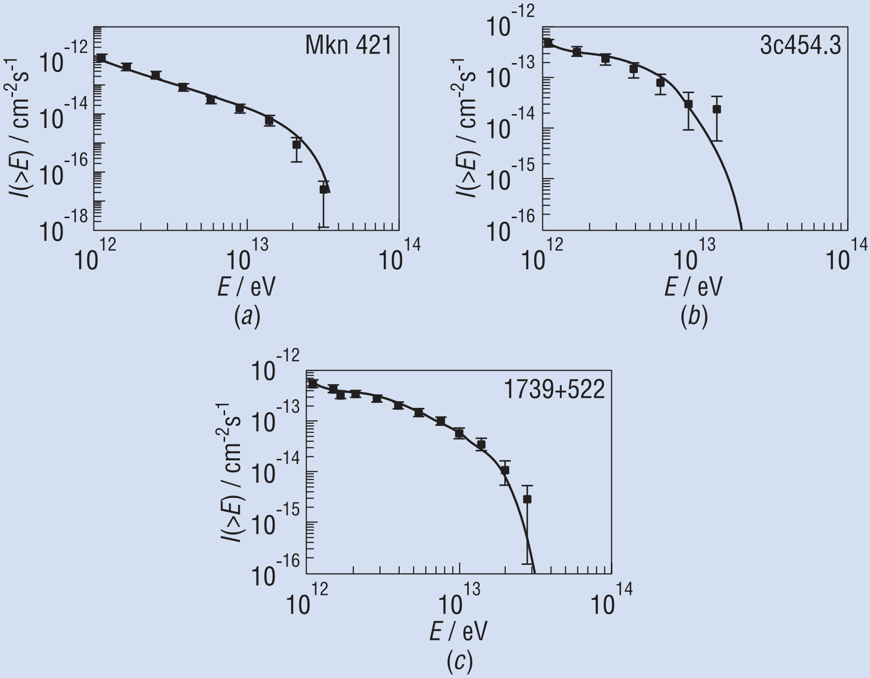


Figure 7: The measured spectra for Mkn 421, 3c454.4 and 1739+522 (black squares) together with spectra attenuated by EBL (see Fig. 6)

Tycho's SNR and Geminga. In: XLIVth Rencontres De Moriond. Very high energy phenomena in the Universe. Eds. J. Dumarchez and J. T. Thanh Van. "The Gioi" Publs. 77–80.

3. Völk, H. J., E. G. Berezhko, and L T. Ksenofontov. 2008. Internal dynamics and particle acceleration in Tycho's SNR. A&A 483(2):529–35.

4. Sinitsyna, V. G., R. M. Mirzafatikhov, F. I. Musin, S. I. Nikolsky, and V. Y. Sinitsyna. 2009. Extragalactic Supernova Remnant SN2006gy and flaring activity of Mkn 421 and Mkn 501. Nuclear Phys. B (Proc. Suppl.) 196: 251–54; 433–45.

5. Sinitsyna, V. G., S. I. Nikolsky, F. I. Musin, V. Y. Sinitsyna, and G. F. Platonov. 2009. Metagalactic distant sources of gamma rays of ultrahigh energies 1739+522 and 3c454.3. Izvestiya RAN. Physics ser. 73(5): 696–99. [In Russian.]

6. Sinitsyna, V. G. 2008. Detection of TeV to PeV neutrinos and gamma-rays with SHALON. In: Proc. XX Rencontres de Blois, Challenges in particle sstrophysics. Eds. J. Dumarchez and J. T. Thanh Van. "The Gioi"Publs. 309–12.

7. Sinitsyna, V. G., A. A. Malyshko, F. I. Musin, S. I. Nikolsky, and V. Y. Sinitsyna. 2009. Detection of TeV to PeV neutrinos and gamma-rays with the high mountain SHALON mirror Cherenkov Telescope. J. Physical Society of Japan (Suppl. A, Proc. Int. Workshop Advances in Cosmic Ray Science) 78:92–96; 192–205.

Project Number:	#T-1086
Full and Short Title:	Meteor showers as indicators of cometary nature of Near Earth Asteroids (NEAs) and physical properties of meteoroids **Meteor showers associated with NEAs**
Tech Code / Area / Field:	SAT – AST, SAT – SAF / Space, Aircraft and Surface Transportation / Astronomy, Space Safety
Status:	Project completed
Technology Development Phase:	Basic research
Allocated Funding :	$175 409,75 (EU)
Commencement date:	May 1, 2005
Duration:	36 months
Leading Institute:	Institute of Astrophysics, Academy of Sciences of the Republic of Tajikistan (TajikINASTR), Dushanbe, Tajikistan
Contact Information:	Phone: +7 (992 37) 227 46 14 Fax: +7 (992 37) 221 49 11
Supporting Institutes:	No
Collaborators:	Astronomical Institute of the Academy of Sciences of the Czech Republic, Ondrejov, Czech Republic (Borovicka J.) Queen Mary University of London, London, UK (Williams I. P.)
Project Manager:	KOKHIROVA Gulchehra
Contact Information:	Phone: +7 (992 37) 227 46 24 Fax: +7 (992 37) 221 49 11 E-mail: kokhirova2004@mail.ru
ISTC Senior Project Manager:	RYZHOVA Tatiana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (499) 978 46 37 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

Understanding the physical nature, dynamical evolution, and origin of NEAs is important both scientifically and because they can represent a long-term danger for the biosphere and the human species since they can cross the Earth's orbit. According to the available data regarding the NEAs, they may originate either from the main belt of asteroids or be extinct comets. The main mechanism for removing asteroids from the main belt requires the help of gravitational resonances with the planets, especially Jupiter. Such NEAs may be expected to be stony or iron bodies.

Another part of NEA population could be composed of extinct or "dormant" cometary nuclei. These NEAs are the end state of normal cometary nuclei after multiple perihelion passages, resulting in loss of all their available volatiles or being covered by mantle that prevents sublimation of subsurface ice. Any NEA formed by this process would contain a substantial proportion of frozen volatiles and have a very weak structure. The existence of asteroids identifiable with extinct or dormant comets (2060 Chiron, 4015 Willson–Harrington, 1986 TF Parker–Hartley) confirm the cometary origin for some NEAs. An extinct cometary nucleus hitting the Earth would produce events like the Tunguska fall. Thus, NEAs from both sources are hazardous for the Earth, though differently.

From groundbased observations of NEAs, it is difficult to distinguish between the different origins. Hence, it is very important to use any additional criteria which can help understanding the nature of specific asteroids, identifying them as "dead" cometary nuclei and determining the fraction of extinct comets in the asteroid population. One of the possible criteria is the existence of meteoroid streams formed during the period of cometary activity and producing meteor showers. The presence of meteor showers associated with some NEAs is the evidence that such asteroids have a cometary origin, i. e., they are extinct cometary nuclei.

Naturally, a meteor shower can only be produced from the meteoroid stream that intersects the Earth's orbit. Therefore, the search for dead comets through the use of associated meteoroid streams can only be meaningful when conducted amongst the NEA population. At present, NEAs number about two thousand and the number of newly discovered NEAs is increasing very rapidly. Up to now, only a few asteroids have been shown to have associated meteor showers, the most famous being the association of asteroid 3200 Phaethon with Geminid meteor shower, and the associations of Taurid complex asteroids with about 40 observable meteor showers.

Investigation of NEA-meteor showers association is important not only for confirmation or denial of NEA cometary origins, but also for the receipt of important information about NEA sources — comets from outer regions of the Solar system and real asteroids from the main belt. The identification of extinct cometary nuclei allows recognizing differences within the physical data from observations of NEAs of different origin. The results of the investigations will be helpful for the setting of new scientific goals for in situ observations of NEAs by space vehicles.

Meteoroids are known to be the products of disintegration of cometary nuclei and asteroids. Thus, the investigation of meteoroid orbits and physical characteristics is important and is of great interest for understanding the physical features of meteoroids' parent bodies.

Two-station photographic observations of meteors allow one to study in detail the processes of disintegration of meteoroids in the Earth atmosphere as well as the meteor phenomena. In this project, on the basis of light curves of bright meteors photographed in the former USSR, and taking into account the quasi-continuous fragmentation, the mean bulk density of meteoroids belonging to different meteoroid streams and the sporadic background were determined.

Project Objectives

The objectives of the Project were:

- identify NEAs that may be of cometary origin;
- find new meteor showers and meteoroid streams genetically related with NEAs;
- identify new interrelation between the small bodies of the Solar system; and
- determine the physical properties of meteoroids on the base of photographic observations of meteors.

Description of the Works

The Project objectives were attained through the investigation of the NEAs orbital evolution using the methods of celestial mechanics such as Gauss–Halphen–Goryachev and Everhart's methods and integrators, and the determination the NEAs' theoretical radiants, i. e., conditions for the possible collision of the bodies or their fragments with the Earth. Moreover, it was necessary to use all available observational data on meteor showers and individual meteors, which had to be compiled as a database for computer reduction. The completion of the project allowed identifications of extinct cometary nuclei among NEAs and found new meteor showers and new interrelations between minor bodies of the Solar system. It also illustrated the types of orbital evolution that NEAs can follow, the Earth-crossing class of NEAs and conditions for the possible encounter of NEAs' fragments with the Earth.

The method of determination of NEAs' cometary origin consisted of the following stages: (i) to investigate NEAs orbital evolution under the perturbing action of planets and to determine theoretical orbital elements and the geocentric coordinates of radiants and velocities of possible meteor showers related to NEAs; and (ii) to search for meteor showers and meteor associations related to NEAs in the catalogues of observed meteor showers, individual meteors, and fireballs.

For investigating the relation between NEAs and meteoroid streams, it was necessary to use all available observational data base on the NEAs moving on comet-like orbits and catalogues on coordinates of radiants, as well as velocities and orbital elements of meteor showers, individual meteors, and fireballs. Orbital evolution of each NEA had to be carried out with account of the perturbing action of six planets (Mercury to Saturn) using the numerical Gauss–Halphen–Gorjachev and Everhart's methods and integrators by software developed in the Institute of Astrophysics AS RT early.

Meteoroid densities had to be determined on the base of data on initial mass and velocities, zenith angles and light curves of meteors, and physical theory of meteors taking into account quasi-continuous fragmentation of meteoroids in the Earth atmosphere.

Double-station photographic observations of fireballs during 1.5–2 years, in the periods of activity of main meteor showers, had to be carried out using fireball cameras supplied with "fish-eye" objectives and the aggregates of meteor patrol supplied with MK-75 cameras (D/F = 1:3.5; F = 750 mm) destined for photographing by the method of instantaneous (0.5 ms) exposures (Fig. 1).

Figure 1: All-sky camera equipped with the Zeiss Distagon "fish-eye" objective (f=30 mm, D/f = 1:3.5) with 180o field of view

The astrometric and photometric reduction of obtained double-station photographs of fireballs had to be carried out using the method developed within the European fireball network. The precision of determining the celestial coordinates of a fireball in this method is close to the theoretical limit and the standard deviation of the measured position does not exceed 1 min of arc. As a result of double-station photographic observations of fireballs, the atmospheric trajectories, coordinates of radiants and velocities, orbital elements, as well as initial masses, magnitudes, and light curves of detected fireballs had to be determined. Using these data, the density and porosity of meteoroids produced fireballs had to be calculated.

Obtained Results

All goals of the project were met and the following results were obtained:

1. The NEAs were revealed which were the parent bodies of meteoroid streams and so of meteor showers. More specifically, 140 asteroids out of 182 NEAs under investigation were identified to be of cometary origin or to be extinct cometary nuclei.

2. New interrelations between asteroids, comets, meteoroid streams, and meteor showers were obtained.

3. Two hundred and forty previously unknown meteor associations were identified from the data bases of individual meteors observed by different methods.

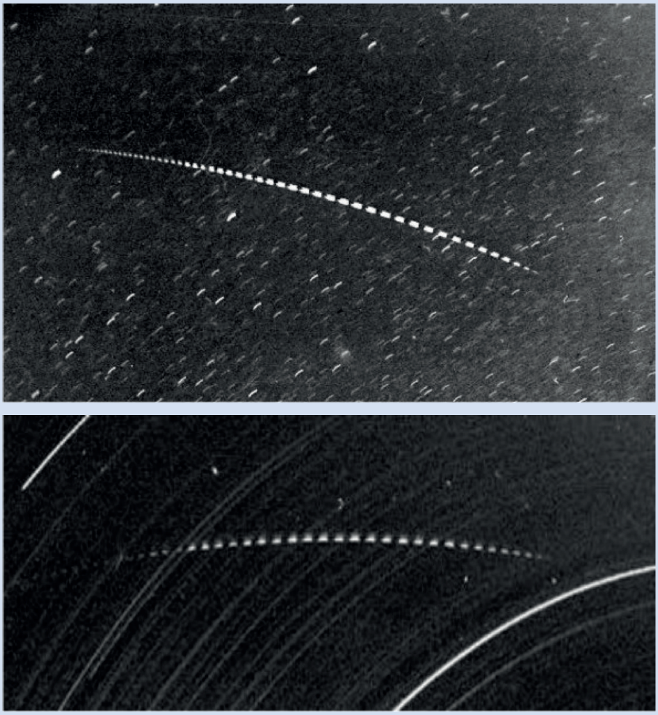


Figure 2: Photographs of the TN130907 fireball, taken with the moving all-sky camera (GisAO) and with the fixed camera (Sanglokh) on September 13, 2007 at 23h13m25s UT. The maximum of – 8.3 absolute magnitude at the height of 43.1 km, initial mass — 1.7 kg

4. On the basis of the results of double-station photographic observations of meteors and using the physical theory of meteors, which takes into account fragmentation of meteooids in the atmosphere, densities and porosity of meteoroids belonging to different meteoroid streams and sporadic background were determined.

5. Two-and-a-half-year double-station photographic observations of fireballs were carried out during the periods of activity of the main meteor showers (Fig. 2). As a result of astrometric and photometric reduction of obtained double-station photographs of fireballs, the data on radiants, atmospheric trajectories, orbits, masses, absolute magnitudes, and light curves of these fireballs were determined.

6. As recommendations for the future investigation of NEAs and meteor matter, it was suggested to continue searching for fireball showers and individual fireballs produced by large meteoroids and associated with NEAs, to identify near-Earth objects of cometary origin among the NEAs discovered during last four years. Observations of fireballs should be carried out from more stations to improve the accuracy of astrometric reduction of fireball photographs and thus to improve the value of determined data of registered fireballs.

List of publications

Monographs:

1. Babadzhanov, P. B., ed. 2006. Summary catalogue of orbital elements and light curves of the meteors photographed in the Institute of Astrophysics, Tajik Academy of Sciences (Dushanbe). Dushanbe: Donish. 208 p.

2. Babadzhanov, P. B., and G. I. Kokhirova. 2009 Meteor showers of the Earth-crossing asteroids. Dushanbe: Donish. 185 p.

Papers:

3. Babadzhanov, P. B. 2008. Near-Earth asteroids among the Piscids meteoroid stream. *Astronomy Astrophys*. 489:249–55.

4. Babadzhanov, P. B., I. P. Williams, and G. I. Kokhirova. 2008. Near-Earth objects of the Taurid complex. *Monthly Notices Roy. Astronomical Soc*. 386(3):1436–42.

5. Babadzhanov, P. B., I. P. Williams, and G. I. Kokhirova. 2008. The meteor showers associated with 2003EH1. *Monthly Notices Roy. Astronomical Soc*. 386(4):2271–77.

6. Babadzhanov, P. B., and G. I. Kokhirova. 2009. Densities and porosities of meteoroids. *Astronomy Astrophys*. 495(1):353–58.

7. Babadzhanov, P. B., G. I. Kokhirova, J. Borovicka, and P. Spurny. 2009. Photographic observations of fireballs in Tajikistan. *Solar System Res*. 43(4):353–63.

Information on patents and copy rights

The "Summary Catalogue of Orbital Elements and Light Curves of the Meteors Photographed in the Institute of Astrophysics, Tajik Academy of Sciences (Dushanbe)" was registered in the National Patent and Information Centre: Certificate # ЗИ-02.1.047TJ, October 12, 2007.

Project Number:	#T-1629
Full and Short Title:	Fireball network in Tajikistan and search for near-Earth objects associated with fireball showers \ **Fireball network in Tajikistan**
Tech Code / Area / Field:	SAT – AST, SAT – EXP, SAT – SAF /Space, Aircraft and Surface Transportation / Astronomy, Extraterrestrial Exploration, Space Safety
Status:	Project continuing
Technology Development Phase:	Basic research
Allocated Funding :	$245925,72 (EU)
Commencement date:	October 1, 2008
Duration:	36 months
Leading Institute:	Institute of Astrophysics, Academy of Sciences of the Republic of Tajikistan (TajikINASTR), Dushanbe, Tajikistan
Contact Information:	Phone:+7 (992 37) 227 46 14 Fax:+7 (992 37) 221 49 11
Supporting Institutes:	No
Collaborators:	Astronomical Institute of the Academy of Sciences of the Czech Republic, Ondrejov, Czech Republic (Borovicka J.) Queen Mary University of London, London, UK (Williams I.P.)
Project Manager:	KOKHIROVA Gulchehra
Contact Information:	Phone: +7 (992 37) 227 46 24 Fax: +7 (992 37) 221 49 11 E-mail: kokhirova2004@mail.ru
ISTC Senior Project Manager:	RYZHOVA Tatiana Borisovna
Contact Information:	Phone: +7 (495) 982 3280 Fax: +7 (499) 978 46 37 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

The meteoroid population of interplanetary space consists of bodies of a variety of sizes that have different physical and chemical properties as well as origin. If sufficiently large, they produce bright meteors, brighter than Venus (–4 magnitudes), named fireballs, when they enter the Earth's atmosphere. Occasionally, they can survive the passage through the atmosphere and produce a fall of meteorites on the Earth's surface.

The parent bodies of meteoroids producing fireballs are comets and asteroids. They offer very different danger for the Earth, because comets burst in the Earth's atmosphere, while asteroids may impact with the Earth's surface.

Since a dead or dormant comet can look superficially like an asteroid, it is very difficult to distinguish them from each other. One of possible ways is to investigate the fragments that enter the Earth's atmosphere and produce fireballs.

With a view to investigate fireballs, it was intended to organize a fireball network in Tajikistan. The unique astronomical climate of Tajikistan with 1700 clear night hours per year could ensure the success of the fireball network. The planned network included 5 observational stations equipped by the fireball cameras with "fish-eye" lenses and by the digital (CCD — charge-coupled device) cameras, all located in the southern part of Tajikistan. It could be the first fireball network in the Central Asia.

Organization a fireball network in Tajikistan was also important because it could be located at a distance of more than 4–5 h of longitude relative to the European fireball network (EN). Observational data on fireball showers obtained on different longitudes are very important for obtaining information on the structure of the meteoroid streams producing the fireball showers. Hence, the data on fireballs planned to be obtained in Tajikistan could greatly enhance the data obtained by EN and other fireball networks.

In addition to the scientific value of the new data regarding the physics and dynamics of the meteoroids, the fireballs have significant applied importance. For protecting space vehicles, it is necessary to have detailed information on the near-Earth meteoroid environment. In order to solve the problem of preventing a damaging collision, it is important to know the toughness and structure of incoming meteoroids.

All-sky fireball cameras can be used for fireball observations associated with streams, but can also simultaneously detect all sufficiently bright objects appearing on random positions on the sky. For example, obtained photographs may be useful for searching optical flashes of γ-ray busters, and for the registration of bright nova outbursts. All these are of interest both scientifically and from the point of view of possible commercialization of the results of the investigations.

Preliminary experience of double-station fireball observations in Tajikistan during 2005–2007, within the framework of the ISTC project T-1086, showed its high efficiency: during 2.5 years the photographs of 85 fireballs were obtained, 35 of them were double-station. Astrometric and photometric reduction of the double-station fireball photographs were also carried out. As the results, the atmospheric trajectories, coordinates of radiants, geocentric and heliocentric orbits, masses, absolute magnitudes of these fireballs, and their relation to known meteor showers were determined.

Project Objectives

The objective of the project was to obtain new data on the meteoroid surrounding of near-Earth space (for large bodies producing fireballs) and to introduce it into the existing world data bank used for solving various problems in spacecraft technology.

For this aim, the following tasks had to be solved:

• Organize a fireball network in Tajikistan consisting of 5 stations located on the mutual distances of 80–90 km from each other.
• During 3 years, carry out photographic observations of fireballs by cameras equipped with the "fish-eye" Zeiss Distagon lenses and by digital (CCD) cameras.

• Determine, using the photographic observations, the orbits and physical parameters of meteoroids producing fireballs.

• Search for those Near-Earth Objects (NEOs), among known comets and asteroids crossing the Earth's orbit, which might be associated genetically with fireball showers and individual fireballs.

Description of the Works

The project goals were accomplished by the systematic observations of fireballs in clear cloudless nights by determining the geocentric and heliocentric parameters of fireball trajectories.

Multistation photographic observations of fireballs allowed a detailed study of the processes of disintegration of large meteoroids in the Earth's atmosphere as well as the fireball phenomena. Furthermore, photographic photometry of fireball photographs allowed the masses and physical parameters of meteoroids producing fireballs to be determined.

The NEOs, which could be parent bodies of meteoroids producing fireballs, had to be searched and identified by means of investigating orbital evolution of these meteoroids and of their possible associated NEOs using the methods of celestial mechanics. It was intended to use all existing data on fireball showers and individual fireballs which alongside with obtained data on new fireballs detected in Tajikistan as well as by EN, Prairie Network (PN), and Canadian Network (MORP) form the database for computing process.

The relationship between fireball showers and NEOs of comet or asteroidal nature had to be obtained. To confirm that a fireball shower is associated with a specific NEO, it is necessary to investigate evolution of their orbits under the perturbing action of major planets for the time interval of 5–10 kyr back herewith trailing the variations of values of criteria of closeness between a fireball shower and the NEO with time.

The results obtained within the project were expected to be important for taking into account the asteroidal–meteoroid danger for space vehicles.

Results

The following results are obtained:

1. The Central Asia's first fireball network in Tajikistan consisting of 5 stations equipped with photographic cameras ("fish-eye" Zeiss Distagon lenses, f = 30 mm, f/D = 1:3.5) and digital (CCD) cameras "Nikon D2X" and "Nikon D300" ("fish-eye" Nikkor lenses, f = 10.5 mm, f/D = 1:2.8) has been organized.

2. Systematic photographic observations of fireballs (meteors brighter than –4 magnitude) were performed for 3 years during all clear cloudless nights.

3. Altitudes of beginning, maximum of brightness, and disappearance, as well as velocities, radiants, and orbits of fireballs were photographed from at least 2 stations.

4. Based on the photometric reduction of fireball photographs, masses, and physical parameters of meteoroids producing fireballs were determined.

5. Possible association of photographed fireballs to the known meteor and fireball showers or to their branches was suggested.

6. The catalogue of atmospheric trajectories, coordinates of radiants, orbital elements, absolute magnitudes, preatmospheric masses, and membership of new fireballs to known meteor and fireball showers was created. This catalogue complement significantly the existing world's data of fireball observations.

7. The parent bodies of meteoroids producing fireballs among the NEOs (comets and asteroids) were searched. Among the NEOs, extinct comets and real asteroids whose fragments produced fireballs were revealed.

Three new points of photographic observations of fireballs have been organized on the territories of the following operating meteorological stations of Tajikistan: Rasht, Khovaling, and Kurgan-Tube (Fig. 1). As a result, today the fireball network in Tajikistan consists of 5 observation points covering the territory of about 11 thousand km^2.

The precise geographical coordinates of the observational points and mutual distances between them (in kilometers) are presented in Tables 1 and 2, respectively.

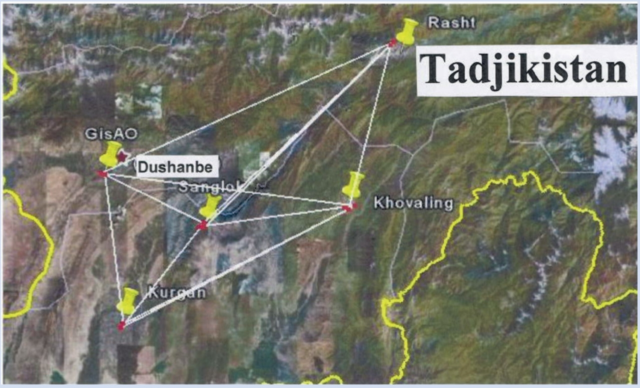


Fig.1. The map of observational points of the Tajikistan fireball network

Table 1: Coordinates of observational points in the Tajikistan fireball network

Observational point	Longitude	Latitude	Height, m
Sanglokh	69°13'.02	38°15'.43	2291
Gissar	68°40'.54	38°29'.23	721
Rasht	70°17'.40	39°00'.22	1315
Khovaling	69°58'.52	38°21'.13	1446
Kurgan Tube	68°46'.19	37°51'.13	427

Table 2: Distances between observational points in the Tajikistan fireball network (in km)

Observational point	Sanglokh	Gissar	Rasht	Khovaling	Kurgan Tube
Sanglokh	—	53.1	124.9	67.9	59.8
Gissar	53.1	—	151.3	115.0	71.0
Rasht	124.9	151.3	—	77.7	184.0
Khovaling	67.9	115.0	77.7	—	120.0
Kurgan Tube	59.8	71.0	184.0	120.0	—

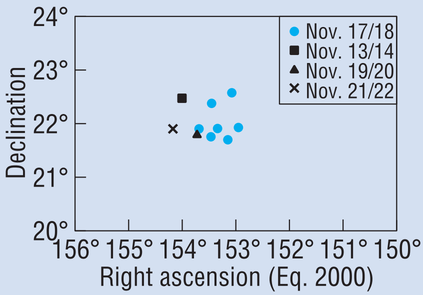


Figure 2: Radiant dispersion of Leonid fireballs photographed on November 13–21, 2009 in the Tajikistan fireball network

Figure 3: Photographs of the TN180809 fireball, taken with the digital camera at the Sanglokh on August 18, 2009 at 23h03m25s UT

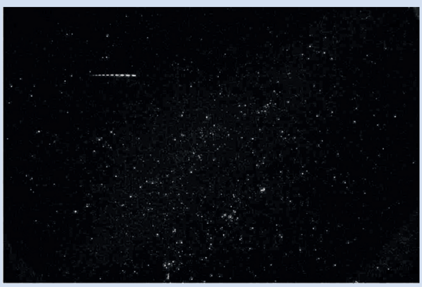


Figure 4: Photographs of the TN171109a Leonid fireball, taken with the digital camera equipped by the objective rotating shutter at the Sanglokh on November 17, 2009 at 20h39m09s UT. The maximum of –7.2 absolute magnitude at the height of 90.7 km, initial mass — 11g

The simultaneous photographic and digital observations of fireballs were carried out at five points — Sanglokh, Gissar, Rasht, Khovaling, and Kurgan-Tube during more than 1500 h according to the observation schedule and taking into account weather conditions (Figs. 2–4). As a result:

– more than 70 fireballs were detected by all-sky cameras. Among them, multistation photographs of 50 fireballs were selected; and

– more than 2000 objects such as fireballs, satellites, busters (2) were detected by digital cameras. Among them, 20 fireballs were the fireballs detected with all-sky cameras. Using several digital fireball images, the exact moments of fireball flights were determined.

On November 16–18, 2009, observations of the Leonid meteor shower in the Tajikistan fireball network were carried out jointly with Czech astronomers — project collaborators Dr. J. Borovicka and Dr. P. Koten. Obtained results were presented at the International Conference "Meteoroids-2010" (Breckenridge, Colorado, May 24–28, 2010) and will be published.

As a result of the astrometric and photometric reduction of the multistation images of more than 20 fireballs, the coordinates of radiants, as well as atmospheric trajectories, velocities, decelerations, orbital elements, light curves and luminosity of these fireballs and preatmospheric masses, densities, and porosity of the meteoroids producing these fireballs were calculated.

On the base of the catalogue (http://newton.dm.unipi.it/neodys/neodys.cat) of the Near-Earth Asteroids (NEAs) discovered during 2005–2008 the database of selected 1456 Earth-crossing NEAs of the Apollo (1207 NEAs), Amore (18 NEAs), and Aten (231 NEAs) groups was created. This database lists the name, epoch (MJD), orbital elements, mean anomaly, and magnitude for each NEA.

The criteria were calculated for discrimination between asteroidal and cometary type of orbits, and determination of the NEAs moving on comet-like orbits. The values of mean motions of the selected NEAs were calculated and the commensurabilities with Jupiter were determined.

Using the calculated criteria for discrimination between asteroidal and cometary type of orbits, 154 NEAs moving on comet-like orbits were revealed. So, 154 asteroids of Apollo and Amore groups, moving on comet-like orbits and crossing the Earth orbit, remain for further investigations of orbital evolution.

The distribution of their calculated mean motions shows that 40 NEAs move in resonance with Jupiter; therefore, their orbital evolution was investigated by Everhart's method, and the secular perturbations of orbital elements of remaining 114 NEAs were carried out by the Halphen–Gorjachev method for the time intervals embracing one cycle of variations of the argument of perihelion (from ± 5 to ± 10 thousand years).

As a result of orbital evolution investigation, the conditions of crossing the Earth orbit by these 154 NEAs were determined.

Using the results of investigation of orbital evolution of selected 154 NEAs and conditions of crossing the Earth's orbit, the database was created for calculation of the theoretical geocentric radiants and velocities of meteor and fireball showers possibly associated with these selected NEAs. For each crossing of the Earth's orbit by the given NEA, this database contains (out of four or eight possible) the name and orbital elements: a — semimajor axis; e — eccentricity; i — inclination; Ω — longitude of ascending node; and ω — argument of perihelion.

As a result of calculation, the theoretical geocentric radiants and velocities of meteor and fireball showers possibly associated with all selected NEAs were determined. Among them, 15 are octuple Earth-crosser asteroids and the rest are quadruple Earth-crosser asteroids. Consequently, according to the theory of evolution of meteoroid streams developed in the Institute of Astrophysics AS RT, theoretically, the first NEAs can produce eight meteor showers, and the second — four meteor showers, namely, a nighttime shower with northern and southern branches, and a daytime shower also with northern and southern branches.

List of publications

1. Babadzhanov, P.B., I.P. Williams, and G.I. Kokhirova. 2009. Near-Earth asteroids among the Iota Aquariids meteoroid stream. *Astronomy Astrophys*. 507(2):1067–72.

2. Kokhirova, G.I., and J. Borovicka. 2010. Observations of the Leonids 2009 by Tajikistan fireball network. NASA Technical Report.

Extraterrestrial exploration

List of Projects

In total, 12 projects were funded by the ISTC Parties.

#0036

"Development of thermal protection systems for interplanetary flight"

(Space Thermal Protection)

– Moscow State University / NIIM (Mechanics), Moscow, Russia

– Central Research Institute of Machine Building (TsNIIMash), Korolev, Moscow reg., Russia

– Russian Academy of Sciences / Institute for Problems in Mechanics, Moscow, Russia

– Central Aerodynamic Institute, Zhukovsky, Moscow reg., Russia

#0092

"Testing of feed system for nuclear propulsion technology under consideration for exploration of Mars"

(Nuclear Rocket System Testing)

– Keldysh Research Center, Moscow, Russia

– Research Institute for Chemical and Constructional Machine Building, Sergiev Posad, Russia

– Chemical Automatics Engineering Design Corp., Voronezh, Russia

#0335

"Development of the Conceptual Project of Nuclear Thermal Power Propulsion System (NTPP) for Space Exploration. Conducting of Fuel Testing in the IVV-2 Reactor. Development of Principles to Ensure Nuclear and Radiation Safety of NTPP"

(Nuclear Propulsion System for Mars Mission)

– Federal State Unitary Enterprise Research and Development Institute of Power Engineering named after N. A. Dollezhal, Moscow, Russia

– Kurchatov Research Center, Moscow, Russia

– NPO Lutch, Podolsk, Moscow reg., Russia

– VNIITF, Snezhinsk, Chelyabinsk reg., Russia

#0417-2

"Feasibility Study of Seismo-Electromagnetic Phenomena Using Satellite Observations"

(Seismo-Electromagnetic Phenomena)

– IZMIRAN, Troitsk, Moscow reg., Russia

– Design Bureau "Arsenal," St. Petersburg, Russia

#1068

"Review of Air-Bag Extending Expansion Mechanism for Planet Probe Spacecraft"

(Soft Landing System)

– Lavochkin Association, Khimki, Moscow reg., Russia

#1068-2

"Review of Air-Bag Extending Expansion Mechanism for Planet Probe Spacecraft"

(Soft Landing System)

– Lavochkin Association, Khimki, Moscow reg., Russia

#1172

"Preliminary Project for Exploring Mars"

(Mars Expedition)

– Keldysh Research Center, Moscow, Russia

– NPO Energia, Korolev, Moscow reg., Russia

– Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia

– Russian Academy of Sciences / Space Research Institute, Moscow, Russia

– Federal State Unitary Enterprise Research and Development Institute of Power Engineering named after N.A.Dollezhal, Moscow, Russia

#1239

"Investigation and Development of the Ultrahighsensitive Terahertz Frequency Band Hot-Electron S–LN–S Microbolometer for Extra Atmosphere Astrophysics Observations and Measurements"

(Microbolometer for Astrophysics Observations)

– Russian Academy of Sciences / Institute of Radioengineering and Electronics, Moscow, Russia

– P.L.Kapitza Institute of Physics Problems, Moscow, Russia

– FIAN Lebedev / Astro Space Center, Moscow, Russia

– Moscow State University / Department of Physics, Moscow, Russia

#1440

"Experimental Investigations of Non-Equilibrium Radiation and Physical-Chemical Processes in Shock-Wave Layer Ahead of Body Passing through Mars or Venus Atmosphere with Second Cosmic Velocity"

(Space Objects in Extraterrestial Planet Atmosphere)

– Moscow Institute of Physics and Technology, Dolgoprudny, Moscow reg., Russia

#1549

“Problems of Aerothermoballistics, Radiation Gasdynamics, Heat and Mass Transfer for Planet Sample Return Missions”

(Aerothermoballistics Problems in Interplanetary Mission)

– Moscow State University / NIIM (Mechanics), Moscow, Russia

– Central Aerodynamic Institute, Zhukovsky, Moscow reg., Russia

– Central Research Institute of Machine Building (TsNIIMash), Korolev, Moscow reg., Russia

– Russian Academy of Sciences / Institute for Problems in Mechanics, Moscow, Russia

#2365

“Solar-Powered Rocket Engine (Using Hydrogen and Oxygen Fuel) with a Purpose of Shifting Satellites from Low Earth Orbit to Stationary Orbit “

(Solar-Powered Rocket Engine)

– Keldysh Research Center, Moscow, Russia

#3506

“Arrays of Superconducting Direct Detectors for Supersensitive Imaging Radiometers of 1.0–0.2 mm Waveband Region”

(Submillimeter Detector Arrays)

– Russian Academy of Sciences / Institute of Radioengineering and Electronics, Moscow, Russia

Project Number:	#0036
Full and Short Title:	Development of thermal protection systems for interplanetary flight **Space Thermal Protection**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding :	$500,000 (EU)
Commencement date:	July 1, 1996
Duration:	36 months
Leading Institute:	Moscow State University / NIIM (Mechanics), Moscow
Contact Information:	Phone: +7 (495) 939 31 21 Fax: +7 (495) 939 01 65 E-mail: common@imec.msu.ru Website: http://www.imec.msu.ru
Supporting Institutes:	Central Research Institute of Machine Building (TsNIIMash), Korolev, Moscow reg., Russia Russian Academy of Sciences / Institute for Problems in Mechanics, Moscow, Russia Central Aerodynamic Institute, Zhukovsky, Moscow reg., Russia
Collaborators:	Aerospatiale Espace and Defence, Aerodynamic and Structure Department, France European Space Agency/ESTEC, Manned Spaceflight Programme Department, The Netherlands
Project Manager:	LOSEV Staly Andreyevich
Contact Information:	Phone: +7 (495) 939 54 72 Fax: +7 (495) 939 25 98 E-mail: losev@imech.msu.ru, piljugin@inmech.msu.su
ISTC Senior Project Manager:	UREZCHENKO Vladimir Makarovich
Contact Information:	Phone: +7 (495) 982 31 21 Fax: +7 (499) 978 36 03 E-mail: urezchenko@istc.ru
ISTC Website:	http://www.istc.ru

Background

Various international programs plan to implement in XXI century a series of extensive explorations of the Solar system planets and their satellites by means of interplanetary missions. Both space apparatus flights near the objects to be studied and various scenarios of space exploration apparatus entry into planet atmospheres are considered.

The specialists participating in ISTC Project #0036 together with European collaborators concentrated their efforts on the Mars mission as a basis of the investigations conducted. The investigations were in accordance with the works performed by the European Space Agency (MARSNET, INTERMARSNET, and MARSEXPRESS). Project #0036 considered entry of small space vehicles in Mars atmosphere and development of systems of their thermal protection.

Project Objectives

Objective of the Project was to develop better thermal protection systems for interplanetary space ships that take into account aerodynamic heating, dust erosion, ablation, and heat exchange in gaps of heat protecting constructions in the course of object motion in the Mars atmosphere.

The particular goals of the Project included:

– development and verification of numerical models and codes for simulating flow around space vehicles and their construction units that move at hypersonic velocities in the Mars atmosphere with allowance for real properties of the high-temperature gas phase in the shock layer near the apparatus surface;

– elaboration and experimental verification of the kinetic models of physicochemical processes proceeding in high-temperature gases associated with energy exchange processes, excitation of electron states of atoms and molecules, decomposition of molecules, and ionization at temperatures of up to 40,000 K to be applied in calculations of heat fluxes near the vehicles moving in the Mars atmosphere (CO_2–N_2–Ar); and

– numerical modeling with the use of full Navier–Stokes equations governing an axially symmetric nonequilibrium flow around the front vehicle surface with the purpose of assessment of the heat flux (including radiation) toward the surface.

Description of the Works

The work dealt with solving the problems of heat transfer and optimization of thermal protection systems in designs of descending apparatus of various shape that move along diverse trajectories under real environment conditions, including dusted layers in a lower planet atmosphere:

– experimental and theoretical investigations of atmosphere dustiness effects on the heat transfer processes. Consideration of ablation of thermal protection materials;

– experimental and theoretical investigations of erosive influence of a dusted flow on the thermal protection system of a Mars descent apparatus (MDA);

– experimental studies of oxidation and thermal stability of thermal protection materials, including investigations performed in a dissociated carbon dioxide flow with sample preheating that reproduces real trajectory conditions of a module landing in the planet atmosphere;

– elaboration, based on the numerical and experimental investigations, of the methodology and software for complete thermal computation of an MDA, including optimization of its thermal protection and insulation systems with account taken of all the basic factors of the environment (gas medium composition, dustiness, nonequilibrium, and so on);

– complex investigation of aerothermoballistics of an apparatus descending in Mars atmosphere and optimization of recommended thermal protection and thermal insulating systems, descent schemes, and aerodynamic shapes of the MDA;

– assessment of catalytic properties of the modern thermal protection coatings under conditions of thermal and chemical interac-

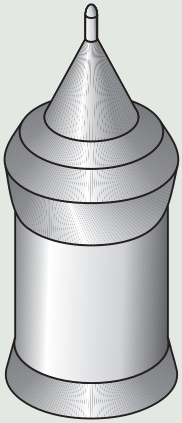


Figure 1: General view of the head block

tion of the thermal protection material with subsonic flows of dissociated carbon dioxide that model conditions of MDA entry in the atmosphere; and

– numerical modeling of an axially symmetric flow near the head-body surface with local unevenness with the use of the full set of Navier–Stokes equations. Studies of the effect of circular and radial gaps on the convective heat exchange in the domain of gradient gas flow at the head-body surface (Fig. 1) and calculation, with allowance for convective and radiation heat exchange, of thermal protection shield heating in the zone where the gaps are positioned.

Obtained Results

Quantitative data have been obtained that provide evidence of the importance of allowance for nonequilibrium effects in assessing heat flux (nonequilibrium radiation of atoms and molecules) and formation of plasma zones (nonequilibrium ionization) near an apparatus flying in the Mars atmosphere:

• aerothermoballistic grounding of a promising basic concept of an MDA with a segment-conical configuration was carried out. The apparatus complies with the required goal task, namely, provision of landing of the MDA at the preset area on the Mars surface;

• modifications of the synthesized basic MDA were elaborated. They are intended to provide the best realization of various versions of apparatus landing on the planet surface: apparatus landing from the approach interplanetary trajectory; transfer of the MDA to a Mars satellite orbit; and apparatus landing on the planet surface from the Mars artificial satellite orbit (Fig. 2);

• it was found that provision of the lowest weight of the balancing load at the MDA (at nonzero balancing angles of attack) calls for a modification of the promising shaped basic

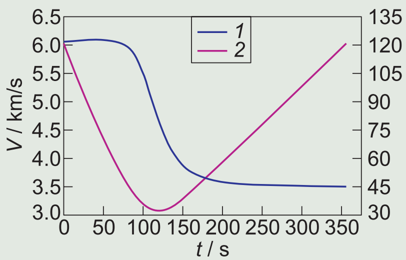


Figure 2: Flight trajectory parameters of MDA with aerodynamic flaps

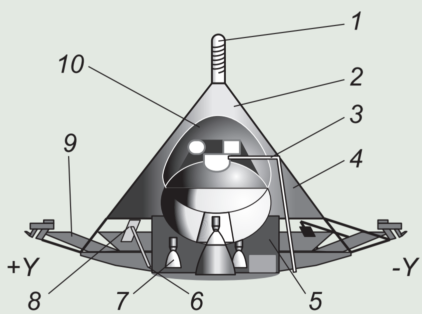


Figure 3: Assembly scheme of the orbital-descent space apparatus: 1 — antenna; 2 — parachute compartment; 3 — soil sampler; 4 — protective casing; 5 — instrumental casing; 6 — head shield; 7 — descent engines; 8 — descent device; 9 — casing with flaps; and 10 — take-off rocket

MDA equipped with aerodynamic flaps positioned on the windward side of the face brake screen (Fig. 3);

• methodology and software for thermal calculation of the MDA were worked out. They take into account all the basic factors of environment and specific features of the aerodynamic shape of the MDA (atmosphere composition, dustiness, catalytic properties of the thermal protection material, angle of attack, presence of flow separation zones at the apparatus surface, boundary layer transition, etc.);

• thermal regimes and heat protection systems of prospective versions of MDA were calculated, in particular, for the European "Mars Express Probe" (A and B) projects and for Russian projects implemented by Lavochkin Association and present Project team. These apparatus versions should land on the surface of Mars or decelerate in its atmosphere with return to an orbit of an artificial Mars satellite. The relative weight of the head-shield thermal protection system of an MDA that executes a ballistic descent in the Mars atmosphere was shown to range between 3% and 13% of the overall apparatus weight depending on the apparatus type and thermal protection material applied;

• a technique was elaborated for testing thermal protection materials (both removable and of multiple use) in a dissociated carbon dioxide flow preheated in a high-frequency induction plasmatron within the range of parameters (stagnation enthalpy and pressure) that simulate the conditions of apparatus descent in the Mars atmosphere. The fundamental difference of thermal protection material tests in a CO2 flow compared to those in air or nitrogen flow is that the radiation component of the heat flux in the infrared spectral region contributes significantly to the overall heat flux;

• feasibility of acceleration of fine particles in the nozzle of a pulse wind tunnel to hypersonic velocities was proved by both calculations and experiments. The presence of fine solid particles (1 μm or less in size) in the flow even in a low concentration (of order of few percent) is shown to significantly enhance heating of the head apparatus surface, which must be taken into account in assessing the thermal protection shield of the MDA; and

• systematic calculations of the gas flow at the gap zone of the thermal protection shield performed with the use of the full set of Navier–Stokes equations allowed correlation formulas for calculating the heat transfer coefficient in gaps as a function of the basic governing parameters to be derived. Based on analysis of the experimental and calculated data on flow parameters in the zone of gaps and protrusions, a technique and software for assessing heat exchange and thermal protection shield heating in the gap zone were developed. Calculations have demonstrated a significant local temperature increase in the construction in the gap zone. The technique developed permits calculations of thermal protection shield preheating in the gap zone to be refined and their reliability to be enhanced.

The results of investigations were published in the Proceedings of the Third European Symposium on Aerothermodynamics for Space Vehicles, November 24–26, 1998, ESTEC, Noordwijk, The Netherlands, ESA SP-426.

Project Number:	#0092
Full and Short Title:	Testing of feed system for nuclear propulsion technology under consideration for exploration of Mars **Nuclear Rocket System Testing**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration FIR-ENG / Fission Reactors / Reactor Engineering and NPP
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding :	$1,166,000 (EU: $583,000, US: $583,000)
Commencement date:	April 1, 1995
Duration:	36 months, extended by 3 months
Leading Institute:	Keldysh Research Center, Moscow, Russia
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
Supporting Institutes:	Research Institute for Chemical and Constructional Machine Building, Sergiev Posad, Moscow reg., Russia Chemical Automatics Engineering Design Corp., Voronezh, Russia
Collaborators:	Rockwell International, Rocketdyne Division, Canoga Park, CA, USA SEP (Soceite Europeenne de Propulsion), Vernon, France
Project Manager:	SEMYONOV Vitali Felixovich
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
ISTC Senior Project Manager:	TOCHENY Lev Vasil’evich
Contact Information:	Phone: +7 (495) 982 31 13 Fax: +7 (499) 978 46 37 E-mail: tocheny@istc.ru
ISTC Website:	http://www.istc.ru

Background

A closed scheme of economy tests of a Liquid Hydrogen Feed System (LHFS) and development of a heat-exchanger-recuperator for this scheme were the main tasks of the Project. The nuclear rocket engine scheme and its parameters have been chosen in the Project on the basis of USA and Russian investigations of nuclear rocket engines conducted in these countries since 1950 with account taken of the contemporary positions and requirements imposed on such an engine by its use in a manned mission to Mars. The basic characteristics of the engine feed system are such that they can be used in development of liquid rocket engines.

The Project comprised theoretical and experimental parts in which thermal and hydraulic processes taking place in the inlet manifold of the LHFS of the rocket engine were considered. In the theoretical part, thermal and hydraulic processes in the inlet manifold of the LHFS of the rocket engine were investigated by means of modeling cavitation phenomena and vapor generation at the booster pump inlet with assessment of the volumetric vapor content. The experimental part was presented by the results of cavitation tests of the booster pump and the LHFS in the form of generalized cavitation and energy characteristics.

Project Objectives

Elaboration of a set of new technologies that make cheaper prospective space hydrogen-fed engines, including a nuclear rocket engine.

Description of the Works

The set of new technologies included:

• provision of long-term (from 5 to 10 h) operation of the LHFS of space engines under condition of space flight;

• formulation of the optimal composition and parameters of the LHFS of space engines operating at a low pressure in the tanks, i. e., with a two-phase hydrogen flow at the booster pump inlet;

• reduction of the cost of ground LHFS development by hydrogen utilization in the course of testing;

• reduction of liquid hydrogen expenditures for cooling the LHFS of promising engines;

• introduction of new materials, new technological processes that improve the characteristics and quality of the onboard hydrogen heat exchangers.

The following works were accomplished within the Project:

• calculations and theoretical investigations of thermal and hydraulic processes occurring in the rocket engine LHFS;

• project and design works aimed at development of the experimental LHFS and modification of the NIIKhimMash test bench to make it suitable for liquid hydrogen tests;

• fabrication of an experimental LHFS;

• methodology of and software for experimental studies that permit the results of tests performed at various hydrogen vapor content at the booster pump inlet to be predicted;

• experimental studies of the pumps and turbines with the use of model working fluids. The booster pump and LHFS were tested using liquid hydrogen as a working fluid in regimes close to the nominal one and in cavitation regimes with a volumetric hydrogen content at the booster pump inlet of about 100%; and

• the measures to reduce the cost of liquid hydrogen tests with the aid of hydrogen utilization were suggested.

The results of calculations and experimental studies performed with the use of a model working fluid and results of liquid hydrogen tests were treated and presented as comparative energy and cavitation characteristics.

Obtained Results

The major result of the Project implementation was the creation of the experimental SPRD-111 Feed System for a nuclear rocket engine with a 111-kN thrust value (hydrogen flow rate of 10 kg/s) (Fig. 1). Selection of ag-

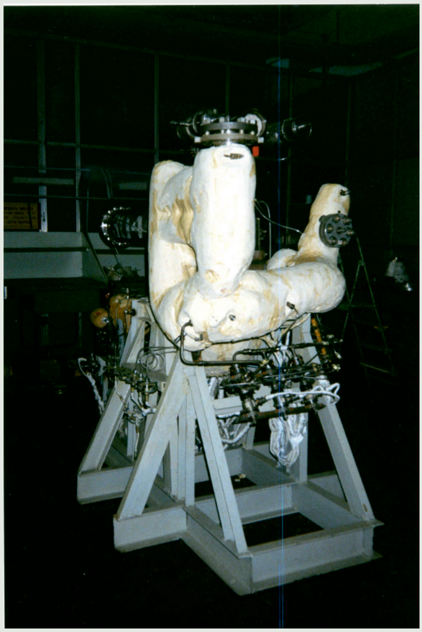


Figure 1: SPRD-111 Feed System modulus on the NIIKhIMMASH test bench before tests with liquid nitrogen

gregates from propulsion systems applied at present in other systems and a specially designed booster pump with improved cavitation characteristics was the main specific feature of the present LHFS. A scheme of LHFS testing that makes it possible to model thermal and hydraulic characteristics of the reactor section of a nuclear rocket engine, associated with hydrogen supply to the turbine of the basic pump, was elaborated. The scheme allows one to return back in tests more than 50% of hydrogen after the main pump and also to partially accumulate the evaporated cold hydrogen in the test bench tanks with its subsequent use in multiple-cycle SPRD-111 tests according to the suggested closed scheme. Estimates demonstrated that the closed scheme permits one to spare 40% of liquid hydrogen more compared to an open scheme and throttling, in tests of 3600-second duration with hydrogen flow rate of 10 kg/s.

Project Number:	#0335
Full and Short Title:	Development of the Conceptual Project of Nuclear Thermal Power Propulsion System (NTPP) for Space Exploration. Conducting of Fuel Testing in the IVV-2 Reactor. Development of Principles to Ensure Nuclear and Radiation Safety of NTPP. **Nuclear Propulsion System for Mars Mission**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration FIR-REA / Fission Reactors / Reactor Concept
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding :	$200,000 (EU)
Commencement date:	March 1, 1996
Duration:	15 months, extended by 3 months
Leading Institute:	Federal State Unitary Enterprise Research and Development Institute of Power Engineering named after N. A. Dollezhal, Moscow, Russia
Contact Information:	Phone: +7 (499) 263 73 13, 264 46 10 Fax: +7 (499) 788 20 52 E-mail: nikiet@nikiet.ru Website: http://www.nikiet.ru
Supporting Institutes:	Kurchatov Research Center, Moscow, Russia NPO Lutch, Podolsk, Moscow reg., Russia VNIITF, Snezhinsk, Chelyabinsk reg., Russia
Collaborators:	CEA / DRN / DMT/CEN Saclay, Saclay, France Technische Universitat Munchen, Munich, Germany Aerojet, Sacramento, CA, USA
Project Manager:	SMETANNIKOV Vladimir Petrovich
Contact Information:	Phone: +7 (499) 267 74 35 Fax: +7 (495) 788 20 52 E-mail: abalina@nikiet.ru
ISTC Senior Project Manager:	TOCHENY Lev Vasil'evich
Contact Information:	Phone: +7 (495) 982 31 13 Fax: +7 (499) 978 46 37 E-mail: tocheny@istc.ru
ISTC Website:	http://www.istc.ru

Background

Search for engineering solutions of the problems relevant to manned flights to Mars and other planets, as well as unmanned vehicle flights outside the Solar system keeps going on despite serious difficulties arising that include also funding difficulties. A great number of transport devices must be created to perform an interplanetary mission; an interplanetary tug-ship is one of them. This Project supported by the International Science and Technology Center was aimed at development of the conceptual project of a nuclear rocket engine (NRE) for an interplanetary moon tug-vehicle. Despite the early stage of development, the important specific feature of the project is that the principal engineering solutions incorporated in it have been tested experimentally in the course of accomplishment in the 1960–80s in the former Soviet Union of the science and technology program aimed at NRE creation. The project rested on Russian achievements in this engineering area.

Project Objectives

The objective of the Project was to elaborate an engineering pattern of NRE capable of solving not only the payload transportation problem in the course of intense Moon exploration but also the problem of selecting such engine reactor concept that would permit one to readily formulate on its basis, with a certain modification, a concept of nuclear energy propulsion system (NEPS), without which the extraterrestrial exploration problem cannot be solved.

Description of the Works

The requirements imposed on the NRE by the Moon tug-vehicle flight task, as well as the requirements imposed by nuclear and radiation safety of the propulsion system were formulated. They are nearly identical to the requirements imposed by French CNES on national designs of a nuclear engine formulated within the Mars program.

Input Project characteristics

When selecting the input nuclear engine characteristics, the following reasoning was taken into account in the Project:

– the NRE parameters must provide the most efficient solution of the global problem considered because its realization would require huge material expenditures. Hence, the NRE construction should rest on the most advanced technology that provides high thrust engine characteristics and delivery to the destination site of a payload of the as large as possible weight, increasing, thereby, economic efficiency of the nuclear tug-vehicle;

– the technology of breeder elements on the basis of solid-phase solutions of uranium carbide, zirconium, and niobium capable of providing attainment of the average hydrogen temperature at the exit from the active zone as high as 2900 K and, respectively, the specific thrust impulse of ~ 940 s which can warrant high characteristics of NRE with a solid-fuel active zone. This technology would permit the payload delivered to Moon to be increased by 20% or 30% as compared to the payload transported with the aid of NRE on the basis of the NERVA reactor or reactor concept developed within the Mars program; and

– the overall cost of NRE development can be reduced at the expense of engine unification, so that it can be applied to several flight tasks, using a principle of module construction of the space vehicle propulsion (energy-propulsion) system. The largest module size is mostly dictated by the technical opportunities of the test bench with a closed exhaust of the working fluid in NRE or NEPS development on the ground. According to the contemporary notions, it is expedient to limit the thermal power of the engines tested by a level ranging between 300 and 500 MW, and their thrust should be limited to 700 or 100 kN. One or two (maximum) NRE modules per an interorbital tug-vehicle are sufficient to solve the problem of Moon transportation, while the Mars mission would necessitate, e. g., in the interplanetary space ship, three or four NEPS modules.

Table 1: Basic project NRE characteristics

Parameter	Value
NRE thrust (in vacuum), kN	68
Specific impulse, s:	
– theoretical	940
– actual	900
Thermal reactor power, MW	340
Duration of the engine operation*, s:	
– at start from a near-Earth orbit	810
– at deceleration on a near-Moon orbit	210
– at start from a near-Moon orbit	65
– at deceleration on a near-Earth orbit	135
Duration of the passive Earth–Moon flight*, h	90
Number of flights toward Moon*	5
Permissible radiation loads on the electronic instruments and payload*:	
– γ-radiation doze absorbed, Gr	
– fluence of fast neutrons ($E > 1$ MeV), cm^{-2}	$10^4/5 \cdot 10^3$
	$10^{14}/10^{12}$
Number of NRE modules*	1

**CNES requirements.*

In this connection, when working out the technical pattern of a NRE for the Moon tug-vehicle, the basic characteristics listed in Table 1 were used.

Technical NRE pattern

Description of the reactor construction

The NRE reactor is an apparatus of a channel-casing type (Figs. 1 and 2) with a heterogeneous intermediate-neutron active zone in which 30 fuel rod arrays (FRA) with the nuclear fuel are mounted in a porous massive retarder block in the form of a bundle of tightly packed profiled zirconium hydride rods. The active zone is surrounded with a side neutron reflector made of beryllium and sectioned both in height and azimuth directions. It contains rotating control drums (RD) with neutron absorbers made of boron carbide. The RD drive gears of the electric and mechanical type are applied as the most well-developed and reliable system. Each drive gear actuates two RD simultaneously via a reducer. The reactor in its operation state is governed by 12 controlling drums. Seven additional nuclear safety rods (NSR) are provided to prevent reactive accident in emergency cases. They are introduced by individual electric-mechanical drive gears. The RD and NSR gear drives are the executive organs of the reactor control and protection system (CPS).

Fuel rod array (Fig. 3) comprises heating block (FR) containing uranium, thermal insulation, input block (axial reflector), bearing and exhaust block, and casing.

The heating block is made of eight sections with variable material composition, each of the

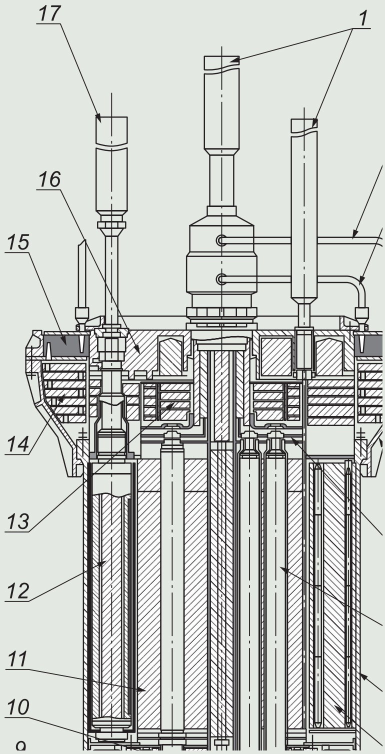


Figure 1: Design scheme of the NRE reactor (longitudinal section)

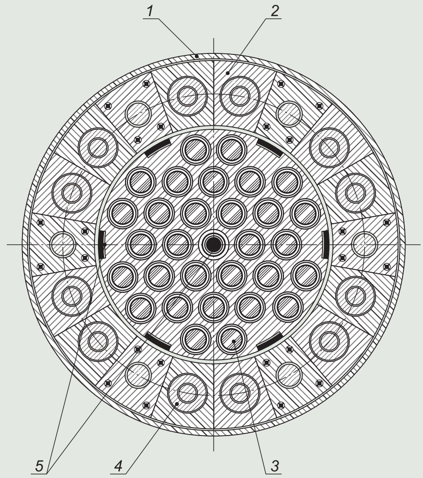


Figure 2: Design scheme of the NRE reactor (cross section)

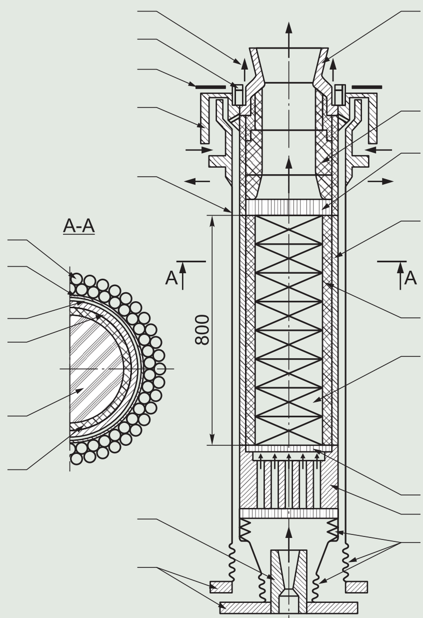


Figure 3: Schematic of the fuel rod assembly

sections is a bundle of tightly packed twisted rods 100 mm long 2.2×1.35 mm in transverse sizes. The first (input) three fuel rods are made of a solid ZrC–Uc–C solution, two central and three output FR are made of ZrC–UC and ZrC–Uc–NbC solutions, respectively. To compensate for the block-effect and to make radial energy release distribution more even, the heating sections are assembled of fuel rods containing different amounts of uranium.

A set of cylindrical bushes of various material composition (pyrographites and porous carbides), depending on the working temperature interval, serve as thermal insulation.

The FRA casing is fabricated in the form of a double-layer shell: the outer thin-walled steel layer provides tight sealing of the casing, while the inner layer composed of beryllium bushes makes the casing resistant to action of the external radial difference in the working fluid pressure.

The working fluid flow rate in each FRA is controlled by a throttling device, which is profiled to support the critical pressure difference within a wide range of variation of the parameters.

The FRA construction is elaborated both technologically and experimentally, but its casing is designed to operate at a relatively low temperature. Therefore, if further on it is to be used not only in NRE but in the active zone of a NEPS reactor as well, the construction should be modified, in particular, to change casing and to make one more molybdenum alloy sheath around FRA, which entail an increase in the uranium concentration in the fuel composition and would necessitate additional investigations,

The NRE radiation protection system incorporated in the reactor construction and meeting the requirements of permissible radiation loads indicated in Table 1 is presented in the Project by one component only. According to calculation estimates taking into account protective functions of the reactor metal constructions, the choice was restricted with zirconium hydride $ZrH1{,}85$ with 1 %(wt.) of boron that exhibited good protective properties with respect to both neutron and γ-radiation. The radiation protection block cooled with hydrogen consists of two parts: central part is positioned directly above the active zone and the lateral one forms a shade cone within which all the Moon tug-vehicle equipment is arranged during the flight, its opening angle is 130^o.

A lamellar recuperative heat exchanger is built in the top reactor cover, it provides preheating of hydrogen before it is fed to the reactor cooling manifolds.

Solution of the nuclear and radiation safety problems

Nuclear and radiation safety is provided in the NRE conception considered by a complex of design solutions incorporated in the reactor construction (RD combined with NSR, dual-action CPS drive gears), by optimization of the configuration and material composition of the active zone (ratio of the hydrogen and uranium-235 concentrations, FR arrangement steps), by negative temperature coefficient of reactivity, by the necessary safety difference between the operation parameters and their permissible limiting values, by doubling the equipment responsible for working fluid feed and the channels of control of the measured engine parameters. When the Moon tug-vehicle components are joined or detached, the radiation safety level can be raised due to an increase in the opening angle of the shade cone to $\sim 20^o$, which is permissible for the facilities applied to put the Moon tug-vehicle into a working near-Earth orbit.

The basic safety requirements imposed on space nuclear objects and fundamental solutions applied in the NRE concept considered are listed in Table 2.

The final NRE design characteristics

Neutron-physical and heat-hydraulic investigations performed to provide a basis for the design development work and also the necessary strength estimates have shown that creation of a NRE with a high specific impulse and acceptable weight and size parameters (Table 3) on the basis of the engineering solutions inferred from previous experimental studies is quite feasible. The size and weight parameters of the nuclear engine permit it to be mounted in head parts of the modern launchers putting objects into near-Earth orbits.

Moon tug-vehicle configuration

In compliance with the anticipated scenario of apparatus operation on the “Earth–Moon–Earth” trajectory and with technical capabilities of the contemporary facilities used to put objects into orbit, a Moon tug-vehicle configuration which consists of two modules has been suggested (Fig. 4). The NRE block is multiply used. It is delivered together with a recoverable fuel tank to a basic radiation-safe near-Earth orbit by the Russian-made launcher of the “Zenit-M” class. The other block is

Table 2: Concept of safety provision in NRE of a Moon tug-vehicle

Problem	Approach to solution	Safety measures undertaken in the NRE concept
Safety provision in normal operation	Optimal assembling of the active zone and selection of the fuel, retarding, construction, and protection materials	High fuel thermal stability (3300–3700 K), application of a prospective fuel with a low yield of the fission products, heterogeneous active zone structure, optimal FRA spacing (75 mm)
Prevention of reactive accident:		
– in the course of normal operation	The use of controlling drums in the side reflector	12 RD would warrant subcritical state even if one of them fails (K_{eff} < 0.97)
– in the rest of stages of the apparatus life cycle and in emergency situations	Combined use of controlling drums and additional absorbing rods	The overall RD and SPS efficiency exceeds by 2.6% the maximum reactivity effect in emergency situations
Compensation for the temperature and power effects in the reactivity	Designing a reactor with temperature coefficients and control systems that would ensure the optimal safety an reliability	A small negative reactivity temperature coefficient (– 0.5%) is provided
Preclusion of a thermotechnical accident caused by heat carrier loss or failure of reactor control system	Application of the doubling approach to working fluid feed aggregates and to reactor extinguishing and cooling systems	The scheme provides two TPA modules, electromagnetic and mechanical systems of CPS drive gears activation by the signal from AP, reactor cooling under working fluid pressure in the main and starting tanks

the unrecoverable fuel tank with the payload delivered by the “Proton-M” class rocket. French launchers “Arian-4” and “Arian-5” can also be used along with the Russian launchers. The blocks dock automatically on the obit.

Thus, hydrogen in the Moon tug-vehicle is stored in two tanks one of which is emptied at the first flight stage, i. e., toward Moon, and then it is detached, while the second one feeds the engine at the second flight phase, i. e., toward Earth, and remains in the NRE construction throughout its service life. The tank used in the course of the return flight is refilled between the first and last flights with hydrogen from a replaceable tank delivered by a launcher rocket from the Earth for each new trip.

Technical and economical tug-vehicle parameters

The nuclear tug-vehicle is assumed to perform no less that 5 trips to Moon and, as the energy and ballistic calculations have shown, it can deliver in each trip a 4- or 5-ton payload with landing on the Moon or 8–10-ton payload to a near-Moon orbit. Separate put-

Table 3: Technical characteristics of the Moon tug-vehicle NRE

Parameter	Value
Heat NRE reactor power, MW	340
Working fluid	Hydrogen
Temperature of the working fluid in the nozzle chamber, K	2900
Working fluid pressure in the nozzle chamber, MPa	6
Working fluid flow rate, kg/s	7.1
Working fluid temperature in the tank, K	18
Working fluid pressure in the tank, MPa	0.1
Turbopump block power, MW	2.28
Rotation frequency, rpm:	
– of booster forepump	6450
– of the major turbopump	64950
Head pressure of the pump, MPa	175
Reactor active zone sizes, mm:	
– diameter	472
– height	800
Fuel composition	Solid solutions
	UC–ZrC, UC–ZrC–NbC
Average UC content in the fuel, %	12.8
Fuel enrichment with ^{235}U, %	90
Load of ^{235}U, kg	20.1
Number of FRA in the active zone	30
Diameter of the fuel FRA portion, mm	47
Retarder	$ZrH_{1,85}$
FRA spacing, mm	75
Thickness of the lateral beryllium reflector, mm	130
Number of control drums	12
Number of safety rods	7
Maximum engine sizes, mm:	
– diameter (recoverable/unrecoverable block)	3500/4400
– length of the reactor block with the nozzle	4000
– length of the recoverable NRE block	15000
– overall length	30000
NRE weight (without fuel ranks), kg:	2890
Thrust-to-NRE mass ratio (without fuel tanks), kg(force)/kg	2.40

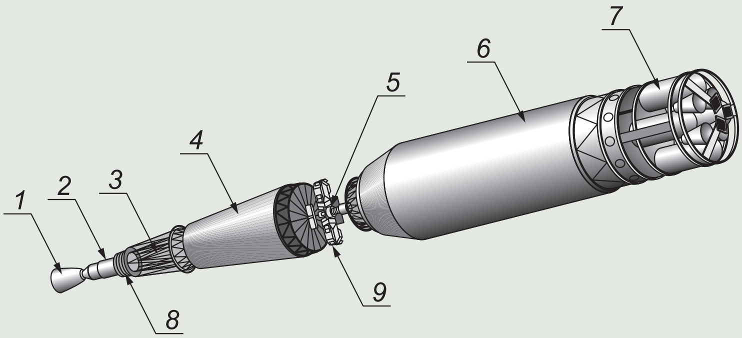


Figure 4: Moon nuclear tug-vehicle with a payload: 1 — nozzle; 2 — reactor; 3 — aggregate compartment; 4 — recoverable hydrogen tank; 5 — docking unit; 6 — unrecoverable hydrogen tank; 7 — Moon descent apparatus with a payload; 8 — radiation protection block; and 9 — container for instruments (SAU and SU)

ting into a near-Earth orbit and fuel module docking with the payload can about double the aforesaid figures, i. e., increase them to 6–10 t for delivery to the Moon surface and up to 20 t for delivery to a near-Moon orbit. One or two Moon interplanetary tug-vehicles of such carrying capacity can provide freight flow of about 100 t per year during development of the first continuously functioning Moon base with 4 or 10 inhabitants and for arrangement there industrial production of oxygen and other materials from the Moon subsurface. Then, as the Moon exploration expands, the expected freight flows can increase to about 500 t per year, so that the nuclear tug-vehicle would be the major link of the “Earth–Moon–Earth” transport conveyor because any other facilities, e. g., chemical unrecoverable rockets, would hardly be able to efficiently solve the transport problem.

According to preliminary estimations, the cost of delivery of 1 kg of payload with the aid of Russian launch rockets and nuclear tug-vehicle can amount to about $15 k or $20k even if oxygen synthesized on the Moon is not used for vehicle return to the Earth. The use of foreign launchers with the cost of their launch would undoubtedly increase the above figures, but in any case, the cost of payload delivery to the Moon by a nuclear tug-vehicle would about twice as low as that of transportation by chemical rockets.

Obtained Results

- A conceptual design of a NRE for an interorbital Moon tug-vehicle was worked out.
- The fundamental technical solutions to be included in the reactor design and in the basic technological NRE equipment were analyzed and grounded by calculations.
- Technical design of the NRE configuration was elaborated, including the equipment specification.
- Technical requirements imposed on NRE and reactor safety systems (space flight, ground tests) were formulated.

Concluding Remarks

Development of the NRE concept for a Moon tug-vehicle performed within ISTC Project #0335 has shown that the significant scientific and technical reserve of design solutions for the basic engine components available at present makes its realization quite feasible. The NRE creation problem should be considered as a purely engineering task, solution of which in the near future depends completely on the funding amount.

Project Number:	#0417-2
Full and Short Title:	Feasibility Study of Seismo-Electromagnetic Phenomena Using Satellite Observations **Seismo-Electromagnetic Phenomena**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration
Status:	Project completed
Technology Development Phase:	Feasibility study
Allocated Funding :	$116,000 (JP)
Commencement date:	March 1, 1998
Duration:	18 months
Leading Institute:	IZMIRAN, 142190, Troitsk, Moscow reg., Russia
Contact Information:	Phone: +7(496) 751 01 20 Fax: +7(496) 751 01 24 E-mail: izmiran@izmiran.ru Website: http://www.izmiran.ru
Supporting Institutes:	Design Bureau "Arsenal", 1-3 Komsomola Str., St .Petersburg 195009, Russia Phone: +7(812)292 4940 Fax: +7(812)542 2060 E-mail: kbarsenal@peterlink.ru Website: http://www.kbarsenal.ru
Collaborators:	JAXA / Earth Observation Research Center (EORC), Tokyo, Japan (Kodama T., Molchanov O.) University of Electro-Communications, Tokyo, Japan (Hayakawa M.)
Project Manager:	CHMYREV Vitaly Mikhailovich
Contact Information:	Phone: +7 (495) 988 20 31 Fax: +7 (495) 988 20 31 E-mail: gtech@geoscan.org
ISTC Senior Project Manager:	RYABEVA Elena Vasilevna
Contact Information:	Phone: +7 (495) 982 31 37 Fax: +7 (499) 978 13 31 E-mail: ryabeva@istc.ru
ISTC Website:	http://www.istc.ru

Background

Presently, a number of experimental facts is known which point to existence of the earthquake precursors, i.e. processes and phenomena generated in the atmosphere and near-Earth plasma hours, days, and weeks prior to the actual onset of earthquake. The nature of these phenomena is not clear and is still the subject of many research efforts. Both satellite and ground-based observations during various stages of the earthquake preparation process showed formation of the anomalous electromagnetic emissions in the frequency range from fractions of hertz to tens of megahertz, amplitude and phase disturbances in signals of the ground-based VLF (very low frequency) radio transmitters at the appropriate propagation paths, changes in the ion composition, plasma density and direct current (DC) electric field strength in the ionosphere, an excitation of air glow over the earthquake region, changes in the atmospheric gas composition and formation of aerosol clouds. In IZMIRAN, significant volume of the data on plasma and wave measurements in the ionosphere, obtained within the framework of space experiments, carried out in 1970–80s (the programs “COSMOS” and “Intercosmos”) is at the moment available.

Project Objectives

The primary Project objective was study of seismoelectromagnetic phenomena by satellite observations and the development of physical model for the lithosphere-ionosphere coupling.

The particular Project objective was to find statistically reliable confirmation of the ionospheric plasma effects caused by seismic activity. To achieve this, it was supposed to use the advantage of having large databases obtained in previous Russian satellite experiments, which allowed:

– processing long-term plasma density and wave data sets from Russian satellites “Aktivny,” “Cosmos-900,” and “Cosmos-1809;”

– statistical analysis and interpretation of the obtained results;

– theoretical modeling of the lithosphere-ionosphere coupling; and

– substantiation of satellite system for monitoring earthquake precursors.

Description of the Works

The methodology of activities under the Project was based on realization of experimental (processing and analysis of the satellite data) and theoretical studies. The basic accent of theoretical activities was connected with the development of models for interpretation of retrospective satellite data related to the ionosphere response on earthquake preparation processes.

The following tasks have been solved:

• the concept for the lithosphere processes impact on the near-Earth space at the preparatory phases of earthquakes was developed;

• main principles of the advanced concept were theoretically grounded; and

• existing experimental data were systemized and analyzed and generation mechanisms for electromagnetic and plasma precursors to earthquakes were developed.

Shortly, the mechanisms of seismogenic modification of environment can be described as follows. Processes taking place in the Earth’s crust prior to earthquakes change the chemical composition of underground water and atmospheric gases at the epicenter of earthquake and increase the intensity of emissions of radioactive substances and charged aerosols into the atmosphere. These changes, in turn, cause temperature anomalies in the area of the potential earthquake and alter the electric conductivity of near-Earth atmosphere, as well as electric current parameters in the Earth-ionosphere circuit. As a result, the changes occur in all major ionospheric characteristics before an earthquake, such as DC electric field intensity, plasma transfer rate, the altitude distribution of electron concentration, ion plasma composition, the structure of small-scale ionospheric inhomogeneities and geomagnetic field-aligned electric currents, wave disturbances in various frequency ranges, etc. All of these disturbances can be registered by modern scientific instruments used in space and atmospheric research. As these alterations appear in the atmosphere and the ionosphere several hours, days, or weeks (depending on a disturbance type) prior to an earthquake, they can be considered as the precursors and be used for earthquake forecasting purposes. It was shown that similar effects of the atmosphere and ionosphere modification can be induced by the development of tropical cyclones (typhoons) and volcano eruptions.

Figure 1 presents a scheme of the processes responsible for the atmosphere–ionosphere coupling connected with these phenomena. Experimental study of such processes was the major target of several space missions, which have been under development that time including the COMPASS-1 and PRECURSOR-E in Russia and DEMETER in France.

Considerable contribution in study of seismo-ionospheric interaction in a course of the Project implementation has been made owing to COSMOS-1809 satellite experiments. The data from this low-orbiting satellite were used to search for a correlation between seismic activity and increases in extremely low frequency (ELF)/VLF emissions and plasma density fluctuations in different regions. The data from about 100 satellite orbits were chosen for this study. Analysis enabled to draw the following conclusions.

Electromagnetic emissions in the frequency range of 140 to 450 Hz were regularly observed within the L-shells with the root in seismoactive zone. Near a zone of seismic activity ($\Delta\lambda = \pm 6$) at the altitude ~950 km, bursts of ELF radiation were observed at fre-

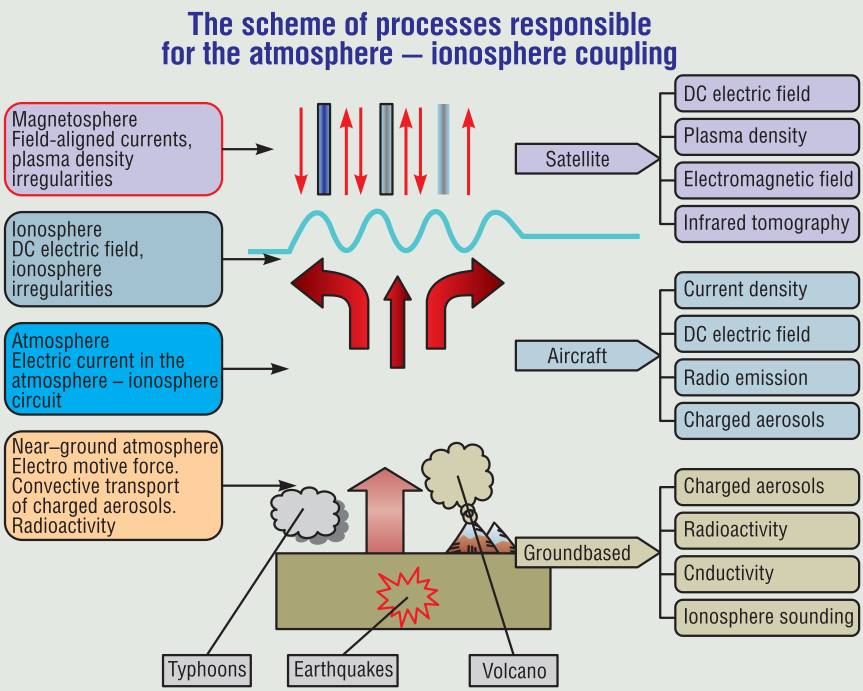


Figure 1: Scheme of the atmosphere–ionosphere coupling

quencies f ~ 140 and 450 Hz in the magnetic and electric components. The radiation intensity exceeded the background level more than an order of magnitude. The radiation bursts were observed minutes to hours beforehand an earthquake and during several hours after it. The sizes of the disturbed regions were usually ~ 400–600 km along the orbit. The small-scale plasma irregularities dN_e/N_e ~ 3%–8% with characteristic scales 4–10 km have been revealed in geomagnetic field tubes connected with epicenter regions in which the seismogenic ELF emissions were observed simultaneously.

For measurement of ELF/VLF emissions during the COSMOS-1809 mission the five-band parallel spectrum analyzer was used with central frequencies f_0 = 140, 450, 800, 4500, and 15,000 Hz and bandwidth $\Delta f = f_0/6$. The sensitivity in ELF range for the electric component was 5^{-10}–7 V/(m·Hz$^{1/2}$) and for the magnetic component it was (1–5) pT/Hz$^{1/2}$, the dynamic range was 60 dB. For measuring the ionosphere plasma density Ne and its fluctuations dNe, the capacitance high-frequency (HF) impedance probe IZ-2 was used through which Ne and dNe were determined by means of measuring a variation of the probe capacitance depending on variations of the dielectric permittivity of the ionosphere at the generator frequency f = 5.025 MHz. The circuit capacitance was changing with plasma density variation and, respectively, its resonance frequency was also changed. This method provided high sensitivity and time resolution. The instrument time constant was determined by the HF-filter and had the value 20 µs. Using the filter provided the detection of rapid component of plasma density variations — the small-scale N_e variations. Maximal spatial resolution was determined by the interrogation rate of the instrument in telemetry and for the presented results it was ~20 km in the channel of N_e measurements and ~4 km in the dN^e channel.

After strong earthquake in Armenia on December 7, 1988, during almost three months, aftershocks of various intensities were registered near the earthquake focus. In this connection, the instruments aboard the "Cosmos-1809" were switched to the monitoring mode (ZAP-4) and operated in this mode during January–February, 1988. Unfortunately, during the main shock, the satellite devices were switched off. During that aftershock period, a great number of weak earthquakes occurred on the territory of Central Asia, Kazakhstan, and Thian Shan.

The satellite monitoring regime during this period enabled the selection of a great number of passages (more than 50) near the foci of earthquakes ($\Delta\lambda = \pm 6^o$), in the temporal window of several hours either before an earthquake or after it. An example of the data is shown in Fig. 2, which presents the distributions of the radiation intensity in the magnetic component at frequencies f ~ 140 and 450 Hz as well as the values of plasma density Ne and its variations dNe over the zone of seismic activity ~3.4 h beforehand the rather strong aftershock of the Spitak earthquake with energetic class E = 8 on January 20, 1989. The time instant 00.04.06 UT when the satellite crossed the geographic latitude of the earthquake focus, is marked with vertical arrow. The measurements were carried out in the night-time sector at the conditions of the recovery phase of geomagnetic storm (K_p = 30). As seen from Fig. 2, an intensity burst of electromagnetic radiation at frequency f ~ 140 Hz (bottom panel) with amplitude of up to 10 pT was observed in the longitude range $41.6^o < \lambda < 42.0^o$, i. e., approximately 2^o to the West from the focus and in the latitude range $30^o < \phi < 33.1^o$. A weaker increase of electromagnetic noise (up to 3 pT) was observed also at frequency f ~ 450 Hz.

At higher frequencies, no increase of the radiation level was registered. In both active channels, the radiation maximum was located in the L-shell (L = 1.42), which crossed the ionosphere lower boundary (h = 100 km) above the earthquake center. The region of increased values of the radiation intensity is marked by vertical dotted lines in Fig. 2 and has the dimensions ~450 km along the satellite orbit. One should note that both at frequencies ~140 and ~450 Hz a quasi-regular modulation of the intensity with the period 5–6 s was observed. In the disturbed region, the small-scale dNe fluctuations with characteristic spatial scales l = 4...8 km and the magnitude dN_e/N_e up to 8% were also observed (upper panel in Fig. 2).

These results have stimulated the development of the generation mechanism for ELF electromagnetic precursors to earthquakes. The generation mechanism of ELF electromagnetic precursors to earthquakes is illustrated by Fig.3. The chain of processes responsible for this mechanism includes the excitation of pre-earthquake DC electric field, acoustic-gravity wave instability and related small-scale irregularities of plasma density and electric conductivity in the ionosphere over earthquake center. Scattering by these irregularities of intense lightning induced electromagnetic pulses and their trapping in the upper ionosphere produces the observed effect of significant enhancement of electromagnetic ELF wave intensity over the seismic zone.

Empirical model for the spatial distribution of seismoelectromagnetic emissions observed during relatively weak seismic activity was developed for the Black Sea – Central Asia region. The results have shown clear evidence in favor of reliable detection of seismo-ionospheric phenomena. The effect was most pronounced in the magnetic component at frequencies f_0 ~ 140 Hz. The regions of seismoelectromagnetic emissions were shifted by 5° to 10° towards the equator relative to the earthquake foci. This was explained by the

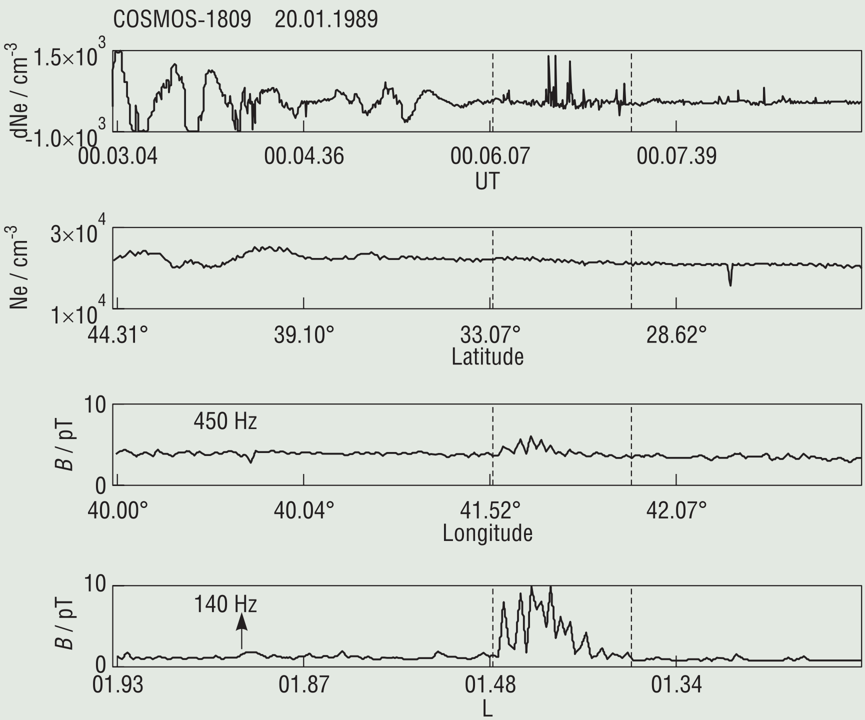


Figure 2: The ELF emission intensity for the magnetic component B in the frequency channels 140 and 450 Hz, plasma density Ne and its variation dNe over the Spitak seismic zone ~3.3 h before the shock on January 20, 1989

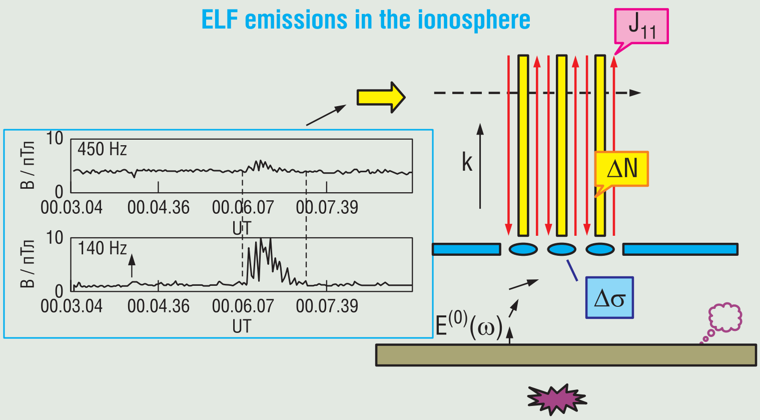


Figure 3: Generation mechanism of ELF electromagnetic precursors to earthquakes

character of ELF wave propagation from the lower boundary of the ionosphere up to a satellite orbit. This shift depends on the magnetic inclination and, therefore, on the latitude of the earthquake focus. At higher frequencies, no stable effects similar to those described above were detected. Only in few cases, a weak seismo-electromagnetic signals were registered at frequencies f_0 ~ 800 Hz. Unfortunately measurements at frequencies below 140 Hz were not performed onboard the "Cosmos-1809" satellite.

Basing on the empirical model, the main features of seismic related ELF emissions have been formulated as follows:

Frequency range. The ELF precursors display maximum of intensity at frequencies f_0 ~ 140 Hz, and they are several times weaker at frequencies f_0 ~ 450 Hz. At higher frequencies, there were virtually no precursor signals. However, it is necessary to note that some other satellite missions have displayed occurrence of the ULF magnetic field oscillations below 1 Hz, which could be considered as the precursors to earthquakes.

Intensities of seismoelectromagnetic signals. Seismic related emissions with the signal to noise ratio exceeding 3 have been considered as earthquake precursors. The absolute magnitudes of their spectral density were shown to be 0.3 to 3 pT/Hz$^{1/2}$ at frequencies 100–500 Hz.

Dimensions of the perturbation area. An area where increased emission intensity was observed for great number of earthquakes has the latitude extension $\Delta\lambda = \pm 6^{\circ}$ with respect to the earthquake focus. An equator ward shift of disturbed region depends on the geomagnetic field inclination.

Accompanying plasma effects in the ionosphere. Bursts of earthquake related ELF emissions were accompanied by the plasma density irregularities with relative amplitudes ~3%–8% and characteristic spatial scale ~4–10 km along the satellite orbit.

Probability of detecting the seismo-electromagnetic signals. Statistical analysis of seismo-ionospheric effects for the Caucasian-Central Asia region has shown that the probability of appearance of ELF wave and plasma precursors was ~75%. This estimate was based on the data for ~50 earthquakes. In all the considered events, the precursor signals have been observed less than 8 h before earthquake.

Other ionospheric precursors to earthquakes considered in the Project. Analysis of experimental data from the "Intercosmos-Bulgaria 1300" satellite has shown the excitation of DC electric field ~10 mV/m and small-scale geomagnetic field-aligned currents in the ionosphere over earthquake region hours to days before the shock.

It was shown that in the chain of seismoionospheric interactions, an important role belongs to electrodynamic processes in the atmosphere and, therefore, the lightning activity should be subject to monitoring. This issue is additionally important to separate the false effects in electromagnetic emissions and correlated plasma density fluctuations from actual precursor signals in the ionosphere.

Thus, the data analysis and theoretical models give evidence to existence of a generic relationship between a definite class of atmospheric and ionospheric disturbances and the lithospheric processes. Consequently, multidiscipline observations by a dense network of ground-based stations are required to conduct seismological, geochemical, and geophysical monitoring of earthquake-prone areas, which should be coordinated with the satellite monitoring of local plasma and field parameters in the near-Earth space and the remote sensing of the Earth's surface, atmosphere, and ionosphere for clarification of this relationship and the development of experimental base for future short-term earthquake forecasting system.

Recognition of such a need based on the Project results has allowed defining the structure of combined experimental system for comprehensive study of earthquake precursors with use of space-based, airborne, and ground platforms. Figure 4 shows the composition of this system. Details of the platforms performance and the useful payload are given in Fig. 5 for the space segment and in Fig. 6 for the aviation segment. The ground-based observations

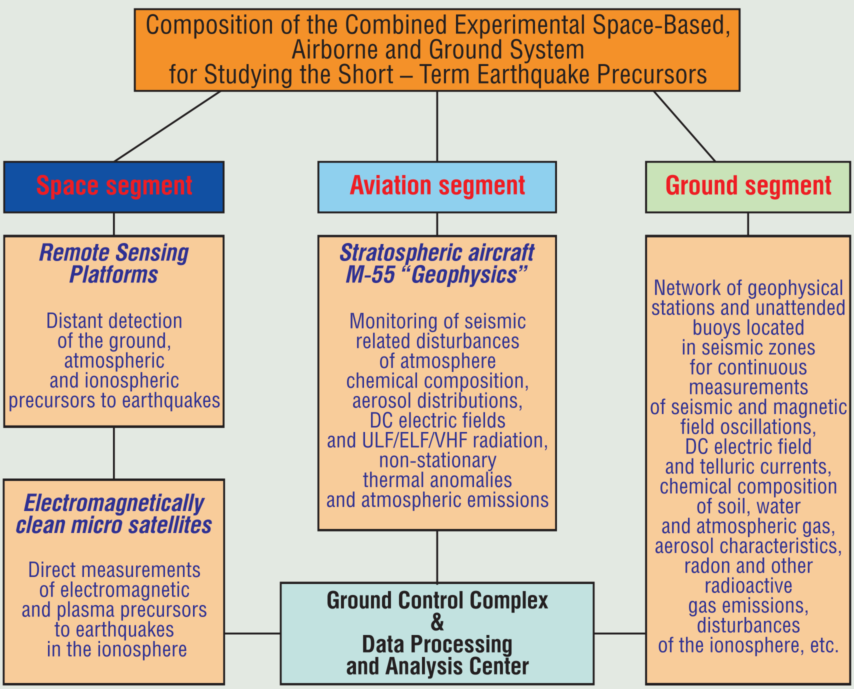


Figure 4: Experimental system for studying the short-term earthquake precursors

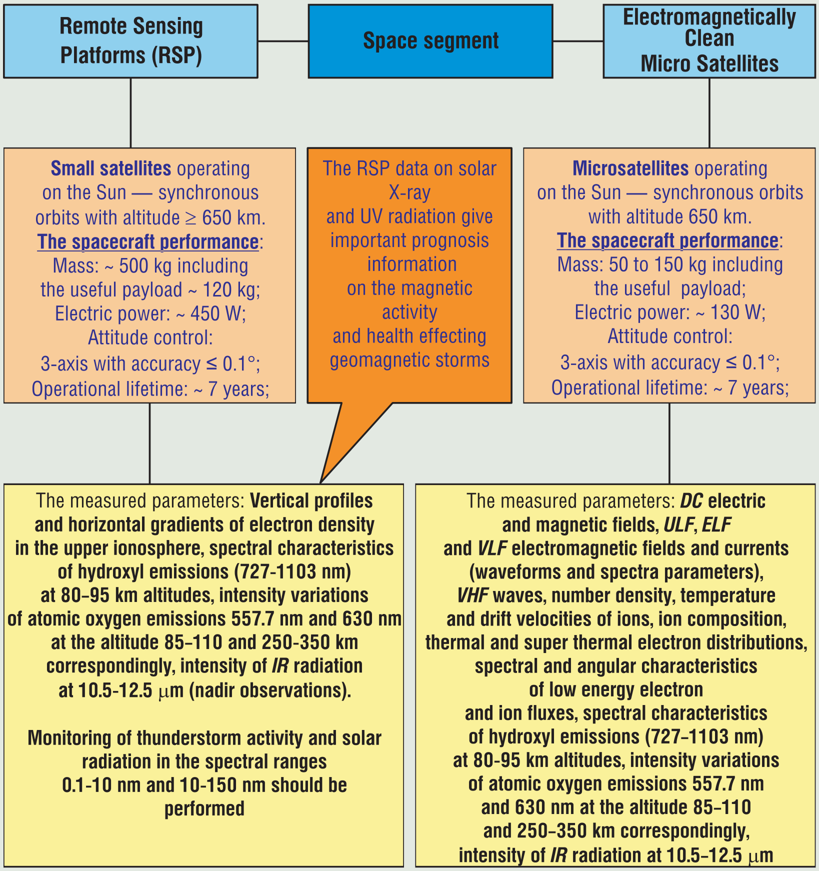


Figure 5: Requirements to the remote sensing and the electromagnetically clean micro satellite platforms and the payloads

in seismic zones should include continuous measurements of seismic and magnetic field oscillations, ULF/ELF/VLF and VHF electromagnetic emissions, atmospheric DC electric field and telluric currents, chemical composition of soil, water and atmospheric gas, aerosols characteristics and the disturbances of D, E and F layers of the ionosphere. All geophysical stations should be connected with ground control and data processing centers.

Experimental system configuration outlined in the Project has foreseen the opportunity for step-by-step development of the system and usage of different types of platforms for remote sensing including the manned space vehicles such as Mir station and the International Space Station (ISS) complemented with the subsatellites (microsatellites) for precise direct measurements of electromagnetic field and plasma parameters of the ionosphere. Some of the scheduled experiments to be performed onboard the Russian segment of the ISS are currently under the preparation in Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation of the Russian Academy of Sciences.

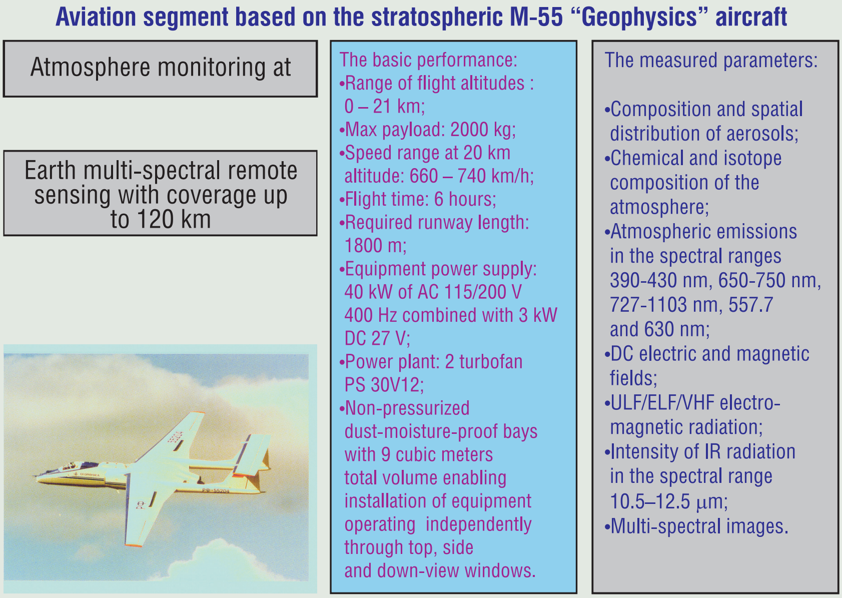


Figure 6: M-55 "Geophysics" stratospheric platform

Obtained Results

Basing on the detailed analysis of available satellite and ground-base data, the comprehensive theoretical model of the lithosphere–atmosphere–ionosphere coupling has been created and the generation mechanisms for electromagnetic and plasma precursors to earthquake were found. The obtained results have allowed to outline the structure of combined space-based, airborne and ground experimental system for comprehensive study of earthquake precursor signals in the ionosphere, atmosphere and on the Earth surface as the first step on a way to the development of practical methods and tools for the short-term forecasting of earthquakes. Technical requirements to the satellite platforms and the useful payloads as well as a list of the parameters to be measured by space, aviation, and ground segments of the system were presented.

Five relevant publications of the Project participants:

1. Chmyrev, V.M., N.V. Isaev, O.N. Serebryakova, V.M. Sorokin, and Ya.P Sobolev. 1997. Small-scale inhomogeneities and correlated ELF emissions in the ionosphere over an earthquake region. *J. Atmos. Solar-Terr. Phys.* 59: 967–74.

2. Sorokin, V.M., V.M. Chmyrev, and N.V. Isaev. 1998. A generation model of small-scale geomagnetic field-aligned plasma inhomogeneities in the ionosphere. *J. Atmos. Solar-Terr. Phys.* 60:1331–42.

3. Borisov, N., V. Chmyrev, and S. Rybachek. 2001. A new ionospheric mechanism of electromagnetic ELF precursors to earthquakes. *J. Atmos. Solar-Terr. Phys.* 63:3–10.

4. Sorokin, V.M., V.M. Chmyrev, and A.K. Yaschenko. 2001. Electrodynamic model of the lower atmosphere and the ionosphere coupling. *J. Atmos. Solar-Terr. Phys.* 63:1681–91.

5. Sorokin, V.M., A.K. Yaschenko, V.M. Chmyrev, and M. Hayakawa. 2005. DC electric field amplification in the mid-latitude ionosphere over seismically active faults. *Natural Hazards Earth System Sci.* 5:661–66.

Project Number:	#1068
Full and Short Title:	Review of Air-Bag Extending Expansion Mechanism for Planet Probe Spacecraft **Soft Landing System**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration
Status:	Project completed
Technology Development Phase:	Technology demonstration
Allocated Funding :	$60,000 (JP)
Commencement date:	July 1, 1998
Duration:	12 months
Leading Institute:	Lavochkin Association, Khimki, Moscow reg., Russia
Contact Information:	Phone: +7 (495) 251 67 44, 573 56 75 Fax: +7 (495) 573 35 95 Website: http://www.laspace.ru/rus/index.php
Supporting Institutes:	No
Collaborators:	JAXA / Tsukuba Space Center, Tokyo, Japan
Project Manager:	ZAITSEV I. P.
Contact Information:	Phone: +7 (495) 573 57 38 Fax: +7 (495) 573 35 95
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 31 57 Fax: +7 (499) 978 46 37 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

An inflatable damping device (IDD) is applied at a final portion of the trajectory of apparatus landing on an unprepared surface area when the apparatus touching the surface still has a significant vertical and lateral velocity components or when the surface relief is complicated or unknown. In these cases, the IDD suppresses the residual velocity and protects the apparatus against damage by local obstacles.

Lavochkin Association applied IDD for the first time in 1954 to land on the ground of survived pilotless LA-17M target planes. In 1966 the unmanned "Luna-9" station was for the first time successfully landed on the Moon with the aid of IDD, then the "Luna-13" followed. Later on, an IDD landing system of the unmanned Mars station was developed and tested. Elaborated was also IDD system for landing of Mars and Moon rovers within the Mars and Moon exploration programs. According to assessment by Russian and American scientists, application of IDD simplifies significantly the requirements imposed on the landing control equipment and appreciably reduces the cost of both the system and the mission as a whole.

Up to now, Lavochkin Association is the only company in Russia that has experience in successful creation of landing systems of this type.

Project Objectives

The Project was aimed at systematization of the available materials on designing IDD for space apparatus ("Luna-9" and "Mars-96").

Description of the Works

The materials on IDD were analyzed and systemized with the use of the results of work done by the Project participants that were published previously only partially.

Analysis of the available data covers the following areas:

I. Analysis of the conditions under which it is expedient to apply IDD.

II. Analysis of the schemes of soft landing with the use of IDD.

III. Analysis of the experience of creation and running of the soft landing systems that use IDD.

IV. Survey and appraisal of the versions of IDD soft landing system realization.

I. The analysis of the conditions under which it is expedient to apply IDD include consideration of:

• landing sites from the point of view of mission goals. An engineering Moon-surface model was presented that comprised surface relief, bearing ground capability, friction coefficients, presence of stones, and temperature regime. The mission goals and restrictions that they impose on the choice of landing site were considered;

• feasibility of the "on-the-fly" detection of the planet relief state at the landing site and opportunity of near-planet maneuver;

• possible landing schemes and limitations imposed. Classification of the schemes included three basic groups:

(*i*) soft landing with an oriented overload of up to 10g on the landing legs without apparatus turnover,

(*ii*) semihard landing with a nonoriented multifold overload of up to 100*g* on damper bags and of up to 500*g* when a honeycomb or foamed plastic damper is used; and

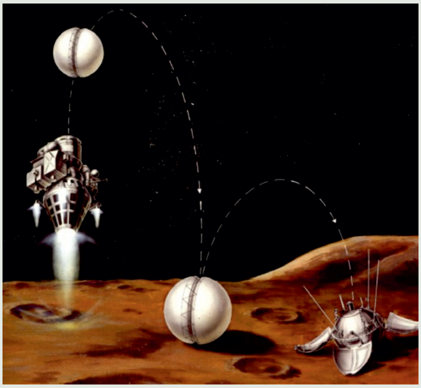
(*iii*) hard landing with an oriented overload exceeding 500*g* penetrators;

• landing schemes applied as the basic version in the unmanned Moon station mission "Luna-9" (Fig. 1); and

• schemes of landing of a small unmanned station (SUS) in the Mars-96 project (Fig. 2).

II. An analysis of the soft landing schemes with the use of IDD included consideration of:

• methods for suppressing the vertical and horizontal velocity components at soft landing on the surface of atmosphere-free planets. Inasmuch as the aerodynamic braking cannot be applied in apparatus landing on the surface of an atmosphere-free planet, the only possible braking method to be applied in this case is active apparatus deceleration with rocket en-



Moon landing velocity .... 20 m/s
Maximal axial overload 95*g*
Soft landing device .... IDD
Working gas of the damper device ... Helium
Pressure .... 0.07…0.09 atm
Calming time .... 100 s
Landing velocity .... 20 m/s
Maximal axial overload .... 200 g
Soft landing device .... IDD
Working gas of the damper device ... Helium
Pressure .... 0.2…0.3 atm
Calming time .... 100 s

Figure 1: Landing schemes applied as the basic version in the unmanned Moon station mission "Luna-9"

Landing velocity .... 20 m/s
Maximal axial overload 200*g*
Soft landing device .... IDD
Working gas of the damper device ... Helium
Pressure .... 0.2–0.3 atm
Calming time .... 100 s

Figure 2: Schemes of landing of a small unmanned station (SUS) in the Mars-96 project:

Table 1: The stages of apparatus landing on an atmosphere-free planet

1st stage Active braking	V = 2.5 km/s V_{vert} = 5...50 m/s V_{hor} =1...10 m/s	High-thrust rocket engines
2nd stage Braking at landing	V = 2.5 km/s V_{vert} = 5...50 m/s V_{hor} = 1...10 m/s	Low-thrust engines Damping devices Energy absorbing platforms Energy absorbing legs

Table 2: Input data for IDD calculation

Input data	UMS "Luna-9"	UMS "Mars-96"
The landing apparatus weight, кг	90	42.5
Landing velocity, m/s		
• vertical	5...12	25±2,5
• horizontal	0...7	0...11
Permissible overload, g units	200	200
Number of bags	2	2
IDD size, m	1.3-1.9	1.54-1.7
Pressure in the damper bag before impingement, kPa	61.9 + 8.8	17.5-20.1
Initial working gas temperature, °C	10+40	–35 °C + +40 °C
Admissible pressure in the damper bag, kPa		40
Surface slope, degree	0...30	0...30
Stoniness, %	5	5
Atmosphere temperature near the surface, K	–	207–245
Atmosphere pressure, Pa	–	600... 740

gines. The process of apparatus landing on an atmosphere-free planet can conditionally be split into two stages (Table 1);

– input data for IDD calculation (Table 2) and substantiation of inflatable-device necessity

– IDD operation conditions that are conditionally divided into external (pertaining to the landing spot) and internal (caused by changes in the dynamic parameters of the landing module during its contact with the ground) conditions. Examples of calculated internal IDD operation conditions in unmanned system (UMS) UMS "Luna-9" and UMS "Mars-96" are presented; and

– methods for suppressing the vertical and horizontal velocity components in the course of soft landing on planets with atmosphere (Table 3).

III. Analysis of the experience in the field of creation and running of the soft landing systems using IDD includes consideration of:

– IDD of MS "Mars-96," including requirements imposed on IDD, operation concepts, damper calculation scheme, and the IDD diameter effect on the damping device properties;

– IDD of "Luna-9," including requirements imposed on the BNV-2 dampers, their operation concepts, and calculation scheme;

– IDD construction of "Mars-96" and "Luna-9" and materials used.

The IDD "Luna-9" constructions consisted of two shells. Each shell contained a tightly sealed chamber and a load-bearing cover. Feed valves and manometric nipples were mounted on each shell. In mounting UMS "Luna-9" in IDD, the shells enveloped the descent apparatus body. Being inflated with the gas, the standard IDD acquired an oval shape 1900 × 1900 mm in size.

IDD of MS "Mars-96" consisted of two shells. Each shell contained a tightly sealed chamber and load-bearing cover. In mounting MS in the IDD, the shells embraced the device with force belts located on the inner side of each shell. The belts were tightened with each other with a cord. The cord was inserted in a pyrotechnic knife mounted in MS. Tightening tapes were put through the straps sown on the outer surface of each shell;

– major units and aggregates of "Luna-9" and "Mars-96" IDDs;

Table 3: Methods for suppressing the vertical and horizontal velocity components in the course of soft landing on planets with atmosphere

Descent stage	Velocity	Braking device
Stage 1 Preliminary aerodynamic braking	V = 5...6 km/s (Mach number M = 30...40) V = 200...500 m/s (Mach number M = 0.8...2)	• Aerodynamic (head screen with a heat protection coating) • Inflatable heat-protection constructions • Ballutes
Stage 2 Main aerodynamic braking	V = 200...500 m/s (Mach number M = 0.8...2) V = 5...50 m/s	• Parachute system • Inflatable bags • Rotor systems
Stage 3 Braking at landing	V = 5...50 m/s V ~ 0 m/s	• Soft landing engines • Damping devices • Energy absorbing platforms • Energy absorbing legs

– schemes of untightening and possible untightening versions from the point of view of reliable IDD detachment from LA; and

– schemes of IDD shell dropping from UMS and MS.

IV. Survey and appraisal of variants of soft landing realization with the use of IDD.

The variants of apparatus landing were considered with emphasis made on the design schemes of auxiliary constructions applied at different stages (Fig. 3).

1. Start on 31.01.1966 at 2 h 41 min 37 s PM.

2. The section of operation of the initial launcher rocket stages.

3. Intermediate orbit.

4. Start from the Earth satellite orbit toward Moon.

5. Moon rocket detachment.

6. Near-Earth session of trajectory measurements.

7. Trajectory measurements and transmission of telemetry data.

8. Adjustment of the onboard systems for correction.

9. Moon rocket orientation. Correction of trajectory on 01.02.1966, at 10 h 29 min PM.

10. Trajectory without correction.

11. Trajectory after correction.

12. Adjustment of the onboard systems for deceleration.

13. Propulsion system axis orientation along the Moon vertical line.

14. Start of the propulsion system for deceleration.

15. Landing on 03.02.1966 at 9 h 45 min 30 s PM.

Obtained Results

The results of an analysis performed and of systematization of the available materials on IDD designing indicated that:

• landing of space apparatus on a planet surface was provided by different techniques, namely, due to braking by the aerodynamic drag force, by rocket engines, or with the aid of combination of these techniques. However, the aforesaid braking versions depended on whether the planet explored has atmosphere or is atmosphere-free;

• aerodynamic braking is optimal from the point of view of energy expenditures in landing on a planet with atmosphere, although its efficiency at the final apparatus motion stages

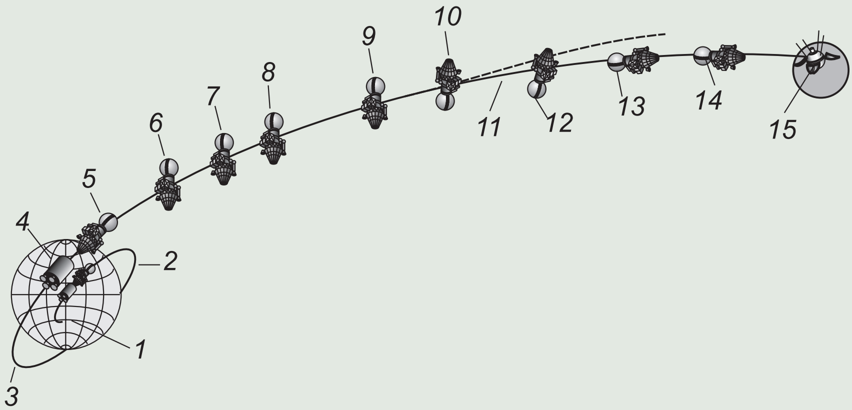


Figure 3: General scheme of UMS "Luna-9" landing on the Moon

can be lowered by the necessity of taking into account near-surface flows (winds) and errors in trajectory measurements that would necessitate application of active braking;

• the descent process in atmosphere is conditionally divided into three stages:

(i) velocity reduction from a hypersonic value to supersonic values;

(ii) then to subsonic values; and

(iii) braking at landing.

The aerodynamic drag force quenches both the vertical and horizontal velocity components at the first two stages, while at the last stage they can be suppressed virtually completely with the aid of soft landing engines.

The active landing at the last stage is combined with landing devices of various sorts

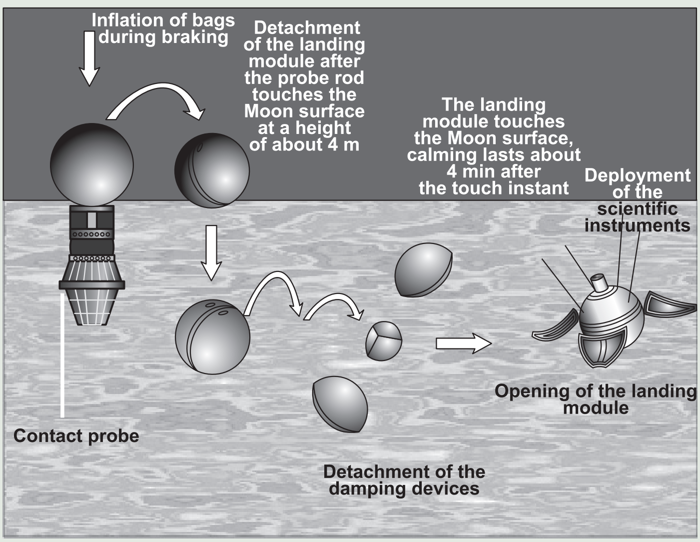


Figure 4: Schematic of operation and detachment of the inflatable damping device

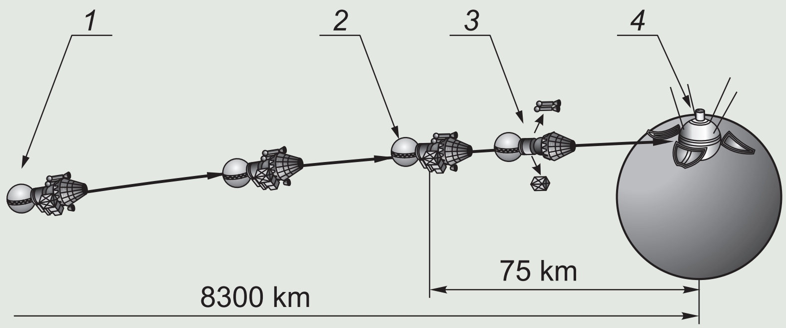


Figure 5: Sequence of operations performed by the "Luna" unmanned station: schematic of the "Luna-9" Moon UMS maneuvers

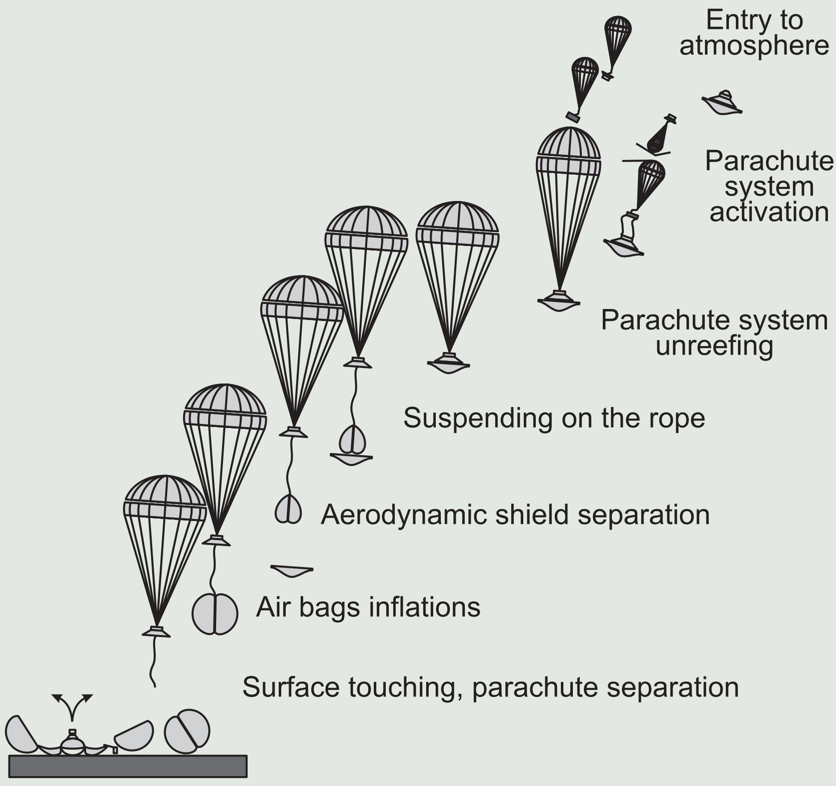


Figure 6: General scheme of the "Mars-96" MS landing with sequence of operations performed during descent in the atmosphere and small station landing

including damper devices (different materials, inflatable dampers). Accomplishment of the MARS-96 project serves as an example of landing on a planet with atmosphere;

• if there is no atmosphere on the planet, aerodynamic braking is ruled out, so that braking with rocket engines is the only method to be applied. Descent to the planet proceeds in two stages. At the first stage, high-thrust engines reduce the apparatus velocity from its entry value to a value of few tens of m/s, then, at the second stage, soft landing engines and landing devices are activated. The last stage is identical to the final descent stage in landing on a planet with atmosphere. Successful accomplishment of the LUNA-9 and LUNA-13 projects exemplify landing on an atmosphere-free planet;

• there are various construction schemes of landing devices, the choice among them is dictated by the requirements imposed on the landing process (the lowest mass, high reliability of the landing module systems, and feasibility of confirming the workability and reliability of the system chosen);

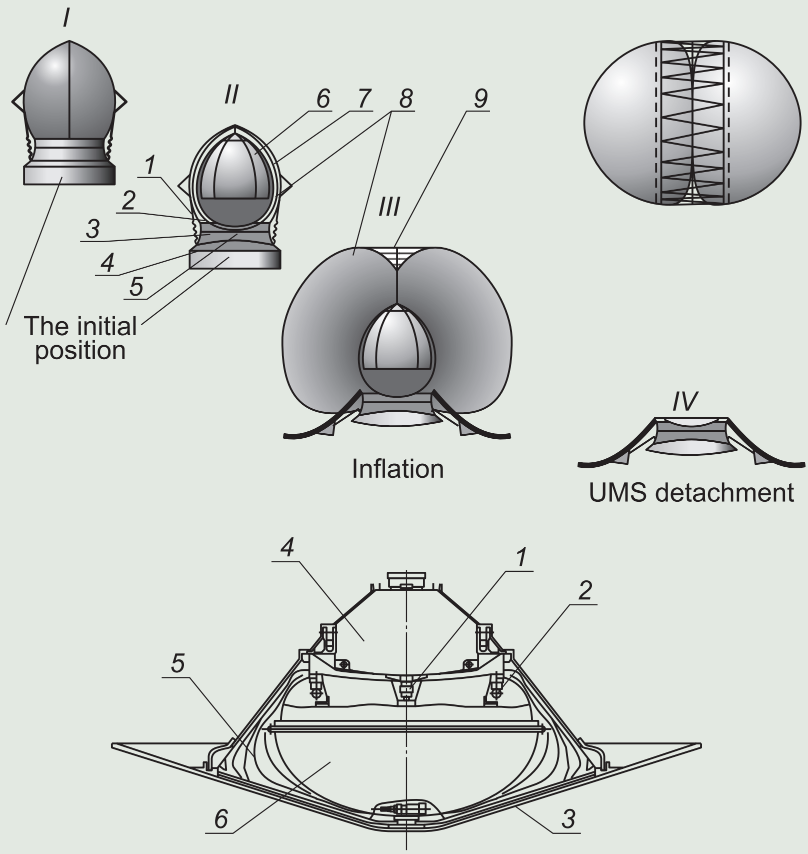


Figure 7: Design schemes of "Luna-9" UMS fixing on the transfer apparatus (a) and of "Mars-96" SUS in the landing module (b)

• an analysis of the landing apparatus versions showed that an inflatable damping device is most suitable for low weight modules (Fig. 4). It does not require a complicated control system, is applicable in nonoriented landing, ensures minimum overloads, and is well arranged in the landing apparatus scheme. Possible impingement of the landing module on the parachute system in the course of landing on a planet with atmosphere and possible drop on sharp stones were indicated as drawbacks of this scheme;

• calculations of the IDD construction take into account (apart from the apparatus construction itself) characteristics of the atmosphere near the surface, of planet surface layer, parameters of the landing-module motion, and so on;

• the vertical and horizontal components of the landing velocity and the slope angle of the surface at the landing spot are the dominant factors affecting the landing process dynamics. Engineering investigation methods were employed to study the landing process dynamics;

• calculations of the inner conditions of inflatable-device operation consider the damper characteristics, assess the maximum pressure in the damper bags and the highest overload arising at the instant when the unmanned station impinges the ground surface.

Calculations of the internal operation conditions for LUNA-9 inflatable devices impacted in the directions of X and Y axes were presented, they assess changes in the volume of and pressure in the damper bags. The damping characteristics of impacts in the X and Y axis directions were presented, it is worth noting that the overloads in the Y direction were higher. No special precautions were taken to suppress the horizontal velocity component in LUNA-9 landing (Fig. 5), it was quenched by damper friction on the Moon ground;

• one of the calculation versions of the inflatable device to be used in Mars-96 landing considered landing on sloped area with the maximum plane inclination angle and maximum vertical and horizontal velocity values (Fig. 6). The damper experienced the highest deformations under these conditions; and

• the inflatable damping devices designed for Luna-9, Luna-13, and Mars-96 (Fig. 7) differed in their inflation systems (helium or combustion products)

Project Number:	#1068-2
Full and Short Title:	Review of Air-Bag Extending Expansion Mechanism for Planet Probe Spacecraft. Stage 2: Tests and testing equipment **Soft Landing System**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration
Status:	Project completed
Technology Development Phase:	Technology demonstration
Allocated Funding:	$90,000 (JP)
Commencement date:	August 3, 1999
Duration:	12 months
Leading Institute:	Lavochkin Association, Khimki, Moscow reg., Russia
Contact Information:	Phone: +7 (495) 251 67 44, 573 56 75 Fax: +7 (495) 573 35 95 Website: http://www.laspace.ru/rus/index.php
Supporting Institutes:	No
Collaborators:	JAXA / Tsukuba Space Center, Tokyo, Japan
Project Manager:	ZAITSEV I. P.
Contact Information:	Phone: +7 (495) 573 57 38 Fax: +7 (495) 573 35 95
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 31 57 Fax: +7 (499) 978 46 37 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

The present work was the second part of Project #1068. The first part generalized the experience accumulated by specialists at Lavochkin Association in the field of application of inflatable damping devices (IDD), considered the conditions under which IDD application can be recommended, and analyzed the IDD design calculation problems.

Project Objectives

The second Project part was aimed at generalization of the experience accumulated by specialists at Lavochkin Association in ground finalizing and testing of inflatable damper devices and at comparison of the IDD calculation results with the data furnished by tests.

Description of the Works

The techniques, schemes, amount of tests, application of the test facilities to finalize on the ground the inflatable damping devices designed for space apparatus (SA) LUNA-9 and MARS-96 (Fig. 1) were considered.

The system of hanging out of the MARS-96 landing module within IDD

The landing-module hanging-out system is intended to preclude covering of the module by the main parachute canopy upon landing. The hanging-out system consists of a halyard with damping sections 100 m in overall length. The hanging-out system is unrolled at the parachute descent stage after detachment and departure of the face aerodynamic screen.

Packing and storing "Luna-9" and "Mars-96" SA IDD

The main task to be solved in working out approaches to packing and storing IDDs was to ensure integrity and safety of their shells. All the construction units were fabricated in accordance with the standard design documentation. Various techniques of packing and of arranging IDD construction units in the volume where they were supposed to be arranged within SA were tried.

Inflation of IDD bags in SA (landing module)

Inflatable damping device bags in "Luna-9" and "Mars" apparatus were filled (inflated) with a gas according to the following schemes:

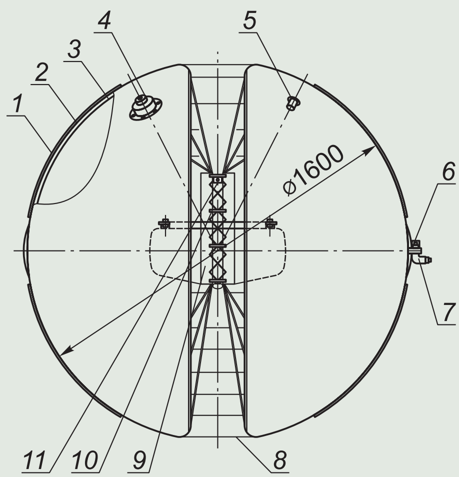


Figure 1: Schematic of the inflatable damping device of "Mars-96:" 1 — straps; 2 — cover; 3 — chamber; 4 — gas generator; 5 — filling valve; 6 — lock; 7 — lock pyrotechnic bolt; 8 — tightening tapes; 9 — force belt; 10 — fixation units; and 11 — pyrotechnic knife

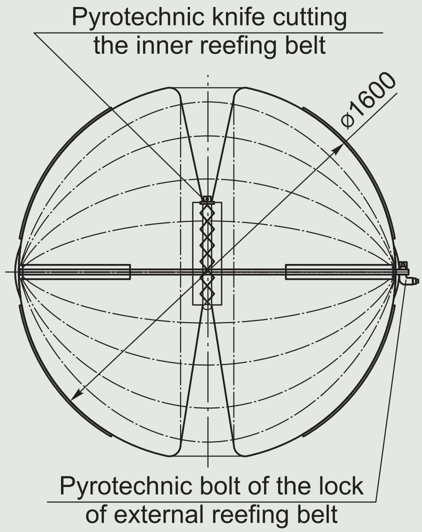


Figure 2: Inflatable damping device configuration at the impingement on the surface

– bags in the "Luna-9" apparatus were inflated with a gas stored in spherical bottles mounted on its case; and

– IDD bags in the "Mars-96" apparatus were inflated with a gas produced by gas generators mounted on each IDD unit.

Dropping of IDD bags after landing

The IDD device keeps bouncing after the first touching the planet surface till its complete calming. The bags are dropped only after the inner and outer belts fastening the landing module on the IDD bag constructions are untied.

Mechanisms of IDD bag operation (stages)

Stage 1 — filling the bags within a short period of time until the correct initial IDD configuration is attained.

Stage 2 — Absorption of the kinetic energy during the impingement on the planet surface (Fig. 2).

Stage 3 — detachment of the damping bags from the landing module after they accomplish their main task, namely, absorption of the impact energy at landing.

After removal of the external tightening under action on the bag walls of the pushing

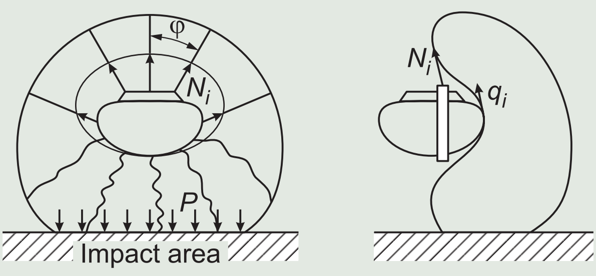


Figure 3: Schematic of IDD deformation

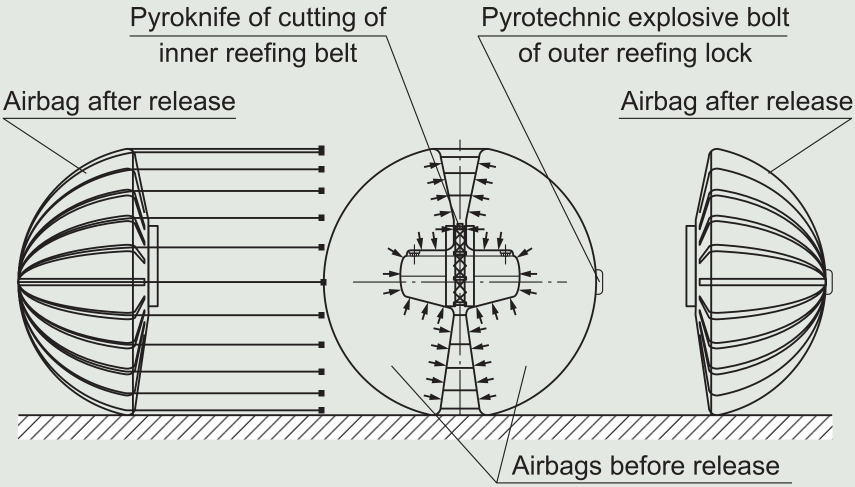


Figure 4: Schematic of airbag release

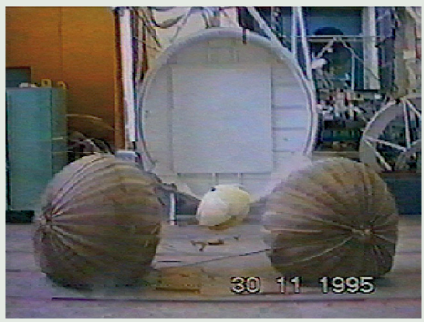


Fig. 5 Drop tests of IDD on the test bench

away force caused by the gas pressure in IDD (Fig. 3), the bags expand through no less that 3 m (Fig. 4).

Test benches (general description)

The IDD of "Luna-9" and "Mars-96" apparatus were finalized on the test benches where they were subjected to action of loads in the regimes close to real ones (Fig. 5).

Analysis of the results of theoretical considerations as applied to the practical experience

An analysis of the theoretical results and of "Mars-96" IDD tests. An analysis of the theoretical results and tests of "Luna-9" IDD BNV 2.

Grounding of the necessity and schemes of drop tests

Correctness of the choice of the materials, fabrication technologies, and force scheme used in calculations can be confirmed in the course of IDD development only after the strength and dynamic tests are performed.

Versions of improvement of the damping IDD construction properties.

Selection of the shape

The shape that provides the lowest surface area at identical volume is spherical or close to the spherical one. This shape warrants isotropic damping at nonoriented impingement and is optimal in terms of strength properties.

Selection of the size

The inflated damper size serves as a parameter used to optimize many dynamic and inertial parameters, such as:

– velocity of contact with the surface; and

– initial inflation pressure in the damper.

As a result, the optimal payload-to-damper weight ratio is achieved.

The landing damping system

The following input data were taken into account when analyzing the landing process:

– the landing module (LM) weight of 120 kg (payload of 100 kg and damper with bracings of 20 kg);

– a vertical impact was considered;

– friction coefficient between the landing module and surface is 0.35–0.4;

– energy recovery coefficient for the rigid surface is 0.64 (derived from experiments within the “Mars-96” project);

– the landing module mass center is located at the geometric damper center;

– damper diameter is 2.5 m;

– the initial pressure in the damper is 20,000 Pa (varied between 10,000 and 30,000 Pa); and

– the vertical landing velocity varies between 2 and 14 m/s.

The LM design parameters were selected based on the following requirements:

– the highest overload value at the LM contact with the surface does not exceed 100 units;

– the maximum permissible pressure in the damper is 40,000 Pa; and

– diameter of the station is 1150 mm.

At the present design stage, a model was applied that permits the concept of the landing scheme selected to be evaluated and the landing module design parameters to be chosen.

The following assumptions were used in the model:

– spherical damper shape;

– the damper is deformed only at the area where it contacts with the ground, the contact spot is circular;

– the pressure in the bags is assumed to be identical, which is reasonable for a nearly vertical impact;

– module displacements within the damper are neglected;

– the Moon surface is assumed to be absolutely rigid and flat;

– energy dissipation due deformation of the bags (see Fig. 3), ground sagging, etc. is taken into account by the energy recovery coefficient assessed experimentally;

– dissipation of the heat evolved due to gas compression in the damper is neglected.

The calculation results were presented in the form of damper deformation as a function of damper diameter and velocity at which landing apparatus (LA) approaches the surface.

IDD inflation system

In designing an inflatable damping device of an LA, the inflation system type was selected based on comparison of the characteristics of various construction units and flight requirements depending on the landing device purpose.

Basic schemes of IDD inflation

Gas filling system

Inflation system based on solid fuel gas-generators

The “Luna-9” unmanned system (UMS) was equipped with a gas system of IDD inflation.

The main specific features of the inflation systems based on solid-propellant gas generators are:

– simplicity of the construction;

– constant readiness for starting;

– high reliability;

– simplicity of running;

– extensive industrial and raw material bases; and

– high technical and economy properties.

"Mars-96" IDD inflation system

The damper bags were inflated with gaseous products from gas generators.

– Each of the two bags was equipped with one gas generator.

– The gas-generator operation time was ~ 30 s.

– The time of pressure stabilization in the bags was ~ 50 s.

– The gas pressure in the bags after the termination of inflation procedure was Pinfl =0.176…0.21 bar.

– The maximum temperature of the bag walls during inflation with hot gas generator products did not exceed 313 K.

• Gas generator

The gas generator is intended to inflate IDD bags of the small "Mars-96" station (Fig. 6).

Analysis of various gases filling IDD bags from the point of view of weight efficiency.

The inflation system at "Luna-9" was filled with a 50 percent helium–air mixture.

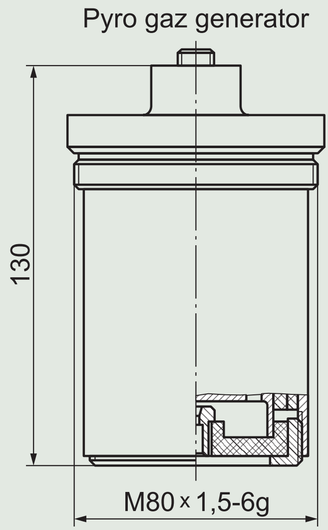


Figure 6: Gas generator construction

Two versions of IDD bags filling were considered in the "Mars-96" SA.

The gain in the construction weight of the system of bag inflation with the aid of gas-generator is owing to the gas mixture pressure, namely, the pressure in the bottle with the helium–air mixture is 320 atm, whereas in the gas-generator system, it is 10 atm.

Grounding of the necessity of a protection IDD sheath in "Luna-9" and "Mars-96" SA.

This necessity resulted in addition of passive-protection flaps to the "Luna-9" SA (the flight duration is 3.5 days only), while the "Mars-96" SA was additionally equipped with metal cases and thermal regulation system (long flight duration, more than 300 days).

• Structure and purpose of the metal bearing construction (flanges) of IDD bags.

A metal bearing construction designed to fix the gas-generator and feed valve was mounted on each of the IDD bags of "Mars-96".

The blanket and chamber material was fixed between the case and cover.

• Protective sheath properties.

The IDD bags of the "Luna-9" LA were packed underneath protective lamellas made of caprone tissue.

The IDD bags are placed in a void protected by three walls made of AMg6 aluminum alloy, the spacer has a panel thermal protection coating.

Experiments in which these reactors impacted the "Luna-9" and "Mars-96" IDD materials were conducted.

Reliability of UMS and "Mars-96" landing module detachment.

The UMS "Luna-9" is mounted at the top edge of the instrument container, which is profiled at this site to fit the shape of IDD inflated for standard application.

Unmanned system is detached upon activation of the pyrotechnical device and departs from the instrument container under action of the force arising as a result of IDD bags inflation and drops on the Moon surface.

Analysis of possible applications of the inflatable braking devices in space technologies

Inflatable braking devices (IBD) can be used to deliver to Earth various payloads from orbits of artificial Earth satellites, among them: waist upper stages of the launcher rockets and boosters, expensive equipment of orbital stations, expensive satellites which have failed or come to the end of their life, parts of orbital stations and their modules, various payloads, etc. Application of IBD as a means of landing scientific probes and exploration stations on Solar-system planets is one of the areas of technology development of ballutes.

Obtained Results

The final report "Designing and development of inflatable damping devices for soft landing of space vehicles. Stage 2. Tests and test facilities:"

• described the techniques, schemes, amount of tests, application of test facilities in ground elaboration of IDD of "Luna-9" and "Mars-96" space apparatus;

• reported technological peculiarities of the soft shell construction, materials applied, IDDs and their hard units, such as flanges for fastening the inflation system and its units;

• analyzed various designs of foreign analogs of damping devices to be used in soft landing of exploration equipment on the Mars surface ("Pathfinder," "Beagle-II," and "Marsnet" projects).

"Pathfinder" is a multisectional device. "Beagle-II" construction is close in its design to the "Luna-9" IDD. "Marsnet" is a torus-shaped damping device with additional attachments that preclude repetitive impacts and overturning;

• partially listed the basic characteristics of the inflatable constructions of various destination applied at Lavochkin Association, such as inflatable elastic separators, elastic pressing diaphragms, etc.; and

• analyzed prospective lines of development of constructions that use inflatable braking devices for SA entry in atmosphere of Earth and other planets and for aerodynamic braking with the purpose of delivery of various objects from orbits to the Earth.

The concluding Report part presented a new line in application of inflatable constructions in space technology, namely, inflatable braking devices that can provide in nearest future safe descent in atmosphere of planets, safe landing of space vehicles and parts of rockets, and rescue of spaceship crews.

The materials included in the report have never been published in their full extent; however, the essence of the patents (invention formula) relevant to these constructions was not disclosed.

Project Number:	#1172
Full and Short Title:	Preliminary Project for Exploring Mars **Mars Expedition**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding :	$198,500 + 180,337 € (EU: 180,337 €, US: $198,500)
Commencement date:	May 1, 1999
Duration:	18 months, extended by 3 months
Leading Institute:	Keldysh Research Center, Moscow, Russia
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
Supporting Institutes:	NPO Energia, Korolev, Moscow reg., Russia Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia Russian Academy of Sciences / Space Research Institute, Moscow, Russia Federal State Unitary Enterprise Research and Development Institute of Power Engineering named after N.A.Dollezhal, Moscow, Russia
Collaborators:	Boeing Northamerican / Rocketdyne Division, Canoga Park, CA, USA (Shea Dan) CNES, Paris, France (Vassaux Didier) European Space Agency / European Space and Technology Center, Noordwijk, The Netherlands
Project Manager:	SEMYONOV Vitali Felixovich
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
ISTC Senior Project Manager:	TOCHENY Lev Vasil'evich
Contact Information:	Phone: +7 (495) 982 31 13 Fax: +7 (499) 978 46 37 E-mail: tocheny@istc.ru
ISTC Website:	http://www.istc.ru

Background

Man landing on the Moon and scientific experiments performed with participation of astronauts within the “Apollo” program is one of the epochal events of the second half of the XX century. This fact has demonstrated the technical potential that the mankind had at the end of the 1960s and beginning of the 1970s of the passing away century. Man landing on Mars and scientific experiments performed there with participation of the crew members would demonstrate further progress in science and technology achieved during first decades of the next century. Mars exploration would significantly contribute to studies aimed at answering the question that warms up the interest in Mars exploration, namely, is there proof of biological activity on the red planet? The project of tentative Mars exploration must substantiate:

– selection of the most efficient Scenario of the manned mission to Mars in terms of lowest cost and risk and the maximum yield (scientific, technical, educational, public resonance);

– selection of the propulsion and energy provision of the manned mission to Mars;

– the structure of the international cooperation team executing the manned mission to Mars;

– tentative time frame and cost of realization of the manned mission to Mars; and

– the amount of work needed to accomplish the second Project phase “Draft project of the manned mission to Mars.”

Project Objectives

The Project was aimed at implementation of the first project phase, namely: tentative Project of manned mission to Mars based on scientific and engineering achievements of the international cooperation participants.

Content of the Work

The General requirements and Concept of the manned mission to Mars were worked out and coordinated.

Realization of the manned mission to Mars requires solution of five basic problems.

Problem 1. Efficient launcher rocket

The work within this Project showed that irrespective of what energy source would be used onboard — solar, chemical, or nuclear — the start weight of interplanetary ships ranges between 400 and 600 t. This necessitates module construction of the ship with assembling on orbit. The project elaboration has shown that the minimum reasonable module magnitude amounts to 35 t with the outer diameter of 6.2–6.5 m and length of 20–22 m.

Problem 2. Efficient space power source

In Russia, electric rocket engines (ERE) are extensively used in space since 1982. They need power sources. Nuclear and solar energy sources were considered. Solar energy sources based on thin-film solar photocells made of amorphous silicon were chosen as the most efficient.

Problem 3. Efficient ERE

Project implementation showed that the ion ERE that uses argon as the working fluid is the most efficient propulsion system for the manned mission to Mars. Its optimal power is 50 kW. So far, such engines are lacking, the power of Xenon engines that are in operation at present ranges between 1 and 10 kW.

Problem 4. Efficient takeoff and landing complex

Landing on and takeoff from Mars is the most important mission phase. The Project grounded the feasibility of parachute-free crew landing on Mars. Till now, all robot landings were carried out with the use of parachutes.

Problem 5. Efficient radiation protection of the crew

One of the chief problems pertinent to long-term space man flights is crew protection against action of the natural sources of ionizing radiation:

– Earth radiation belts;

– Solar flares; and

– Galactic space rays.

The calculation results indicated that the density of the onboard radiation protection system must amount to 100 g/cm2; it is expedient to implement the flights in years of active Sun when the increased magnetic field of the Sun nearly halves the Galactic radiation intensity.

Obtained Results

“Tentative project of a manned mission to Mars” was issued.

The major results of the Project are as follows:

1. The manned mission to Mars should be considered as a component of new tasks in space exploration (Fig. 1).

2. Scientific tasks of the manned mission to Mars include:

– exploration of Mars structure by seismic and electromagnetic methods;

– investigation of groundwater as the most probable site of life existence;

– exploration of the geological history of Mars, its climate, the effect of internal processes and catastrophic impacts by asteroids and comets; and

– assessment of the asteroid threat for the Earth as a result of long-term observations from a near-Mars orbit and from Mars surface.

3. The tentative real beginning of the manned mission to Mars is 2014 or 2015.

4. The cost of preparation and realization of the first manned mission to Mars, provided it is organized in international cooperation, is assessed at ~ 20 billion USA dollars (with no account taken of the expenditures for creation of the new launcher rocket).

5. A launcher rocket with a load capacity of 35 t is suggested for the mission.

6. A scenario of landing on Mars from an orbit of a crew consisting of 6 members is chosen.

7. Two schemes of the interplanetary mission complex (IMC) are chosen for their further elaboration at the next project stage:

– IMC-I based on one ship with solar electric engines only; and

– IMC-II based on two ships: (i) freight interplanetary orbital vehicle with a solar electric propulsion system and (ii) manned interplanetary orbital ship that uses a liquid rocket engine and solar electric engines.

8. The nuclear power-propulsion systems considered permit the initial weight to be diminished and the mission duration to be reduced, but they call for solution of the radiation safety problem.

9. It is demonstrated that the takeoff–landing complex (with a crew) weighing 35 t can be landed on Mars using only aerodynamic braking in the Mars atmosphere and braking rocket liquid rocket engines. The absence of a parachute system would enhance reliability and precision of landing on Mars.

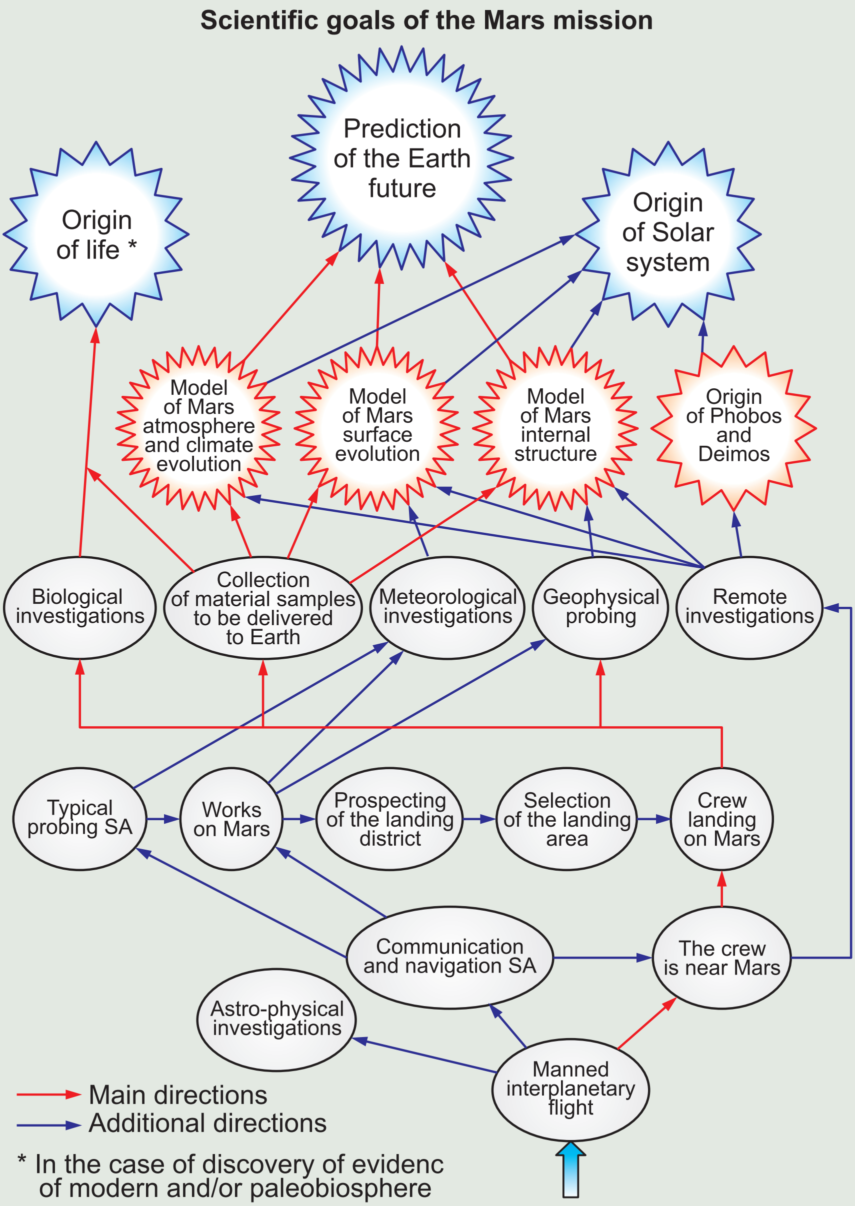


Figure 1: Scientific goals of the Mars mission

Project Number:	#1239
Full and Short Title:	Investigation and Development of the Ultrahighsensitive Terahertz Frequency Band Hot-Electron S-LN-S Microbolometer for Extra Atmosphere Astrophysics Observations and Measurements **Microbolometer for Astrophysics Observations**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration INS-MEA / Instrumentation / Measuring Instruments INF-SIG / Information and Communications / Sensors and Signal Processing
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding :	$300,000 (US)
Commencement date:	April 1, 2000
Duration:	36 months, extended by 5 months
Leading Institute:	Russian Academy of Sciences / Institute of Radioengineering and Electronics, Moscow, Russia
Contact Information:	Phone: +7 (495) 629 35 91, 629 35 74 Fax: +7 (495) 629 3678 E-mail: gulyaev@cplire.ru Website: http://www.cplire.ru
Supporting Institutes:	P.L.Kapitza Institute of Physics Problems, Moscow, Russia FIAN Lebedev / Astro Space Center, Moscow, Russia Moscow State University / Department of Physics, Moscow, Russia
Collaborators:	California Institute of Technology / Jet Propulsion Laboratory, Pasadena, CA, USA NIST / Boulder Colorado Laboratories, Boulder, CO, USA (Martinis J)
Project Manager:	Vystavkin Alexander Nikolaevich
Contact Information:	Phone: +7 (495) 203 53 89, 200 52 58 Fax: +7 (495) 203 84 14 E-mail: vyst@delta.cplire.ru
ISTC Senior Project Manager:	Horowicz L.
Contact Information:	Phone: + 7 (495) 982 32 00 Fax: + 7 (499) 982 32 01 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

During the last ten or twelve years, research teams in USA, Europe, Japan, and Russia perform investigations aimed at creation of space telescopes in the terahertz frequency range (0.3–10 THz) for exoatmospheric astrophysical observations. The schematic of such Russian space telescope elaborated within the "Submillimetron" project of the Russian Space Agency and Russian Academy of Sciences is shown in Fig. 1. The telescope chief mirror is 70 mm in diameter. It is intended to operate in cooperation with the International Space Station (ISS, Fig. 2). The telescope must operate in the autonomous regime. It is attached in Fig. 2 to ISS for conducting assembling works and for refilling refrigerants.

In accord with the aforesaid, of the greatest interest is observation of space objects emitting in the terahertz frequency range remote from the Earth at distances of the order or more of ten billion of light years, from which information about the processes that occurred at the very early stage of Universe development after the Big Bang could be obtained.

Extremely high-sensitivity terahertz radiation sensors are very important components of such telescopes. Detectors of various types

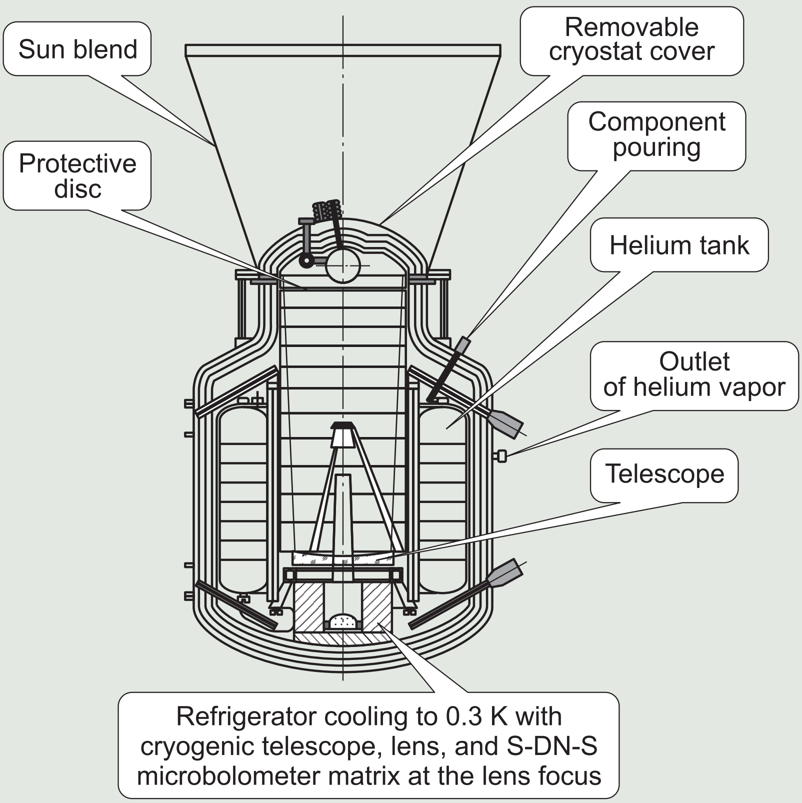


Figure 1: Schematic construction of the Russian space telescope of the terahertz frequency range developed within the "Submillimetron" Project sponsored by the Space Agency and Russian Academy of Sciences

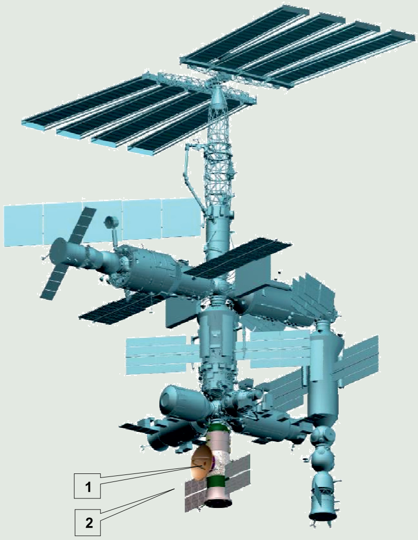


Figure 2: International Space Station: 1 — telescope module attached to the Russian ISS compartment; and 2 — telecommunication antenna

are considered; among them direct detectors based on superconducting microbolometers occupy an important position.

In the present Project, a superhigh-sensitivity microbolometer with a radiation absorber based on a thin long film made of a normal metal (DN) and incorporated in an electronic measuring circuit with the aid of superconducting electrodes (S) has been chosen as the basic development and investigation object. This gives the microbolometer name: "S-DN-S microbolometer." The mechanism of radiation detection with such a bolometer is based on radiation absorption by electrons in the film made of normal metal and their heating. One or two superconducting electrodes are additionally connected to the metal film to measure the temperature of hot electrons. The voltage increment ΔV and the respective current increase ΔI, or response, in the circuit of this/these electrodes, called reading electrodes, when the normal-metal film absorbs radiation, are proportional to the power of radiation P_{rad} absorbed by the metal film; thereby, they turn out to be a detected signal.

Project Objectives

The main objective of the Project was development and investigations of the above described microbolometer capable of providing the maximum ratio of the response to the power absorbed

$$S^\circ = {}^\circ\Delta V/P_{rad}\ ,$$

i. e., the maximum signal, and as a low as possible noise, or the lowest mean square root overall noise voltage $\sqrt{u^2_{noise}}$ at a reading SIN (superconductor – insulator – normal metal) transition (transitions) that limits the signal detected. Shortly, the Project team's main goal was the creation of a microbolometer that possesses superhigh sensitivity. The noise equivalent power (NEP), i. e., a received power at which the response

$$\Delta V^\circ = \sqrt{u^2_{noise}}\ .$$

is the basic characteristic of the microbolometer considered that specifies its sensitivity.

From the two relationships for NEP indicated above, one derives

$$NEP = [P_{rad}]_{lim} = \sqrt{u^2_{noise}}\ /S.$$

Attaining an as low as possible NEP value specified the main goal of the work performed within the Project. This included investigations of the microbolometer operation mechanism and optimization of the conditions under which it operates. Apart from that, the Project objectives included provision of efficient, with the lowest loss, transfer of the radiation received from the telescope input to the microbolometer, and transmission of the detected signal from the microbolometer to the recording device by means of amplifying and transforming circuits with no additional noise and distortions, i. e., creation of an efficient inlet microbolometer chamber and efficient reading, amplifying, and transforming circuits. Investigations (see below) of the S–ND–S microbolometer chosen in the Project showed that its anticipated limiting sensitivity NEP $\approx 10^{-17}\ldots10^{-18}$ W/Hz$^{-1/2}$.

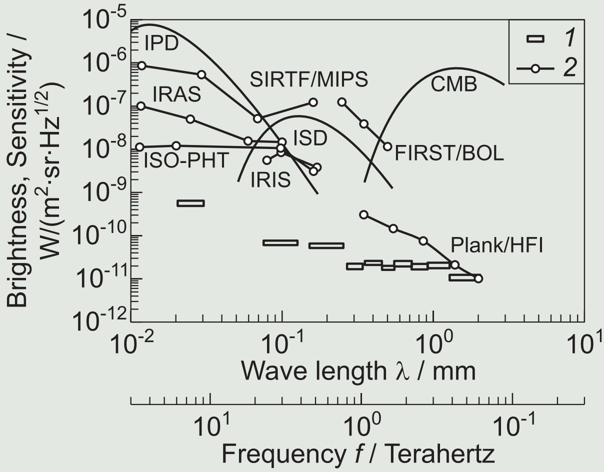


Figure 3: Space background radiation: SMB — space microwave background; ISD — interstellar dust emission; and IPD interplanetary dust emission (refer http://www.radioastron.ru/index.php?dep=21&submillim=1)

Inasmuch as telescopes should provide two-dimensional (2D) images of the observed space objects, in addition to the above-listed Project objectives relevant to creation of microbolometer and its application in observations, there naturally arose a purpose of constructing 2D matrices of microbolometers and arranging their joint operation.

Description of the Works

1. Brief review of astronomic objects to be observed in the terahertz frequency range and assessment of the limiting sensitivity of direct detectors needed for this purpose

The task formulated at the period of ISTC Project #1239 implementation (2000–2003) was summarizing the data on radiation of the space background with errors in anisotropic measurements reduced with the use of detailed information about the foreground sources. Along with this task, the Project was aimed at comparison of the expected sensitivity of the cryogenic terahertz ISS telescope equipped with an S–DN–S microbolometer matrix with other similar telescopes, the results for which are also presented in Fig. 3. As seen from the figure, selection of S–DN–S microbolometers for the space terahertz telescope being designed within the “Submillimetron” project turned out successful at the time of Project #1239 beginning.

2. Development of the construction and technology of manufacturing of S-DN-S microbolometers

The S–DN–S microbolometer construction has a fairly simple structure (its schematic is shown in Fig. 4). It consists of a normal metal (Cu) strip (N, red color) of the following sizes: 6 μm long, 0.3 μm wide, and 75 nm thick and of two superconducting aluminum reading conductors (S, blue color). Superconductors operate at a temperature < 1.2 K, their sizes are: 0.2 μm in width and 50 nm in thickness. The structure is fabricated on a silicon support employing the electron lithography method with spraying through a shade mask at various angles. The films are deposited by the thermal evaporation technique in a vacuum chamber at a residual gas pressure of order of 10^{-6} mbar. First, superconducting (Al) electrodes of the size indicated above are applied. After that, oxygen is admitted to the

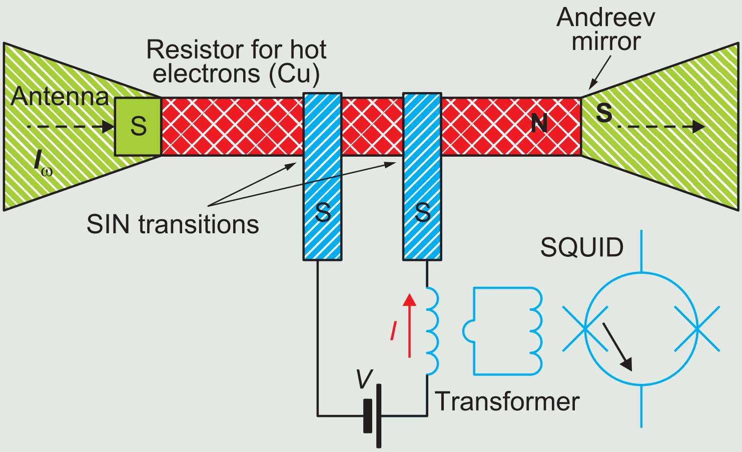


Figure 4: Schematic construction of an S–DN–S microbolometer with a SQUID-reader (explanation in the text)

chamber to a pressure 0.66 mbar for 5 min to produce an insulating barrier layer (I, not seen in the figure), then oxygen is pumped out to the above-indicated residual gas pressure. The sample is overturned and a copper strip (absorber) of the indicated sizes is sprayed at another angle. In this way, two SIN transitions have been formed in a single cycle without interruption of vacuum in the chamber. Led contact antenna areas (S, green color) 175 nm thick are sprayed in another cycle. The electric resistance of the copper strip is 10 Ohm at a temperature below 1 K, it remains the same as

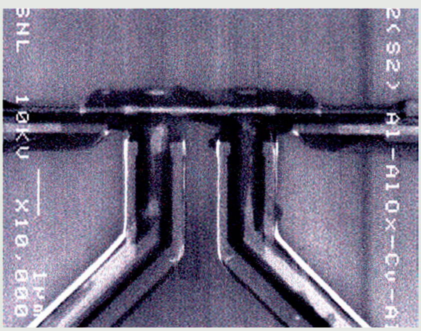


Figure 5: Microphoto of an S–DN–S microbolometer the schematic construction of which is shown in Fig. 4

the temperature drops further. This resistance is called residual resistance of a normal metal. The microphoto of the above described structure is displayed in Fig. 5.

3. Electronic circuit of signal reading from S-DN-S microbolometers

The circuit is shown in Fig. 4 together with an S–DN–S microbolometer. It comprises a double transformer. The primary winding of the first transformer is connected in series with the bias source V while its secondary winding applies voltage at the primary SQUID winding. The secondary SQUID winding is made in the form of a ring with two Josephson transitions included in it. Superconducting quantum interference device yields the SQUID abbreviation. Functionally, it is a superlow-noise amplifier of weak signals, because its noise level is negligibly small as compared to the noise of S–DN–S microbolometer itself.

4. Investigation of electric characteristics of an S-DN-S microbolometer aimed at assessment of its limiting sensitivity

To assess the limiting S–DN–S microbolometer sensitivity, volt-ampere characteristics (VAC) of SIN transition were measured with the use of a circuit shown in the inset in Fig. 6. To simplify the procedure, a circuit with a sin-

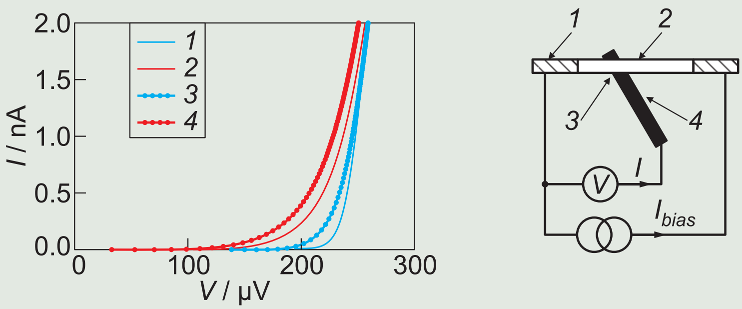


Figure 6: Volt-ampere SIN-transition characteristics. Solid thin curves pertain to temperatures of 40 (right) and 300 (left) mK at a zero bias current through the copper absorber. Thick curves dotted below pertain to a 40-millikelvin temperature at the direct current bias power dissipated in the absorber of 20 fW (right) and 2 pW (left). The basic measurement scheme is displayed in Fig. 4. The power dissipated in the absorber resistance equals , where R is the absorber resistance value

gle SIN transition was applied. The conditions under which measurements were conducted are indicated in the caption to Fig. 6. Variation of the voltage drop at the SIN transition vs. the bias power dissipation (Fig. 7) was studied using the same circuit. The specific response or volt–watt microbolometer sensitivity was assessed at 10^9 V/W at 100 mK from the dependence displayed in Fig. 7. The noise voltage measured at the input of the SIN transition signal amplifier amounted to ≅ 3 nV/Hz$^{1/2}$, which, at a volt–watt sensitivity of 10^9 V/W, corresponds to the electric (i. e., calculated

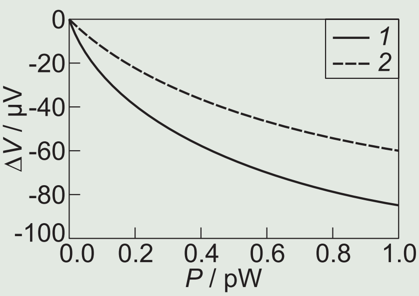


Figure 7: Voltage at the SIN-transition with a normal resistance value of 20 kOhm vs. the power dissipated in the absorber at a transition current of 0.1 nA and temperatures: 1 — T = 100 mK; and 2 — T = 300 mK

from the volt–watt sensitivity measured at a constant current) limiting S–DN–S microbolometer sensitivity $P_{lim} \approx 10^{-18}$ W/Hz$^{1/2}$. The analysis of the level of space background in the submillimeter wavelength range (or terahertz frequency range) shows that this sensitivity value is quite sufficient to perform observations under conditions pertaining to Fig. 3.

5. Receiver chamber

The receiving chamber used to introduce radiation from the telescope into a microbolometer was studied on a prototype shown in Fig. 8. The terahertz radiation input device consists of a silicon elliptic lens with clearing coating and dipole two-slot antenna glued to the lens at its focal plane. The microbolometer is incorporated in the antenna (see insert). The measured directivity diagram of such a lens together with a flat two-slot antenna (Fig. 9) ensures good matching to the optical terahertz telescope system.

6. Signal multiplexing in arrays of direct detectors

As noted in the “Objectives of the Project” Section, solution of many astrophysical problems necessitates application of direct detector arrays of dimension $N \times N$ of up to 100×100 and more. Bias applying to the detectors and transmission of the detected signals would re-

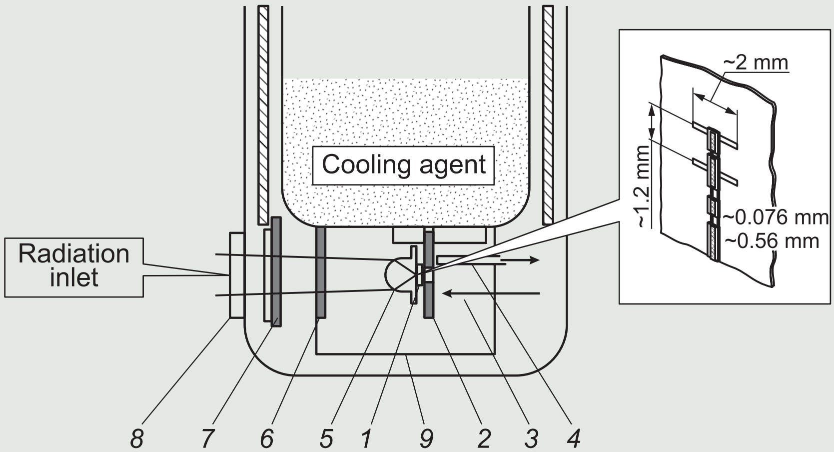


Figure 8: Receiving chamber prototype: 1 — microbolometer incorporated in a dipole two-slot antenna displayed in the right-hand inset; 2 — contact plate; 3 — bias voltage; 4 — transfer of the detected signal to the SQUID-amplifier; 5 — silicon elliptic lens with cleaning coating; 6 — thermal filter at T = 4.2 K (polyethylene); 7 — thermal filter at T = 77 K (quartz); 8 — inlet Mylar window; and 9 — magnetic screen (cryoperm)

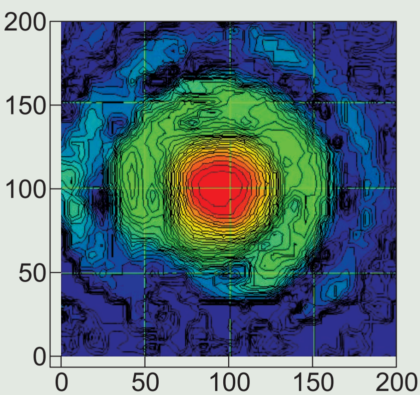


Figure 9: Directional diagram of the "elliptic lens-flat antenna with a detector device at its center" system; a SIS-mixer served as a detector in this case. The antenna is a two-dipole slot device; the measuring source shift along the two reference axes is in mm and spacing of the contour lines is 1 dB

quire in this case introduction of a great number of conductors (up to tens of thousands) into the superlow-temperature zone of the refrigerating cryogenic system, which would entail influx of an intolerably high heat power in the refrigerator, which undoubtedly would not cope with such a high heat influx. Various methods signal multiplexing (commutation, grouping, group transmission, and subsequent separation) in arrays of detectors were suggested to solve this problem.

A new method of signal multiplexing in arrays of superlow-temperature direct detectors of terahertz radiation was suggested. It is based on the following (Fig. 10):

(1) direct detectors, namely, micronanobolometers, are connected in parallel between each other and to the common bias shunt in a row, their summed-up current is supplied to the input coil of one SQUID reader in each row;

(2) the set of current increments in SQUID readers which are detected signals induced by the received radiation are assumed, together with the noise current in all rows, to be a projection that is analogous to that in computer tomography;

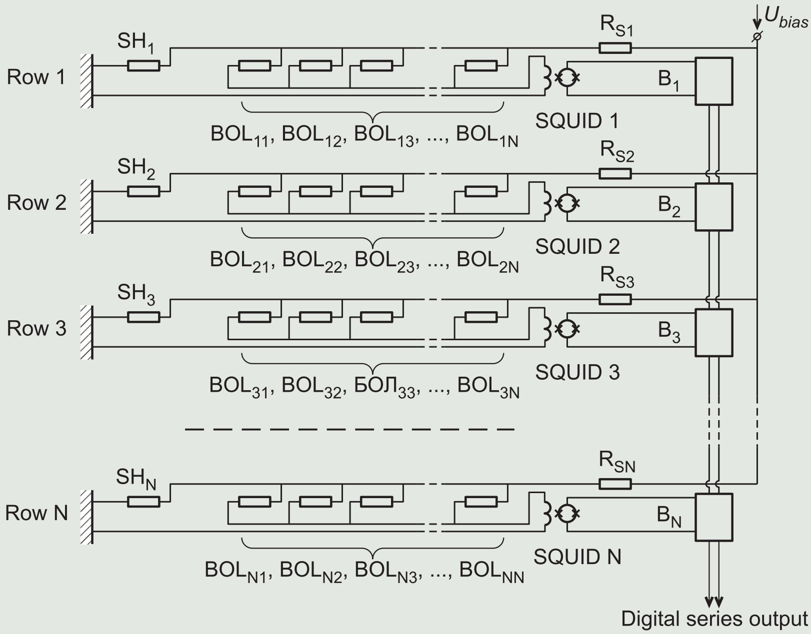


Figure 10: Parallel electric connection of bolometers with output to SQUID-amplifiers (N rows with N bolometers in each row): BOL — bolometers with identical resistance values RB and operation temperature; SH — shunts, from which a preset bias voltage V is applied to the bolometers; RS — series resistances of the bias circuits; Ubias — the source of bias voltage; B — electronics blocks of SQUIDs, analog-to-digital converters, and series digital data transmission

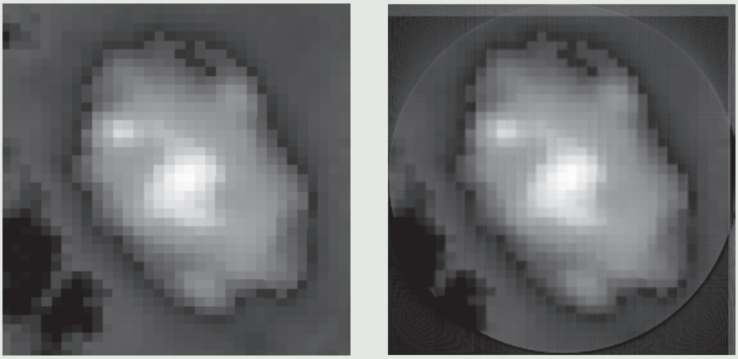
(3) in one of the possible approaches, the received image of a radiation source is rotated at small angular steps relative to the direct detector array in their common plane from 0 to ϖ, which yields a set of projections at a great number of angles; and

(4) the original image is reconstructed from the projections by means of the algorithms elaborated in computer tomography. The method suggested makes it possible to drastically reduce the number of conductors connected to direct detectors and SQUIDs in the superlow-temperature zone, to significantly diminish the needed number of SQUID-based reading amplifiers, and also to essentially simplify the circuit connecting bolometers and SQUIDs as compared to the other known multiplexing methods.

The method of multiplexing of signals in direct detector arrays with the use of projections was numerically simulated. Figure 11 presents the modeling results, which validate the method applied.

Obtained Results

• Summarizing the available data on space background radiation and comparison of the expected sensitivity of the cryogenic terahertz ISS telescope equipped with an array of S–ND–S microbolometers selected for it with other analogous telescopes allowed the Project team to conclude that the choice of the S–DN–S microbolometers for application in the space terahertz telescope being developed within the “Submillimetron” project turned out quite successful.



(*a*) (*b*)

Figure 11: Original M33 galactic image taken at a wavelength λ = 100 μm (a) and result of mathematical modeling of the multiplexing procedure with the use of M33 galactic image as an original (b)

• The construction and technology of fabrication of S–DN–S microbolometers were elaborated.

• The electronic circuit of a superlow-noise amplifier reading signals from S–DN–S microbolometers was worked out.

• Electric characteristics of the S–DN–S microbolometer were investigated to assess its limiting sensitivity. The investigations showed that its sensitivity was quite sufficient for efficient observations under the chosen conditions (see Fig. 3).

• It was proved that the receiving chamber designed for radiation transmission from the telescope to microbolometers provided good matching with the optical terahertz telescope system.

• A new method of signal multiplexing in arrays of superlow-temperature direct detectors of terahertz radiation was suggested. The method makes it possible to drastically reduce the number of conductors connected to the direct detectors and SQUIDS in the superlow-temperature zone, to significantly diminish the needed number of SQUID-based reading amplifiers, and also to appreciably simplify the circuit connecting bolometers with SQUIDs, as compared to the other known multiplexing methods.

Anticipated sensitivity values of the designed space terahertz telescopes: rectangles — “Submillimetron” space terahertz designed for ISS; open circles joined by lines — data furnished by other projects (their names are indicated in the vicinity of lines).

All the values are given in $W/(m^2 \cdot sr. \cdot Hz^{1/2})$. As applied to space background, plotted is the background intensity per unit surface area and unit solid angle (sr. = 1 steradian). As applied to telescope, plotted is the limiting sensitivity of the direct telescope detector also calculated per unit surface area and unit solid angle of telescope vision in order to equalize the conditions under which the sensitivity of different telescopes is compared.

Project Number:	#1440
Full and Short Title:	Experimental Investigations of Non-Equilibrium Radiation and Physical-Chemical Processes in Shock-Wave Layer Ahead of Body Passing through Mars or Venus Atmosphere with Second Cosmic Velocity **Space Objects in Extraterrestial Planet Atmosphere**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration
Status:	Project completed
Technology Development Phase:	Basic research
Allocated Funding :	$150,000 (US)
Commencement date:	September 1, 2002
Duration:	36 months
Leading Institute:	Moscow Institute of Physics and Technology, Dolgoprudny, Moscow reg., Russia
Contact Information:	Phone: +7 (495) 408 45 54 Fax: +7 (495) 408 42 54 Website: http://www.mipt.ru
Supporting Institutes:	No
Collaborators:	CNRS / Institut Universitaire des Systemes Thermiques Industriels, Marseille, France Fluid Gravity Engineering, Hants, UK (Smith Arthur)
Project Manager:	KUDRYAVTSEV Nikolai Nikolaevich
Contact Information:	Phone: +7 (495) 408 57 00 Fax: +7 (495) 408 68 69 E-mail: rector@mipt.ru
ISTC Senior Project Manager:	BUNYATOV Karen Stepanovich
Contact Information:	Phone: +7 (495) 982 31 99 Fax: +7 (499) 978 46 37 E-mail: bunyatov@istc.ru
ISTC Website:	http://www.istc.ru

Background

Development of multiply used space vehicles, creation of air-space planes, and other high-velocity rocket-space devices flying in rarified atmosphere resulted in the last few years in a significant progress in the field of hypersonic aerodynamics. The characteristic times of gasdynamic, chemical, and relaxation processes become comparable in the order of their magnitudes under conditions of high flight velocity and rarified environment, which signifies that all these processes are coupled and must be considered jointly.

Thus, the key characteristics of hypersonic flows are directly dependent on the kinetics of gas-phase and surface chemical reactions and concomitant relaxation processes. The study of these processes is directly related to solving the problems of creation of a high-altitude space plane, aerodynamic braking of space vehicles, and to other important tasks of exploration of the near and remote space.

Investigations of heat exchange in supersonic flows around solid bodies were traditionally limited to consideration of the equilibrium chemical kinetics assuming complete transfer of the energy released by gas-phase chemical reactions directly to the translational degrees of freedom of the chemical reaction products, while heterogeneous reactions were assumed to transfer their energy to the solid body surface. Application of this approach was dictated, in particular, by the lack of many necessary data on energy deposition to the internal degrees of freedom of the reaction products, on kinetic reaction rate constants of excited species and on rates of homogeneous and heterogeneous quenching of excited states.

Recently, intense development of chemical kinetics and new necessary kinetic data made it possible to perform investigations of heat exchange in supersonic flows around solid bodies with allowance for formation and quenching of electron-vibrationally excited species and chemical reactions with their participation.

Project Objectives

The objective of the Project was to study experimentally and theoretically nonequilibrium radiation and physicochemical processes taking place in the shock layer in front of bodies entering the Mars and Venus atmospheres at the second space velocity.

Description of the Works

The data on nonequilibrium radiation in the Earth atmosphere obtained previously were extended to investigations of nonequilibrium phenomena occurring in the course of body entry at a high velocity in the Mars and Venus atmosphere.

The Mars atmosphere contains mostly carbon dioxide and minor components: nitrogen (2.5%–3%), argon (1%–1.5%), hydrogen and other components. Hence, the major components which are present in the shock layer are C, CO, C_2, and CN. Radiation from the nonequilibrium zone in the Earth atmosphere at entry velocities of about 10 km/s is known to be of great importance. The ratio between radiation from the nonequilibrium and equilibrium zones at various flight velocities in the Mars atmosphere is not known, therefore the attention in experiments was concentrated on assessment of the size of the nonequilibrium zone and on its contribution to radiative heat transfer.

Nonequilibrium chemical reactions in standard atmospheres were studied in shock tubes under conditions simulating various altitudes of body flight. The effect of vibrationally and electronically excited species on the radiative heat flux to a body entering Mars and Venus atmospheres at hypersonic velocities was investigated.

Chemical reactions with participation of a great number of species containing carbon, oxygen, and nitrogen atoms are most important in the chemical relaxation processes behind a shock front in CO_2–N_2 mixtures; radiation from CN, C_2, and CO controls the radiation heat flux in these mixtures. The complete kinetic mechanism includes also the electron excitation processes and ionization of atoms and molecules.

Experimental studies of the structure of strong shock waves were carried out in shock tubes and aerodynamic wind tunnels. Theoretical models and numerical algorithms were elaborated to calculate the shock wave structure.

Strong shock waves were generated in a stainless steel shock tube 77 mm in inner diameter with a 5.5-meter long low-pressure section (Fig. 1). The shock tube and diagnostic equipment were adapted to measurements of the nonequilibrium kinetics and radiation. The high-pressure section was filled with a helium-hydrogen-oxygen mixture that was ignited with an electric spark. Evacuation of the low-pressure section with a high capacity pump ensured 10^{-3} Torr vacuum. Shock waves with a Mach number of up to M = 25 at an initial pressure in the tube of 1 Torr were generated. The diagnostic instrumentation (Fig. 2) comprised pressure gauges and schlieren systems used to measure shock wave velocity and pressure behind the shock front and three systems for monitoring radiation. Time histories of radiation in spectrally resolved individual lines behind the shock front in the 110–500-nanometer spectral range were recorded with a LaVision ICCD camera. The time-resolved spectra in the vacuum ultraviolet (UV) and visible range were recorded with a spectral system based on the high-speed photo-electron converter camera (Hamamatsu) and spectrometer (ISAN) attached to the evacuated tract. Experiments were conducted with various gas mixtures at diverse gasdynamic parameters with the purpose of attaining exact similarity to the spectra of nonequilibrium radiation of an object entering the atmosphere.

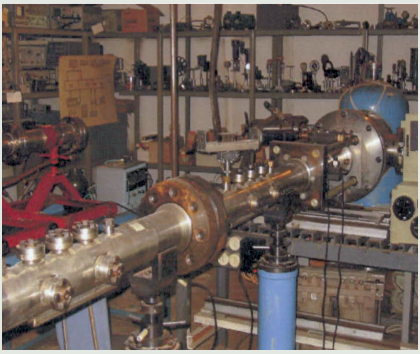


Figure 1: Experimental setup

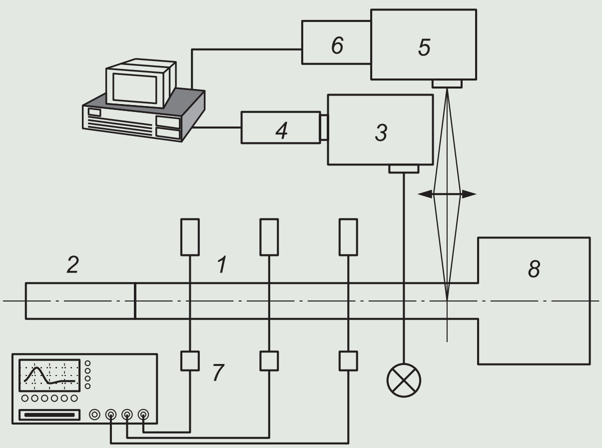


Figure 2: Part of the spectral diagnostics system: LPC — low-pressure chamber; HPC — high-pressure chamber; MC — monochromator, PEM — photoelectron multiplier; SG — spectrograph; CCD — charge-coupled device (or ruler); and SchS — Schlieren systems used to measure shock wave velocity

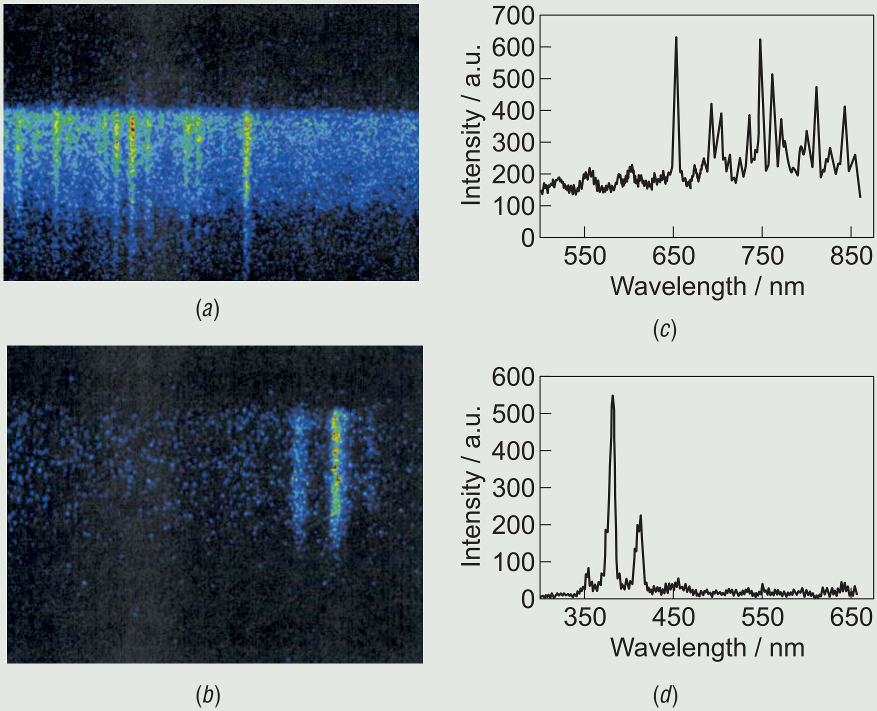


Figure 3: Representative images taken with a streak camera and results of experimental data processing: (a) experimental spectral distribution recorded at a shock wave velocity in Argon of 6.095 km/s; (b) experimental distribution recorded at a shock wave velocity in a CO_2–N_2 mixture of 6.25 km/s; (c) spectral composition of radiation of shocked Argon; and (d) spectral composition of radiation of shocked CO_2–N_2 mixture

In the trial experiments, the basic parameters and gas radiation behind incident and reflected shock waves in mixtures N_2, O_2, Ar, and He were measured. The most informative experimental regimes at Mach numbers of up to M = 25 and initial pressures in the 1 to 10 Torr range were ascertained.

Experiments were conducted with various gaseous mixtures. The following atmosphere compositions were studied at Mach numbers between 3 and 20 and initial pressures between 1 and 10 Torr: CO_2–N_2 mixtures, and N_2–O_2–CO_2–CO mixtures. The Mach number range for the N_2–O_2–CO_2–CO–Ar mixture varied between 3 and 25. Figure 3 displays the representative images taken by the streak camera and the results of processing the experimental data. The results of investigation of the non-equilibrium zones are illustrated in Fig. 4.

To perform a detailed analysis of the translational relaxation zone structure behind the shock front experiments were conducted in a hypersonic vacuum wind tunnel that provided continuous gas flow with M = 4…10 and static pressures of 10^{-3}–10^{-1} Torr. The free path length of molecules in these flows varies from 0.1 to 1 mm which corresponds to the translational relaxation zone length of few millimeters. Such a length value permits one to directly measure the gas parameters in the translational relaxation zone. Figure 5 shows photos of the integral emission of the carbon

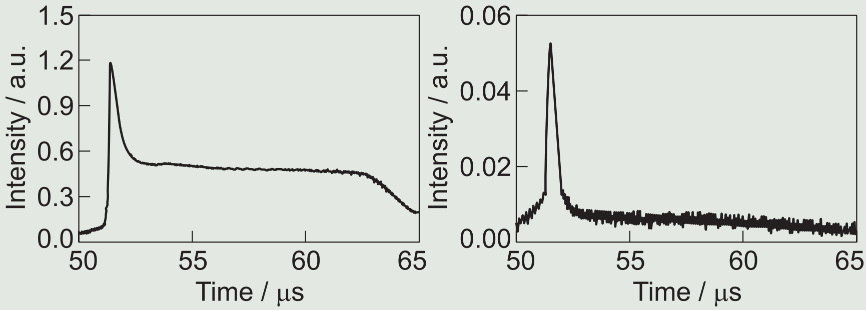


Figure 4: Time histories of violet CN radiation (a) and CO radiation in the fourth positive system (b) recorded in a 7:3 = CO:N_2 mixture at a shock wave velocity of 6.2 km/s and pressure P_1 = 1.5 Torr

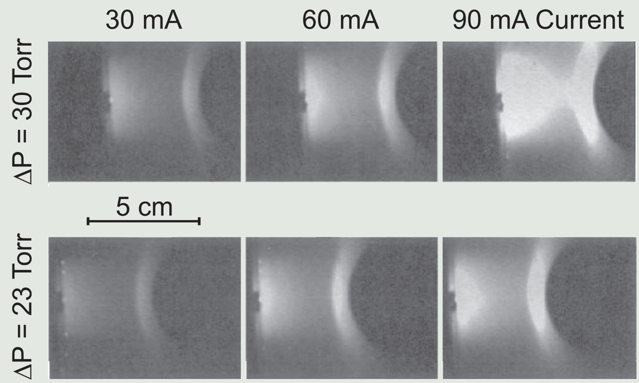


Figure 5: Photos of various flow-around regimes

dioxide gas in the flow that demonstrate the well resolved shock wave structure at various glow discharge current values.

Plasma in the boundary layer was generated by the high-frequency discharge. Figures 6 and 7 display examples of plasma radiation in a supersonic flow. The flow is photographed with the aid of a schliern system and the discharge was excited with a high-frequency wave.

The dynamics of flow interaction with an obstacle was studied experimentally within a wide range of conditions and at diverse gas mixture compositions (pure CO_2; CO_2–N_2 mixture, N_2, O_2, CO_2, CO mixture; and N_2, O_2, CO_2, CO, Ar, Xe, He mixture), the ranges of the Mach number and pressure were 4–9 and 0.001–1 Torr, respectively.

A kinetic mechanism was elaborated for calculating the emission parameters under conditions of the above-described experiments (Fig. 8). The mechanism took into account electron excitation and the vibration-level kinetics of the major gas mixture components. Translational and vibrational temperature distributions calculated for the initial CO_2–N_2–Ar mixture at a temperature of 10,700 K and distributions of the mole fractions at this temperature are shown in Fig. 9.

The calculation results are consistent with experiment.

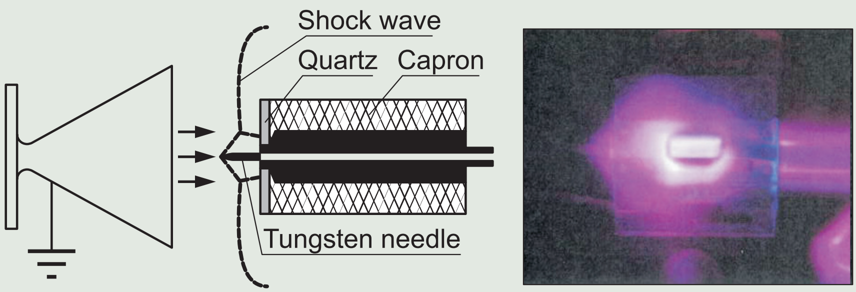
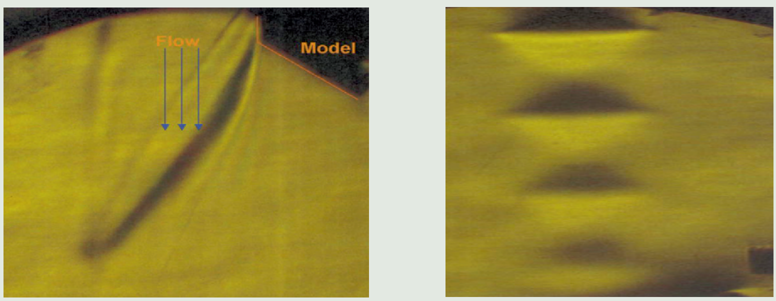
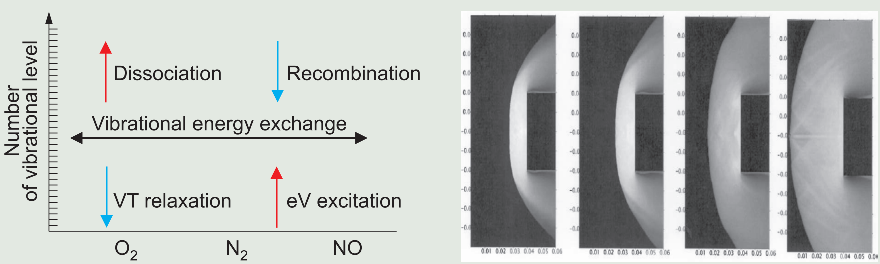


Figure 6: Model with a needle (a) and photo of discharge (b) at low pressure. Front view



(*a*) (*b*)

Figure 7: Density distribution in a flow around the model (a) and visualization regime demonstrating the shock wave structure in a tube (b)



(*a*) (*b*)

Figure 8: Scheme of the processes that are taken into account in modeling (a) calculated flow around the model (b)

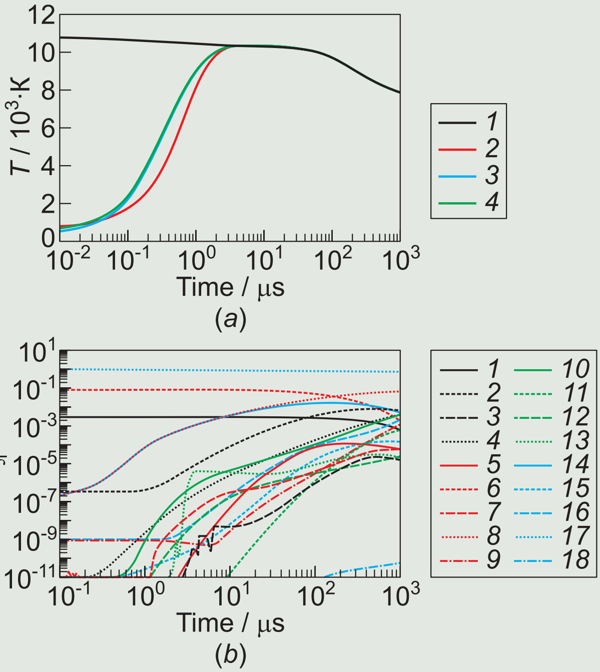


Figure 9: Variation of the translational and vibrational temperature distribution with time (a) and distributions of mole fractions of charged and neutral species in the calculated mixture versus the intrinsic time of the system (b)

Obtained Results

• The results of experimental and calculation studies of the molecular gas relaxation in strong shock waves in mixtures whose composition is as close as possible to that of the Mars atmosphere were reported.

The space and time resolved emission spectra of various gas mixtures within a wide temperature range were recorded, contribution of various molecular bands to the overall radiation pattern was analyzed. The data on radiation of strong shock waves in the vacuum UV spectral diapason were obtained for the first time. The special recording system permitted gas emission in the 130- to 800-nanometer range to be monitored in each run. Simultaneous recording of the time histories of emission in individual molecular bands made it possible to analyze the kinetic processes and verify the numerical model.

• Regimes in which parameters of a supersonic flow around a body change significantly were revealed by experiments with a glow discharge in the flow. The regimes ascertained were analyzed additionally by means of non-intrusive temperature electric field intensity control. It was shown that changes in the flow pattern in the range of parameters studied were caused by gas preheating in the glow discharge. The data on discharge emission were used in verifying the kinetic model.

• An application package was elaborated for calculating gas parameters in an incident shock wave, spectral distribution and absolute intensity of nonequilibrium radiation, and chemical and radiation kinetics. The analysis of vibrational and chemical relaxation processes and of electron excitation behind the shock front took into account the experimental data obtained. The data on populations of the electron degrees of freedom indicated that they were not equilibrated with the ground electron state. This pointed to the fact that under the conditions of experiments equilibrium population of the electron degrees of freedom by collisions proceeded slower than their depopulation with transition to the ground state due to emission. The lack of equilibrium among the electron degrees of freedom observed in this study is important and calls for taking into account this effect in construction of kinetic mechanisms depicting emission under similar conditions.

The results can be used both in assessing thermal loads and in verifying calculation and theoretical models developed.

Project Number:	#1549
Full and Short Title:	Problems of Aerothermoballistics, Radiation Gasdynamics, Heat and Mass Transfer for Planet Sample Return Missions **Aerothermoballistics Problems in Interplanetary Mission**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding :	380,000 € (EU)
Commencement date:	December 1, 2000
Duration:	24 months, extended by 6 months
Leading Institute:	Moscow State University / NIIM (Mechanics), Moscow
Contact Information:	Phone: +7 (495) 939 31 21 Fax: +7 (495) 939 01 65 E-mail: common@imec.msu.ru Website: http://www.imec.msu.ru
Supporting Institutes:	Central Research Institute of Machine Building (TsNIIMash), Korolev, Moscow reg., Russia Russian Academy of Sciences / Institute for Problems in Mechanics, Moscow, Russia Central Aerodynamic Institute, Zhukovsky, Moscow reg., Russia
Collaborators:	Aerospatiale Espace and Defence, Aerodynamic and Structure Department, France European Space Agency/ESTEC, Manned Spaceflight Programme Department, The Netherlands
Project Manager:	LOSEV Staly Andreyevich
Contact Information:	Phone: +7 (495) 939 54 72 Fax: +7 (495) 939 25 98 E-mail: losev@imech.msu.ru piljugin@inmech.msu.su
ISTC Senior Project Manager:	NIETZOLD Dietrich
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (499) 978 01 10 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

International scientific interest has shifted a few years ago to the area of flights with return to the Earth with planet samples, i. e., to missions that consist of an entry into the planet atmosphere of relatively large devices that collect planet samples and of return to the Earth of small capsules. Reduction of the weight of heat protective systems and accepted descent scheme still remain, in this case, the most important problems to be solved. The problems can be solved solely if information about the properties of the medium surrounding a capsule is sufficiently full and the heat protection system materials and construction are chosen with a thorough analysis of the environment properties.

The weight parameters of a space apparatus launched to planet surrounded with atmosphere and returning to the Earth can be significantly reduced if gasdynamic braking is applied. This would appreciably lower the fuel consumption in the course of the space apparatus braking at its approach space trajectory portion. If gasdynamic braking is applied, the space apparatus can entry the planet atmosphere at very high velocities (up to superorbital ones). This inevitably enhances the requirements imposed on the efficiency of a heat protection system. Designing of heat protection systems calls for conducting complex investigations in the aerodynamics, thermodynamics, and ballistics areas. This Project suggested recommendations on optimal heat protection and thermal insulation systems, descent scenarios, and choice of space apparatus aerodynamic shapes.

An appreciable role played by the radiative flux in the apparatus return to the Earth with superorbital velocities is a very important specific feature of such missions. Ablation of the heat protection materials (HPM) in this case becomes so significant that the boundary layer separates from the space apparatus (SA) surface. The heat transfer problems must be solved in this case employing the methods of radiation gasdynamics.

Project Objectives

The Project was aimed at development and grounding of the sketch project of mission intended to deliver Mars ground samples to the Earth. The particular purposes of the works within the Project included applied and fundamental investigations.

The applied investigations included the following activity areas:

- development of the concept of mission to Mars with delivery of the Mars samples to the Earth;
- selection of the basic space apparatus shapes optimizing descent to Mars and return to the Earth and SA trajectories; and
- selection of heat protection materials and development of heat protection systems for SA.

Fundamental studies included a series of investigations intended to provide a scientific basis for applied investigations and further development of high-temperature gasdynamics:

- elaboration of thermochemical and radiation-gasdynamic models of shock-preheated mixtures of the Mars and Earth atmospheric gases with the products of ablation of heat-protection materials;
- elaboration of models of high-temperature gas interaction with the SA surface that take into account ablation of the heat protection materials and surface catalysis;
- experimental validation of the thermochemical and radiation models developed; and
- numerical analysis of the aerodynamic and heat exchange parameters of the chosen SA configurations based on the physicochemical models developed.

Description of the Works

The work accomplished within the Project included theoretical and experimental investigations.

The theoretical studies were performed with the use of simplified engineering methods and contemporary numerical techniques of modeling high-temperature gas flows based

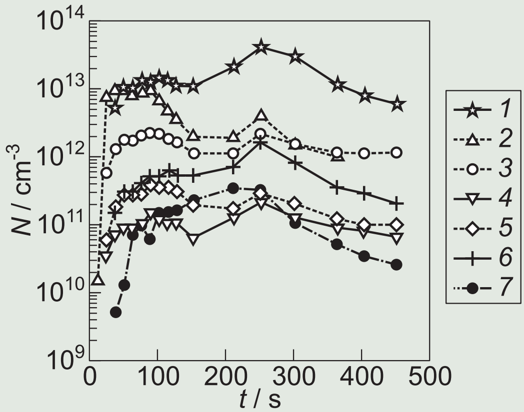


Figure 1: Concentrations of atoms injected from the AT-1

on the Navier–Stokes equations. The elaborated thermochemical and radiation models took into account all the basic physical and chemical processes occurring in the gas and on the surface flown around with the gas that affect the aerodynamic characteristics and heat exchange parameters of mission SA. The termochemical and radiation models were provided with local data bases on thermodynamic, transport, kinetic, and radiation gas properties based on the global databases and an analysis of publications and experimental results.

An electric-discharge shock tube UT-1, pulse setup IY-1M TsAGI, induction plasmatron IPG-4 IPM RAS, and a number of tests facilities at TsNIIMash were used to perform experiments. The experimental results were used to investigate the problems considered, verify, and improve the numerical models, and refine the parameters of the thermochemical models.

The Project presented the technique and results of complex investigations of black-reinforced plastic stability to impacts of high-enthalpy flows, evaluated convective and radiative heat exchange parameters, and the values of the thermal protection shield thickness assessed for a descending apparatus with Mars ground samples that enters the Earth atmosphere after the mission.

The calculated distributions of radiative heat fluxes over the head surface of the reentry apparatus were incorporated in the engineering method and the values of the radiative heat flux component associated with the nonequilibrium nature of the physicochemical processes taking place in the shock layer were specified more correctly. This permitted the thickness and weight of the thermal protection system of the ship returning to the Earth to be assessed.

Ablating heat protection materials are usually used in the heat protection systems of space vehicles entering atmosphere at high velocities. Heat exchange at high altitudes at which the gas flow in the boundary layer is essentially non-equilibrium was calculated with allowance for the joint effect of the decomposition products injected in the boundary layer and finite catalytic activity of the surface (Fig. 1).

Conditions of descent apparatus flight in the Earth atmosphere along two descent trajectories were analyzed. A gas-phase chemical model chosen to describe the flow in the shocked layer with account taken of ablation of the carbon-containing heat protection material included 21 components: O, O_2, N, N_2, H, H_2, C, C_2, NO, CO, C_2H, CO_2, C_3, C_2H_2, NO^+, O_2^+, N_2^+, O^+, N^+, H^+, and e^-. Several models of thermal kinetics were considered to assess the effect of thermal nonequilibrium on the convective and radiative heating of descent apparatus. These thermal kinetics models took into account various mechanisms of exchange between the internal degrees of freedom. The chemical kinetics model included dissociation and recombination of neutral species, exchange reactions, associative ionization, ionization by electron impact, recharging reactions, and ion–molecular reactions. The effect of thermal nonequilibrium on the rates of chemical reactions was also taken into account.

Based on the analysis of trajectory data, parameters (full enthalpy, stagnation pressure, velocity gradient at the critical point) governing the heat transfer in a capsule (in the form of a flat disc 380 mm in diameter) of a SA returning from Mars and descending in the Earth atmosphere along a ballistic trajectory were evaluated. A multiparametric calculation analysis of the regimes of VGU-4 setup operation was performed in order to attain subsonic air flows with the maximum stagnation enthalpy as high as 60 MJ/kg, needed to simulate the actual heat transfer to the surface of a SA returning from Mars. Samples of the ablating thermal protection material supplied by the Babakin Research Center were fabricated; their ablation rate in high-enthalpy subsonic air flows was studied in the VGU-4 plasmatron. The technique for studying thermochemical stability of heat protection material in the VGU-4 plasmatron was worked out; it included double heating of the material with intermediate cooling.

Two-dimensional radiation gasdynamic codes (IPM and TsAGI) were verified. The codes made it possible to solve two-dimennsional (2D) gasdynamic problems and to calculate radiation parameters under conditions when the radiative and convective heat transfer processes are coupled.

Obtained Results

Comprehensive engineering calculations of gasdynamics and heat transfer in the course of descent of two SA configurations along two entry trajectories (entry velocity V_∞ = 11.65 km/s and entry angles of 6° and 11.8°) were performed. The heat and radiative heat fluxes and the rates of thermal protection material were calculated. Although the apparatus shapes differed significantly, the overall heat flux values were comparable and amounted to about 7 or 8 MW/m^2. The radiative heat flux calculated in the equilibrium approximation can amount to ~ 30% of the overall heat flux. Calculations of black-reinforced plastic ablation and of pyrolysis front propagation inward the thermal protection shield demonstrated that the ablated layer Δ was ~ 0.4–0.6 mm and the carbonized layer thickness Δ_{pyr} ~ 4 or 6 mm in all the cases considered (Fig. 2).

The weights of thermal protection layers (black-reinforced plastic and KSSK material) were: 1.5 and 0.5 kg at the face surface, 0.6 and 0.3 kg at the lateral surface, and 0.55 and 0.33 kg at the bottom surface. The weight of whole heat protection system of the descent apparatus was 3.8 kg.

The basic mechanisms responsible for generation of nonequilibrium radiation in the band

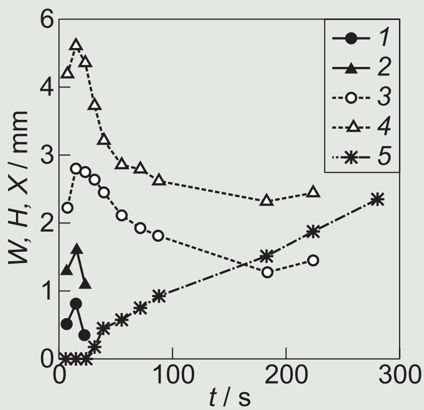


Figure 2: Measured widths W sample surface derived from the time sequence of boundary layer spectra: (2 — Swan C2 bands; 4 — Na line Na) and distances H (1 — Swan C2 band; 3 — Na line); 5 — linear entrainment of carbon filled plastic

systems of N_2^+ (Meinel) and N_2^+ (1–) ions in air flow behind strong shock waves at their propagation velocities exceeding 8 km/s were ascertained. The contribution of electron impact to the kinetics of physicochemical processes (vibrations, dissociation, ionization) and of population of the electron-vibrational states of molecules and molecular ions, of the electron states of atoms and atomic ions in the relaxation zone behind the shock fronts in hypervelocity flows was demonstrated. A model of nonequilibrium emission due to transitions to ground states of N and O atoms and a model depicting the effects of photoionization and photodissociation ahead of the shock front were elaborated.

Specific features of the ionization and radiation processes in shock waves spreading at velocities that exceed 8 km/s were studied experimentally. The ionization and emission levels in the shocked layer at high velocities and at local thermodynamic disequilibrium in the gas differed drastically from their equilibrum counterparts. The aforesaid processes were calculated with the use of an approximate numerical model (Fig. 3).

Two models of thermal protection material ablation were elaborated. The simpler quasi-stationary model assumed that preheating and decomposition of the heat protection material proceeded in the quasi-steady regime in terms of the parameters at the outer heat protection layer surface, while the gas – decomposing material system was in thermochemical equilibrium at the surface temperature. Closure of the quasi-stationary decomposition model necessitated formulation of the mass elemental composition of the protection material and its enthalpy only. The other, more sophisticated, model of thermal protection material ablation took into account the unsteady material preheating. It assumed that the phenol resin pyrolyzed completely at a fixed temperature $T_{pyr} \approx 800\ldots1200$ K with a carbonization number K = 0.5 and that the gas–solid system was thermochemically equilibrated at the heat protection material surface. Unsteady one-dimensional preheating of the thermal protection material was calculated in this model in parallel with calculation, along the descent trajectory in the Earth atmosphere, of the flow around the space apparatus and heat exchange in it (Figs. 4–6).

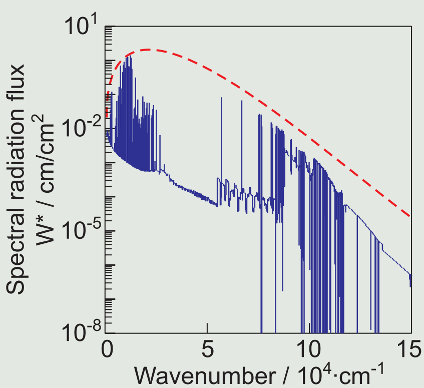


Figure 3: Spectral ("line-by-line") radiation flux to the SA surface. Calculations were performed with the use of the IPM-RGD-1D-EQ code for the 18th second after a segmental-cylindrical RSV enters the vicinity of the critical stream line. Calculations were made at 500 000 spectrum points (spectral intensity of blackbody radiation at the temperature of the surface)

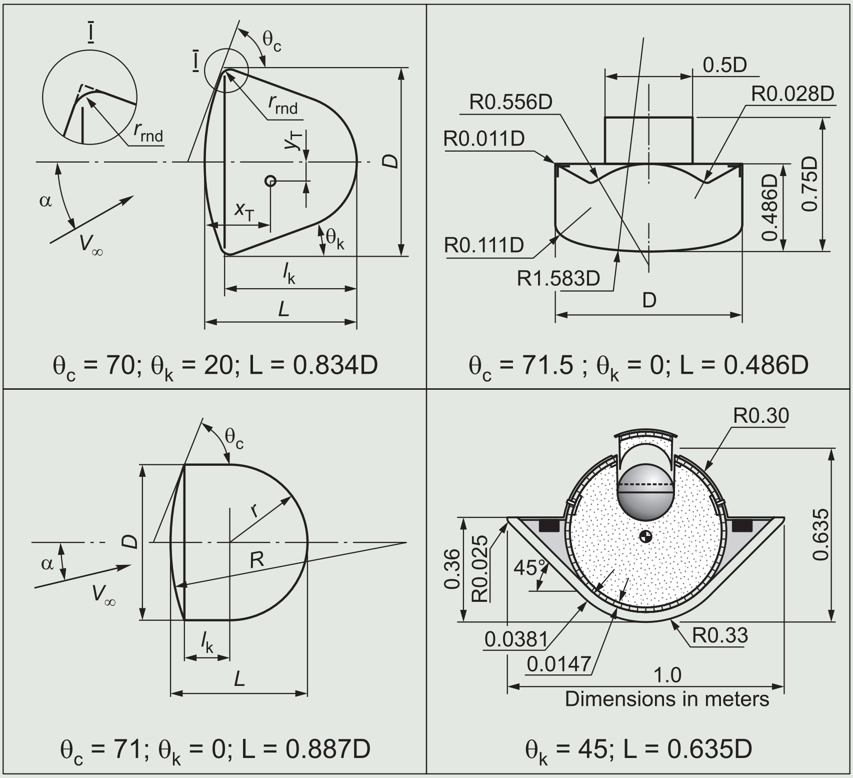


Figure 4: Shapes — candidates for the SA to be landed on Earth (ELA)

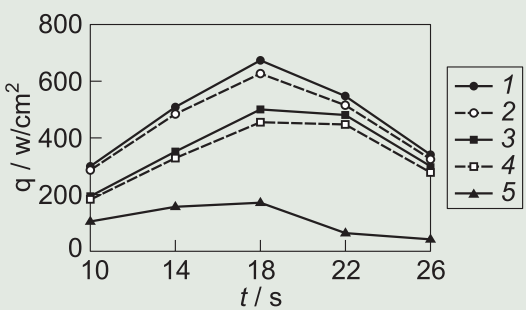


Figure 5: Dynamics of the convective, radiation, and overall heat fluxes at the stagnation point in terms of the time of Earth descent SA entry in the atmosphere. Solid lines — nonablating surface and dashed lines — ablating surface

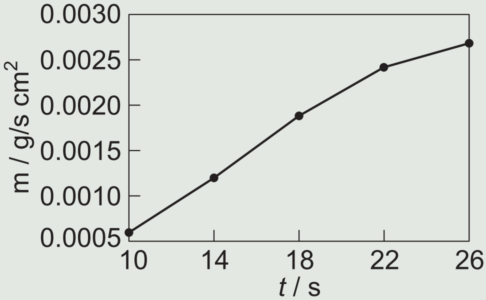


Figure 6: Dynamics of the ablation rate at the critical point in terms of the time of Earth descent SA entry in the atmosphere

Project Number:	#2365
Full and Short Title:	Solar-Powered Rocket Engine (Using Hydrogen and Oxygen Fuel) with a Purpose of Shifting Satellites from Low Earth Orbit to Stationary Orbit **Solar-Powered Rocket Engine**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	280,000 € (EU)
Commencement date:	January 1, 2005
Duration:	24 months, extended by 5 months
Leading Institute:	Keldysh Research Center, Moscow, Russia
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
Supporting Institutes:	No
Collaborators:	EADS SPACE Transportation S.A., Paris, Sedex 16, France (Watillon P)
Project Manager:	POPOV Sergey Alexandrovich
Contact Information:	Phone: +7 (495) 459 96 97 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru
ISTC Senior Project Manager:	RYZHOVA Tatiana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (499) 978 36 03 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

A considerable fraction of modern orbital devices function on high-energy orbits, including geostationary ones. The use in the inter-orbital transportation facilities of nontraditional propulsion systems such as solar-powered rocket engines would significantly extend the capabilities of launchers that deliver payloads to geostationary and other remote orbits. The use of solar energy permits much higher specific thrust impulse values to be attained compared to their values provided by the traditional chemical liquid rocket engines (LRE) and solid propellant rocket engines (SPRE).

Project Objectives

The Project was aimed at developing a conceptual design of the in-flight demonstrator of a solar-powered rocket engine based on multiple-regime rocket engine with electrically heated thermal accumulator that utilizes for thrust generation both the solar energy converted into electric power by photoelectric cells and the chemical energy of cryogenic fuel components (hydrogen and oxygen).

Description of the Works

The following technical approach was used to attain the Project goals:

(a) The range of variation of such engine characteristics as thrust value, operation regimes, energy and weight perfection depending on the ballistic ascent scheme, launcher rockets used, and characteristics of the space apparatus launched, was ascertained.

(b) Requirements imposed on the engine characteristics were formulated based on the analysis of the results obtained, with allowance for feasibility of high-efficiency engine application in combination with various ascent facilities.

(c) Variants of lay-out and schematic solutions for the engine and its systems and units were determined by design-project methods based on the prescribed engine characteristics, calculation methods were employed to distribute the requirements imposed on the characteristics and parameters of particular engine systems and units.

(d) A possible pattern of the engine systems and units was determined by the design-project methods according to the requirements imposed on them, the main technological solutions were grounded by calculations.

(e) Efficiency of the technical solutions suggested for such key devices as the combustion chamber and thermal accumulator was grounded by experimental methods. To this end,

• a model of the multiple-regime combustion chamber operating at a hydrogen temperature at the inlet ranging between 1300 and 1500 K was designed, manufactured, and subjected to fire tests; and

• a model of the heating thermal accumulator zone was designed and manufactured; its thermal efficiency was tested at temperatures of up to 2000 K.

(f) The composition and lay-out engine scheme were refined and the conceptual project was elaborated based on the results of design-project, calculation, analytical, and experimental studies of the engine systems and units.

Obtained Results

1. The results of an analysis of the possible launcher rocket variants with the top stage on the basis of a solar-powered thermal rocket engine starting from the Kourou launching site suggested that it is expedient to focus on launcher rockets of different carrying capacity: from the Soyuz-ST rocket and its modifications, as the easiest variant, to rockets of the Arian-5 family, as the heaviest variant.

2. The chosen multiturn and multipulse scheme of space apparatus transfer from a low near-Earth orbit to a geostationary one with the aid of a top stage based on a solar-powered thermal rocket engine allows this engine with a limited thrust to be efficiently used.

3. As applied to the multipulse transfer scheme, a concept of a solar-powered thermal

rocket engine with an electrically heated thermal accumulator and with afterburning of the heated hydrogen was accepted as the most suitable for space apparatus transfer from a low near-Earth orbit to a geostationary orbit within 30 or 60 days. It warrants the minimum sizes of the fuel compartment in the top rocket stage.

Comparison of the optimal single-regime and double-regime solar thermal rocket engine versions indicated that if the launcher rocket starts from the Kourou launching site and if conventional solar battery, whose mass is included in that of the energy-propulsion system, is used to power the thermal engine, it is expedient to apply the simpler single-regime engine version. It operates solely in the regime with hydrogen afterburning at a constant ratio of the flow rates of fuel components K_m and a constant average temperature of heated hydrogen in the thermal accumulator (T_{av} = 1500 K).

Calculations of the scaling effect of the single-regime solar thermal rocket engine on effi-

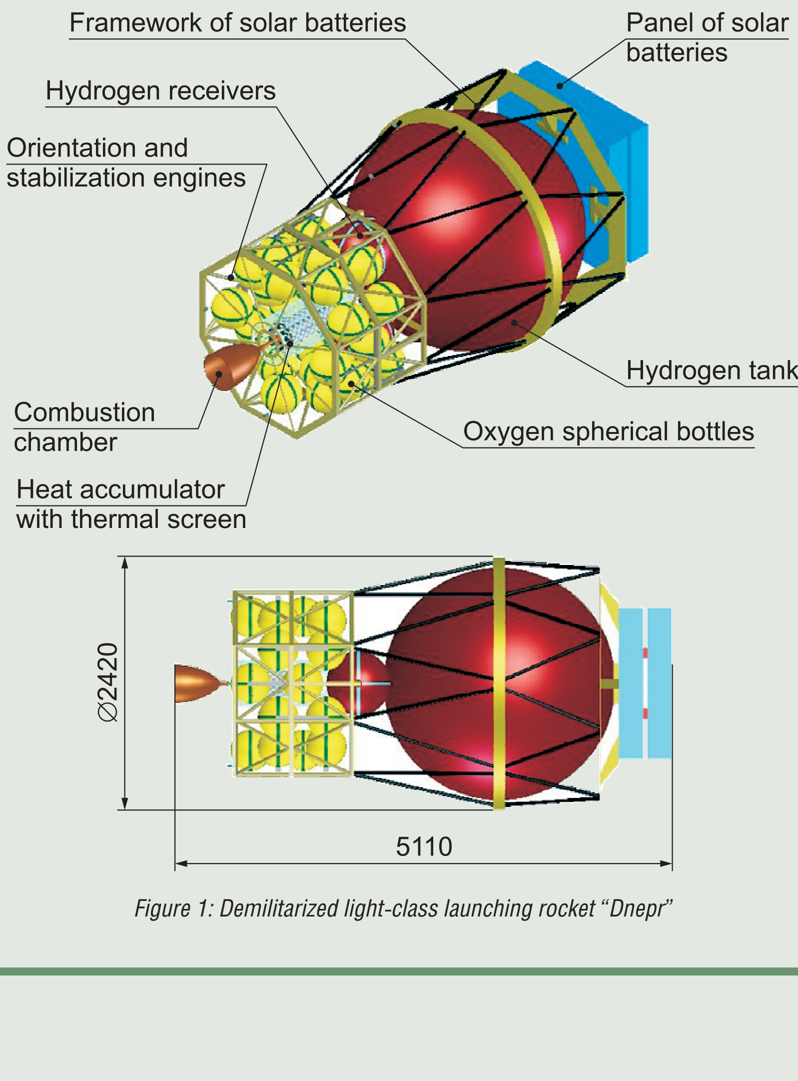


Figure 1: Demilitarized light-class launching rocket "Dnepr"

ciency of its operation indicated that the optimal engine size that fits the top stage of the Soyuz-ST launcher rocket corresponds to the hydrogen flow rate m_{opt} ≈13 g/s, while for the Arien-5 rocket top stage m_{opt} ≈ 26 g/s.

The basic solar rocket engine characteristics were determined for the series of launcher rockets considered with account taken of the possibility of unifying their top stages.

The requirements imposed on the basic systems and units of a solar thermal rocket engine: main engine and its aggregates, additional engines with electrical heating, orientation and stabilization engines, aggregates of fuel components feeding, and the electric power system, were formulated based on the characteristics of the solar-powered thermal rocket engine.

Project-design and calculation-analytical investigations performed to ground the accessible energy and mass characteristics of the solar thermal rocket engine units and systems allowed appraising the state of the solar thermal rocket engine and the top launcher stage under conditions of extended scatter of heat fluxes.

4. The rational composition of the in-flight engine demonstrator and its characteristics were suggested based on parameters of the systems and units of the solar thermal rocket engine analyzed from the point of view of the importance of their demonstration in the space experiment.

5. The requirements imposed on basic systems and units of the in-flight engine demonstrator (the engine itself (combustion chamber and thermal accumulator), orientation and stabilization engines, hydrogen pump and compressor, receiver, locking and regulating devices, and electric power system) were formulated based on the characteristics of the in-flight engine demonstrator.

6. Exploration of the possible versions of launcher rockets and cosmodrom showed that in terms of the “cost-efficiency” criterion the following variants deserve consideration for launching the solar thermal rocket engine demonstrator:

– Russian launcher rocket of the medium class Sojuz-ST started at the Kourou launching site; and

– Russian demilitarized light-class launching rocket “Dnepr” (Fig. 1) started from the Baikonur cosmodrom.

Project Number:	#3506
Full and Short Title:	Arrays of Superconducting Direct Detectors for Supersensitive Imaging Radiometers of 1.0 – 0.2 mm Waveband Region **Submillimeter Detector Arrays**
Tech Code / Area / Field:	INF-ELE / Information and Communications / Microelectronics and Optoelectronics PHY-SSP / Physics / Solid State Physics INS-DET / Instrumentation / Detection Devices SAT-AST / Space, Aircraft and Surface Transportation / Astronomy
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding :	467,326 € (EU)
Commencement date:	March 1, 2007
Duration:	36 months
Leading Institute:	Russian Academy of Sciences / Institute of Radioengineering and Electronics, Moscow, Russia
Contact Information:	Phone: +7 (495) 629 35 91, 629 35 74 Fax: +7 (495) 629 3678 E-mail: gulyaev@cplire.ru Website: http://www.cplire.ru
Supporting Institutes:	Institute of Microelectronics Technology and High Purity Materials, Chernogolovka, Moscow reg., Russia
Collaborators:	California Institute of Technology / Jet Propulsion Laboratory, Pasadena, CA, USA (McGrath W. R., Karasik B.) Cardiff University, Cardiff, UK (Mauskopf P) European Space Agency, Noordwijk, The Netherlands (Armandillo E.) Forschungszentrum Jülich GmbH / Institut fur Microstructure Research, Jülich, Germany (Urban K) National Astronomical Observatory of Japan, Tokyo, Japan (Miyama S.) Physikalisch-Technische Bundesanstalt / Braunschweig Branch, Braunschweig, Germany (Niemeyer J.) State University of New York at Stony Brook / Department of Physics and Astronomy, Stony Brook, NY, USA (Gurvitch M.) Tohoku University / Graduate School of Science, Sendai, Japan (Hashimoto O.)

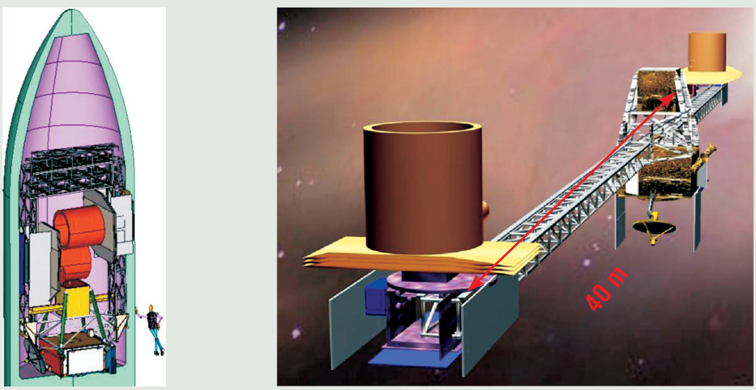
Project Manager: KOVALENKO Alla Grigorievna
Contact Information: Phone: +7 (495) 629 74 32
Fax: +7 (495) 629 36 78
E-mail: alla@hitech.cplire.ru

ISTC Senior Project Manager: TYURIN Igor Alekseevich
Contact Information: Phone: +7 (495) 982 31 96
Fax: +7 (499) 978 36 03
E-mail: tyurin@istc.ru

ISTC Website: http://www.istc.ru

Background

At present superhigh-sensitivity detectors of electromagnetic radiation in the sub-millimeter wavelength range (λ = 1.0…0.03 mm) or terahertz frequency range (f = 0.3…10 THz) are actively investigated and developed. Being combined with various optical (quasi-optical) devices and matching electronic circuits they provide very low radiation losses in the optical telescope parts, high angular and spectral resolution of telescopes at the aforesaid wavelengths, as well as high amplification of the signals received. The interest in them stems from the necessity of creation of new space astronomic observation systems. Among them are: in the first turn, investigations and development of interferometric telescopes, which are space telescopes of the new class capable of observing super-remote astronomic objects (e. g., galactics located at distances of up to ten and more milliard light years from the Earth) with extremely high sensitivity and angular and spectral resolution in the terahertz frequency range (submillimeter wavelengths). During the last four or six years such studies and developments are actively performed



(*a*) (*b*)

Figure 1: Telescope-interferometer of the far infrared range (SPIRIT) NASA: (a) packed before putting into orbit; and (b) unfolded on the orbit to the working state. Mirror antennas are protected with cold glasses transparent for radiation and serving for cooling antennas

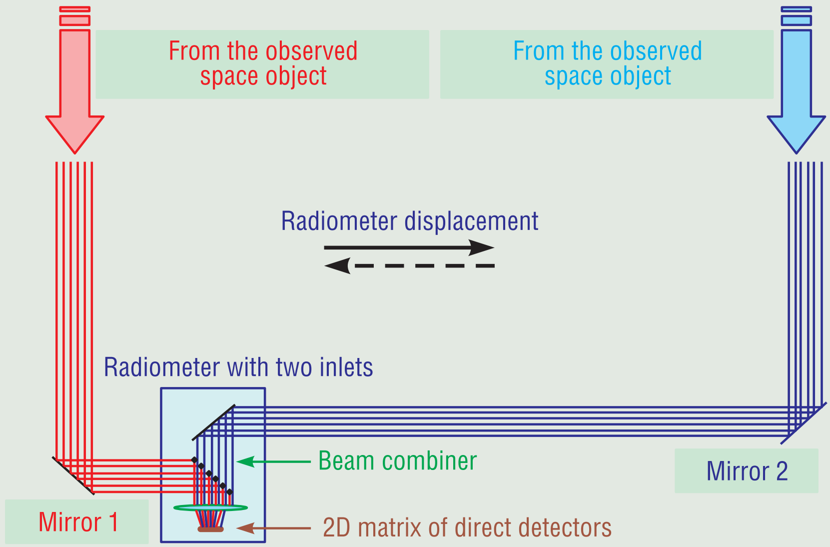


Figure 2: Simplified optical scheme of the SPIRIT telescope-interferometer. The optical interferometer basis length is 40 m (see Fig. 1). The interferometer is of the Michelson type. As the radiometer moves along the optical basis, a set of fringe patterns is recorded the number of which corresponds to the number of direct detectors. Fringe pattern treatment yields frequency spectra and high-resolution images of the objects observed

in USA, Europe, and Japan, Russia is also involved in these studies for the last four or five years. Figures 1 and 2 present an example of of such an interferometric telescope, NASA space infrared interferometric telescope (SPIRIT). A similar project called “Far infrared interferometer (FIRI)” is included in the program of the European space agency.

Arrays of superconducting superhigh-sensitivity direct detectors are to be important components of such telescopes. In this Project nanobolometers-sensors operating at the border of the superconductor transition (SCT) were selected as detector units most suitable for the aforesaid purposes.

Project Objectives

The main objective of the Project was development of the construction of superconducting nanobolometer sensors and technology of their manufacturing.

Description of the Works

Nanobolometers applied in the present Project operate due to heating of the electron gas in the bulk of a thin superconductor film. The limiting sensitivity (NEP) of detectors using the bulk effect is known to be proportional to the square root of their working volume *v*. Therefore, various technology methods were worked out to fabricate radiation absorbers for bolometers whose size ranges from tens of to 100 or 200 nm. The steep temperature dependence of the thin-film sensor resistance at the superconductor transition border is used in detecting radiation with such bolometers. This is why the more common term used for such nanobolometers is SCT nanobolometer (sensor operating at the superconductor transition border).

Two types of SCT nanobolometers applied in detecting submillimeter radiation are distinguished: (a) suspended on diaphragms and (b) incorporated in antennas ones. The ex-

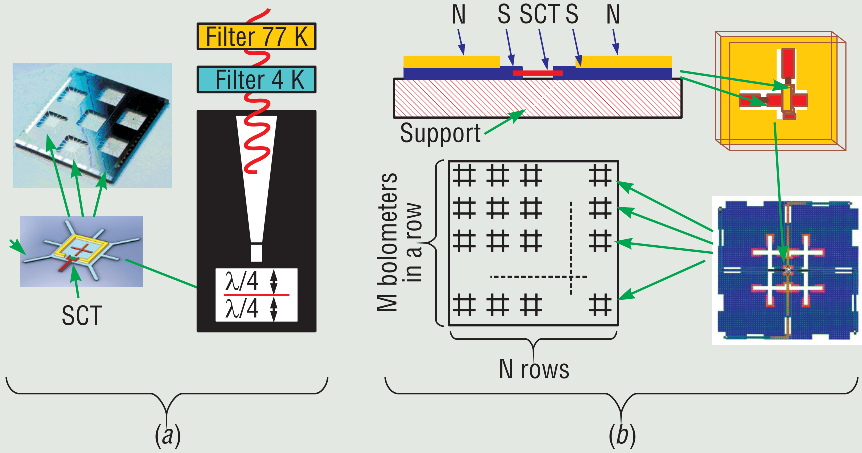


Figure 3: Two SCT-nanobolometer types: (a) nanobolometers fixed on diaphragms, (b) nanobolometers incorporated in slot antennas: C — contacts made of superconductor with a high critical transition temperature that provide Andreev reflection of hot electrons with the purpose of precluding their energy loss due to diffusion through the contacts; and H — coating with a film of a normal metal, e. g. gold, of the superconducting antenna portions to reduce the THz radiation loss in it

amples are shown in Fig. 3. The former differ from the latter in the following. Radiation in former nanobolometers is absorbed by the diaphragm, it is heated and the SCT measures its temperature. Diaphragm is lacking in the latter nanobolometers, SCT is incorporated in the antenna and serves both as an absorber and temperature gauge. The efficiency and, hence, sensitivity increase by more than the order of magnitude in this case. Therefore the second SCT nanobolometer type was chosen for studies in the present Project.

The other objectives of the Project were development of the technology for fabrication of SCT nanobolometers of the type chosen, creation of a setup in which the characteristics of the SCT nanobolometers fabricated had to be measured, designing the detector arrays based on SCT nanobolometers, modernization of the method of signal multiplexing in the arrays of direct super-low-temperature detectors, and elaboration of arrays of direct detectors with subdiffraction resolution by extending the functional capability of the method of signal multiplexing in the arrays of direct detectors.

1. Development of the construction and technology of fabrication of superconductor SCT nanobolometers

Reasoning underlying SCT nanobolometer design was discussed in the previous Section. It is based on the formula

$$\mathrm{NEP} \propto \sqrt{\nu}$$

This formula suggests that one should strive for as low as possible SCT nanobolometer size. Project team experience and experience of other laboratories in various countries indicates that the technology of fabricating nanometer-size structures is the limiting factor in this case. As a matter of fact, the nanobolometer film thickness must not be much less than the size of a Cooper pair, i. e., of two paired electrons in the particular superconductor. This value for titanium used in this Project to fabricate the film structure of the sensor proper operating at the border of superconductor transition (SCT) is 30 or 30 nm. The smallest

Figure 4: Electron lithographer applied at the laboratory of Project performers in combination with the JSM-6460 raster electron microscope (REM) (Jeol, Japan) equipped with an external lithographic extension NanoMaker made by the "Interface" company (Russia). It is applied to fabricate a microcircuit containing SCT nanobolometer, antenna (in which the nanobolometer is incorporated) and respective cross-connections in a single technological cycle

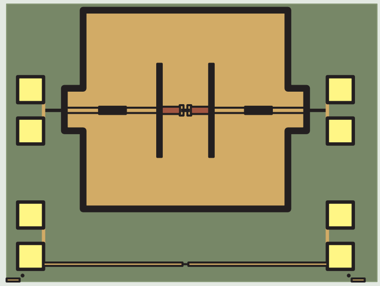


Figure 5: General view (under an optical microscope) of a ready chip of a single receiver unit (at the top). A single SCT-"witness" microstrip structure fabricated in one cycle is shown at the bottom. The "witness" is not included in the antenna, it controls parameters of SCT incorporated in the receiver unit

possible transverse nanobolometer sizes admitted by the electron lithography technology (Fig. 4) were 1 μm × 100 nm. Nanobolometer was considered as a common construction together with the antenna in which it was incorporated (Fig. 5) and fabricated conjointly.

2. Working out of a setup in which characteristics of SCT nanobolometers fabricated are measured

The Heliox AC-V cryostat (Fig. 6) (Oxford Instruments, Great Britain) served as a basis of the measurement setup designed for studies of SCT nanobolometer characteristics. The working temperature controlled with a 10^{-4} accuracy varied from 0.275 K, the accuracy of resistance measurements with the aid of the resistor bridge (Lake Shore Model 370, USA) was 10^{-3}. Typical results of measurement of SCT nanobolometer characteristics are displayed in Figs. 7 and 8. A device with a black-body source of terahertz radiation and with a sweeped temperature introduced in the cryostat was designed and manufactured to measure the spectral characteristics and the limiting sensitivity of SCT nanobolometers (Figs. 9–12).

3. Working out of the detector construction on the basis of a SCT nanobolometer array

The construction of detector arrays with SCT nanobolometers was equipped with an immersion lens which concentrates radiation on the receiving antenna integral microcircuit. A double-slot antenna (see Fig. 5) or a crossed pair of double-slot antennas (see Fig. 3b) were connected to the microcircuit input. Then radiation was directed to microstrip and coplanar lines with SCT nanobolometers incorporated in them, as shown in the above indicated figures. Arrays of a hexagonal or square shape were arranged of such receiving units (Fig. 13).

4. Modification of the method of signal multiplexing in the arrays of superlow-temperature direct detectors

Previously within Project #1239, a method of signal multiplexing was developed, based on parallel detector connection in the array rows (Fig. 14), on reading signals summed up over each row (projections), on rotation of the received images with respect to the arrays, and piling up the sums recorded at various im-

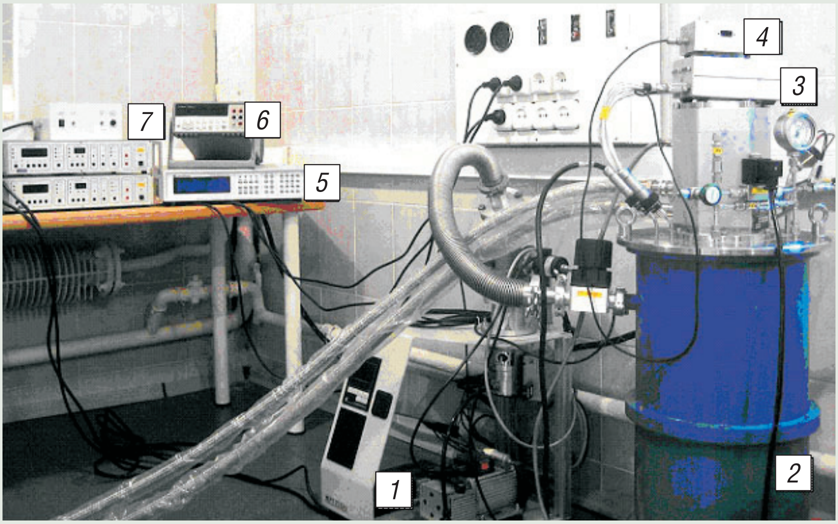


Figure 6: Experimental measurement setup: 1 — pump station; 2 — Heliox AC-V cryostat; 3 — scanner; 4 — DC power source; 5 — Lake Shore Model 370 resistor bridge; 6 — voltmeter measuring VA characteristics; and 7 — thermal controllers

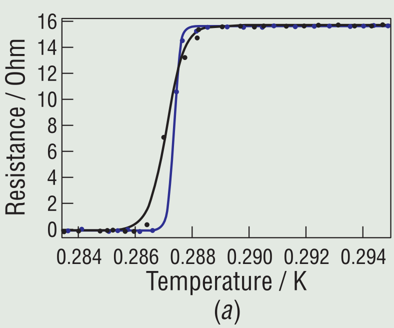


Figure 7: Representative curves of SCT-nanobolometer transition from the normal state to superconducting state

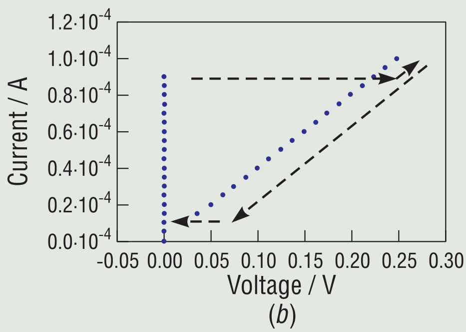


Figure 8: Representative volt-ampere characteristic for SCT-bolometers (with hysteresis)

age angular postions with respect to the arrays. The received images were reconstructed from sets of the recorded projections by the convolution and reciprocal-projection method similar to the method applied in medical X-ray computer tomography. The method made it possible to drastically reduce the number of wires connected to the detectors in the cryostat, to significantly diminish the number of reading SQUID amplifiers, and to simplify the circuit of bolometer connection to amplifiers as compared to the other known multiplexing methods. This is important for lowering cryostat overheating with a great number of conductors. Moreover, this method improved the signal-to-noice ratio in the reading circuit

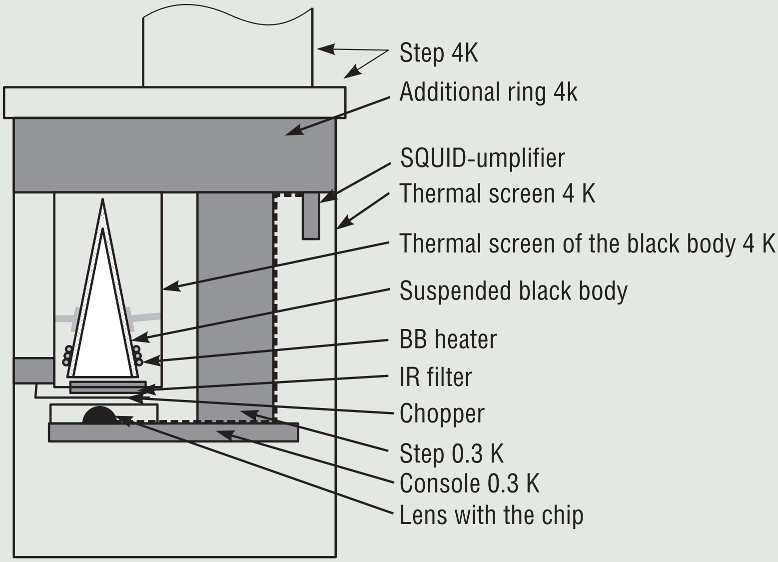


Figure 9: Inset in the cryostat: black-body emitter with a temperature varied from 3 to 15 K and console 0.3 K for mounting a lens with a receiver unit chip

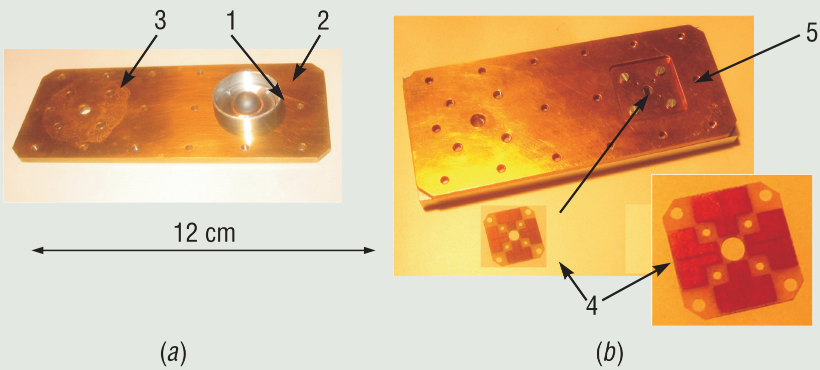
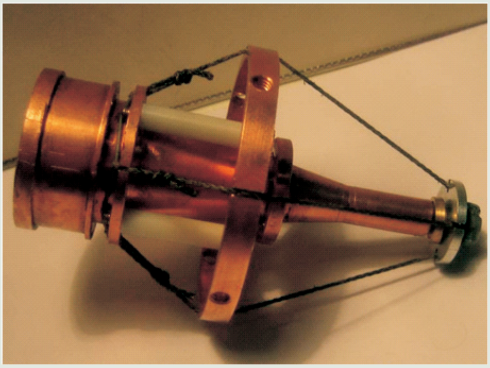


Figure 10: Photo of the console with an integral lens antenna mounted on it: (a) viewed from above and (b) viewed from beneath: 1 — silicon dielectric immersion lens; 2 — aluminum blend; 3 — area for mounting to the cooler; 4 — printed circuit plate for connection to bolometer; and 5 — the site where the printed circuit plate is mounted



(*a*)

(*b*)

Figure 11: Photo of the cone black-body absorber (BB) (a) and absorber cone coated inside, with the Ecosorb CR-110 absorbing layer (b)

Figure 12: Photo of the chopper based on a constant magnet with a movable frame. The chopper is fixed on the black body thermal screen (see Fig. 9)

due to reduction of the number of amplifiers and supply to each of them a sum of detected signals rather than a single signal.

In the present Project, it was suggested to improve the multiplexing method by combining the above described multiplrcing method with multiplexing by the offset frequency separation method (Fig. 15). The essence of the suggestion reduces to bias supply to the circuits with parallel-connected bolometers (see Fig. 14), but from the bias block at various frequencies through a single wire, rather than from an U_{bias} source suplying identical bias via individual wires. The bias in this method was supplied through LC-filters according to the well known circuit shown in Fig. 15) in which individual bolometers were replaced by parallel bolometer rows, as in Fig. 14. This allows one to further reduce the number of conductors aplying bias to bolometers and reading the summed-up signals from them. Thus, the number of amplifiers diminishes which entails additional lowering of cryostat overheating.

5. Elaboration of arrays of direct detectors with subdiffraction resolution

The functional capability of the above described method of signal multiplexomg in arrays of direct detectors was extended to elaborate a new approach to imaging with sub-diffraction resolution in radiovision instruments (RVI) in the millimeter wave length and terahertz frequency range, including astronomic telescopes. The sub-diffraction resolution problem arises when the diameter of the diffraction Airy disc in the focal plane of an optical receiving system, telescope in our case,

$$d = 2.44(\lambda{:}D)F$$

(where λ is the working wavelength, D and F are the diameter and focal distance of the pickup antenna or input mirror) is much greater than the working wavelength λ.

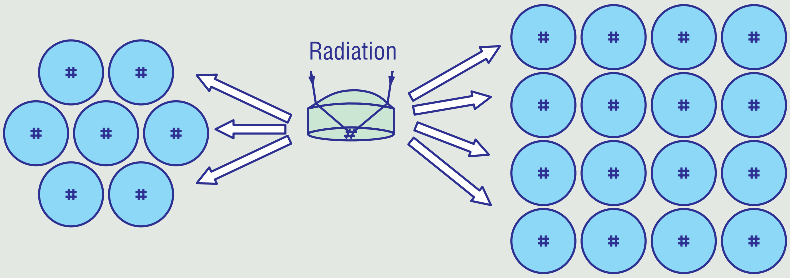


Figure 13: Two sorts of matrices of immersion lenses (hexagonal of the camomile shape and squared) directing radiation to the integral micro-circuits of receiving antennas, i.e., to crossed paired slot antennas and further on to strip and coplanar lines with SCT-nanobolometers incorporated in them, as shown in Fig. 11b

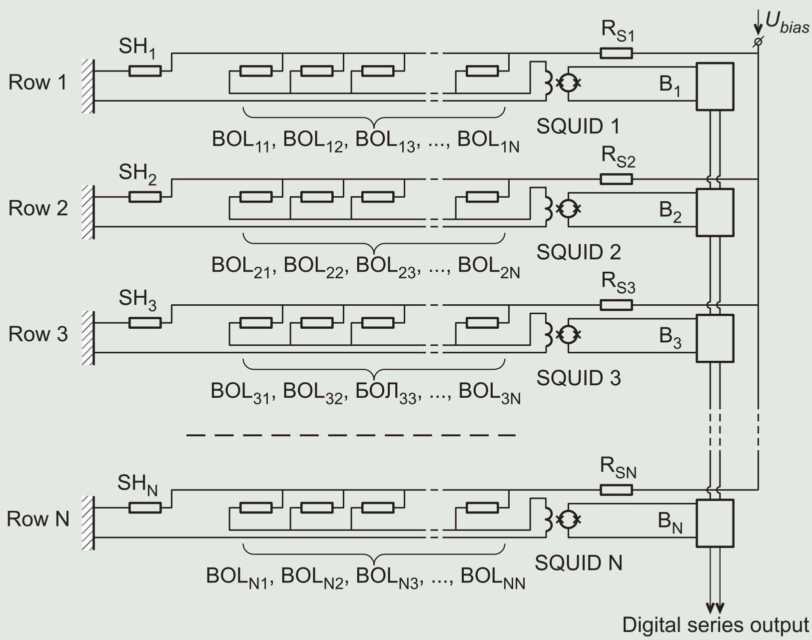


Figure 14: Parallel electric connection of bolometers with output to SQUID amplifiers (N rows with N bolometers in each row): BOL — bolometers with identical resistance RB and temperature of the superconduction transition border; SH — shunts from which a preset bias voltage V is supplied; RS — series resistances of the bias circuits; Ubias — the source of preset bias voltage; and B – electronic blocks of SQUIDs, analog-to-digital converters, and sequential digital data transmission (SQUID feedback circuits are not shown)

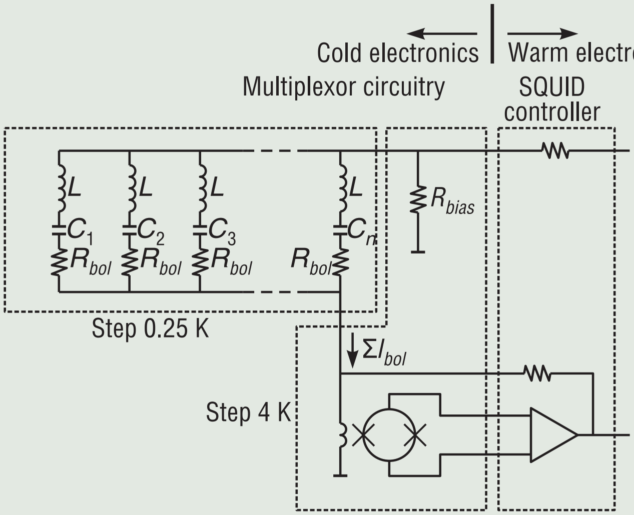


Figure 15: Circuit of signal multiplexing by the bias frequency division

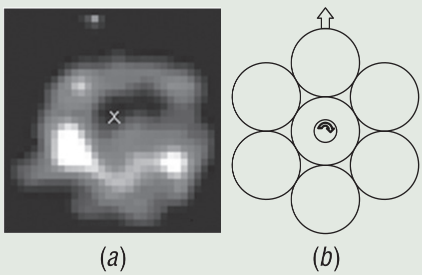


Figure 16: (a) Image of the planetary disc in Σ Eridani star surrounding at the early formation stage observed with the aid of SCUBA-1 of Maxwell telescope at a 850-micrometer wavelength (matrix of 32 × 40 receiving units) that we used as a model for computer simulation of the reconstruction procedure; ☒ — image center; and (b) structure of a matrix of receiving units in the form of a "hexagonal" chamomile, viewed in direction of the received radiation, ◉ — matrix center

The approach was based on circular scanning with the aid of a two-dimensional array of receiving RVI units with a relative circular array displacement with respect to the image (with or without its rotation) in their common plane with a small eccentricity between them. Such a scanning pattern is exemplified in Figs. 16 and 17. Signals recorded by the array detectors are the scanning results; each of them is proportional to the integral of the product of two functions representing distribution of the image field of the object f(x,y) observed with RVI and optical (quasi-optical) transfer function belonging to every detector:

$$r_M(\theta_j) = \int_{-R_M}^{R_M} \int_{-R_M}^{R_M} f(x,y) \cdot H_M[U(\theta_j, x_M, y_M, x, y), V(\theta_j, x_M, y_M, x, y)] dxdy.$$

The second function takes into account the entire pathway of the received radiation beams from the RVI input to each detector, including the effect of diffraction and joint circular scanning. The received image is found by solving the inverse ill-posed set of integral equations formulated above. Computer modeling with the use of the aforesaid approach (Fig. 18) shows that it allows the resolution to be improved almost ten-fold. The method is ori-

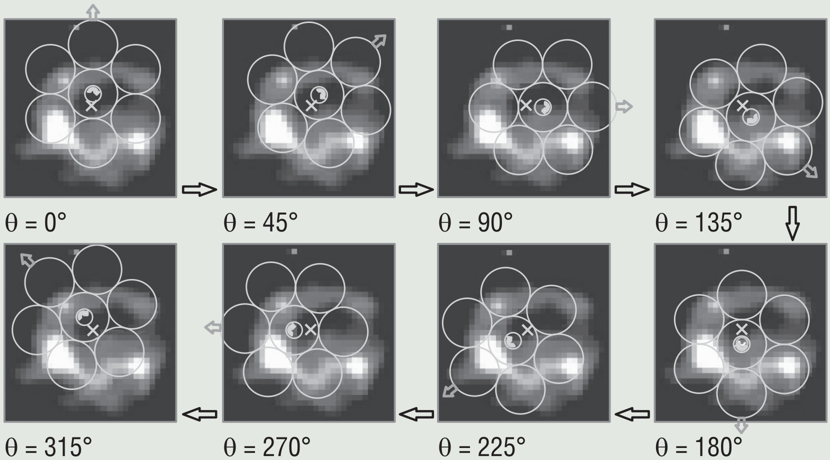


Figure 17: Strategy of circular scanning with rotation of the receiving matrix with respect to the image in their common plane. This is more convenient for perception, in reality, the image rotates with scanning with respect to the fixed matrix, e.g., in a cryostat with the use of a K-mirror; 0^o–315^o — angular positions of the receiving matrix relative to the image. An eccentricity shown in the figure amounts to about $0.5R_d$ where R_d is the receiving unit radius

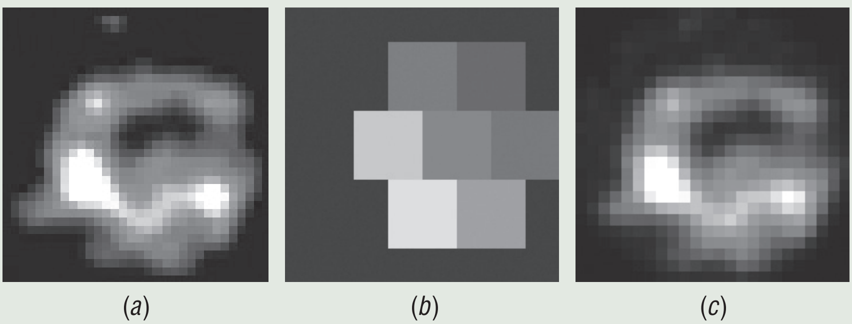


Figure 18: Computer simulation of the image reconstruction procedure as applied to the BTA telescope of the Special Astrophysical Observatory RAS: (a) original image (see Fig. 16a); (b) one of the steps of diffraction dispersion imitation: image (a) multiplication by the modified diffraction function (1) and summing up over the areas of the hexagonal "chamomile" units (see Fig. 16b); and (c) the result of solution to equation (1) in terms of f(x,y) at the reconstruction matrix dimensionality 24×24 pixels

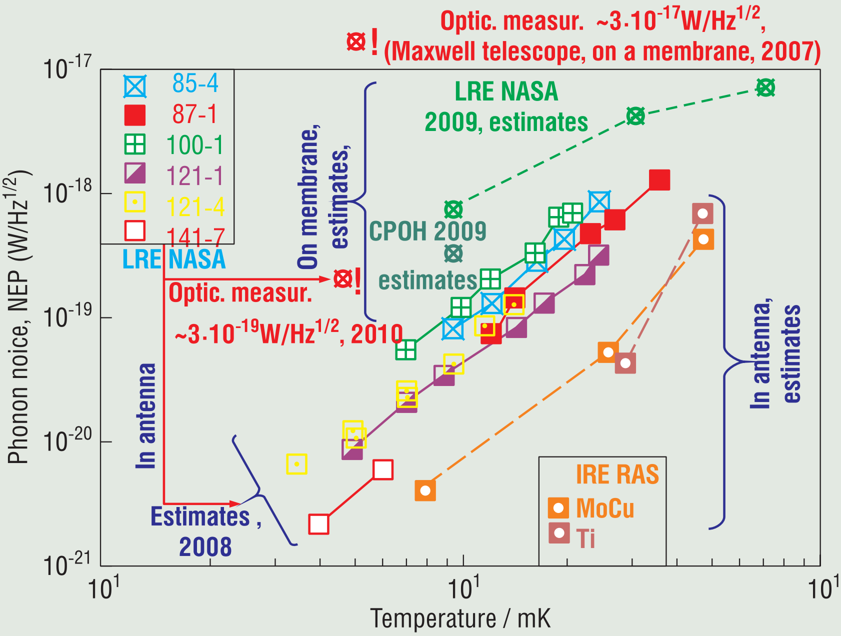


Figure 19: Summary comparative graph of the best estimated and measured limiting values of sensitivity (NEP) of superconducting bolometers with sensors at the transition border (SCT) in terahertz frequency range (see text for explanation)

ented to application in astronomic telescopes, safety systems, and medical diagnostics.

6. Potential capabilities of super-conducting direct detectors as applied to supersensitive radiometers operating in the terahertz frequency range

The results of measurements of the SCT nanobolometer resistance *R*(*T*) temperature dependence (Section 2) made it possible to assess the limiting nanobolometer sensitivity (NEP). Evaluation was performed for titanium SCT nanobolometers by jointly solving the electron energy balance equation and equation specified by the *R*(T) dependence. The results are shown in Fig. 19. The figure displays also the results of similar evaluation made for SCT nanobolometers on the basis of double-layer Mock films, which we studied previously, and data reported by other authors. The data of direct optical measurements of SCT nanobolometer NEP are also presented. SCT nanobolometers of two sorts are considered, they are conditionally indicated in the graph "on a diaphragm" and "in antenna" (see Objectives of the Project section for details). Of special interest is the difference, amounting to one and a half order of magnitude, in the assessed and optically measured NEP values, not in favor of the latter. This points to necessity of further improvement of the construction and technology of fabrication of the SCT nanobolometers in question.

Obtained Results

• The integral construction of superconducting nanobolometer sensors and receiving units on their basis was worked out.

• The received sub=millimeter (terahertz) radiation was concentrated in an extremely attainable small volume of the high-efficiency nanobolometer absorber-sensor with the purpose to achieve an extremely small detectable power of the received radiation.

• Selection of the high-efficiency physical mechanism of direct radiation detection was grounded. Detection was based on application of a super-low-temperature (to 0.3 or 0.03 K) superconducting nanobolometer sensor with hot electrons and a weak electron–phonon coupling. The Andreev reflection of hot electrons from electric contacts connecting the nanobolometer sensor to the external electric circuit precluded the diffusion loss of the electron energy to the external circuit.

• First, nanobolometer absorber–sensor prototypes were fabricated and tested; they demonstrated the anticipated efficiency of the direct detectors chosen.

• Second, the received radiation was concentrated within an extremely small absorber–sensor volume *v*, which ensured an extremely high rise of the electron temperature at a given power of the radiation absorbed, and, consequently, the best limiting nanobolometer sensor (direct detector) sensitivity because NEP of this detector is y^{112}. This was attained owing to application of a two-step electromagnetic circuit concentrating submillimeter radiation on the receiving unit. Immersion lens serves as the first step. It accepts radiation from the telescope output and irradiates the matching two-slot antenna, or two such antennas crossed at right angle, positioned at the focal lens plane, inputting, thereby, the radiation energy in the antenna/antennas. The second step was a microstrip or/and coplanar line with nanobolometer sensors of an extremely small volume incorporated in it, the microstrip or coplanar line was excited by a signal from the two-slot antenna.

• First operable prototypes of a nanobolometer absorber-sensor of a small volume of $10 \times 1 \times 0.03$ μm were manufactured.

• The optimal characteristics of the two-step electromagnetic concentration circuit were determined by the electromagnetic computer modeling method.

• The basic device components: aforesaid absorber-sensor prototypes, two-slot antennas, and immersion lenses, were fabricated and tested.

• The scheme and construction of an integral array of receiving units based on superconducting direct detectors (superconducting nanobolometer sensors) and consisting of the above described receiving units proper, multiplexing circuit with bias supply and reading the detected signals, and circuit reconstructing of the image coming with the received radiation and received by the array of detectors incorporated in a radiometer were elaborated. The basic goal functions of the aforesaid array with the multiplexing and reconstruction circuits are:

– first, drastic reduction of the number of external conductors applying bias to the direct detectors which significantly lowers the thermal load on the final refrigerator stage; and

– second, provision of data collection from individual receiving units together with information about the image received, provision of reconstruction of the image received with both the best signal-to-noise ratio and the best spatial resolution in the presence of diffraction limitations due to the optical telescope system and additional devices.

• The convolution and reciprocal projection method developed for medical X-ray computer tomography and the method of received image scanning suggested by the participants of the present Project were employed in the array with multiplexing and image reconstruction circuits.

• The general analysis of the detector devices elaborated within this Project and by other investigators showed that receiving detectors based on superlow-temperature superconducting nanobolometer sensors incorporated in matching antennas and in arrays of similar detectors and on the methods of signal multiplexing and reconstruction of the received image suggested are capable of meeting hardest requirements pertinent to their application in astronomy.

Manned space station

List of Projects

In total, 7 projects were funded by the ISTC Parties.

#0496

"Infrared Telemeasuring Complex of Medical Control of a Cosmonaut"

(Medical Control of Astronaut)

– NIIIT (Pulse Techniques), Moscow, Russia

Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia

MEPhI, Moscow, Russia

#1360

"Development of Advanced Loop Heat Pipes for Thermal Control of Modern Spacecraft"

(Spacecraft Thermoregulation)

– Ural Branch of RAS / Institute of Thermal Physics, Ekaterinburg, Sverdlovsk reg., Russia

#1962

"Engineering of High-Performance Techniques of Oxygen Production and Respiratory Mixed Gases for Space Systems and Public Health Services"

(Oxygen and Mixed Gases Production Technology)

– VNIIEF, Sarov, N. Novgorod reg., Russia

– Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia

#2120

"Development of Key Technical Means for Manned Planetary Missions"

(Technologies for Manned Planetary Missions)

– Keldysh Research Center, Moscow, Russia

– NPO Energia, Korolev, Moscow reg., Russia

– Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia

– Russian Academy of Sciences / Institute of Space Research, Moscow, Russia

– State Enterprise Krasnaya Zvezda, Moscow, Russia\

#3684

"Preparation of an Experiment for Studying the Vortex Method of Suspension Cultivation of Biological Objects under Conditions of an Orbital Space Flight"

(Space Cultivation of Microorganisms)

– State Research Center of Virology and Biotechnology VECTOR, Koltsovo, Novosibirsk reg., Russia

– Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia

#3871

"Thermal Diagnostics Technologies for Development, Verification and Emergency Prevention of Aerospace Structures"

(Thermal Diagnostics of Aerospace Structures)

– MAI (Moscow Aircraft Institute), Moscow, Russia

– Lavochkin Association, Khimki, Moscow reg., Russia

#G-204

"Development of Proposals to Promoting Biological Safety of Personnel Taking Part in Controlling a Spacecraft of the "Shuttle"-Type in Order to Deliver Scientific Equipment and Other Load in Space"

(Biological Safety of Spacecraft Personnel)

– Tbilisi State Medical University / Research Institute of Experimental and Clinical Medicine / Department of Experimental Neurology, Tbilisi, Georgia

Project Number:	#0496
Full and Short Title:	Infrared Telemeasuring Complex of Medical Control of a Cosmonaut **Medical Control of Astronaut**
Tech Code / Area / Field:	SAT-MAS / Space, Aircraft and Surface Transportation / Manned Space Station
Status:	Project completed
Technology Development Phase:	Feasibility study
Allocated Funding:	$50,000 (JP)
Commencement date:	February 1, 1997
Duration:	6 months
Leading Institute:	NIIIT (Pulse Techniques), Moscow, Russia
Contact Information:	Phone: +7 (495) 321 35 01 Fax: +7 (495) 321 48 55, 787 76 86 E-mail: vniia@vniia.ru Website: http://www.vniia.ru
Supporting Institutes:	Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia MEPhI, Moscow, Russia
Collaborators:	NASDA, Tokyo, Japan (Suemitsu T)
Project Manager:	BURYAKOV Vladimir Leonidovich
Contact Information:	Phone: +7 (495) 321 41 88 Fax: +7 (495) 321 48 55 E-mail: danilenko@vniia.ru
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 31 57 Fax: +7 (499) 978 46 37 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

Extension of the opportunities and enhancement of efficiency of medical control and functional man state diagnostics under different conditions of living and activity in closed compartments with the aid of wireless transmission of the psychophysiological parameters controlled is an important problem in the practice of space, prophylactic, and sport medicine.

Previous investigations have shown that the use of infrared (IR) radiation in transmitting medical control information in closed compartments of various destinations is the most promising type of wireless communication. Application of modern achievements in IR pulse technology as a basis for development of an IR telemetric medical control system brings about a new quality (in terms of reliability and comfort) of the solution to the aforesaid problem both from the medical point of view and from the point of view of application of advanced circuit-engineering, technological, and design solutions.

NIIIT (Research Institute of Pulse Engineering) has developed, in cooperation with the Institute of Biomedical Problems RAS and MEPhI (Moscow Engineering Physics Institute), a proposal aimed at a creation, based on achievements in the area of IR pulse telemetric technology and circuitry, a multipurpose telemetric system for medical control of cosmonauts. The system would provide wireless control of psychophysiological human being parameters in onboard manned compartments of flying vehicles.

Focusing of the Project on the most complicated onboard (space) conditions of application of the IR telemetric medical control complex permits its other operation conditions to be covered (in terms of their rigidity) and feasibility of extended application of the Project results to be warranted.

The technical and economic ground was approved as the first Project implementation stage.

Project Objectives

The objective of the first stage of the Project aimed at creation of a multipurpose telemetric system for medical control of cosmonauts was to provide technical and economic grounding (TEG) of Project realizability.

Description of the Works

To implement the TEG of the Project, computational and theoretical investigations that demonstrated suitability of the physical idea of IR telemetry to a model of a manned space vehicle compartment and its realizability at the most critical sites and positions of an cosmonaut on its board were performed.

Methodological and technical approaches to solution of the Project tasks were considered. The solutions suggested were based on the results of scientific and engineering studies performed previously by the specialists of the Institutes participating in the Project, on patent investigations, and results of calculations of IR radiation spread in a closed volume of a manned orbital station compartment.

The methodology of IR telemetric complex designing rests on the use of the pathogenetic principle of medical control that provides diagnostics of the most probable negative states (syndromes) caused by the effect of space flight factors. The diagnostics efficiency depends on the composition of the set of psychophysiological parameters controlled, succession of the medical control methods used, and the system openness principle, i.e. on the possibility of introducing additional medical control parameters and new diagnosis methods.

Patent and technical investigations were performed in the course of Project TEG implementation. They included:

• review of publications in the IR-telemetry area available in the literature;

• search for, selection, and analysis of the patent and scientific-engineering information relevant to the Project topic; and

• assessing patentability and patent purity of the objects.

Individual blocks and units of the complex (its receiving and transmitting parts) were successively worked over to determine the structural composition of the complex as a whole and to optimize its design. The effects exerted by the external destabilizing factors pertinent to conditions of lodging and functioning of the complex in space vehicle compartments were taken into account.

Technical and economic calculations were performed to assess the cost of the Project the goal of which was to create an experimental specimen of the IR telemetric complex for medical control of cosmonauts and its ground testing under conditions as close as possible to those inherent in orbital manned stations.

Obtained Results

The following results were obtained after accomplishment of the TEG of the Project:

1. The list of the overall set of simultaneously controlled physiological parameters and their optimal number needed to control the functional state of a cosmonaut in orbital flight.

2. Schematic of the IR medical control complex.

3. Circuit and technical solutions for units constituting the IR complex.

The Project aimed at creation of a wireless biotelemetric complex would permit:

• the efficiency of medical control and diagnostics of cosmonaut psychophysiological state under the space flight conditions to be increased (The complex can also be successfully applied in other areas such as professional, preventive, and sport medicine);

• noise immunity and reliability of the information collected to be improved;

• comfort and free movement of a cosmonaut in space vehicle compartments, body reorientation in space, functional investigations of the organism when on a space simulator or occupied with activity of another type (e. g., space vehicle driving) to be provided; and

• weight and size complex parameters to be significantly reduced as compared to those inherent in the existing wired and radiotelemetric systems.

Project Number:	#1360
Full and Short Title:	Development of Advanced Loop Heat Pipes for Thermal Control of Modern Spacecraft **Spacecraft Thermoregulation**
Tech Code / Area / Field:	SAT-MAS / Space, Aircraft and Surface Transportation / Manned Space Station SAT-VEC / Space, Aircraft and Surface Transportation / Space Launch Vehicles and Support Equipment
Status:	Project completed
Technology Development Phase:	3/Technology development
Allocated Funding:	$200,000 + 96,488 € (EU: 96,488 €, US: $100,000, RK: $100,000)
Commencement date:	May 1, 2000
Duration:	36 months
Leading Institute:	Ural Branch of RAS/Institute of Thermal Physics, Ekaterinburg, Sverdlovsk reg., Russia
Contact Information:	Phone: +7 (343) 267 88 01 Fax: +7 (343) 267 88 00 E-mail: itp@itp.uran.ru Website: http://www.uran.ru
Supporting Institutes:	No
Collaborators:	Air Force Research Laboratory, Albuquerque, NM, USA (Gerhart C) Korea Aerospace Research Institute, Yusung Taejon, Korea (Choi S-W) National Aerospace Laboratory NLR, Amsterdam, The Netherlands
Project Manager:	MAIDANIK Yury Foilevich
Contact Information:	Phone: +7 (343) 249 32 93 Fax: +7 (343) 244 54 50 E-mail: maidanik@etel.ru
ISTC Senior Project Manager:	BUNYATOV Karen Stepanovich
Contact Information:	Phone: +7 (495)982 31 99 Fax: +7 (499) 978 46 37 E-mail: bunyatov@istc.ru
ISTC Website:	http://www.istc.ru

Background

At present, the basic theoretical and engineering principles of loop heat pipes (LHP) construction as well as the basis of their production technology are elaborated. The high efficiency of LHP was demonstrated as a result of accomplishment of the preceding ISTC project #0473. At the same time, it is obvious that the potential of LHP development and perfection is far from being exhausted. In particular, there is a real necessity of making not only large and powerful LHPs but small-size ones equipped with capillary pumps-evaporators of various form as well. In developing small-size LHP, one has to overcome serious restrictions inherent in the basic LHP concept and to solve some complicated engineering problems. The idea of creating branched LHPs that include various numbers of evaporators and condensers seems to be fairly promising. The main line of investigations within the present Project stemmed from prospective application of LHPs in systems of space apparatus thermal control. Moreover, LHPs, which are high-efficiency heat-transfer devices capable of operating within a wide range of temperatures and thermal loads, can successfully be used in various ground objects such as cooling systems in electronics and electrical engineering and in diverse energy saving technologies.

Objective of the Project

Objective of the Project was to create improved high-efficiency heat transfer devices, LHPs and their components, with capillary heat-carrier pumping for thermal control systems of modern space objects.

Description of the Works

The following work was accomplished in the course of Project implementation:

– small-size ammonia LHPs 885 mm in length equipped with cylindrical and flat disc-shaped evaporators and with a liquid and vapor manifold 2 mm in diameter were designed, manufactured, and tested;

(*a*)

(*b*)

Figure1: Photo of small-size LHPs: (a) LHP with a disc-shaped evaporator; and (b) LHP with a cylindrical evaporator

– a branched ammonia LHP 1 m in length equipped with two evaporators and two condensers positioned parallel to each other and symmetrically with respect to the vapor manifold was designed, manufactured, and tested; and

– cylindrical capillary pumps-evaporators 24 mm in diameter with an active zone length of 250 mm equipped with wicks made of low heat conduction materials (iron oxide and silicon oxide) were designed, manufactured, and tested.

Figure 1 displays the photo of small-size LHPs with a flat disc-shaped and cylindrical evaporator.

Figure 2 shows a branched LHP mounted on the test bench.

Evaporators equipped with low-heat-conducting wicks are shown in Fig. 3.

Obtained Results

• In tests of a small-size LHP with a cylindrical evaporator, the maximum power of 60 W was attained at the evaporator temperature of 25 °C. The small-size LHP with a disc-shaped evaporator exhibited the maximum power of 80 W at 35 °C.

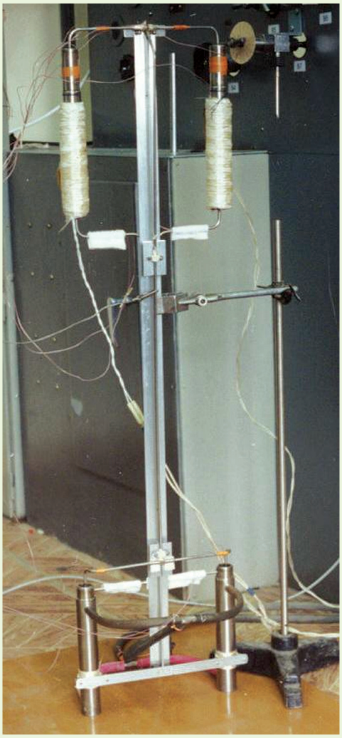


Figure 2: Branched LHP mounted on the test bench

Figure 3: Evaporators with no-heat-conducting wicks

• The maximum power attained in tests of the bidirectional LHP was 900 W. The lowest thermal resistance in the course of direct and reverse heat transfer was attained at a 400-watt heat load and amounted to 0.028 K/W.

• Tests of the bidirectional LHP have demonstrated the device operability at heat load values ranging between 10 and 1100 W both at symmetric and asymmetric heat load distributions between the evaporators.

• The maximum power detected in tests of evaporators with low-heat-conducting wicks incorporated in a two-phase loop 2 m long with ammonia serving as a heat-carrier ranged between 800 and 1000 W depending on the wick material.

Project Number:	#1962
Full and Short Title:	Engineering of High-Performance Techniques of Oxygen Production and Respiratory Mixed Gases for Space Systems and Public Health Services **Oxygen and Mixed Gases Production Technology**
Tech Code / Area / Field:	SAT-MAS / Space, Aircraft and Surface Transportation / Manned Space Station
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	460,000 € (EU)
Commencement date:	November 1, 2002
Duration:	24 months, extended by 5 months
Leading Institute:	VNIIEF, Sarov, N. Novgorod reg., Russia
Contact Information:	Phone: +7 (83130) 44 802 Fax: +7 (83130) 21 435 E-mail: staff@vniief.ru Website: http://www.vniief.ru
Supporting Institutes:	Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia
Collaborators:	Astrium GmbH, Bremen, Germany (Preiss H.)Centre National d'Etudes Spatiales/Utilisation Station Spatiale, Toulouse, France (Leffe A.)Divers Alert Network, Durham, NH, USA (Bennett P. B.) Humboldt Universität / Charité Universitätsklinikum, Berlin, Germany (Gross J.) KHW Medical Foundation, Inchon, Korea (Woncheol)
Project Manager:	REPIN Pavel Borisovich
Contact Information:	Phone: +7 (83130) 45 584, +7 (83130) 42 568 Fax: +7 (83130) 45 384, +7 (83130) 54 565 E-mail: pavel-repin@yandex.ru
ISTC Senior Project Manager:	TOCHENY Lev Vasil'evich
Contact Information:	Phone: +7 (495) 982 31 13 Fax: +7 (499) 978 46 37 E-mail: tocheny@istc.ru
ISTC Website:	http://www.istc.ru

Background

The basic Project idea rests on the following points established at the Institute of Biomedical Problems (IMBP) RAS:

1. Physicochemical and biological properties of oxygen can be changed purposefully by properly choosing the technique and technology of its production.

2. Preparation of respiratory mixtures based on oxygen and gaseous components that have been until recently considered to be biologically inert (helium, argon, and others) permits a protective effect in extreme situations and a positive result of bronchopulmonary deceases curing to be achieved.

This opens a feasibility of development of high-efficiency life-support systems of a new generation, remedies of human being rescue in extreme situations, and apparatuses for human being treatment and rehabilitation.

Multiyear investigations carried out at IMBP RAS resulted in development of several lines of studies that opened basically new approaches to preparation of respiratory gas mixtures (RGM) actively affecting the human organism:

1. The isotope composition of oxygen can be varied by changing the technology of its production. Generators capable of purposefully changing the isotope composition of oxygen produced by short-cycle adsorption (with no preheating) from solid oxygen containing compounds were worked out.

An electric discharge ignited in a gas phase is an efficient technique that changes its state (ionization and excitation of the molecules).

Studies of various modes of gas discharge have been performed at RFNC–VNIIEF in the course of several decades. The level of understanding of the processes that control gas discharge formation, of design elaboration of electric discharge devices for diverse applications, and the available diagnostics techniques serve as a basis of development of a device with pulse-periodic gas discharge designed to precisely control changes in the physicochemical parameters of RGM. The use for breathing of oxygen with changed properties is expected to enhance man workability in sealed compartments and underground, to keep to be highly resistant to unfavorable factor of the environment, and to significantly improve oxygen therapy in medicine.

2. Changes in the composition of RGM and in physicochemical properties of their components would allow the physical and intellectual activity of living organisms to be purposely and efficiently affected.

Oxygen–helium RGM prepared according to a special technology exhibits a powerful therapeutic effect, facilitates rapid escape of the organism from deep hypothermia, and permits a number of pulmonological deceases to be healed.

Thus, the results obtained indicate that basically new respiratory media capable of supporting, for a long time period, normal man vital activity under tensed space flight conditions and in extreme situations can be prepared. This medium would presumably support man workability at a level sufficient to efficiently eliminate the accident source and save, thereby, the life. Respiratory media showing therapeutic and preventive effects on bronchopulmanological deceases in the first place can also be made.

Project Objectives

The Project was aimed at developing a complex high-efficiency oxygen supply technology for extreme living conditions, including long-term manned space flights, and for the needs of practical medicine.

Description of the Works

Development of new man-made RGM with preset biological properties calls for both a complex of new technology designs and investigation of their effect on living organisms of various organization levels: cells in vitro, microorganisms, laboratory animals, and human being. Experiments on laboratory animals are needed to make a primary selection of the RGM, to detect possible physiological

Table 1: Content of microadmixtures and isotopic composition of oxygen produced with the aid of diverse adsorption generators

Oxygen samples produced by	O^{16}	O^{17}	O^{18}
Medical prototype specimen of the adsorption generator designed by IMBP RAS	99.753	0.033	0.214
"New Life" apparatus	99.827	0.024	0.149
"MZ-30" apparatus	99.780	0.020	0.200
Prototype version of the industry-produced two-step generator of medical oxygen (oxygen is produced from atmospheric air by the low-temperature rectification technique according to GOST 5583-78 "Oxygen gas-phase technical and medical")	99.842	0.020	0.139

effects and response of the whole-organism, organs, and tissue to the changed physicochemical gas phase parameters. Cell structure investigations would allow possible cellular mechanisms of action of the modified gaseous mixtures to be elucidated. Investigations with participation of human beings would permit one to refine possible changes in the physical and intellectual workability and to assess the level of psychophysiological resources, which would be evidence of the adaptation potential increase under action of the new man-made gaseous media. Experiments to study the effect of modified gaseous media on microflora would make it possible to provide microbiological safety of the subsequent application of the RGM and to refine their effect on microecology of a sealed compartment.

The following work was accomplished in the course of Project implementation:

- **Investigations of the physicochemical properties of oxygen produced by various methods.**

The content of microadmixtures and isotopic composition of oxygen produced with the aid of diverse adsorption generators were analyzed (Table 1).

Adsorption activity of the oxygen samples (see Table 1) on zeolites was assessed.

As follows from comparative analysis of the ratio of heavy oxygen isotope contents and diffusion coefficients, the lower content of heavy isotopes in oxygen the lesser the adsorption diffusivity in zeolite.

- **Design of a prototype generator specimen that provides production of oxygen and oxygen-enriched gaseous mixtures with modified physicochemical properties. Fabrication of the prototype apparatus specimen for preparing physiologically active respiratory gaseous mixtures.**

A complex technological scheme of the oxygen generator based on adsorption processes was suggested and designed.

Oxygen concentration after the air separation block and gas mixture flow rate were measured. At the gas mixture flow rate of 10 l/min, the mixture component concentrations were: oxygen 92.2%, argon 4.1%, and nitrogen 3.7%.

The operating prototype apparatus specimen (Table 2) that composed physiologically active respiratory gas mixtures was fabricated (it was applied to arrange close-loop breathing with man-made oxygen–argon mixtures in investigations).

- **Investigations of the effect exerted by the artificial gaseous mixtures on human endotheliocytes in vitro.**

To study the cellular effects exerted by the modified gaseous mixture, an endotheliocyte culture was selected from the human umbilical vein. These cells alter their functional state

Table 2: Parameters of prototype apparatus

1. Range of the apparatus and measurements of volume oxygen content, %(vol.)	28–93
2. Amplitude of pressure oscillations in the respiratory tract in the course of 30 l/min lung ventilation:	
– no more than the indicated number of water column mm in the exhalation tract	335
– no more than the indicated number of water column mm in the inhalation tract	42
3. Maximum respiratory volume, l	1.3
4. Power consumed, no more than	150 W

in vitro after a change of the oxygen content in the incubation medium; therefore, they can serve as a test system in studies of injuring or modifying action of the prepared mixtures.

As the results obtained show, the oxygen–argon hyperoxic mixtures containing 95% and 75% O_2 inhibit proliferation of the multiply exposed cultured endotheliocytes. After oxygen substitution by argon in prepared mixtures (75% O_2 + 25% Ar), the inhibiting effect of the medium on proliferation cell activity gets less prominent, which indicates that oxygen is the major inhibiting agent.

Cultivation of endotheliocytes multiply exposed for 18 h to a hyperoxic (89% O2) gaseous mixture with modified physicochemical properties has revealed that this hyperoxic mixture does not suppress proliferation activity of the cells, as distinct from their exposition in the hyperoxic oxygen–argon mixtures containing 75 and 95 medical oxygen. Distinctions between the effects exerted by the oxygen produced by the adsorption generator and by 95% medical oxygen on cell proliferation range between 30% and 70%, depending on the exposition number.

Thus, experimental studies of cultivated human endotheliocytes have shown that the oxygen produced by the prototype adsorption generator specimen in the hyperoxic gaseous mixture exhibited, at long-term expositions, a lower toxic effect, compared to the medical oxygen at its identical concentrations in the hyperoxic mixtures, although it slightly decreases endotheliocytes proliferation in vitro because of its high concentration.

• Investigation of artificial gaseous mixtures with modified properties in experiments with laboratory animals.

Content of oxygen in peripheral tissues is one of the basic indicators of organism provision with oxygen.

There were conducted 30 experiments in which pure oxygen and oxygen–argon mixtures of the O2/Ar = 75/25 and O2/Ar = 95/5 compositions were used. Rats of the “Wistar” line served as an investigation object. The results furnished by the tests performed according to the following three schemes were treated:

(i) air–hypoxia–oxygen–hypoxia–OAr5%–hypoxia–oxygen–hypoxia–OAr5%, and so on (5 tests);

(ii) air–oxygen–OAr5%–oxygen–OAr5%–oxygen, and so on (7 tests); and

(iii) air–oxygen–air–OAr5%–air–oxygen–air–OAr5%, and so on (5 tests).

After transition from medical-oxygen breathing to adsorption-oxygen breathing, the tissue oxygen tension in the animal shows trend to lowering. Lung ventilation lowers because of the reduction of the inhalation deepness rather than due to a respiratory rate decrease.

Hemodynamics and oxygen-transport blood properties change significantly in the hyperoxic gaseous media. Exclusion by oxygen of the endogenic carbon oxide contained in blood organism tissues serves as an integral estimate of changes in the CO and O_2 affinity to hem-containing structures and provides evidence of changes in the number of open capillaries in tissues and blood flow rate in them.

Statistic analysis has demonstrated a high authenticity of the discrepancies between the amount of excluded CO (p = 0.0027) and CO exclusion rate at the maximum of the curve of CO exclusion by oxygen (p = 0.003) in tests with breathing with oxygen + 25% argon and oxygen + 25% nitrogen mixtures. No reliable comparative data on the amount of excluded CO and its evolution rate were obtained when rats breathed with 100% O_2 and a mixture containing 95% O_2 and 5% Ar.

Embryonal development of birds in its various aspects is of great interest for many researchers. The bird embryons growing outside the mother organism possess active adaptive properties that allow them to respond to changes in the environment factors within the reaction norm.

The experiments with 10% of adsorption oxygen in the gas mixture (hypoxic) were conducted. Each experiment lasted 4 days.

An analysis of the results showed that the number of embryons exhibiting pathology in their growth amounted to 20.7%, while in control-1 (medical oxygen produced according to the acting GOST), it was twice as high — 44.8%. Nine pathology cases were observed in 6 embryons, because two or more abnormalities were detected in one and the same embryon. In the control-1 group, 13 embryons exhibiting anomalies showed 17 cases of abnormal embryon growth in a hypoxic medium.

• Assessment of the effect exerted by the artificial respiratory gaseous mixtures with modified properties on the physical and mental status of a human being.

Physical workability and gaseous metabolism of a man under conditions of long-term stay in a normal oxygen–nitrogen–argon medium (ONAM) were investigated. The argon content was 5% or 25%.

An analysis of the entire set of experimental data presented shows that the presence of argon in RGM in amount of 25% causes various physiologic changes in the human organism. No such physiologic changes are observed in the presence of argon in an amount of 5% in RGM.

The effect of two types of oxygen (medical according to the operating GOST, produced by cryogenic technique, and adsorption oxygen produced by the pilot adsorption oxygen generator) on the physical and mental workability and on the state of the human cardiorespiratory system is studied. Healthy volunteers participated in the experiments: eight women of an age ranging between 20 and 23 years.

Breathing with the two oxygen sorts did not entail appreciable changes of the lung diffusivity and CO content.

The two oxygen sorts were found to differently affect the real part of the respiratory impedance. The changes are small, however, quite appreciable.

Oxygen breathing (both oxygen sorts) does not change the physical workability. An increase in the real respiratory impedance part signifies that the breathing tract resistance is increased. Although the changes observed pertain to the high frequency range (6 Hz and higher), the strong correlation between the oscillatory and normal resistance values revealed previously allows to assert that the respiratory resistance at frequencies of spontaneous breathing increases also. It should be noted that this increase is observed after breathing with the two oxygen sorts. The adsorption oxygen causes a more significant increase in the resistance. Breathing with the adsorption oxygen results presumably in a greater increase in the tonus of unstriated lung muscles.

• Studies of microflora of tectorial tissues and mucous membranes of the human upper respiratory tracts affected by artificial gaseous mixtures with modified properties.

The upper domains of respiratory tracts experience the heaviest microbe load because they are adapted physiologically to bacteria precipitation from inhailed air. The normal bacterial flora plays a crucial role in biotope protection against pathogenic microorganisms. Action of extreme factors on human organism is one of the important mechanisms triggering dysbacteriosis development, particularly, when in a gas medium with modified properties.

Assessment of colony formation ability of bacterial cells in the oxygen, oxygen–argon (5% of argon), and oxygen–argon (25% of argon) gaseous media.

Four in vitro experiments were carried out in various gaseous media: oxygen, oxygen–argon (5% of argon), and oxygen–argon (25% of argon).

An analysis of the investigation results has not disclosed any appreciable changes in the culture properties of the microorganisms placed in the medium with an increased content of oxygen produced by the adsorption generator as compared to those of the microorganisms subjected to action of medical oxygen produced by the traditional cryogenic technology.

The frequency of R-plasmids transfer, which is one of the governing factors of bacteria drug resistance, was studied under conditions of an increased argon partial pressure. Museum Escherichia coli K-12 JF 238 and K-12 JM 83 strains served as the investigation objects. Strain K-12 JF 238 (donor) contains an RP1 plasmid that deposits stability to ampicillin, tetracycline, and kanamycin. Strain K-12 JM 83 (recipient) is stable with respect streptomycin . E. coli is of sanitary importance, it is a potential causative agent of infection human deceases.

Incubation gaseous media are pAr/pN2/pO2: atm (1 atm = 105 КПа): #1 — 0.0/0.8/0.2 (atmospheric air, control); #2 — 1.0/0.8/0.2; #3 — 0.0/1.8/0.2; and #4 — 1.0/1.8/0.2.

Argon presence at pAr = 1 ата in the incubation medium of a conjugation mixture lowers for sure the frequency of RP1 plasmid transfer from strain E.coli K-12 to E.coli K-12 LM 83 (recipient) by a factor ranging from 10 to 100. An increase in the partial nitrogen pressure pN2 from 0.8 to 1.8 atm entails no trustworthy decrease in the RP1 plasmid transfer frequency; however, the combined action of increased argon and nitrogen pressure provides a maximum 100-fold trustworthy lowering of the transfer frequency.

Investigation of microflora of human mucous membranes subjected to action of artificial gaseous mixtures in vivo in a medium containing an increased content of oxygen produced by the adsorption generator revealed no notable changes in the level of microbe population of the biotopes studied as compared to its counterpart observed in experiments with the medical oxygen produced according to the traditional cryogenic technology.

- **Assessment of microbiological safety of the apparatus that prepares artificial gaseous mixtures.**

The analytical investigations performed led to an inference that both the physical and chemical methods of pulmonological apparatus treatment are quite acceptable. The physical factors preclude completely formation of supertolerant strains.

In compliance with the investigation program, the microbe semination was analyzed by the method of washout from the surface of units and parts of the apparatus producing artificial gaseous mixtures prior to and after the healing cycle. Generally, the microbiological state of the apparatus after conducting a 5-day curing cycle give no reason for concern. Some alarming fact is that there exists a nonzero level of microbe semination of the respiratory bag (inhalation line) and buffer volume (exhalation line). Their semination increases after the healing cycle to identical levels. Sterilization of these units by full pouring with a disinfecting solution is recommended.

The component parts, individual units, and apparatus blocks were decontaminated with a 3% hydrogen peroxide solution with a 60-minute exposition, further washing with sterile water, and subsequent drying under sterile conditions. Zero growth indicators were detected for the microorganism groups studied, which confirms efficiency of the decontamination measures undertaken.

• **Comparative analysis of the quality of a gas medium formed by biological life-support systems based on higher plants and by physicochemical life-support systems.**

At present, there are no standard (space-oriented) life-support systems based on higher plants, lower autotrophs or higher heterotrophs. Therefore, a comparative analysis of the quality of a gas medium formed by life-support systems on the basis of higher plants can be solely performed using results of ground tests of manned sealed-object imitators. Human being is the basic unit of biological systems. The vital crew activity products escaped from the gastroenteric and urinary tracts, lungs, and through skin contribute significantly to the gas medium composition in a manned sealed compartment. This source of unhealthy microadmixtures is constant, so that lowering of their supply rate is problematic.

No continuous accumulation of unhealthy admixtures observed in long-term experiments, their content oscillated around some average value.

Obtained Results

• The oxygen generator was assembled and started (Fig. 1). The generator comprises an oil-free air compressor aggregate, block of adsorption air separation (concentrating oxygen), block changing the physicochemical oxygen properties that consists of an adsorption block changing the isotope composition, adsorption block concentrating argon, high-pressure oxygen compressor, control system, receivers, stop valves, and connecting gas hose pipes. As follows from the ratio of heavy isotope contents, the lower the heavy isotope concentration in oxygen, the lower the adsorption diffusivity in zeolite. The results obtained call for further investigations of the factors affecting the oxygen adsorption, adsorption mechanism, and molecular composition of the samples.

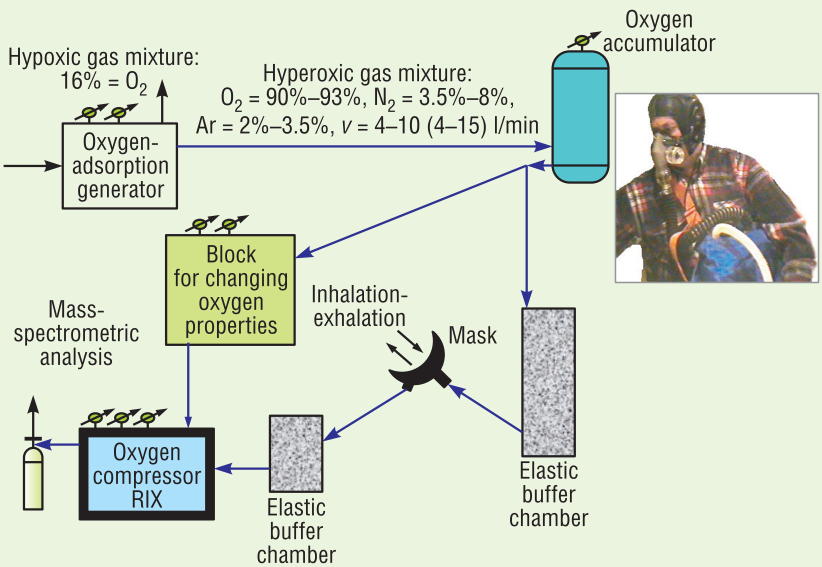


Figure 1: Assessment of changes in the oxygen properties. Scheme of experiment and results

• Technologies and documents elaborated before Project # 1962 was launched were used to design, fabricate, and test in the normal mode an operating prototype specimen of the apparatus producing physiologically active gaseous mixtures. It is designed to arrange closed loop breathing with artificial oxygen–argon mixtures for investigation purposes.

• Experimental studies of cultivated human endotheliocytes have demonstrated that oxygen produced by the pilot sample of the adsorption generator contained in a hyperoxic gaseous mixture shows a lower toxic effect, as compared to that of medical oxygen, in long-term exposition experiments at identical concentrations in hyperoxic mixtures, although it slightly lowers endotheliocytes proliferation in vitro because of its high concentration.

• Experiments with animals demonstrated that oxygen consumption in the course of breathing with a hypoxic (6% O_2) RGM based on the adsorption oxygen with modified physicochemical properties was higher than oxygen consumption observed in experiments with medical O_2 produced by the low-temperature rectification method.

• Investigation of embryons incubated in gaseous mixtures with a low oxygen content (10%) confirmed the available data on worsening of the embryon growth in hypoxic me-

Schematic of the setup used to feed
the gas mixture and to study gas exchange in rats

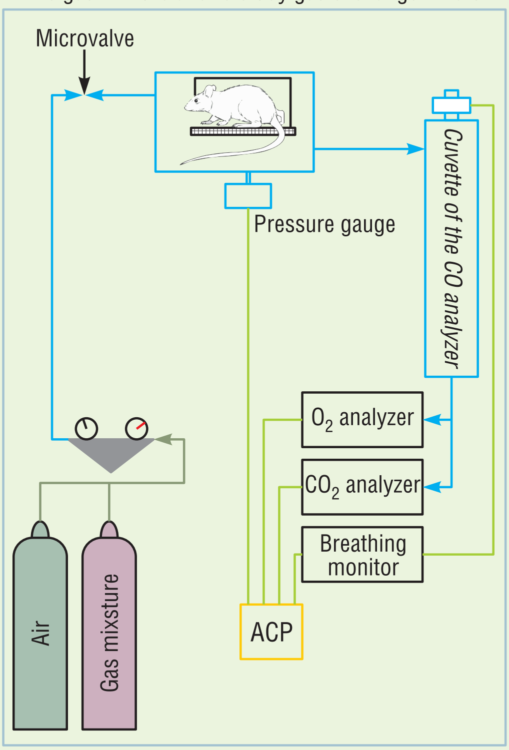


Figure 2: Schematic of an apparatus used to study artificial gaseous mixtures on laboratory animals (rats)

dia. However, comparison of the experimental and control data suggests quite unambiguously that the results obtained in the experimental group, in which eggs have been incubated in a gas mixture containing adsorption oxygen with modified physicochemical properties, significantly differ from their counterparts obtained in control with the use of medical oxygen produced by the traditional method of low-temperature rectification (30 embryons):

– the number of embryons and number of cases with morphological abnormalities was much less (6 and 9 against 13 and 17);

– the number of embryons with pathological eye development was twice as low (3 and 6, respectively); and

– no embryons with abnormal brain development were found (3 in control).

• Investigations with human being participation demonstrated that the protective organism response to hyperoxic action in the external breathing system was different in experiments in which participants have breathed with medical oxygen and adsorption oxygen with modified physicochemical properties; medical oxygen reduced the respiratory volume, whereas the adsorption oxygen did not. The other human state indicators studied were virtually independent of the oxygen sort used.

• The in vitro and in vivo effects of the medium with an increased content of adsorption oxygen on the cultural properties of the microorganisms studied differed insignificantly from that of the medium containing medical oxygen.

• Efficiency of the suggested approaches to decontamination of units and parts of the apparatus producing artificial gaseous mixtures operating in a normal regime was demonstrated (Figs. 2 and 3). The apparatus was decontaminated with a 3-percent hydrogen peroxide solution with a 60-minute exposition, then it was washed with sterile distilled water and dried under sterile conditions.

• Intake of organic and inorganic species in the gas medium of inhabited closed compartments, including compartments of space vehicles and orbital stations, was analyzed (full-scale investigations in ground experimental complexes, manned space objects within the "Soyuz," "Mir," "Apollo," "Space Shuttle" programs, and others). A comparative analysis showed that the gaseous medium of sealed objects of various application contained more than 200 microadmixtures.

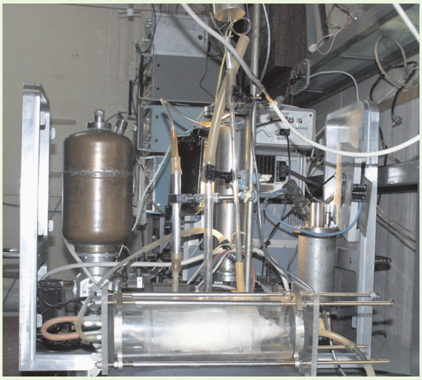


Figure 3: General view of the apparatus applied to study artificial gaseous mixtures on laboratory animals (rats)

It is shown that the presence of microadmixtures in the gaseous medium of sealed compartments can significantly affect vegetation of higher plants, which necessitates cleaning of the gas medium supplied to the compartment where plants are cultivated.

Biological components of the life-support system based on the use of higher plants and lower autotrophs were shown to evolve chemical compounds in the environment that can cause negative reactions in the human organism and negatively affect other plants. Thus, the necessary conditions of the use of higher and lower plants can be formulated as follows. Firstly, the gas medium coming from the compartment with plants to manned compartments must be thoroughly cleaned and, secondly, the types of plants must be experimentally selected so that their antagonistic interactions be ruled out.

Project Number:	#2120
Full and Short Title:	Development of Key Technical Means for Manned Planetary Missions **Technologies for Manned Planetary Missions**
Tech Code / Area / Field:	SAT-MAS / Space, Aircraft and Surface Transportation / Manned Space Station
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$700,000 (US)
Commencement date:	June 1, 2002
Duration:	30 months, extended by 5 months
Leading Institute:	Keldysh Research Center, Moscow, Russia
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
Supporting Institutes:	NPO Energia, Korolev, Moscow reg., Russia Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia Russian Academy of Sciences / Institute of Space Research, Moscow, Russia State Enterprise Krasnaya Zvezda, Moscow, Russia
Collaborators:	Alenia spazio, Rome, Italy (Somma R) Boeing Northamerican / Rocketdyne Division, Canoga Park, CA, USA (Mott M I) European Space Agency, Noordwijk, The Netherlands NASA, Washington, DC, USA (Mankins J C)
Project Manager:	SEMYONOV Vitali Felixovich
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
ISTC Senior Project Manager:	TOCHENY Lev Vasil'evich
Contact Information:	Phone: +7 (495) 982 31 13 Fax: +7 (499) 978 46 37 E-mail: tocheny@istc.ru
ISTC Website:	http://www.istc.ru

Background

Manned space missions have been always of special interest in Russia where space exploration is based on the most advanced technologies. Leading research institutes and design bureaus that determine the industry progress level in Russia paid attention to the problems of manned mission to Mars from the very beginning of space exploration era.

Creation of a manned complex for Mars mission would require realization in practice of many newest technologies closely combined in the most complicated space object. At the same time, this challenging effort would open the lines of application of the technologies developed in the interests of human society, which to a great extent would facilitate the stable world progress.

Objective of the Project

Objective of the Project was to elaborate the key technical facilities for manned interplanetary missions, including the manned Mars mission, with the purpose of ascertaining the role played by a man in exploration and developing of planets and assessment of the man functioning conditions during the mission.

Description of the Works

The project presents, by way of Mars mission example, a list of engineering means developed in order to provide exploration of the solar system. On the whole, the manned Mars mission serves as an object that integrates efforts of scientific organizations, industry, and national space agencies.

The main document that formulates the lines of investigations within the present Project is “General requirements imposed on the manned Mars mission.” These requirements were formulated within the ISTC Project # 1172. Based on it, the key engineering means were ascertained. The work was performed along 6 main lines:

Line 1. In the area of the system and investigations of the Mars mission architecture.

Line 2. In the area of the propulsion systems (PS) and power supplying systems on the Mars surface.

Line 3. In the area of space transport based on multiple-start PS nonhazardous for the environment.

Line 4. Landing planetary module.

Line 5. Bio-medical technologies for manned interplanetary mission.

Line 6. Onboard equipment and equipment for the work on the planet that provides efficient planet exploration.

Obtained Results

The Mars mission architecture has been worked out. The architecture and pattern of the interplanetary mission complex (IMC) were chosen keeping in mind the necessity of its maximum reliability and safety, lowest cost, and shortest duration of development and taking into account the basic tasks, flight stages, functions, and requirements. The configuration and characteristics of the interplanetary orbital vehicle (IOV) are elaborated for crews of 4 and 6 persons (Fig. 1). The configuration versions of working-fluid tanks and technique of their mounting on IOV were elaborated. The interior IOV assembling was worked out with real instrument and aggregate configurations taken into account.

The pattern and characteristics of the energy and PS complex (EPSC) based on a solar power plant (SPP) and of its subsystems were ascertained. Various versions of solar batteries (SB) were considered to select the most suitable one. The basic version and method of orientation of solar batteries and EPSC were defined. The technology of the solar EPSC battery manufacturing was developed. Preliminary dynamic characteristics of the EPSC solar battery construction and of its deformation form at the complete assembling stage were assessed.

A concept of a nuclear energy propulsion system with electric jet thrust and of an energy propulsion block based on four modules of a

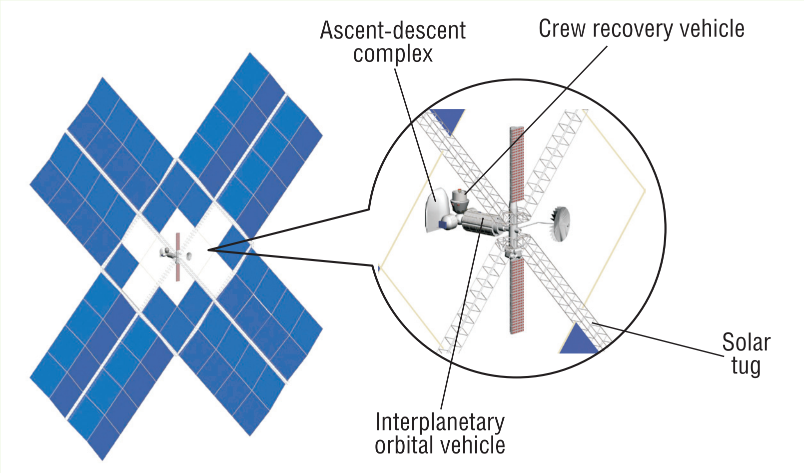


Figure 1: General view of Interplanetary Expedition Complex

bimodal NRE was elaborated. The Project presented also conceptual developments of the power plant to be settled on the Mars surface, the on-planet atomic power station intended to supply electric energy to consumers staying long time on the Mars surface.

The concept and design pattern of the Mars landing complex (MLC) were developed. The complex fulfils the chief task of the mission — provides conveyance to the Mars surface of the crew, instruments and equipment, needed to accomplish the exploration program, from the orbiting vehicle and subsequent return to the orbiting vehicle of the crew and exploration results. The concept and design pattern of MLC depend on the characteristics of the transport-space system that puts the mission complex modules into orbit.

The input data concerning the mission tasks, crew activity on the Mars surface, and Mars suit were refined. The pattern, composition, and preliminary characteristics of the base visited (outpost), as well as the way of constructing and expansion of the base were formulated. The pattern and tentative characteristics of the transport Mars rover that should provide building and running the base were ascertained.

The key technologies to be used in the biomedical provision system to enhance crew efficiency and safety were defined.

The scientific program and scientific equipment of the manned Mars mission were developed based on:

• defining the preliminary scientific tasks of the program of investigations by means of unmanned space vehicles — predecessors of the manned mission — performed for the sake of manned Mars mission interests;

• defining the technical requirements imposed on the model unmanned Mars rover equipped with a handler to demonstrate feasibility of astronaut functioning in the teleoperator regime; and

• defining the pattern, composition, and characteristics of the instrumental complex designed for monitoring the asteroid hazard and refining the choice of the landing sites of the manned Mars mission.

The major results of accomplishment of Project # 2120 can be found in the below indicated volumes, they are presented at the international meetings and conferences at which the Project has been discussed:

Volume 1. General Mars mission characteristics.

Volume 2. Solar energy propulsion system.

Volume 3. Nuclear energy propulsion system.

Volume 4. Power supply systems on the Mars surface.

Volume 5. Multiple start transport space system.

Volume 6. Book 1. Mars landing complex. Book 2. Manned Mars rover.

Volume 7. Biomedical provision of manned Mars mission.

Volume 8. Onboard and planetary scientific equipment for the manned Mars mission.

Volume 9. Pattern and characteristics of the first manned Mars mission in 2018.

Project Number:	#3684
Full and Short Title:	Preparation of an Experiment for Studying the Vortex Method of Suspension Cultivation of Biological Objects under Conditions of an Orbital Space Flight **Space Objects in Extraterrestial Planet Atmosphere**
Tech Code / Area / Field:	SAT-EXP / Space, Aircraft and Surface Transportation / Extraterrestrial Exploration SAT-MAS / Space, Aircraft and Surface Transportation / Manned Space Station BIO-MIB / Biotechnology / Microbiology BIO-IND / Biotechnology / Industrial Biotechnology
Status:	Project underway
Technology Development Phase:	Basic research
Allocated Funding :	409,255 € (EU)
Commencement date:	February 2, 2008
Duration:	30 months
Leading Institute:	State Research Center of Virology and Biotechnology VECTOR, Koltsovo, Novosibirsk reg., Russia
Contact Information:	Phone: +7 (383) 336-60-10 Fax: +7 (383) 336-74-09 Website: http://www.vector.nsc.ru
Supporting Institutes:	Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia
Contact Information:	Phone: +7 (499) 195-2363, (499) 195-1500 Fax: +7 (499) 195-2253 E-mail: info@imbp.ru Website: http://www.imbp.ru/
Collaborators:	Commercial Space Technologies Ltd, London, UK (Webb G) European Space Agency, Noordwijk, The Netherlands (Lasseur C.)
Project Manager:	BORODULIN Alexander Ivanovich
Contact Information:	Phone: + 7 (3833) 36 74 69 Fax: +7 (3833) 36 74 09 E-mail: borodulin@vector.nsc.ru
ISTC Senior Project Manager:	CROCKER Wendy Elizabeth Murray
Contact Information:	Phone: +7 (495) 982 31 34 Fax: +7 (499) 978 02 27 E-mail: crocker@istc.ru
ISTC Website:	http://www.istc.ru

Background

Medical and biological experiments for studying the influence of space factors on living organisms were started in 1957 when the second artificial satellite of Earth was launched. Then, the studies were continued in the series of experiments on the space ships-satellites at a period of 1960–1961. These studies have demonstrated an opportunity of flight of a man to space and have opened up the age of mantended space missions. The "BION" program was the first program for complex investigations of animal and vegetative organisms in the flights of specialized satellites — biosatellites in the interests of space biology, medicine, and biotechnology. The basic results of the biological research in the conditions of microgravity was that the injure effects of the weightlessness state on cell division cycles, cell genetic apparatus, intracellular processes, embryogenesis, and ontogenesis were not discovered.

At present, this field of space biology is developed in the frames of the flights of "Photon M" space satellites. In particular, the influence of the weightlessness state on the genetic structures and gene expression was studied in "Photon-M" No.2 space apparatus flight. "Photon-M" No.3 space apparatus flight is planned on the basis of data obtained in the "Photon-M" No.2 experiments. The "Bion-M" No.1 space apparatus flight is being prepared at present in the frames of Bio-Kosmos-1 Project. In particular, the "Plant-Bion" experiments are planned to study the influence of space flight factors on the growing and development of higher plants as well as to develop the technology of their cultivation in the weightlessness state conditions. Thus, the considerable proportion of the programs is directed to the development of space biology.

The development of space biotechnology requires the solution of both fundamental and applied problems. The most important applied task is the development of methods for cultivation of microorganisms in the conditions of microgravitation. The solution of these tasks opens a way to commercial use of biotechnology in space: to manufacture the proteins, cells and humane genes; to produce tissue-like structures for use in surgery; to provide cosmonauts with food during long flights in space and many other applications.

Thus, the development of methods for cultivation of microorganisms in the conditions of space flight is an important and urgent practical task.

Bioreactors for suspension cultivation of biological objects (cultures of cells of animals, plants, insects, bacteria, fungi, and viruses) with mixing device are the most mobile ones in control and maintenance the mixing and mass transfer with needed intensity. Bioreactors of this type are widely used in practice for production of enzymes, amino acids, antibiotics, medical preparations, etc. The developed "Earth" technologies of cultivation cannot be transferred directly to the space flight conditions. The improvement of the hydrodynamic of bioreactor with mixing device by the use of vortex motion of medium can be used as one possible technical solution in the development of the bioreactor for suspension cultivation of biological objects in space can be. During more than 10 years, the theoretical and experimental research of momentum, heat and mass transfer processes in the vortex flows are conducted with participation of the experts of FSSI SRC VB "Vector" (Federal State Science Institution, State Research Center of Virology and Biotechnology "Vector"). A bioreactor with vortex-gas mixing of cultural medium "BIOK" is the practical result of the cycle of researches.

The principle of mixing and aeration of cultural medium by the vortex motion of aerating gas over the free surface of liquid, i.e., the principle of "controlled tornado" is used first in the "BIOK" bioreactor. Research has shown that the advantages of such devices are their high efficiency, sparing (soft) conditions of the mixing of biological objects, optimal conditions of aeration and high production of the cultivation process even at the high viscosity of cultural medium. It is possible to assert that the bioreactor with gas–vortex mixing of cultural medium is the most suitable variant from the available prototypes for use in the conditions of microgravity. It is also proved by its characteristics, simplicity of operation, and low consumption of energy.

The “BIOK” bioreactor is protected by patents of Russia, USA, Japan, and by six European patents. However, direct copying the “BIOK” bioreactor for employment in space experiments will not lead to positive result. Fundamental changes in the bioreactor construction with conserving the gas-vortex method of mixing of cultural medium are needed. A variant of bioreactor that is able to conserve the advantages of the vortex method of cultivation and ensure its operation in the space flight conditions has been proposed at FSSI SRC VB “Vector.” The prototype of bioreactor was tested in experiments. Patenting of the method and apparatus is being prepared on the base of the test results.

Project Objectives

The Project objective is preparation of an experiment for studying the suspension cultivation of biological objects under microgravity conditions.

Cooperation of the two Institutes and use of unique scientific and practical experience of SRC RF Institute of Medicobiological Problems RAS in the field of preparation and carrying of space medicobiological research as well as the developments of FSSI SRC VB “Vector” in the vortex methods of cultivation of biological objects will allow to prepare the experiment that will be used as a basis for high efficient space biotechnology.

Description of the Works

In accordance with the Work plan, the main tasks of the Project are:

– development of the conception and methodology of the space experiment;

– development and manufacture of prototypes of the space vortex bioreactor; laboratory trials;

– development and manufacture of the pilot model of the orbital plant for testing the space variant of the vortex bioreactor;

– development of the mathematical model of the vortex bioreactor;

– creation of a program package to study the processes occurring in the vortex bioreactor; carrying out numeric experiments.

The technical approach is based on the variant of the vortex bioreactor developed previously by FSRI SRC VB “Vector.”

The approaches to the development of the conception and methodology of the space experiment were formulated. The group of non-pathogenic anaerobic microorganisms of Bifidobacterium genus and thermophilic streptococci, which can be used for utilization of the waste of human vital activities under orbital space flight conditions, was determined. The possibility of biotransformation of the main groups of waste, which can be formed under space flight conditions, was confirmed: used hygienic products and waste of plant origin (greenhouse waste).

The study of limitations and peculiarities of spacecrafts influencing the bioreactor technical characteristics was performed. The schemes of several variants of the model of the vortex bioreactor suitable for work under weightlessness conditions were developed. Their physical trials were performed. Biological experiments were performed using a real nutrient medium to determine optimal characteristics and the stable work mode of the bioreactor providing the necessary growth rate of yeast culture. The dependence of biodegradation of vegetable substrates on the cultivation period was obtained. The carried out work justified the variant implementing the vortex method of cultivation with excitation of gas vortex by a fan, which requires smaller power inputs and device dimensions.

The preliminary list of requirements and conditions, which will be included in the final variant of the Requirements specification for the development of the orbital bioreactor and will be necessary for a successful experiment on the study of the vortex method for suspension cultivation of biological objects under orbital space flight conditions, was made.

The analysis of the main thermohydrodynamic processes of the vortex method for cultivation of biological objects under space flight conditions was performed, and requirements for the mathematical model were formulated. The general statement of the problem of mathematical modeling of gas and liquid flows in the vortex bioreactor was performed.

The theoretical analysis of geometrical properties of the gas–liquid interface in the vortex bioreactor under orbital flight conditions was performed. The mathematical study of the shape of the free surface at the liquid-air interface for different angles of wetting of the side wall of the bioreactor with liquid was performed.

The mathematical model of the vortex bioreactor was developed. A system of differential equations and edge conditions was formu-

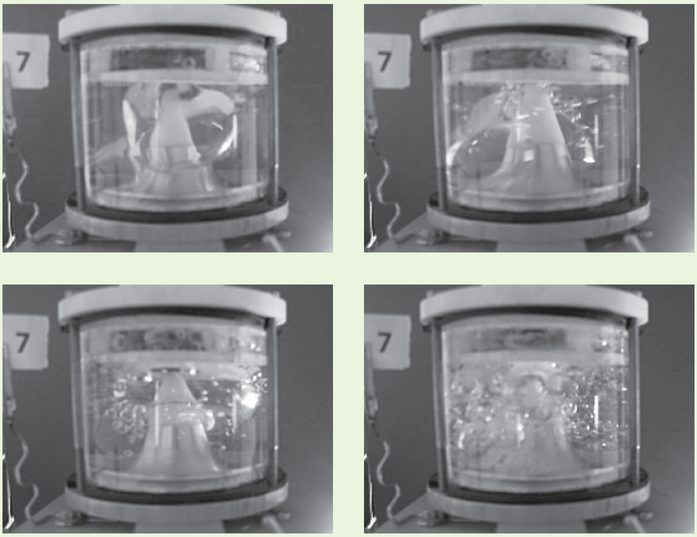


Figure1: Initial stage (hyper loading)

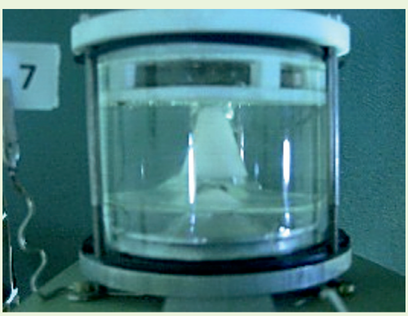


Figure 2: Stage weightlessness

Figure 3: Stage after weightlessness

Figure 4: The working ability of the unit was evaluated in Burgas Univ., Bulgaria, in the research group, headed by Prof. Denchev

lated. The solution algorithm was described, and difference grids and difference methods for solution of initial equations were determined.

Obtained Results

– Technology of biodegradation of orgainc matter with further purification of liquid substances with the aid of thermo- and mesophylic microorganisms was elaborated.

– Bioreactor for biotechnology experiment was created — both in metallic and plastic mode. The latter is devoted to experiments in parabolic flight as mockup studies to evaluate effectiveness of its exploration in weightlessness.

In Figs. 1 to 3, several stages of the flight are presented.

The working ability of the unit was evaluated in Burgas Univ., Bulgaria, in the research group, headed by Prof. Denchev (Fig. 4).

Project Number:	#3871
Full and Short Title:	Thermal Diagnostics Technologies for Development, Verification and Emergency Prevention of Aerospace Structures **Thermal Diagnostics of Aerospace Structures**
Tech Code / Area / Field:	SAT-MAS / Space, Aircraft and Surface Transportation / Manned Space Station
Status:	Underway
Technology Development Phase:	Applied research
Allocated Funding:	$344, 889 (EU)
Commencement date:	January 1, 2009
Duration:	36 months
Leading Institute:	Moscow Aviation Institute (Technical University) — MAI, Moscow, Russia
Contact Information:	Phone: +7 (499) 158 13 43 Fax: +7 (499) 158 29 77 Website: http://www.mai.ru
Supporting Institutes:	Lavochkin Association
Collaborators:	ESTEC/ESA Noordwijk The Netherlands (Constantinos Stavrinidis) DLR Bonn, Germany (Ali Gulhan, Patrick Gruhn) EADS Bremen Germany (Wolfgang P. P. Fisher) Ecole Polytechnique de l'Universite de Nantes Nantes France (Yvon Jarny) University of Rome, Rome Italy (Mario Marchetti) University of Leeds, Leeds, UK (Derek B. Ingham)
Project Manager:	NENAROKOMOV Aleksey Vladimirovich
Contact Information:	Phone: +7 (499) 158 47 90 Fax: +7 (499) 158 00 23 E-mail: aleksey.nenarokomov@cosmos.com.ru
ISTC Senior Project Manager:	RYZHOVA Tatiana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (499) 978 36 03 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

Optimal design of heat-loaded objects as well as thermal control during operation time and corresponded emergency monitoring is actually an important problem in the presence of weight and cost restrictions on structures developed for any mission, for example, manned space stations, unmanned spacecraft, and, especially, space systems like "Space Shuttle," "Hermes," etc. The modern approaches to a thermal control of spacecraft assume broad application of mathematical and physical simulation methods. However mathematical simulation is impossible if there is no true information available on the external heat fluxes, temperatures, etc. of objects analyzed. In the majority of cases, in practice, the direct measurement of thermal states or external heat loading for space structures, especially of complex composition, is impossible. There is only one way, which permits to overcome these complexities — the indirect measurement. Mathematically, such an approach is usually formulated as a solution of the inverse problem: through direct measurements of some characteristics of system state (available temperature, component concentration, etc.) define the total thermal state of a system analyzed, for example, the heat fluxes or/and temperature at the external surface. Violation of cause-and-effect relations in the statement of these problems results in their incorrectness in mathematical sense (i. e., the absence of existence and/or uniqueness and/or stability of the solution). Hence, to solve such problems, special methods usually called regularization methods were developed. The approaches to estimate thermal states of complex space structure based on methods of ill-posed problem solving were widely analyzed in Russia (USSR) and in other countries having displayed efficiency in the development and investigation of modern structure in spacecraft, aircraft, automotive industries, metallurgy, power engineering, etc. A new technology of diagnostics of thermal analysis of space structure being developed is a combination of sufficiently accurate measurements of primary heat values in testing conditions to the maximum approximate to full-scale conditions and ultimately correct mathematical treatment of experimental data based on the theory of inverse problems.

Project Objectives

The Project objective was the development of the methods and tools of thermal diagnostics for widely implementation into practice of thermal control and emergency monitoring of spacecraft.

The achievement of this purpose was connected with

• the application of mathematical simulation methods permitting the analysis of structure operation as a component of the technical object;

• the application of modern high-effective methods and facilities for thermal diagnostics, based on the technique of inverse heat transfer problems; and

• the implementation of above technology as experimental-computational system providing to efficiently analyze the data of thermophysical experiments and to estimate thermal state of spacecraft structures.

Description of the Works

Experimental and computational methods based on the solution of the boundary inverse heat-conduction problem form an intensively developing direction in the field of transient heat transfer processes. When analyzing high-temperature processes, it is often necessary to use nonlinear mathematical models of heat transfer with thermal properties dependent of temperature. The above circumstances lead to additional difficulties, when working out the algorithms for solving the corresponding inverse problems. During the past years different algorithms were developed to solve the one- and multidimensional boundary inverse heat-conduction problems. The majority of them can be applied only to the linear inverse problems. The algorithm developed in the present proposal was suggested to consider the nonlinear inverse heat transfer problems and was based on iterative methods for inverse problem solving, because the kind of mathematical model of the considered heat transfer processes is not so essential for such algorithms.

At the first year, the researchers have done an analysis of heat transfer mathematical models in structures of spacecraft and other technical systems. The structure of mathematical heat transfer models was chosen for the next classes of materials (by priority principle):

1. Low-density fibrous thermal insulating materials.

2. Low-density carbon foam materials.

3. Sublimated materials (surface destruction).

4. Charred materials (given the physical and chemical transformations zone).

For each class of materials, there were the following subtasks:

– selection of structures of mathematical models; and

– analysis and selection of algorithms of numerical solution of the corresponding boundary value problems.

After the meeting with project collaborators, the low-density fibrous thermal insulating materials and low-density carbon foam materials were selected for more detailed analysis their thermal state. The researchers have done an

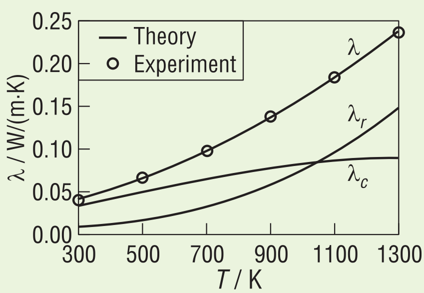


Figure 1: Calculation and experimental results for fibers low density material: λ — overall: λ_r —radiative; and λ_c — conductive thermal conductivity

analysis of heat transfer mathematical models in structures of spacecraft and other technical systems. Irregularity, local heterogeneity, and anisotropy of composites essentially constrict a gamut of possible approaches to mathematical simulation of their structure and properties. The basis for the method proposed is the direct mathematical simulation for global structure of the complex irregular systems each being determined by the property of local regularity. This allowed to divide a complex system into the regular elements and to describe their properties by means of adequate stochastic models.

Also at this period researchers developed methods to estimate external heat fluxes based on existed methods for solving boundary one-dimensional (1D) heat conductive inverse problems for nondestructive materials. In the project, the development of methods for estimating heat fluxes was carried out for two types of materials. The first type is thermally stable high-temperature insulating materials. For such materials, the goal was to estimate their heat loading as time functions by using results of measuring temperature histories inside the specimens under consideration. The second type of materials is sublimative material. For these materials, the goal was to determine all set of the materials characteristics on the external surfaces. The iterative regularization method was outlined as one of the most efficient and universal ones for solving the ill-posed inverse problems, which arise in the course of the diagnostics. Therefore, an extreme method of solving of ill-posed problems of heat transfer was developed. This method is based on iterative regularization principle. The stability of the solution was achieved by timing the number of iterations in the gradient methods of the first order with the error of initial data. In the beginning, rigorous mathematical results were stated in brief substantiating this approach with respect to the most widely spread gradient algorithms, i. e., steepest descent and conjugate gradients, namely, information was supplied on regularization of the mentioned methods by the number of iterations and legitimacy of using or residual criterion to choose the number of the last iteration or restart the iterative process.

To solve the inverse problems, there have been developed iterative computational algorithms, implementing a minimization through gradient methods of residual functional, characterizing the square deviation of temperature values computed and measured by means of the assumed mathematical model. Here, the unknown functions were approximated by the cubic B-splines and the inverse problem was thus reduced to a definition of the unknown parameter vector. The gradient of residual functional was computed using the solution of boundary-value problems for the adjoint variable. In the approach under consideration, all experimental information was used to estimate heat transfer characteristics as time or temperature functions on the all temperature interval of interest.

The research in the project has involved the development of effective algorithms for solving inverse heat transfer problems for identification of mathematical models in composite materials in different formulation (in particular, for decomposed and noncomposed composite materials).

The experimental research was carried out in MAI using the experimental facilities TVS-2, developed for studying of nondestructive materials and structures thermal states, using nonstationary radiative or contact heating. Set of equipment and tools included:

– water-cooling horizontal vacuum chamber;

– systems: vacuum treatment, power supply, circulating water supply; test bench controller;

– special experimental modules, which provides high temperature nonstationary heating of unidirectional action with fast-response high temperature heaters of ohmic type based on refractory metal foil (Mo, Ta, Nb, W);

– specially manufactured equipment for installation of thermosensors in polymerizing and high porous materials;

– X-ray apparatus to control position of thermosensors based on radiator REC-I; and

– automatic control system for heating, measuring data collecting and data processing based on PC.

Figure 2: Overall view of test facilities TVS-2

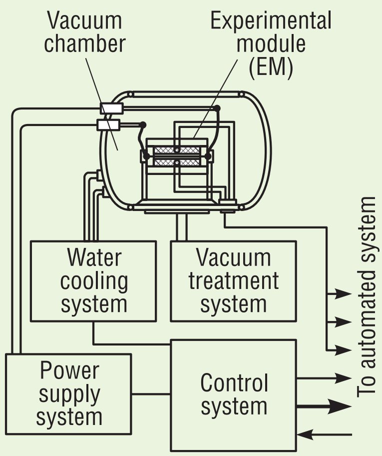


Figure 3: Overall diagram of test facilities TVS 2

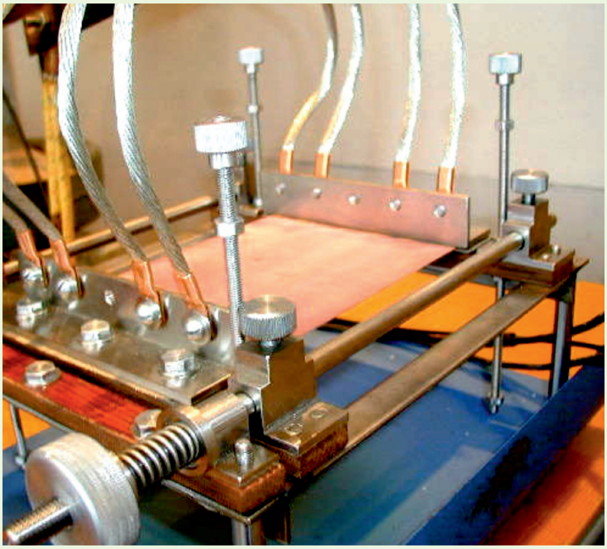


Figure 4: Test of heating element

Methodological base of experimental research included:

– methodic of thermal test supplement and execution;

– applied software based on numerical simulation and experiments design methods;

– applied software based on Inverse Problems methods;

– special software for measured-controlled device based on LabVIEW and NI DAQ of National Instruments.

The modern equipments and special software for data collecting and processing of National Instruments were used for implementation, when prototype of measured-controlled device for real-time thermal diagnostics was developed as well as the portative Automatic control systems (on the base of Note Book and modules NI DAQPAD-4350 and NI DAQ-PAD-6015). The planned modernization of the equipment used while performing the project work was concerned, mainly, with the automated data collecting and processing system on the facility TVS-2.

Expected Results

The project implementation will provide development of the technology of thermal diagnostics of the thermal state of elements of structure and whole complex thermal systems, taking into consideration of nonstationarity, nonlinearity, multidimensioness of processes, etc. There will be developed and introduced in practice for development, verification, and emergency prevention of space structures:

• the nonlinear mathematical models (one-, two-, and three-dimensional) for heat transfer analysis at space structures;

• the computational algorithms and software for solving the problems of thermal analysis for diagnostics of a thermal state and estimating of external heat fluxes at the surface of the complex structures at nonsteady heating based on inverse methods;

• the computational algorithms and software for solving the problems of thermal analysis, to estimate total thermal state of structures on-line (at real time, express-diagnostics);

• technique to estimate thermal stress state of structure;

• measurement tools (thermosensors, heat flux sensors, etc.);

• a prototype of automatic control system of thermal diagnostics;

• a prototype of movable (portative) automatic control system of thermal diagnostics;

• hardware of test facilities TVS-2 (including electromechanical tools, data recording tools and creating new special modules);

• a methodical support for providing and executing thermal testing for experimental verification of the developed methods and tools of thermal diagnostics;

• the experimental-and-computational study at stand TVS-2 for verification the developed methods and tools of thermal diagnostics; and

• the experimental-and-computational study of some thermal loaded structures according to interest of the Project collaborators.

The methodology of investigations being developed will permit

• on a common theoretical base to solve a set of problems emerging in designing, developing, and operating thermal-loaded structures;

• to consider to the maximum the actually existing nonstationarity, nonlinearity, and multidimensionality of heat-and-mass transfer processes running in space structures and on the surface of structures, this sufficiently increasing the accuracy of the results of research;

• to increase the information efficiency of experiments and tests; provide a possibility to conduct them in the conditions approximate to the maximum to full-scale conditions; and

• to reduce largely the volume of necessary experimental investigations and tests, and, consequently, the expenses in resources and time for the development of technology prototypes.

Project Number:	#G-204
Full and Short Title:	Development of Proposals to Promoting Biological Safety of Personnel Taking Part in Controlling a Spacecraft of the "Shuttle"-Type in Order to Deliver Scientific Equipment and Other Load in Space **Biological Safety of Spacecraft Personnel**
Tech Code / Area / Field:	SAT-MAS / Space, Aircraft and Surface Transportation / Manned Space Station
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$34,260 (US)
Commencement date:	July 1, 2000
Duration:	24 months
Leading Institute:	Tbilisi State Medical University / Research Institute of Experimental and Clinical Medicine / Department of Experimental Neurology (at present: Center of Life Sciences, Laboratory for Experimental Neurology), Tbilisi, Gotua str. 14, Georgia
Contact Information:	Phone: (995) 32 54 24 39, 32 54 24 39 44 Fax: (995) 32 54 24 41 E-mail: pr@tsmu.edu, iad@tsmu.edu Website: http://www.tsmu.edu
Supporting Institutes:	No
Collaborators:	No
Project Manager:	OKUJAVA Vazha Mikhailovich
Contact Information:	Phone: (995) 32 23 35 51, (995) 32 39 17 09 E-mail: okujava@geo.net.ge, temnat@ymail.com
ISTC Senior Project Manager:	BUGAEV Dmitry Vladimirovich
Contact Information:	Phone: +7 (495) 982 31 90 Fax: +7 (499) 978 13 31 E-mail: bugaev@istc.ru
ISTC Website:	http://www.istc.ru

Background

The principal obstruction to work in space is the well known as so-called “cosmic adaptation syndrome” (CAS), i. e., the cosmic version of the motion sickness, appearing in weightlessness. The Project was aimed at elucidation of the specific role of the visual–vestibular interaction in the development of the spatial disorientation in humans and in animals under the terrestrial modeling of micrograviation.

Project Objectives

The objective of the project was to study the neurophysiological mechanisms of the so-called CAS.

Description of the Works

Work included the following tasks:

– arrangement of equipment to model micrograviation in terrestrial conditions — uniform rotation of the cat along horizontally placed longitudinal axis of its body with the frequency of 24 revolutions per minute (0.4 Hz);

– design of equipment for telemetric monitoring of electric activity of the cat’s brain structures under the conditions of micrograviation;

– behavioral study of spatial orientation and spatial memory in cats being subjected to micrograviation;

– electrophysiological analysis of summary and single cell activity in cat’s association brain structures immediately after sessions of micrograviation; and

– elaboration of the quantitative model of CAS.

The methods of analyzing the currently used terrestrial systems of modeling micrograviation for clearing the reasons for triggering CAS were based upon the perspective model employing uniform rotation of the experimental cats around the horizontally placed longitudinal axis of the body for provoking the very important symptom of the CAS — space disorientation. Success depends on the arrangement of the appropriate facility, i. e., the design of the equipment for formation of micrograviation by means of uniform rotation of the cat around the horizontally placed longitudinal axis of its body (the so-called “bar-

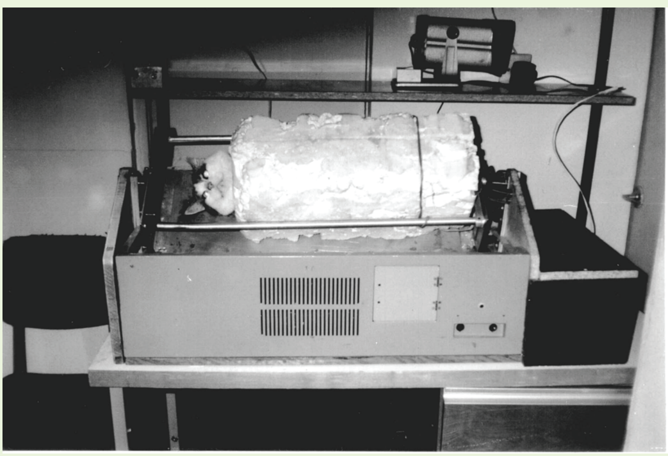


Figure 1: Photograph of the cat placed in the gondola of the apparatus

becue-spit rotation") with the frequency of 24 revolutions per minute (0.4 Hz). The problem of clearing the CAS mechanisms and possibilities of its pharmacological correction, as well as the problem of preventive selection of the space crew, will be solved by working out the quantitative models of the "sensory conflict" hypothesis between visual and vestibular signals under microgravitation, also methods of calculating the "critical zones" within the "conflict hypothesis" model, getting into which will enhance the chance to provoke the CAS. The routine electrophysiological techniques were used in conducting the tasks belonging to elucidation of the intimate neuronal mechanisms of the possible nature of the CAS.

For experimental investigations, a home-made apparatus was arranged on the basis of the engine XEROX X B 597-220 with reductor, which permitted the uniform rotation of an animal placed in the frame connected to the engine, around the horizontally placed its longitudinal axis under frequency of 24 revolutions per minute (Fig. 1). For telemetric recordings of summary and single unit electrical activity from the animal's cerebral structures, a telemetric system was arranged.

Experimental behavioral tests were performed on the animals (cats) being subjected to the uniform rotation on our apparatus under different conditions (rotation in complete darkness, rotation in the lighted internal envi-

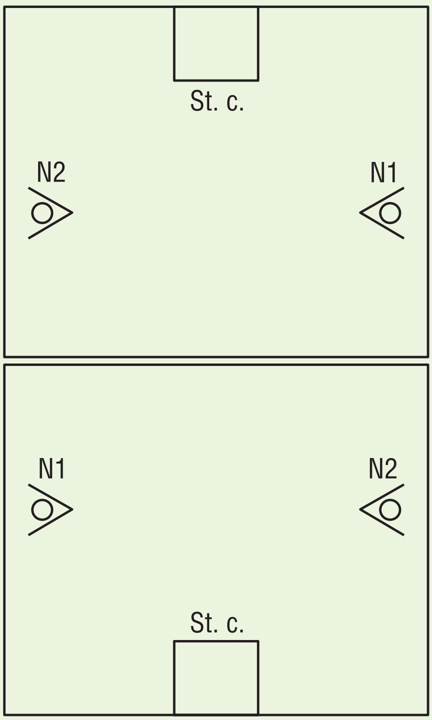


Figure 2: Schematic representation of the situation in which testing of the cats in the classical and inverted delayed responses proceeded. Abbreviations: "St. c." — start cage in which the animal was situated during delay and intertrial intervals; "N1" and "N2" — foodwells in which the food was placed during the baiting phase of the tests. Other details are presented in the text

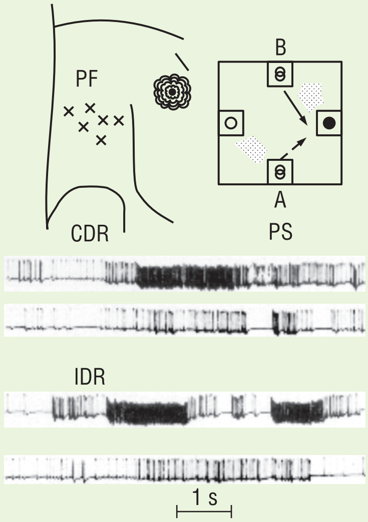


Figure 3: Illustration of the "place unit's" activity picked up from the prefrontal cortex in the freely moving cat, solving CDR and IDR behavioral tasks in the test-situation, which completely lacked any visual external landmarks, or which was completely darkened by turning down all the lights in the situation. Top: on the left — schematic representation of the prefrontal cortex of the cat, from which the microelectrode recordings were made; and on the right — the schematic representation of the test-situation in which CDR and IDR tasks were run. These test-situation lacks any landmarks and thus represents the so-called "Personal System for Spatial Localization" (PS). The "place fields" are indicated by dots for CDR task and by crosses for IDR task. Solid line in the same schemata going from the initial cat's position to the baited foodwell represents the correct reaction for the CDR task, while the interrupted line going from the cat's position after inversion to the same baited foodwell represents correct reaction for the IDR task. Bottom: 4 records of the Schmitt-triggered activity of a single prefrontal "place cell" are shown. Each of them corresponds to the correct or incorrect performance of the CDR and IDR tasks, as is indicated; "1" and "2" — left and right foodwells

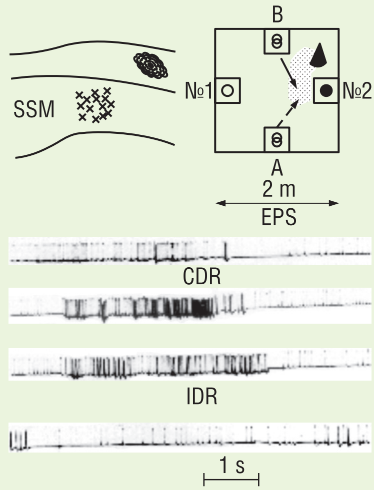


Figure 4: Illustration of the "place unit's" activity picked up from the parietal cortex in the freely moving cat, solving CDR and IDR behavioral tasks in the test-situation, which is rich of the visual external landmarks. Top: on the left — schematic representation of the parietal cortex of the cat, from which the microelectrode recordings were made; and on the right — the schematic representation of the test-situation in which CDR and IDR tasks were run. This test-situation is reach of visual external landmarks, but here, for the sake of simplicity, they are represented by single black pyramid and thus represents the so-called EPS. The "place fields" are indicated by dots for CDR task and by crosses for IDR task. Solid line in the same schemata going from the initial cat's position to the baited foodwell represents the correct reaction for the CDR task, while the interrupted line going from the cat's position after inversion to the same baited foodwell represents correct reaction for the IDR task. Bottom: 4 records of the Schmitt-triggered activity of a single prefrontal "place cell" are shown. Each of them corresponds to the correct or incorrect performance of the CDR and IDR tasks, as is indicated; "1" and "2" — left and right foodwells; SSM — middle Suprasylvian gyrus

ronment and rotation in the lighted external environment). Spatial orientation and spatial memory were tested using classical version of the delayed response and our version of the so-called inverted delayed response (in this case, animal in its starting cage was passively transported by an experimenter to the symmetrical place of test-situation, from which it was released after the cessation of delay) (Fig. 2). From the data gathered, the main conclusion emerged: cats subjected to microgravitation had significant deficits both in the spatial orientation and in spatial memory, especially when the latter was tested in the situations completely lacking any external visual landmarks.

The attempts to elucidate neuronal mechanisms of CAS might be summarized as follows. We were able to record units in the prefrontal and parietal cortices in the freely moving cats, activity of which were placed specific in the following way: all the animals in which single cell recordings were to be made during behavioral tasks (classical and inverted delayed responses — CDR and IDR in the personal and extrapersonal test-situations; for further details, see preceding paragraph) were slightly overtrained in order to have reliable behavioral basis. During such overtraining, the possibility existed for an animal to visit all the places in the test-situation. Units were monitored after such overtraining during actual tests performances in order to check whether their activity will be locked to places visited. From Fig. 3, one can conclude the existence in the prefrontal cortex of the freely moving cat the so-called "place units," that is, the cells, which firing frequency markedly increases in some delimited spatial portions of the test-situation. The same conclusion may be inferred from Fig. 4, in which the "receptive place field" for one unit from posterior portion of the middle suprasylvian gyrus in the cat is shown. But from the authors' point of view, most interesting is the firing behavior of the prefrontal and parietal "place units" during two behavioral tests used (classical delayed response — CDR and inverted delayed response — IDR) performed in two different test-situations — the first one, the so-called personal system (PS) and the second one — extrapersonal system (EPS). One can see that in the PS which completely lacks any external landmarks "spatial fields" of the single cell after the procedure of inversion, that is, during IDR testing changes its position in such a way that its relative position to the cat situated in the start-cage remains the same after inversion, as it was before it. In contrast, for the same behavioral tests performed in the EPS situation, reach with external visual landmarks the "spatial receptive fields" do not move at all after inversion procedure, that is, their locations in EPS system are determined mainly by the visual landmarks (see Fig. 4). All these statements concern prefrontal and parietal "place units" behavior in CDR and IDR tasks before rotation of the animal. On the other hand, after rotation was performed immediately after its cessation the same behavioral and electrophysiological technique has shown that "spatial receptive fields" of the prefrontal units became uniform (see Fig. 3), while such fields for parietal units although they still show some spatial specificity, their precise locations in the test-situation during the performance of the both CDR and IDR tasks floats in the quite unpredictable fashion. From these data, we may conclude that during CAS, the "place units" activity seriously deteriorates because of the invalid balance between the vestibular and visual afferentations, which normally contributes to proper spatial abilities (spatial orientation, spatial memory) of the animals in the conditions of the Earth gravity.

Obtained Results

The following results have been obtained:

– induction in animals CAS by uniform rotation around the horizontally placed longitudinal axis of the body with frequency 0.4 Hz;

– among symptoms of the CAS appearing in such conditions, the spatial disorientation is most prominent;

– the symptoms could not be cured by tranquilizers and /or antiepileptic drugs;

– induction of CAS in the case is dependent on the mismatch between the vestibular and visual stimuli;

– the mismatch is dependent on the integrating properties of the neurons located in the association cortex of the cat;

– neuronal integrators were identified by extracellular recording methods in the mentioned cerebral areas; and

– the model was proposed which is adequate in description of both the integrating processes and the genesis of CAS in microgravitation.

Space safety

List of Projects

In total, 11 projects were funded by the ISTC Parties.

#0385

"Creation of the Permanent Space Patrol of Solar EUV and X-ray Radiation"

(Space Patrol of Solar Radiation).

– Vavilov State Optical Institute (GOI), St. Petersburg, Russia

#0385-2

"Creation of the Permanent Space Patrol of Solar EUV and X-ray Radiation"

(Space Patrol of Solar Radiation)

– Vavilov State Optical Institute (GOI), St. Petersburg, Russia

#0427

"Working out of the Technology of Utilization of High-Toxic Component of Rocket Fuel — 1,1-dimethylhydrazine and Producing of a Number of Valuable Products on its Basis"

(Utilization of Rocket Fuel)

– Siberian Branch of RAS / Institute of Organic Chemistry, Irkutsk, Russia

– Scientific Research Institute of Chemistry and Technology of Organo-Element Compounds, Moscow, Russia

– Russian Scientific Center of Applied Chemistry, St. Petersburg, Russia

#1334

"Study of the Spacecraft Vital Elements Response to Space Debris Impact"

(Space Debris Impact on Spacecraft)

– VNIIEF, Sarov, N. Novgorod Region, Russia

#1420

"Gas-Filled Pressure Vessels under Hypervelocity Impact of Space Debris Particles: Development of Numerical Simulation Methodology and Survivability Analysis"

(Pressure Vessels under Impact of Space Debris)

– VNIIEF, Sarov, N. Novgorod Region, Russia

– Samara State Aerospace University, Samara, Russia

#1523

"Creation of the X-Ray Spectrometer for Permanent Space Solar Patrol"

(X-Ray Spectrometer for Permanent Space Solar Patrol)

– Vavilov State Optical Institute (GOI), St. Petersburg, Russia

#1917

“Development of the Design Technology of the Lightweight Shielding Protection for the Pressurized Hulls of Spacecraft and its Theoretical, Experimental and Computational Justification”

(Shield Protection for Spacecraft)

– Research Institute of Aviation Systems, Moscow, Russia

– Institute of Applied Mechanics, Moscow, Russia

– Institute of Advanced Study, Moscow, Russia

– Central Research Institute of Machine Building (TsNIIMash), Korolev, Moscow Region, Russia

#2128

“The Development and Creation of Unified Shielding Construction for the Protection of Spacecraft from Meteoroid and Space Debris Impacts”

(Meteorite Protection of Spacecraft)

– Central Research Institute of Machine Building (TsNIIMash), Korolev, Moscow Region, Russia

– NPO Energia, Korolev, Moscow Region, Russia

– Research Production Center DIPROK, Korolev, Moscow Region, Russia

#3392

“Development of Means and Methods to Ensure Microbiological Safety of Long-Operating Space Equipment”

(Microbiological Safety of Space Equipment)

– Russian Academy of Sciences / Institute of Biomedical Problems, Moscow, Russia

– FEI (IPPE), Obninsk, Kaluga Region, Russia

#3412

“Investigation of Astrosols in Near-Earth Space Using the Onboard Measurements and Computer Modeling Analysis of Astrosol Effect on Components of a Spacecraft”

(Astrosols in Near-Earth Space)

– Research Institute of Aviation Systems, Moscow, Russia

– Institute of Applied Mechanics, Moscow, Russia

#3779

“Development of a Portable High-Energy Neutron Spectrometer for Active Diagnostics of Radiation Environment in Spacecraft”

(Neutron Spectrometer for Spacecraft)

– Khlopin Radium Institute, St. Petersburg, Russia

Project Number:	#0385
Full and Short Title:	Creation of the Permanent Space Patrol of Solar EUV and X-ray Radiation. **Space Patrol of Solar Radiation**
Tech Code / Area / Field:	SAT-SAF / Space, Aircraft and Surface Transportation / Space Safety
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	$50,000 (EU)
Commencement date:	April 1,1996
Duration:	6 months
Leading Institute:	All-Russian Scientific Center S.I. Vavilov State Optical Institute (SOI), St. Petersburg, Russia
Contact Information:	Phone: +7 (812) 331 75 50 Fax: +7 (812) 331 75 58 E-mail: vncgoi@mail.ru Website:http://ns1.npkgoi.ru/investigations/lab_aero_ph_opt/lab.htm
Supporting Institutes:	No
Collaborators:	DaimlerChrysler Aerospace (Satellites), Friedrichshafen, Germany (Pailer N.) Fraunhofer Institute of Physical Measurement Testing, Freiburg, Germany Institut d'Astrophysique Spatiale (IAS), Orsay, France (Delaboudiniere J.-P.)
Project Manager:	AVAKYAN Sergei Vazgenovich
Contact Information:	Phone: +7 (812) 552 45 14, +7 (812) 323 88 39 Fax: +7 (812) 328 21 33 E-mail: avak@soi.spb.su
ISTC Senior Project Manager:	LAPIDUS Oleg Viktorovich
Contact Information:	Phone: +7 (495) 982 31 16 Fax: +7 (499) 978 36 03 E-mail: lapidus@istc.ru
ISTC Website:	http://www.istc.ru

Background

Till present, the study of solar influence on terrestrial phenomena was based on available data, so-called substitute (proxy) indices, which are not the main parameters of solar-geomagnetic activity. As a result, the progress in developing scientifically reliable predictive models on solar-terrestrial relations was virtually stopped. However, for global security of the mankind, it is absolutely necessary to study such problems as "Sun — weather and climate," "Sun — biosphere," and "Sun — earthquakes" that could be possible only if monitoring of short-wave solar radiation, namely, Space solar patrol, is established. At present, such monitoring does not exist.

This fact is connected exclusively with technical and methodological difficulties of space measurements in that range of spectrum. This ionizing solar radiation includes both soft X-ray and extreme ultraviolet (EUV) radiations and can be measured only outside the atmosphere — in space.

Creation of permanent patrol would make it possible to essentially advance in forecasting various geophysical events (including catastrophic magnetic storms), evaluating the role of solar events in meteorology, medicine, and predicting the failure of onboard instruments in spacecraft and satellites, disturbances in distant radio communication, etc.

For permanent patrol, it is necessary to design and create a hardware for real-time measurements of absolute values and spectral structure variations of EUV and X-ray fluxes of solar radiation in the range from 0.14 to 125 nm.

Numerous attempts to solve this problem led to the creation of permanent patrol in narrow spectrum bands (0.05–0.8 nm, USA). In Russia, the Institute of Applied Geophysical Research provides such measurements episodically in a large part of the spectrum without determining the main parameter — spectral structure.

As a matter of fact, the importance of obtaining the continuous and complete information (including spectral modifications) on solar short-wave activity is doubtless for humanity. During solar flares, solar radiation exhibits the largest changes just in the given range of wavelength whereas these changes determine to a large extent the variations in solar-terrestrial interactions.

The Project was expected to provide the complete solution of the problem including building an optical apparatus, development of measuring techniques, data calibrating and processing, installation of the apparatus on a special solar platform in regular satellites (communicational, geodesics, remote sensing, etc.).

Results of such spectral monitoring could stimulate studies in several scientific fields such as:

– solar physics (the state of all regions in the solar atmosphere);

– meteorology and physics of the atmosphere (impact of short-wave solar activity on the global changes, weather and climate including the effects of atmospheric electricity);

– aeronomy, cosmonautics (influence of solar activity on the density of the upper atmosphere and the drag of space vehicles, on the parameters of their atmosphere and satellite anomalies);

– radiophysics (determination and prediction of planetary ionospheres and conditions of radio wave propagation);

– heliobiology (the possible role of solar variability in biology and medicine); and

– possibly seismology and probably sociology.

Space Solar Patrol will be also important for interplanetary flights because it provides monitoring of solar activity during interplanetary expeditions (for example, to Mars). After space ships leave the terrestrial magnetosphere (at a distance of 10 Earth radii), onboard cosmonauts can be subjected to the action of high-energy solar protons and electrons in the periods of strong flares. Flashes of these corpuscles can be predicted using information obtained from monitoring solar X-ray and EUV radiation as wave radiation arrives to the Earth orbit in 8 min after the flare, whereas high-energy particles arrive in more than 20 h later. Therefore, there is some time (as for the Mars orbit, this time is even longer by a factor of 1.5) for protecting cosmonauts against dangerous impacts.

Project Objectives

The main objective of the first stage of Project #0385 was to substantiate a feasibility of launching a full Project "Creation of the Permanent Space Patrol of Solar EUV and X-ray Radiation" based on the obtained results.

Description of the Works

The technical approach for creating the Patrol was based on the methodology developed in the State Optical Institute. The methodology consists in simultaneous registration of solar fluxes using soft X-ray and EUV-grating spectrometers in wavelength ranges 1.8–60 and 55–125 nm with spectral resolution of 2 nm, on the one hand, and X-ray and EUV-radiometer in wavelength range 0.14–125 nm with multiple filters (about 20 filters made of foils, submicron films, and crystals), on the other hand (Fig. 1). The spectrometers and radiometer are equipped with the same electron multiplier (developed in the State Optical Institute) with a BeO photocathode, which is "solar blind" and characterized by high sensitivity in soft X-ray and EUV regions and by large dynamic scope equal to 10^7. The latter characteristic allows measurements both at quiet Sun and during solar flares.

The spectrometers measure the detailed spectral function and its variations whereas radi-

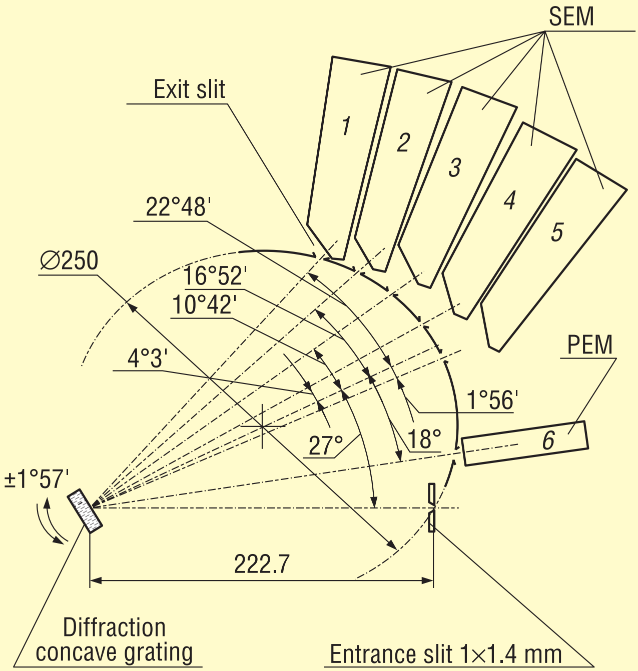


Figure 1: Extreme ultraviolet spectrometer for Solar Patrol Mission. Optical scheme. The wavelength channels: 1 — 16–34 nm; 2 — 28–63; 3 — 57–92; 4 — 89–124; 5 — 118–153; and 6 — 195–230 nm

ometer optical sensors (six sensors for different pitch-angles) give the initial information which enables to extract solar flux signals and to correct absolute measurements by taking scattered light in the spectrometers into account. Two signals one of which is generated by solar photons in the radiometer and the other by magnetospheric electrons and protons in the spectrometers are separated based on the comparison of readings of two optical sensors one of which is orientated towards Sun while the other (with the same or nearly the same pitch-angle) registers charged particles. The corresponding tools and methods were tested in Soviet satellites "Cosmos-262" and "Cosmos-381." Unfortunately, these satellites had no orientation towards the Sun and it was impossible to implement patrol measurements. Nevertheless, at episodic appearances of the sun disk in the field of view of spectral and radiometric tools, they demonstrated operability and reliable functioning during the entire active lifetime of the satellites and allowed obtaining much new data on the absolute fluxes of solar ionizing radiation and their intensity variations during periods of solar flares.

Obtained Results

Technical achievements were as follows:

• Methodology of permanent Space Patrol of solar EUV and soft X-ray radiation has been developed which allows continuous absolute spectral measurements of solar radiation, including periods of solar flares.

• Advanced technical solutions in X-ray optics and electronic pulsed technology have been analyzed and the most effective variants have been chosen for reliable work in space.

• Recommendations for updating optical-electronic tools for Space Patrol have been developed taking into account a set of requirements for continuous monitoring, reliability, and accuracy of absolute measurements.

• Draft schematics of the optical-electronic apparatus, including optical and structural schemes of X-ray and EUV-spectrometers and radiometer, have been developed.

• Modern versions of electronic circuits for the most important units have been worked out. A pulse-forming amplifier for the photoreceiving device with operation frequency up to 30 MHz (several times higher than in the earlier version) have been developed.

• Laboratory tests of the manufactured electronic circuits have been performed and the claimed circuit characteristics were verified.

• A number of open secondary-electron multipliers with dynodes made of beryllium bronze and photocathodes made of beryllium oxide were manufactured according to the technology developed at the State Optical Institute.

• Calibrating tests of open secondary electron multipliers manufactured during this project have been performed. The tests showed their insensitivity ("solar blindness") to visual light. The sensitivity in the X-ray spectral range, measured by y-ray registration of 55Fe isotope at the wavelength near 0.2 nm correlated with an expected value within the order of magnitude.

• Algorithm for initial processing of the data obtained from the space radiometer has been developed which takes into account the real straggling of telemetric signal and existence of mistakes.

• Materials on the main principles of functioning, as well as on the characteristic features of design and electromechanical hardware for the Sun-oriented platform (SOP) have been prepared. The SOP was shown to be capable of keeping optical axes of all the three instruments of the Space Patrol oriented toward Sun with the accuracy of angular orientation better than ten angular minutes at the low-orbit satellite of "Cosmos" series.

• Preparation has been made for using "Cosmos" satellite telemetric system for Space Patrol purposes taking into account the requirements to all optic-electronic hardware. The possibilities of the telemetric system were shown to be sufficient for absolute spectral measurements of solar ionizing radiation. Technical Documentation on the modernized optical-electronic hardware for Space Patrol of solar ionizing radiation for all three instruments: radiometer with filters, X-ray diffraction-grating grazing spectrometer, and five-channel EUV diffraction grating of normal-incidence spectrometer has been prepared.

Results were presented at:

- the 31st Scientific Assembly of COSPAR (Committee on Space Research), Birmingham, United Kingdom, July 1996;
- the 41st International Symposium (Annual Meeting) of SPIE on Optical Science, Engineering and Instrumentation, Denver, CO, USA, August 1996;
- the 25th General Assembly of International Union of Radio Science (URSI), Lille, France, August-September 1996; and
- the 3rd European Symposium on Satellite Remote Sensing, Taormina, Italy, September 1996.

High significance of the Space Solar Patrol project was assured in the letter of Ernest Hildner, Director, Space Environment Laboratory of National Oceanic and Atmospheric Administration, USA:

"The proposed Russian solar patrol, spanning the region approximately in the range 1–103 nm. would immediately allow us (and other agencies dedicated to space weather monitoring) to have direct measurements of radiation affecting the upper atmosphere. These measurements are a key input for deducing atmospheric density, and thus satellite drag; ionospheric charged particle population density, and thus radio propagation; and NO production. These latter two are important for communication and global climatic change research. At the present time, we attempt to infer these properties by the use of proxy indices, such as fluctuations in 10.7-centimeter microwave observations. These measurements specify this source of heat and ionization. However, these data only approximate the actual ionizing radiation and often give poor representation of short-term effects. As the United States' laboratory for the space weather, SEL considers the subdiscipline characterized by Professor Avakyan's project, as a part of its overall mandate. We anxiously anticipate a time when the data from such measurements will be available in a timely, continuous manner. We, therefore, heartily endorse the ISTC project for a solar patrol for ionizing radiation and look forward to participation of an SEL consulting scientist and the use of the resulting data in routine, daily forecasts."

Project Number:	#0385-2
Full and Short Title:	Creation of a Permanent Space Patrol of Solar Extreme Ultraviolet and X-ray Radiation **Space Patrol of Solar Radiation**
Tech Code / Area / Field:	SAT-SAF / Space, Aircraft and Surface Transportation / Space Safety
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$100,000 (EU)
Commencement date:	January 1, 1998
Duration:	18 months, extended by 5 months
Leading Institute:	All-Russian Scientific Center S.I. Vavilov State Optical Institute (SOI), St. Petersburg, Russia
Contact Information:	Phone: +7 (812) 331 75 50 Fax: +7 (812) 331 75 58 E-mail: vncgoi@mail.ru Website: http://ns1.npkgoi.ru/investigations/lab_aero_ph_opt/lab.htm
Supporting Institutes:	No
Collaborators:	DaimlerChrysler Aerospace (Satellites) / Dornier Satellittesysteme GmbH, Friedrichshafen, Germany (Pailer N.) Fraunhofer Institute of Physical Measurement Testing, Freiburg, Germany (Schmidtke Gerhard) Institut d'Astrophysique Spatiale (IAS), Orsay, France (Delaboudiniere J.-P.)
Project Manager:	AVAKYAN Sergei Vazgenovich
Contact Information:	Phone: +7 (812) 552 45 14, +7 (812) 323 88 39 Fax: +7 (812) 328 21 33 E-mail: avak@soi.spb.su
ISTC Senior Project Manager:	LAPIDUS Oleg Viktorovich
Contact Information:	Phone: +7 (495) 982 31 16 Fax: +7 (499) 978 36 03 E-mail: lapidus@istc.ru
ISTC Website:	http://www.istc.ru

Background

The Project #0385-2 was developed within the frame of the Project #0385 and based on the obtained results.

Project Objectives

The Project #0385-2 objective was creation of two basic instruments — extreme ultraviolet (EUV) spectrometer and X-ray-EUV-radiometer which are completely prepared for functioning in a space flight. This apparatus complex should provide real-time patrol measurements of absolute and spectral structure variations of the EUV (10–122 nm) and soft X-ray (0.14–10 nm) fluxes of the solar radiation on the satellites or another space vehicle. This spectral range of solar spectrum is the most geoeffective and strongly influence the near-Earth space weather. The Patrol should provide the permanent control of solar activity parameters, including the periods of solar flares, in the interests of solar-terrestrial physics and also makes it possible to predict adverse and catastrophic events such as disturbances in distant radio communication, failures in large electrical systems, breaks of main gas–oil pipelines, failures in operation of space vehicles, unexpected losses of height of large orbital stations, and, probably, seismic and meteorological cataclysms.

Description of the Works

The apparatus of the permanent solar patrol system for monitoring solar radiation comprised the following units:

1. A space-based patrol radiometer for the 0.14–157-nanometer spectral range with sequential separation of 20 bands of different spectral widths using a disk with filters made from thin metal foils, thin films, and optical crystals.

2. A space-based patrol spectrometer for the EUV radiation measuring solar radiation spectrum in a spectral range from 57 to 153 nm with resolution of 1.0 nm.

The spectral resolution of the spectrometer was chosen taking into account the possibility of isolation of higher-order spectra from the most intense lines in solar spectrum. At the same time, it is low enough to enable obtaining a high signal from a faint solar radiation flux (in the region where the continuous spectrum or low-intensity lines dominate) against a background of the stray light in the spectrometer from the strongest lines. A 3600 grooves per millimeter spherical diffraction grating with a 250-millimeter curvature radius, ruled on a gold layer, was used as a spectrum analyzer. This spectrometer also employed a classical arrangement of the entrance and several exit slits on the Rowland circle at their "middle" position. The spectrum is scanned by rotating the diffraction grating through an angle of ±1.9° relative to its middle position with the entrance and exit slits being slightly displaced from the Rowland circle. The spectrometer is a scanning polychromator which covers a spectral range from 57 to 153 nm by three channels, each one having a bandwidth of about 35 nm and being equipped with its own exit slit and radiation detector. In addition, three more channels are provided: for the 16–34- and 28–63-nanometer spectral regions to carry out trials of the measuring ability of this version of the spectrometer in the given spectral range, and an auxiliary channel for the 195–230-nanometer spectral region to align the spectrometer under the normal atmospheric pressure conditions. In the "middle" position, the angle of incidence of the input beam is 27°, whereas the angle of the diffracted rays ranges from –22.8° to 1.94° in the channels for the vacuum UV spectral region from 16 to 153 nm and amounts to 18° in the channel for the 195–230-nanometer "air" spectral region. All five channels for the EUV spectral region overlap so that all the most intense and important lines in the solar flux at 30.4, 58.4, and 121.6 nm are detected twice during a 72-second measuring cycle. They used open secondary electron multipliers (SEM), developed at the Vavilov State Optical Institute. These multipliers are "solar blind" for UV and visible light.

In the solar patrol set of apparatus described here, several channels were provided for monitoring the stability of its absolute spectral sensitivity. For this case, two 55Fe isotope radiation sources of different intensity are used in the radiometer in the working spectral region around 0.2 nm. This allows the variation in the absolute calibration at this wavelength to be checked after launching. An additional possibility to calibrate both the radiometer and the EUV spectrometer against the solar radiation with wavelengths longer than 150 nm appears in space. To this end, measuring the solar flux at $\lambda > 157$ nm through a quartz crystal is provided in the radiometer, and the long-wavelength measuring channel in the EUV spectrometer is capable of detecting the spectrum up to 153 nm. The spectrometer has an auxiliary channel for the 195–230-nanometer spectral region, wherein the magnitude of variations in solar radiation flux does not exceed several percent during the 11-year activity cycle and the 27-day period of rotation of the Sun.

Lastly, with due account of the success achieved to date in the patrol of ionizing solar radiation at wavelengths shorter than 0.8 nm and longer than 120 nm, a regular reference of the patrol to these data was provided as well.

Obtained Results

As a result of the Project, two main devices from optical-electronics apparatus of Space Solar Patrol (SSP): radiometer and EUV-spectrometer were created and successfully tested in laboratory vacuum chambers SOI and ESTEC.

The unique concave diffraction gratings with the number of grooves per millimeter of 3600 and all other elements of Radiometer and Spectrometer including secondary electron multiplier (SEM) were manufactured in the Vavilov State Optical Institute. To manufacture SEM, a unique technology of the Vavilov State Optical Institute was restored for activation of multiplier dynodes in oxygen.

Analysis of the special measurements of the zone sensitivity of photocathode allowed updating the dynode system of the SEM by using

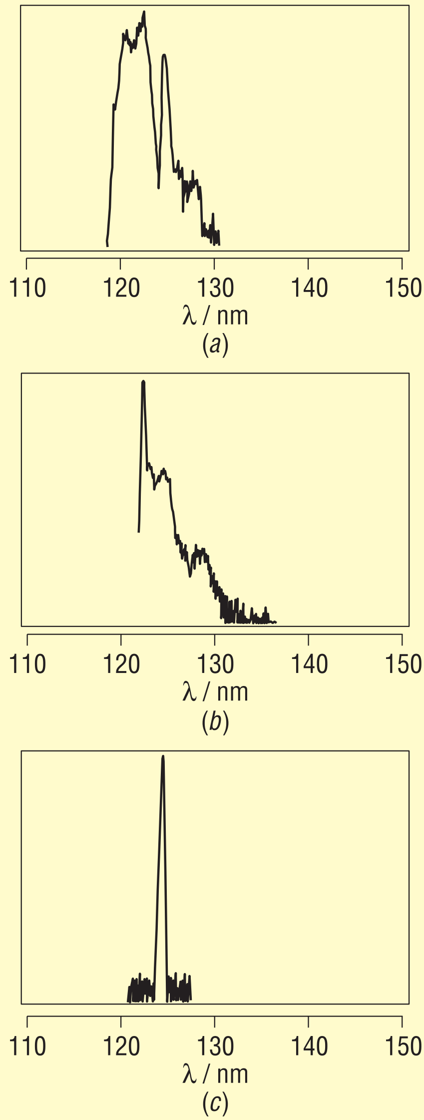


Figure 1: Calibration of SSP EUV spectrometer; spectra obtained on the EUV-spectrometer in a vacuum chamber: (a) and (b) for 4 and 5 channels, respectively, with a lamp DAM-25, and (c) channel 4, with a vacuum ultraviolet krypton resonance lamp

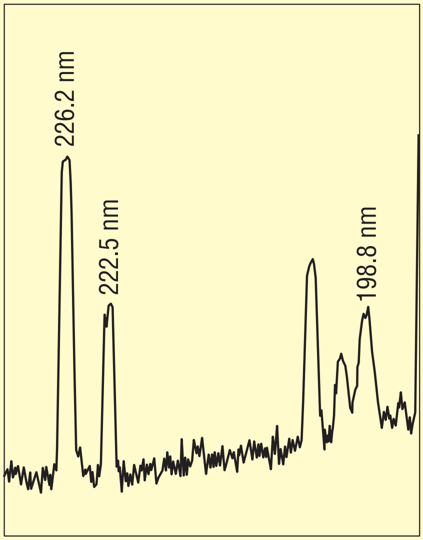


Figure 2: Calibration of SSP EUV spectrometer; spectrum of radiation of a lamp DRGS-12, received on air (sixth) channel of the EUV-Spectrometer for SSP

plane Γ-shape photocathode and increasing its dimensions. As a result of the tests, the calibration characteristics of the optical and electronic units of the Radiometer and Spectrometer were obtained based on specially developed test methods with using standard ultraviolet lamps, isotopes, and X-ray tubes (Figs. 1 and 2). The operation of Spectrometer and Radiometer in test vacuum chamber of the Vavilov State Optical Institute was demonstrated to foreign collaborators — IPM, Freiburg, Germany and Daimler Chrysler AEROSPACE, Germany as well as to ESTEC (Radiometer).

The working registration range of the EUV-spectrometer has been extended from (16) 57 to 153 nm. For this purpose, the additional (fifth) channel equipped with the secondary emission multiplier has been built. Also, the sixth channel with the photoelectron multiplier (PEM-142) that operates in the spectral range 195–230 nm has been added. The sixth channel allows independent check of stability of the diffraction grating characteristics to be carried out during a space flight. This long-wavelength auxiliary channel enables monitoring the stability of the diffraction grating efficiency without solar flares, because the effect of space factors on a PEM-142 photomultiplier was not found at low orbits, in particular, during the mission of Mir orbital station. In that experiment (“Briz” on the module “Spectr”), the workability of kinematics of a similar EUV spectrometer was tested with PEM-142 detectors incorporated instead of SEM detectors.

Project Number:	#0427
Full and Short Title:	Working out of the Technology of Utilization of High-Toxic Component of Rocket Fuel — 1,1-dimethylhydrazine and Producing of a Number Valuable Products on its Basis **Utilization of Rocket Fuel**
Tech Code / Area / Field:	SAT-SAF / Space, Aircraft and Surface Transportation / Space Safety CHE-SYN / Chemistry / Basic and Synthetic Chemistry
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding :	$295,000 (EU: $147,500, US: $147,500)
Commencement date:	October 1, 1996
Duration:	36 months
Leading Institute:	Siberian Branch of RAS / Institute of Organic Chemistry, Irkutsk, Russia
Contact Information:	Phone: +7 (3952) 51 14 31, 42 59 00 Fax: +7 (3952) 41 93 46 E-mail: irk_inst_chem@irioch.irk.ru Website: http://irkinstchem.ru/
Supporting Institutes:	Scientific Research Institute of Chemistry and Technology of Organo-Element Compounds, Moscow, Russia Russian Scientific Center of Applied Chemistry, St. Petersburg, Russia
Collaborators:	BUCK Pinnow, Pinnow, Germany (Hebish) E.S.T., , Germany Flanagan Research Company, Stanford, CA, USA Sandia National Laboratories, Albuquerque, NM, USA (Zanner F J) Société Nationale des Poudres et Explosifts, Le Bouchet, France (Thomé J L) US Department of Defense / Ballistic Missile Defense Organization, Washington, DC, USA (Caveny L H)
Project Manager:	LOPYREV Valentin Aleksandrovich
Contact Information:	Phone: +7 (3952) 46 06 11 Fax: +7 (3952) 35 60 46, 31 14 32
ISTC Senior Project Manager:	KOMARKOV Dmitry A.
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (499) 982 32 01 E-mail: istcinfo@istc.ru
ISTC Website:	Http://www.istc.ru

Background

Unsymmetric dimethylhydrazine (1,1-dimethylhydrazine, N,N-dimethylhydrazine, DMH) is intensely used as a component of a liquid rocket fuel. Its large-tonnage production was developed in the USSR, USA, France, and some other countries. It is well known that its reserves at military stores all over the world amount to few hundreds thousands tons, which is a great threat for mankind.

The ecological hazard of DMH stems from the fact that this compound is highly toxic for every living creature. DMH affects the upper airways and gastrointestinal tract, causes motor excitement, convulsions, hemolysis of erythrocytes, and methemoglobinemia.

The DMH utilization problem became fairly important in recent years because of the large-scale reduction of strategic weapons.

The suggested approach to DMH destruction by its burning is not only extremely unprofitable economically but, according to the opinion of some experts, can cause a unrecoverable harm to the environment.

Converting DMH into practically valuable compounds and materials is a more promising approach.

Therefore, the search for new practically valuable compounds that can be synthesized from 1,1-dimethylhydrazine, development of new technological processes of DMH utilization, and production of new commercially valuable materials and pharmacologically active species on its basis is to be considered as a problem of great importance.

Project Objectives

The objective of the Project was to synthesize new useful compounds from the high-toxicity rocket fuel component 1,1-dimethylhydrazine (unsymmetric hydrazine, DMH) and to work out the technology of their synthesis.

Description of the Works

The following work was accomplished in the course of Project implementation:

• Reactions of 1,1-dimethylhydrazine with higher fat alcohols were studied. New surfactants were synthesized and their physicochemical properties were studied.

• Laboratory schedule was developed for synthesizing based on 1,1-dimethylhydrazine medical and veterinary preparations and also remedies used in plant growing.

• The physicochemical properties of the compounds synthesized were investigated. The processes proposed previously were optimized based on the combination of the physicochemical data assessed experimentally and quantum-chemistry calculations. The methods for express-analysis of the desired compounds and possible products were worked out.

• Recommendations concerning the use or utilization of side products were suggested.

• A pilot production plant at Irkutsk Institute of Chemistry SB RAS was build and the pilot plant in RSC “Applied Chemistry” (Prikladnaya Khimiya) (St. Petersburg) was modernized to produce commercially valuable compounds based on 1,1-dimethylhydrazine.

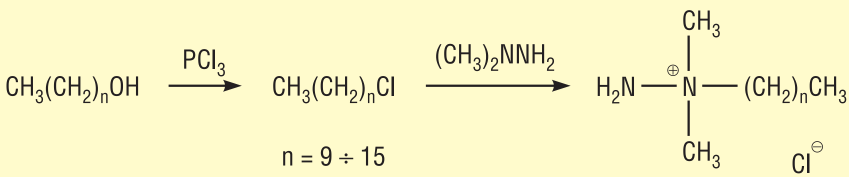
• Test batches of the preparations were produced in amounts of 20 or 50 kg and their consumer properties were tested.

• Technological parameters of the synthesis processes were refined and laboratory samples were synthesized.

• Physicochemical properties of new 1,1-dimethylhydrazine-based compounds were studied. Their toxicity characteristics were assessed.

• New areas of application of the compounds synthesized based on 1,1-dimethylhydrazine were looked for.

Investigations of unsymmetric dimethylhydrazine (UDMH) reactions with higher primary alkane monohalides synthesized from the appropriate alcohols allowed synthesizing compound *I* and to assess its characteristics including surface tension, toxicity, antibacterial activity, protecting properties as a corrosion inhibitor, etc. Its anticorrosion activity (at a concentration of *I* of 0.1 g/*l*) in relation to that of hydrogen sulfide solution at H_2S concentra-



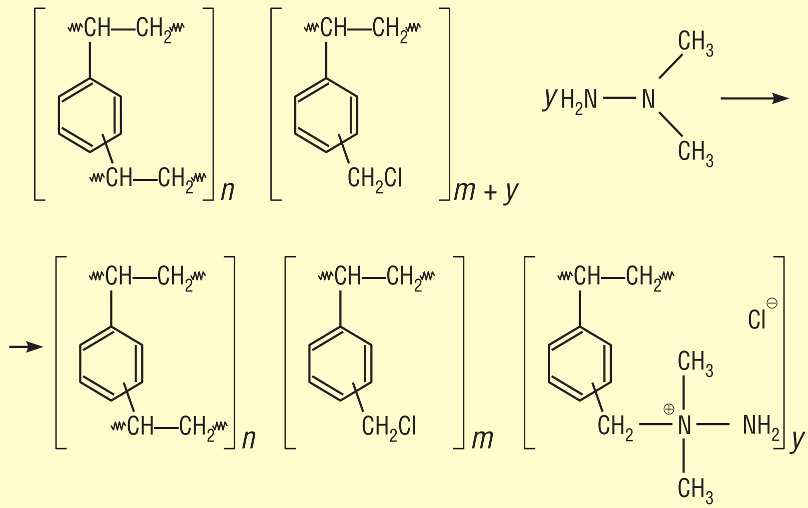
tion ranging between 0.2% and 4% appeared to be 0,85–0,95.

Technology parameters of synthesizing 1,1-dimethyl-1-dodecylchloride were developed and optimized. They are: an 1,1-dimethylhydrazine and dodecylchloride mixture (in a 1:1.1 ratio, with no solvent) is held for 2 or 2.5 h at 75 or 80 °C, with its subsequent heating to 150 °C. The overall duration of the process is 5 h, the desired product yield is 95%.

A mixture of 1,1-dimethyl-1-alkyl hydrazinium chlorides can be synthesized in two stages from a mixture of 1,1-dimethylhydrazine and technical mixture of higher (C_{10}–C_{16}) alcohols. This mixture is shown to be nontoxic and can be applied as surfactant exhibiting anticorrosion properties and as an additive modifying the asphalt-bituminous mixture.

The receipts of aqueous bitumen emulsions stabilized with 1,1-dimethyl-1-alkyl-hydrazinium chloride were optimized and their application in road construction is tested.

The commercial chloromethylated styrene –



divinylbenzene copolymer is modified with 1,1-dimethylhydrazine:

The static volumetric capacity of the modified specimens produced under different conditions with respect to a 0.1 N HCl solution varies from 1,0 to 3,4 mg equiv./g.

Sorption of MnO_4^- and $Cr_2O_7^-$, $FeCl_4^-$, $CoCl_4^{2-}$, $CuCl_4^{2-}$ anions and uranium containing admixtures by an CMPS anionite synthesized by modification of chloromethylated polystyrene with 1,1-dimethylhydrazine was studied. Sorption of the aforesaid anions from aqueous solutions amounted to 98%–99%.

Comparative tests of various sorbents cleaning uranium containing sewage waters were conducted at the Novosibirsk factory of chemical concentrates. Real sewage water was used in these experiments. The sorption activity was

Table 1: Experimental results

#	Sorbent name	Uranium concentration in equilibrium solution, mg/l	Equilibrium uranium content in the sorbent, mg/g	Distribution coefficient, mg/l
1	Amberjet 4400 C1 (highly basic anionite)	0.0055	0.00845	1536.4
2	Purolite S920 (chelate resin)	0.0025	0.00875	3500.0
3	AN-2F	0.0085	0.00815	958.82
4	AV-17-8	0.0023	0.00877	3813.0
5	KhMPS (anionite)	< 0.001	> 0.0089	> 8900.0
6	AB3-NT-3.0 (activated charcoal)	0.088	0.0002	2.27
7	KB3-NT-3.0 (carbonized charcoal)	0.07	0.002	28.57

assessed from the distribution coefficient values. This coefficient was calculated by the formula

$$\Gamma = A \cdot 10^3 / C \text{ (ml/g)},$$

where A is the equilibrium sorption capacity with respect to uranium, mg/l, and C is the equilibrium uranium content in the solution, mg/l.

The experimental results are summarized in Table 1.

As seen from Table 1, the ion exchange sorbent KhMPS based on 1,1-dimethylhydrazine showed the highest capacity for uranium sorption (the distribution coefficient > 8900 mg/l).

The anionite synthesized was tested for its frost-resistance (temperature was varied between 0 and –20 °C, test duration was 120 days). The exchange capacity of the anionite, its specific volume, and mechanical strength changed within the permissible limits in the course of its holding in the frosted state.

The kinetics of dichloroethane interaction with 1,1-dimethylhydrazine has been studied to provide data needed in designing reactors, in which 1,1-dimethyl-1-(2-chloroethyl)hydrazinium chloride had to be synthesized. The interaction process was shown to be depicted by a second-order kinetic equation with a rate constant of $10.2 \cdot 10^{-3}$ l/(mole·min) and activation energy of 70.9 kJ/mole.

Thermal stability of the new compounds (dimethyltetradecyl-hydrazinium-, dimethyldodecyl-hydrazinium-, dimethylakyl (C_{12}–C_{14})-hydrazinium-chlorides) was investigated by differential scanning calorimetry and thermogravimetry techniques. Based on the physicochemical data thus obtained, the optimal pathways of synthesizing the desired products were found and the amounts and composition of the side products were assessed. The lines of utilization of the abundant side products were suggested.

The inhibiting activity of 1-(alkylbenzylsulfo)-1,1-dimethul hydrazide in acidic highly corrosive media was studied. The values of protective action of the sulfohydrazide synthesized were slightly superior to the foreign inhibitors of acid petroleum, such as Correxite and Norust, and Russian inhibitors Neftekhim, Sever, and GIPKh-6.

It was shown that 1,1-dimethyl-1-(2-chloroethyl)hydrazinium chloride exerted a stimulating effect on plant growth.

The effect of 3-(2,2,2-trimethylhydrazinium) propionate on reflexive regulation of arterial pressure, namely, on depressant and pressant reflexes was investigated.

The technology of 1,1-dimethyl-1-alkylhydrazinium chloride synthesis was analyzed. Quaternizarion of 1,1-dimethyl-1-alkylhydrazinium chlorides by a mixture of alkyl chlorides (C_{10}–C_{16}) with no solvents was investigated with the purpose of increasing the desired-product yield and of intensifying the process. The conditions were found under which the yield of alkylation products attained 93% (boiling of a 1.5:1 1,1-dimethylhydrazine: alkylchlorides mixture for 5 h).

A laboratory procedure of synthesis of 3-(1,1,1-trimethylhydrazinium)propionate dihydrate (a promising medical and veterinary preparation) was developed. The following scheme of the process was suggested:

- reaction medium: dichloroethane, 1,1-dimethylhydrazine, isopropanol taken in the ratio 3 : 1 : 1 (45, 28, and 27 %(wt.)), respectively;
- atmospheric pressure;
- temperature 76–80 °C;
- duration of the process 2 h;
- 1,1-dimethylhydrazine conversion 92%–94%; and
- yield per 1,1-dimethylhydrazine converted 72%–75%.

To study the biological activity and to explore the possibility of application of UDMH-based compounds as medical and veterinary preparations, a number of new compounds were synthesized. Antituberculosis activity of fourteen compounds synthesized from 1,1-dimethylhydrazine was tested at the Research

$$CH_2{=}CH{-}COOH \xrightarrow{(CH_3)_3SiCl} CH_2{=}CH{-}COOSi(CH_3)_3$$

$$CH_2{=}CH{-}COOSi(CH_3)_3 \xrightarrow{(CH_3)_2N{-}NH_2} (CH_3)_2N{-}NH{-}CH_2CH_2COOSi(CH_3)_3$$

$$(CH_3)_2N{-}NH{-}CH_2CH_2COOSi(CH_3)_3 \xrightarrow{CH_3Br} (CH_3)_3\overset{\oplus}{N}{-}NH{-}CH_2CH_2COOSi(CH_3)_3 \quad Br^{\ominus}$$

$$(CH_3)_3\overset{\oplus}{N}{-}NH{-}CH_2CH_2COOSi(CH_3)_3 \quad Br^{\ominus} \xrightarrow{C_2H_5ONa} (CH_3)_3\overset{\oplus}{N}{-}NH{-}CH_2CH_2CO\overset{\ominus}{O} \cdot 2H_2O + NaBr + (CH_3)_3SiOC_2H_5$$

Simplicity of conduction of the reaction steps and cheapness of the reagents and solvents used are the major advantage of this procedure.

The optimal technological parameters of synthesis of 1,1-dimethyl-1-(2-chloroethyl)hydrazinium chloride are found:

Institute of Phthisiopneumonology (St. Petersburg). All the compounds tested exhibited antituberculosis activity comparable with that of preparation “pyrasineamide.”

Aqueous 20 percent solution of 1,1-dymethyl-1-alkylhydrazinium chloride was tested as a flotator in cleaning of potassium-containing ores from silicate and carbonate minerals. The flotator efficiency of UDMH-based compounds turned out to be twice as high as that of flotators traditionally applied in potassium producing industry.

1,1-dimethyl-1-alkylhydrazinium (C_{12}–C_{14}) chloride was tested as a biocide in treatment plants and in water preparation plants with a high microbiological activity. It was applied to treat concrete surfaces and as an additive to construction solutions. No mould and fungal formations were noted during the one-year test, whereas in the absence of the product, an active growth of fungal formations was observed in some cases as early as in 2 or 3 weeks.

All the compounds synthesized were investigated by various physicochemical techniques: NMR (nuclear magnetic resonance), IR (infrared), UV (ultraviolet), NQR (nuclear quadrupole resonance), mass-spectrometry; with the use of quantum-chemical analysis (Gaussian-94, 98), the structure of these compounds and composition of reaction mixtures were ascertained. The above physicochemical techniques were recommended for analysis of the desired and side products.

A pilot plant was designed and manufactured at Irkutsk Institute of Chemistry SB RAS for synthesizing commercially valuable products on the basis of 1,1-dimethylhydrazine.

The pilot plant existing at RSC "Applied Chemistry" (St. Petersburg) was modified for producing pilot batches of 1,1-dimetyl-1-(2-chloroethyl)hydrazinium cloride and UDMH derivatives.

The following amounts of compounds were synthesized for investigations:

2 kg 3-(2,2,2-trimethylhydrazinium)propionate;

30 kg 1,1-dimethyl-1-(2-chloroethyl)hydrazinium chloride;

4 kg 1,1-dimethyl-1-alkylhydrazinium;

1 kg anionite (UDMH derivative).

Obtained Results

The following technologies of synthesis of:

- 3-(2,2,2-trimethylhydrazinium)propionate dihydrate, a prospective medical and veterinary preparation (it was patented);
- quartazine preparation, which is an active plant growth regulator;
- 1,1,1-dimethylalkyl(C_{12}–C_{14})hydrazinium chloride, which is a corrosion inhibitor for petroleum industry; and
- asphalt-bituminous mixture for road paving

were developed.

An efficient anionite was synthesized via modification of commercial chloromethylated styrene copolymer with divinylbenzene by 1,1-dimethylhydrazine.

A number of new compounds were synthesized from UDMH, their biological activity was investigated.

Project Number:	#1334
Full and Short Title:	Study of the Spacecraft Vital Elements Response to Space Debris Impact **Space Debris Impact on Spacecraft**
Tech Code / Area / Field:	SAT-SAF / Space, Aircraft and Surface Transportation / Space Safety
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$100,000 + 90,654 € (EU: 90,654 €, JP: $100,000)
Commencement date:	April 1, 2000
Duration:	24 months, extended by 6 months
Leading Institute:	VNIIEF, Sarov, N. Novgorod Region, Russia
Contact Information:	Phone: +7 (83130) 4 48 02 Fax: +7 (83130) 2 94 94 E-mail: staff@vniief.ru Website: http://www.vniief.ru
Supporting Institutes:	No
Collaborators:	DaimlerChrysler Aerospace, Bremen, Germany (Hoffmann J.-P.) European Space Agency / European Space and Technology Center, Noordwijk, The Netherlands Fraunhofer Institut Kurzzeitdynamik, Freiburg, Germany (Schneider E.) National Aerospace Laboratory, Tokyo, Japan (Kibe S.)
Project Manager:	POLEVOY Oleg Nikolaevich
Contact Information:	Phone: +7 (83130) 4 48 02 Fax: +7 (83130) 2 94 94 E-mail: root@gdd.vniief.ru
ISTC Senior Project Manager:	NIETZOLD Dieter
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (499) 982 32 01 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

The probable impingement of space apparatus (SA) on technogenic objects in space is getting now a serious danger because of ever increasing contamination of the near-Earth space environment with various debris. The range of debris size is fairly large: from few microns to several meters. The risk of SA collision with fine particles is quite realistic and must be taken into account in designing and running SA. Collision with particles the average velocity of which is close to 12 km/s (hypersonic impact) can entail catastrophic consequences even for a large space apparatus such as the International Space Station (ISS).

Creation of efficient systems of SA protection against impacts of high-velocity particles, space debris (SD), and meteorites calls for theoretical and experimental studies of hypervelocity impacts.

Project Objectives

The major objective of the Project was to investigate by numerical and experimental modeling techniques a behavior of a new multilayer shield (with a bumper) construction protecting SA against impacts of hypervelocity space debris particles.

Description of the Works

To protect SA against impacts of hypervelocity space debris particles the participants of the Project suggested in 1995 to supplement the Whipple meteoroid shielding with a special damping coating that mitigated the pulse impact of the secondary fragments on the casing of a construction protected.

Checking of the efficiency of the multilayer shield (with a bumper) construction protecting SA against impacts of hypervelocity SD particles included:

– mathematical modeling of the behavior of the shield protecting SA against impacts of hypervelocity SDs particles;

– ascertaining of feasible lines of optimizing SA protective shielding constructions in terms of weight and material characteristics with account taken for the computation results;

– experimental investigations of the behavior of the optimized shielding at hypervelocity impact; and

– comparison of the experimental data with calculations and incorporation of the refinements needed in the mathematical models used.

The SPH (Smoothed Particle Hydrodynamics) code KERNEL developed at RFNC–VNIIEF for three-dimensional (3D) solving unsteady gasdynamic problems and problems of dynamics of elastic-plastic media was used in mathematical modeling.

The experimental investigations comprised:

– preliminary experiments aimed at adaptation of the setups and measurement techniques; and

– experiments verifying the results of mathematical modeling of the behavior of protective shielding impacted by SD particles and tests of the optimized shielding.

The following setups were employed at RFNC–VNIIEF in the experiments:

– setup that uses blast throwing facilities (BTF); and

– light-gas gun (LGG).

The setups were adapted to imitate the space conditions.

The available measuring systems were used in experiments to monitor the impact process, they included high-speed optical camera, X-ray camera, pressure gauges, contact gauges (to measure time intervals), and detection of the final “object” state (measurements of craters, holes, etc.).

The choice of the construction parameters to be studied

The Project collaborators (ESA–ESTEC, Ernst-Mach-Institute) have suggested to perform a computational-experimental exploration of the possibility of applying the suggested shielding construction to protect manned ISS modules, taking as an example the early Columbus version (European module attached to ISS).

The penetration (nonpenetration) characteristics of the conical Columbus section (usually, this section of the outer surface area is subjected to impacts of orbital particles) are computed at the Central Research Institute of Machine-Building (TsNIIMash) for the entire gamut of impacting high-speed particles of orbital debris and meteoroids. The calculations demonstrated that the Whipple protection versions with bumpers developed by NASA for the USA ISS modules (SW MOD-2) and ESA and recommended for the European ISS module (AS2-N4KE4) in 1998 were less efficient than the long-time known two-screen protection device (two separated aluminum alloy shields) optimized at the back wall material (aluminum alloy), its thickness (5 mm), overall separation (170 mm), and specific weight (2.7 g/cm^3) being retained.

The bumper material was chosen at TsNIIMash. The following commercial materials were considered as candidates for protection bumpers:

• mineral porous sound absorbing material "Akmigran;"

• foamed polystyrene;

• glass wool; and

• light-weight hydrophobic thermal insulation plates.

A comparative study of the physicochemical properties of the materials has led to the inference that the light-weight hydrophobic thermal insulation plates were the most promising materials for their further studies as a bumper because they were most resistant to the effects exerted by open space, had a low density (lower than that of glass wool) and high strength of the reinforcing mineral fibers.

Modification of the computational technique

The SPH-code KERNEL developed for 3D numerical modeling of hypervelocity penetration was modified to improve the computation precision, namely, the computational scheme was rearranged, the computational module was modified, and the equation of state of porous materials was incorporated. The computational module of the KERNEL code was parallelized for application to a two-processor computer governed by OS MS Windows NT4/2000. The new code version was tested against known analytical solutions and experimental data, including available data on high- and hypervelocity impacts.

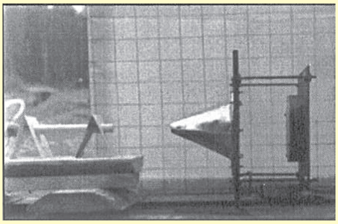
Preparation of experimental setups to performing experiments

The setup with BTF and LGG were adapted to tests of the shielding suggested for SA protection against hypervelocity SD particles. The test bench in which particles were accelerated by explosion of an high-explosive (HE) charge of the "Titov tube" type was worked out to perform full-scale tests with spherical titanium projectiles 5.5 mm in diameter (impact velocity of 4 or 5 km/s) and steel spherical projectiles 5.6 or 8 mm in diameter (impact velocity of 7.3 or 5.4 km/s). Full-scale experiments were conducted with the use of LGGs accelerating spherical aluminum projectiles from 7.5 to 15 mm in diameter to velocities ranging between 4 and 7 km/s. The methodology developed for experimental modeling can be employed to check the shielding devices that protect spacecraft against impacts of hypervelocity SD particles; X-ray photography and high-resolution optical photography can be employed to monitor the impact process.

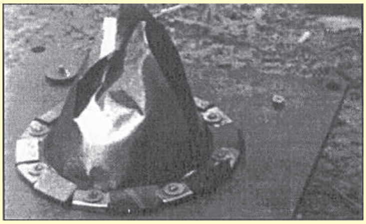
The tests aimed at checking operation of the experimental setups were supplemented by computations by the KERNEL code. The calculation results were used to plan or correct arrangement of tests, while the test results were used to additionally verify the code.

Investigation of the behavior of a high-porosity layer in the assemblies investigated

The full-scale experiments were conducted on the setup in which impactors were accelerated by BTF (Figs. 1–4). To simulate a normal impact of SD particles at a velocity $V \sim 4.5$ km/s, spherical impactors made of a titanium alloy 5.5 mm in diameter (its weight was equivalent to that of spherical aluminum alloy fliers 6.5 mm in diameter) were used.



(a)



(b)

Figure 1: Cutoff device adjustment test (the apex angle ~ 22°): (a) the assembly before the test; and (b) diaphragm deformed after the test

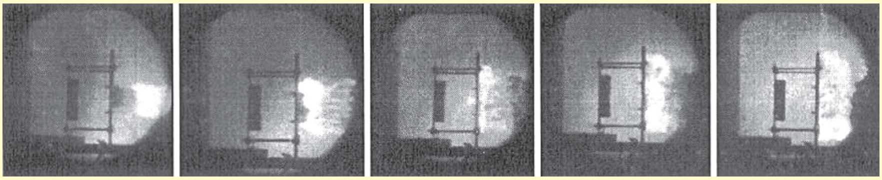
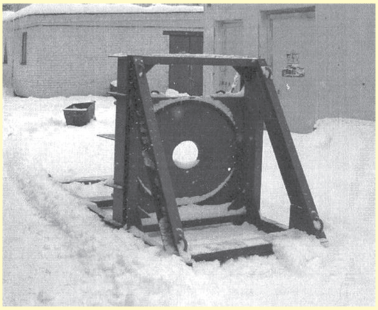
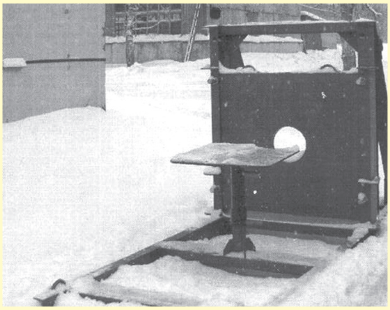


Figure 2: Frames showing interaction of the BTF explosion products with the cutoff device (test with a cone angle of about 15°)



(a)



(b)

Figure 3: Test bench: (a) front view; and (b) back view

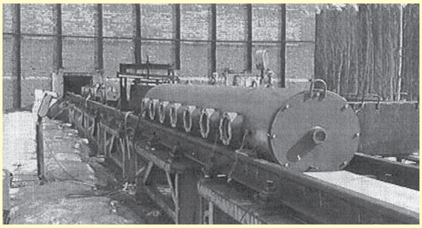


Figure 4: Vacuum chamber (front view)

Three experiments have been conducted with targets 1:2 in scale; they were an optimized two-screen assembly (two separated screens and back wall made of an aluminum alloy and an assembly with the identical first screen and back wall, overall separation (78 mm), and specific weight, but with a reduced thickness of the second screen and with the space between it and back wall filled with a bumper layer 0.066 g/cm^3 in density. The targets were assembled with the aid of stud pins and placed in a steel cylindrical confinement. The first screen served as a face cover and the back casing cover served as a witness plate. The casing was evacuated to a pressure of 0.5 atm which caused a 2- or 3-millimeter (at maximum) sagging of the first screen.

Calculations predicted puncturing of the back target wall at V = 4.0, 4.5, and 5.0 km/s with no bumper and only its bending at the same impact velocities when the target was filled with the bumper.

The impact conditions were virtually identical in the three experiments, identical were also the damage of the two screens and the final result (penetration). However, damage of the back wall was lesser in tests with a bumper: the diameter of the area filled with fine craters on the back surface was much smaller, large craters were lacking, and the damage looked rather like erosion of the surface while the hole was most likely formed due to opening of the cracks.

On the whole, the results of tests showed that at impact velocities between 4 and 5 km/s, the state of the back wall of the assembly with a bumper was not worse than that of the assembly with no bumper of the same specific weight.

Full-scale experiments were also conducted with LGG (Figs. 5–9). To model a normal impact of space debris particles at velocities ranging between 4 and 7 km/s, spherical projectiles made of aluminum alloy 12.5 and 15 mm in diameter were used.

Eight tests were conducted with optimized two-screen assemblies (two separated screens and a back wall made of aluminum alloy) and with assemblies with the identical first screen and back wall, general separation (170 mm), and specific weight, but with a reduced thickness of the second screen and the space between the second screen and back wall filled with a bumper 0.033 or 0.028 g/cm^3

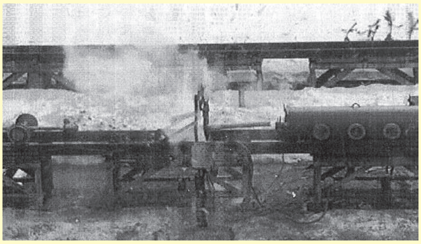


Figure 5: A fragment of the process of LGG shot

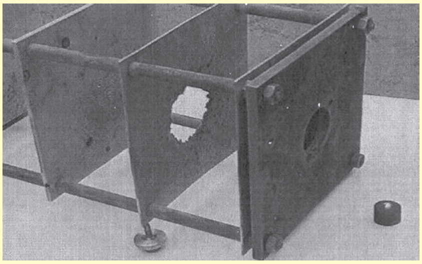


Figure 6: The assembly after interaction with the projectile

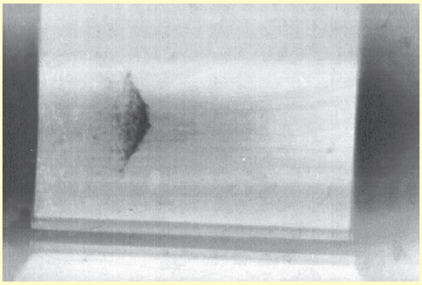
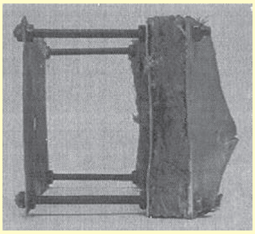
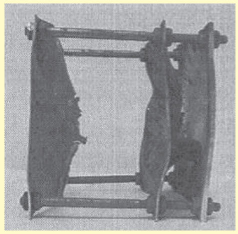


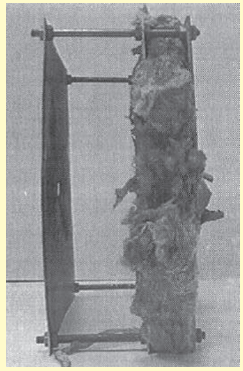
Figure 7: X-ray photography of the secondary flow of fragments after ptojectile impingement on the first assembly sheet



Test #12

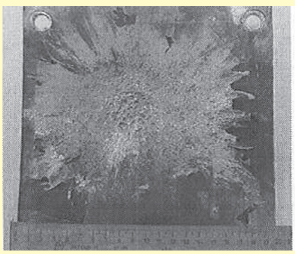


Test #13

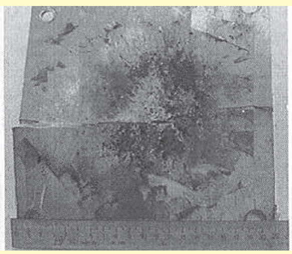


Test #14

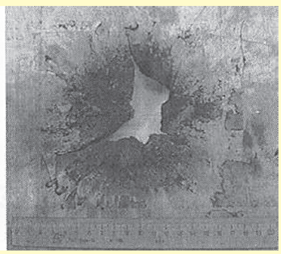
Figure 8: Photos of the targets after tests (assembled)



Test #12



Test #13



Test #14

Figure 9: Photos of the targets after tests (back wall, front view)

in density. All the targets were assembled with the aid of stud pins. For technical reasons, the targets were not evacuated in these tests. The projectile shape and state were controlled by X-ray photographing. The time of projectile impact on the screens and back wall was detected with the aid of contact gauges. The cloud of secondary fragments formed after puncture of the second screen was photographed in X-rays.

The results of full scale testing demonstrated that:

– an impact of an aluminum projectile 15 mm in diameter at a velocity between 4 and 4.5 km/s on targets with and without a bumper caused identical damage of their back walls (they were broken into several large fragments with no notable traces of penetration); and

– an impact of an aluminum projectile 12.5 mm in diameter at a velocity of ~ 6.6 km/s resulted in a petal-shaped punch of the target with a bumper and in bending only of the back wall of the target with no bumper.

Thus, the integrity of the back wall of assemblies with a bumper was found to be not worse than that of assemblies with no bumper of the same specific weight at impact velocities of 4 or 4.5 km/s but it was worse than the integrity of assemblies with no bumper at an impact velocity of 6.6 km/s. It was not anticipated

because the bumper performed its function, it stopped the secondary fragments produced by puncturing of the second screen (in tests with targets filled with a bumper, no large craters were observed on the back wall surface).
Numerical modeling failed to predict this observation, namely, only bending of the back wall was prdicted by calculations with the dynamic values of the yield strength and material strength for targets both with and without bumper. Calculations with static strength values predicted puncturing of the two targets. Perhaps, the calculated results were affected by not a quite adequate simulation of the behavior of the high-porosity bumper in the course of its puncturing with high-velocity fragments.

Obtained Results

1. The ISS construction was analyzed with the purpose of choosing the site where the suggested new multiple-layer shielding with a bumper could be applied. The conical section of the European ISS Module was chosen to demonstrate the feasibility of application of the protection technology suggested.
2. Published data on ballistic curves of typical protective shielding (including those mounted on ISS and being designed) were analyzed. The parameters of contamination with debris of the space environment surrounding ISS modules were analyzed to ascertain impact effects.
3. SPH-code KERNEL, developed at VNIIEF for 3D computations on unsteady gasdynamics and dynamics of elastic-plastic media, was refined to provide better precision and to reduce the computation time. The new code version was verified with the aid of known analytical solutions and available experimental data. The code was validated using the results of experimental modeling of high- and hypervelocity impacts. The methodology of numerical simulation developed can be used to assess the SA protection against impacts of hypervelocity SD particles.
4. Experimental facilities (including vacuum chambers in which the targets and recording equipment is mounted) were adapted to the conditions under which the suggested SA protection shielding against hypervelocity SD particles is to be tested. The elaborated methodology of experimental modeling can be employed to check protection shielding of space vehicles against impacts of hypervelocity SD particles, and X-ray photography and high-resolution optical photography can be used in monitoring the impact process.

5. Trial investigations of the physical and mechanical properties of several commercial materials were performed. Light-weight hydrophobic thermal insulating plates of an initial density of 0.025–0.03 g/cm^3 were chosen as the most promising material to be used as a bumper in the protective shield because of its high stability under space conditions, low initial density, high strength of the fibers, and low cost. The material chosen was studied by numerical and experimental techniques. The results of numerical calculations and of scaled and full-scale tests have demonstrated that integrity of the back wall of an assembly with a bumper was not worse than that of the Whipple shield at impact velocities of 4 or 5 km/s, the screen and back wall material parameters, back wall thickness, screen separation, and specific weight being identical. However, at the impact velocity of about 6.6 km/s, the integral characteristics of penetration (nonpenetration) through the shield with a layer of a high-porosity bumper turned out worse, in spite of the fact that the bumper performed its function, i. e., stopped the secondary fragments produced in the course of second screen puncturing.

The final conclusion concerning expediency of fabrication and application of the considered multiple-layer shielding construction (with a bumper) to protect space vehicles against space debris calls for investigations of impacts at velocities exceeding 7 km/s.

Project Number:	#1420
Full and Short Title:	Gas-Filled Pressure Vessels under Hypervelocity Impact of Space Debris Particles: Development of Numerical Simulation Methodology and Survivability Analysis **Pressure Vessels under Impact of Space Debris**
Tech Code / Area / Field:	PHY-NGD / Physics / Fluid Mechanics and Gas Dynamics SAT-SAF / Space, Aircraft and Surface Transportation / Space Safety
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding :	$80,000 (US)
Commencement date:	September 1, 2001
Duration:	24 months, extended by 6 months
Leading Institute:	VNIIEF, Sarov, N. Novgorod Region, Russia
Contact Information:	Phone: +7 (83130) 4 48 02 Fax: +7 (83130) 2 94 94 E-mail: staff@vniief.ru Website: http://www.vniief.ru
Supporting Institutes:	Samara State Aerospace University, Samara, Russia
Collaborators:	Fraunhofer Institut Kurzzeitdynamik, Freiburg, Germany
Project Manager:	IOILEV Andrey Germanovich
Contact Information:	Phone: +7 (83130) 4 24 83 Fax: +7 (83130) 4 13 58 E-mail: ioilev@vniief.ru
ISTC Senior Project Manager:	ENDRULLAT Burkhard
Contact Information:	Phone: +7 (495) 982 3200 Fax: +7 (499) 978 01 10 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

Hypervelocity impacts of space debris (SD) on sealed shell constructions pressurized internally (pressurized vessels, PV), that are always present in space stations, can result in their catastrophic destruction; therefore, it is this factor that determines survivability of space stations when impacted by SD. The consequences of an impact are to a large extent controlled by the nature and parameters of the medium filling the vessel (gas or liquid). Recent investigations performed at NASA and ESA have demonstrated that the consequences of catastrophic destruction of vessels filled with gas are more hazardous than the damage caused by destruction of vessels containing liquids.

Project Objectives

The objective of the Project was to numerically model the behavior of vessels containing pressurized gas (PV) impacted by a SD particle flying at a hypervelocity.

Description of the Works

The following processes were simulated:

1. Perforation of the wall of a vessel and formation of the cloud of fragments.

2. Expansion of the cloud of secondary fragments in a gas.

3. Generation and propagation of a shock wave (SW) in the gas.

4. Deformation and destruction of the front and rear vessel walls.

To model such phenomena as penetration, formation of the cloud of fragments, generation of SWs and their propagation, behavior of shock-loaded constructions the team at RFNC–VNIIEF developed the following computational techniques:

– computational code KERNEL based on the Smoothed Particle Hydrodynamics (SPH) method for three-dimensional (3D) calculations of the penetration process;

– computational technique B-71 based on the Godunov method for two-dimensional (2D) calculations of SW propagation in areas of complicated geometry and through perforated immobile and mobile partitions and through the cloud of particles; and

- computational technique DRAKON for 3D calculations of the shell dynamics.

The team at SSAU developed a special technique TROTWD capable of computationally modeling incipience of a crack and its unsteady spread from the hole periphery toward the front PV wall.

The following assumptions and restraints underlined the investigations:

1. Normal central impingement of a spherical aluminum impactor at a velocity $V_p > 4$ km/s.

2. No shielding of the front and rear PV walls.

3. Pressurized vessel is a sealed cylindrical (or spherical) construction placed in vacuum and filled with an inert gas at pressure $P_0 > 1$ atm (0.1 MPa):

– the gas is incombustible;

– the secondary fragments do not burn in the gas; and

– the gas is perfect with a Poisson exponent $k = const$.

4. The gas exerts no effect on the process of perforation of the front and rear PV walls.

5. The secondary fragments are neither ablated nor shattered in the gas.

6. Properties of the material of the PV walls are identical in all directions (an isotropic material is considered). Temperature effects in the PV walls are lacking.

7. Pressurized vessel destruction process is not scaled.

The methodology employed to numerically model the entire complicated process of response of a vessel containing pressurized gas to a hypervelocity impact reduces to modeling of individual stages of the process by means of the specialized computational codes available at VNIIEF and SSAU with transfer of the data between them. Preliminary, the available computational techniques were modified to comply with the aforesaid specific features of the process.

The work performed has demonstrated that the main goal of the Project, namely, development of the methodology for end-to-end numerical modeling of all stages of the response of a vessel with a pressurized gas to a hypervelocity impact of a space debris particle was attainable (Figs. 1 to 3). However, insufficient available experimental data precluded the researchers from the proper use of the incorporated models of dynamic deformation and destruction of PV walls, while the limited funding allotted for the Project permitted them to numerically model only individual stages of the process but did not allow the end-to-end calculations to be performed as thoroughly as needed to adequately consider all the physical processes involved.

An analysis of the published experimental data and results of the numerical modeling accomplished allowed the methodology of engineering evaluation of all the basic parameters that characterize the stages of response of a vessel containing a pressurized gas to a hypervelocity impact of an SD particle to be developed. Comparison of calculation results with available experimental data showed that the accuracy of the estimates was quite satisfactory.

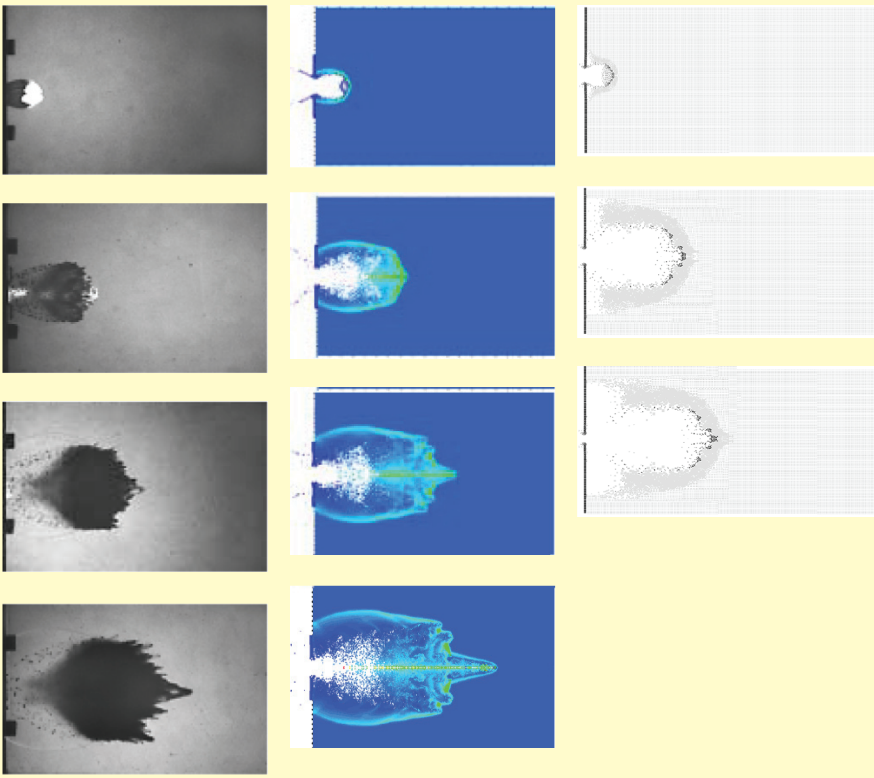


Figure 1: Expansion of a cloud of secondary fragments in a gas (compared with the available experimental and calculation data borrowed from the paper Hiermaier, S., and F. Schaefer. 1999. Hypervelocity impact fragment clouds in high pressure gas numerical and experimental investigations. Int. J. Impact Engng. 23:391–400)

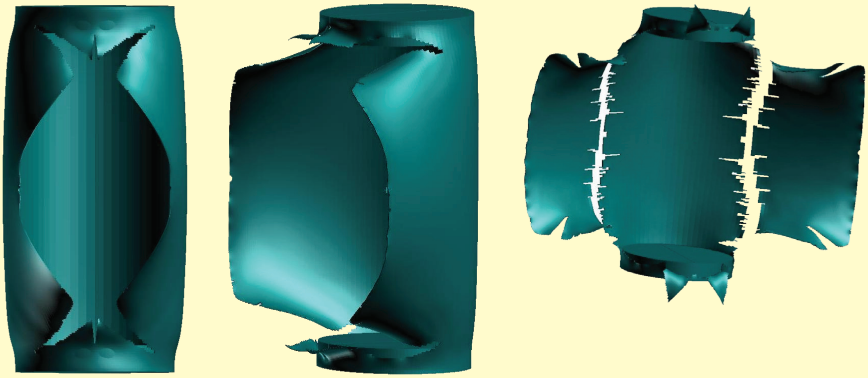


Figure 2: Run #S6: photo of a destroyed PV (borrowed from Schaefer, F., and E. Schneider. 1996. Impact testing — impact on pressure vessels, hypervelocity impacts on aluminum pressure vessels. EMI Report No. EMI-HVI-PVI 001. Freiburg, Germany: Ernst-Mach-Institut) and the calculated patterns of PV shell destruction at various time instants

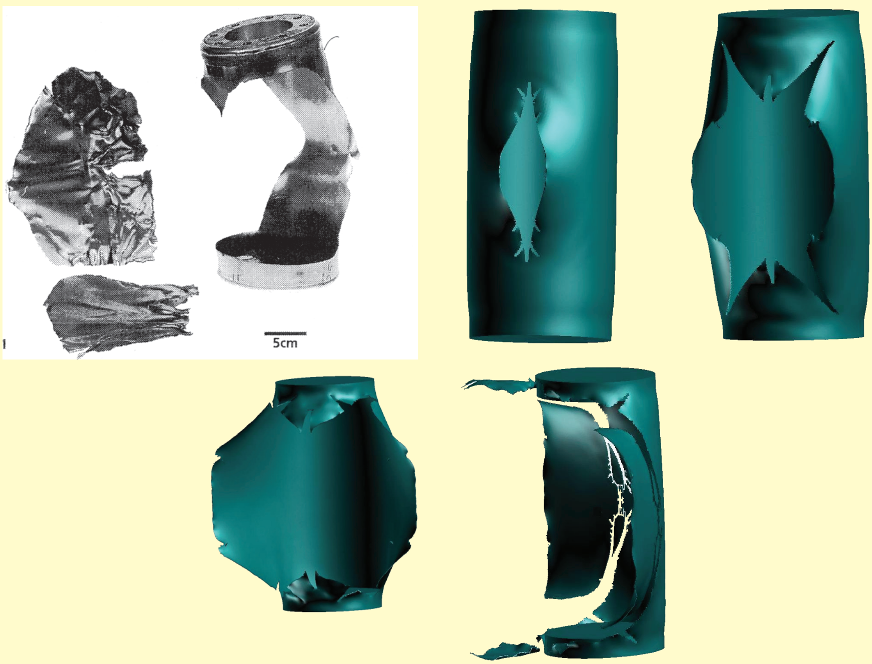


Figure 3: Run #S7: photo of a destroyed PV (borrowed from Schaefer, F., and E. Schneider. 1996. Impact testing — impact on pressure vessels, hypervelocity impacts on aluminum pressure vessels. EMI Report No. EMI-HVI-PVI 001. Freiburg, Germany: Ernst-Mach-Institut)

Algorithms of engineering evaluation of impact results for shielded PV reduced to doubling application of the estimation algorithms suggested for PV with no shielding:

• first, a simplified (with no pressurized gas) "shield-vacuum-front PV wall" object should be considered instead of the "front PV wall – gas-rear PV wall," and

• then, the "front PV wall – gas – rear PV wall" object is to be considered. From the point of view of direct numerical modeling, there is no fundamental difference in objects with and without a shield.

In further investigations, of interest is consideration of an oblique impact on a loaded curvilinear front vessel wall which is attended by asymmetric propagation of the waves, more detailed consideration of the vessel shielding effect, as well as an analysis of the scaling effects to be observed when going from modeling laboratory-scale vessels to an analysis of real constructions.

Obtained Results

1. Computational technique ELLPH.

The technique was developed based on the SPH technique available at RFNC–VNIIEF to perform 3D and 2D calculations of perforation of a vessel containing pressurized gas by a high-velocity particle and of the initial fragmentation stage with fragments moving in the gas.

2. Computational technique GMP2.

It was developed based on the 2D gasdynamic code available at RFNC–VNIIEF specifically to carry out 2D calculations of expansion of the secondary-fragment cloud simulated as motion of a perforated domain with varying boundaries and perforation extent and also calculation of an unsteady gasdynamic loading of the vessel walls.

3. Computational technique PVFrac.

It was worked out on the basis of the code available at SSAU that simulates incipience of a crack and its spread from the hole edge under a preset unsteady loading.

4. Engineering two-phase model of axially symmetric motion of a cloud of fine particles with preset initial parameters, it permits parameters of the cloud of secondary fragments and shock wave in the gas that impact on the rear wall of the vessel containing pressurized gas to be predicted. The initial cloud parameters (taken, e. g., from experiment) include the size of the cloud and particles (the latter are assumed to be of an identical diameter and to have the same velocity). The technique permits simultaneous consideration of several clouds.

5. Analytical model.

It is a combination of particular models describing the processes that attend interaction of a high-velocity particle with an unshielded vessel containing pressurized gas (impacted normally to its wall):

– penetration through the vessel wall, destruction of the particle and formation of the secondary-fragments cloud;

– motion of the cloud of secondary fragments in the gas;

– origination and propagation of a shock wave in the gas caused by the secondary fragments;

– dynamic loading of the vessel walls; and

– incipience of a crack and its unsteady spread from the hole edge toward a front/back vessel wall.

In developing the analytical model the results of calculations performed with the aid of the engineering model were used.

The analytical model can be used to predict the conditions of high-velocity particle impact under which one or another vessel damage mode is to be expected. These predictions could further on be used in working out recommendations on protection of space apparatus against SD.

Project Number:	#1523
Full and Short Title:	Creation of the X-ray spectrometer for permanent space solar patrol **Space Patrol of Solar Radiation**
Tech Code / Area / Field:	SAT–SAF / Space, Aircraft and Surface Transportation / Space Safety
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding :	$43,750 (EU, Republic of Korea)
Commencement date:	April 1, 2001
Duration:	15 months, extended by 5 months
Leading Institute:	All-Russian Scientific Center S.I. Vavilov State Optical Institute (SOI), St. Petersburg, Russia
Contact Information:	Phone: +7 (812) 331 75 50 Fax: +7 (812) 331 75 58 E-mail: vncgoi@mail.ru Website:http://ns1.npkgoi.ru/investigations/lab_aero_ph_opt/lab.htm
Supporting Institutes:	No
Collaborators:	DaimlerChrysler Aerospace (Satellites) / Dornier Satellittesysteme GmbH, Friedrichshafen, Germany (Pailer N.) Fraunhofer Institute of Physical Measurement Testing, Freiburg, Germany (Schmidtke Gerhard) Institut d'Astrophysique Spatiale (IAS), Orsay, France (Delaboudiniere J.-P.) Atmospheric Physics Laboratory, Dept. of Physics and Astronomy, University College London (A. D. Aylward) Korea Astronomy Observatory, Daejeon (Uk-Won Nam)
Project Manager:	AVAKYAN Sergei Vazgenovich
Contact Information:	Phone: +7 (812) 552 45 14, +7 (812)323 88 39 Fax: +7 (812) 328 21 33 E-mail: avak@soi.spb.su
ISTC Senior Project Manager:	LAPIDUS Oleg Viktorovich
Contact Information:	Phone: +7 (495) 982 31 16 Fax: +7 (499) 978 36 03 E-mail: lapidus@istc.ru
ISTC Website:	http://www.istc.ru

Background

The most important problem of the up-to-date science is to understand the basis causes of global changes in environment. The studies of the role of variations in solar and geomagnetic activities in terrestrial phenomena attracted attention of astrophysicists, geophysicists, meteorologists, and biophysicists for a long time. However, before the appearance of satellites and spacecraft, the main results were obtained only from the correlation between effects in the biosphere (including human being), climate, and weather and the so-called proxy indices of solar activity. However, the problem of understanding physical mechanisms (the main problem of solar–terrestrial links) was not solved for many decades after the launch of rockets, satellites, spacecraft, and manned orbiting stations. In the authors' opinion, such a situation is caused by the absence of permanent monitoring of the main solar activity parameter, namely, the spectrum and flux of the ionizing (X/EUV) solar radiation and also the spectrum and flux of the ionizing electrons, precipitating from radiation belts.

The Space Solar Patrol (SSP) has been intended for permanent monitoring of spectra and absolute fluxes of soft X-ray and extreme ultraviolet (X-ray/EUV) radiation from full disc of Sun which ionizes the upper atmosphere of Earth. The permanent solar monitoring at the main part of the ionizing radiation spectra 0.8–115 nm does not exist. The complete spectrum of the Sun in the region from 0.1 to 195 nm is measured by the "SEE" apparatus on the TIMED satellite for approximately 4 min out of each 97 min (the time to complete an orbit). As can be seen, because the solar measurement cycle is very limited in time, the SEE apparatus is not intended for monitoring solar flares. Among experiments, the most metrologically suitable for absolute measurements is the SolACES apparatus (Solar Auto Calibrating EUV/UV Spectrometers), intended for operation on the International Space Station for 15 min on each orbit. Measurements are made in the wavelength interval from 17 to 220 nm, with spectral resolution from 0.3 to 0.9 nm. But the permanent solar monitoring at the main part of the ionizing radiation spectra does not exist.

The apparatus for the SSP has been developed and includes multiyear experience of developing such apparatus in Vavilov State Optical Institute (SOI). The base of this apparatus is the use of unique detectors of ionizing radiation — the open secondary electron multipliers, which are "solar blind" to near ultraviolet (UV), visible, and infrared (IR) radiations of the Sun, and new methodology of these solar spectroradiometric absolute measurements.

Project Objectives

The objective of the Project was the elaboration and creation completely prepared for space flight the last of three basic devices — X-ray spectrometer from complex of the optical-electronic apparatus (OEA) "Space Solar Patrol."

To solve the Project tasks, an experience of SOI was used as well as scientific and technical achievements in developing and running radiometric and spectral devices for the measurements of absolute fluxes of ionizing solar radiation. The following new methodology was used for completing the tasks of development of the permanent SSP. The method consists in the simultaneous registration of solar fluxes by the soft X-Ray and extreme UV (EUV) grating spectrometers and X-Ray and EUV-radiometer. The spectrometers measure the detailed spectral function and its variations whereas the optical sensors of the radiometer (there are two sensors, one of which is oriented toward Sun while the other detects only charge particles) give the initial information which enables to extract solar flux signals and to correct absolute measurements by taking into account the scattered light in the spectrometers.

In accordance with the methodology under development and problems of solar–terrestrial physics, the apparatus of the SSP includes the following:

– grazing-incidence X-ray–UV (XUV) spectrometer with four channels for recording the solar spectrum and its variations in the wavelength region of 1.8–198 nm;

– radiometer for absolute measurements in the region of 0.14–157 nm, with 20 filters: foils, films, and crystals; and

– normal-incidence EUV spectrometer with six channels for recording the solar spectrum and its variations in the region of 17–230 nm.

The following advantages of the SSP apparatus should be pointed out:

– absolute spectroradiometric measurements are carried out continuously; the total spectrum is recorded in 72 s;

– the photometric device in the radiometer and spectrometers has a dynamic range of about six orders of magnitude, which allows measurements both in the quiet-sun periods and at strongest flares;

– it is possible to check the absolute sensitivity of the apparatus every 72 s, using the isotope ^{55}Fe as well as to check the stability of the radioelectronic photodetector channel, using a quartz generator, and the efficiency of the diffraction gratings in both spectrometers from the readings of a standard PEM-142 photomultiplier with a MgF_2 window; and

– all the working channels of both spectrometers can be mutually calibrated on the basis of the overlap of their subranges.

Description of the Works

As a result, X-ray spectrometer for the space patrol of solar ionizing radiation has been made and tests were carried out, which showed that the equipment is ready to operate in space.

Unique development SOI, used in instrumentation, is the concave grating with variable ruling step — 600 grooves/mm, curvature radius — 28 080 mm, gold coating.

In the spectrometer, two basic channels are provided for the spectral ranges of 1.8 to 23 nm and 22 to 63 nm. The working registration range of the X-ray spectrometer has been additionally extended from 60 to 123 nm and for that purpose, the new third channel equipped with the secondary electron multiplier has been built. Also, the fourth channel with the photoelectron multiplier that works at the spectral range 119–198 nm has been added. The fourth channel allows the independent check of the stability of the diffraction grating characteristics to be carried out during the space flight.

The new construction of the X-ray spectrometer has been developed. The windowless scheme was chosen for increase of sensitivity and reliability work. In this case, the maximum of area for gathering of solar radiation, which is limited only by the size of grating, has been got. The spectral scanning was carried out by means of rotating the console with exit slits and photodetector by the angle of 6,41°. In this case, there is no need in the progressive displacement of exits slits. The other distinctive feature of the present approach consists in making use of the modern electronics. Analysis of the special calculation of the zone sensitivity of photocathode allowed to update the dynode system of the SEM by using plane Γ-shape photocathode by enlarging the flat part of the photocathode for use on the solar platform with the accuracy of the angular orientation better than ± 10'.

A new design of scanning slitless grazing polychromatic instrument has been proposed. It allows the registration of the spectral distribution of the solar irradiance in the spectral range of 1.8–63 nm to be carried out during 72 s. The concave grating with 600 grooves/mm and with radius R = 28 080 mm, size $S = 30 \times 20$ mm^2, blaze angle $\delta = 1°$ ($\lambda_\delta = 3$ nm) is used. The variable line space enables the focal curve to be placed as close to the exit slits as possible. The spectrum scanning is performed by means of turning the exit slit together with the detector of radiation. In this case, the entrance window and the grating are not moved. The grazing angle is 2°.

For reliable registration of the spectrum, three channels parallel (λ = 1.8–23 nm, 22–63 nm, and 62–123 nm) equipped with two open secondary electron multipliers are used. The forth air channel (119–198 nm) with photoelectron multiplier PEM-142 serves for checking the grating in flight and also for the spectrometer alignment. Calculated spectral resolution is varied from 0.36 to 1.56 nm and, mainly, less than 0.8 nm depending on the wavelength and sizes of exit slits. The error of reading for λ is 0.17 nm because the solar-oriented platform is unstable (the orientation accuracy is about 10 angular minutes).

Obtained Results

Due to the series of ISTC projects, the novel apparatus of SSP has been created which is capable of permanent monitoring of spectra and absolute fluxes of solar radiation in the range from 0.14 to 157 nm both in the quiet conditions and during the solar flares any balls and classes (see Table 1 and Figs. 1–4). The radiometers of SSP are able to give also important information on electron fluxes precipitating from the radiation belts during magnetic storms.

The unique achievements were obtained (for the first time in the world):

– the analogs to the complex (Radiometers and Spectrometers) of space optical-electronics apparatus for the measurement of ionizing irradiance of Sun was built;

– the analogs to the methodology of the measurement of ionizing irradiance at the space environment which was proposed and realized; and

– the analogs to the technology of the most efficient “solar blind” detector of ionizing radiation for spectral range short that 125 nm — open secondary electron multiplier was reconstructed.

All the above said confirms the global scale of the conducted studies, which were called “a flag of the contemporary solar investigations on automatic spacecraft” by the Nobel laureate in physics, Vice President of the Russian Academy of Science, Academician J. I. Alferov, in its appeal to Roscosmos (the Federal Space Agency of the Russian Federation) on September 30, 2004.

The principle, cost-effective solution of the problem is launching small sun-oriented

*Table 1: Size-mass characteristics and the required power of the unit-by-unit content of equipment of space solar patrol**

No.	Units of equipment SSP	Length, mm	Width, mm	Height, mm	Mass, kg	Required power, W
1	X/EUV-spectrometer	700	210	420	23	60
2	EUV spectrometer	405	190	450	14.3	40
3	General radio-block of radiometers	218	105	46	0.9	3
4	Solar Radiometer	148	150	150	3	7
5	Background Radiometer	148	150	150	3	7
6	Radio-block EUV-spectrometer	242	85	172	2.6	15
Total					46.8	132

*It is possible that there are two variants of the launches:

(1) positions of 1 + 3 + 4 + 5 (mass 29.9 kg, power 77 W); and

(2) positions of 2 + 3 + 4 + 5 + 6 (mass 23.8 kg, power 72 W).

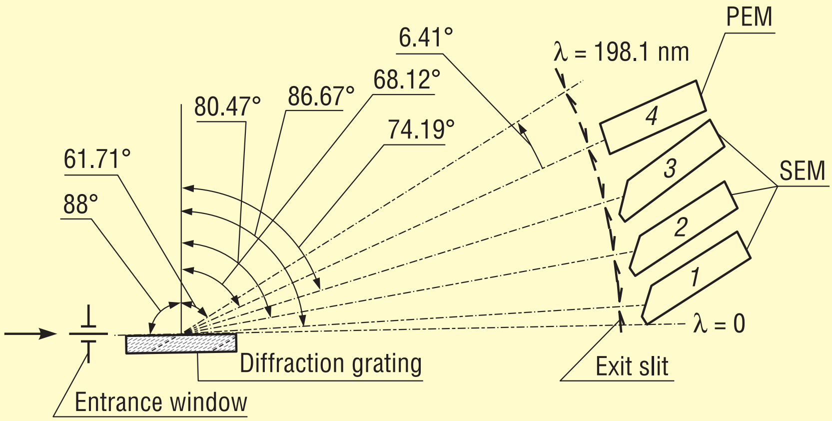


Figure 1: X-ray spectrometer for Solar Patrol Mission. Optical scheme. The wavelength channels: 1 — 1.8–23 nm; 2 — 22–63; 3 — 62–123 nm; and 4 — 119–198 nm

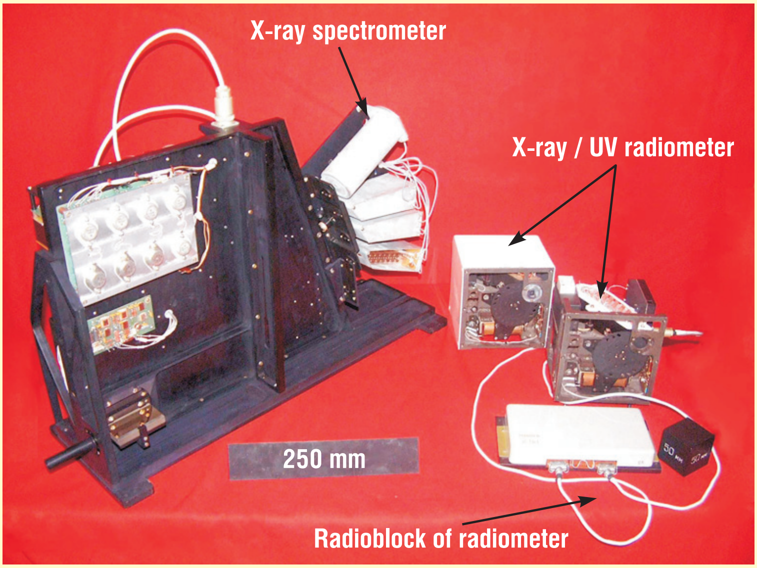


Figure 2: Optical-electronics instrumentation of SSP: X/EUV spectrometer

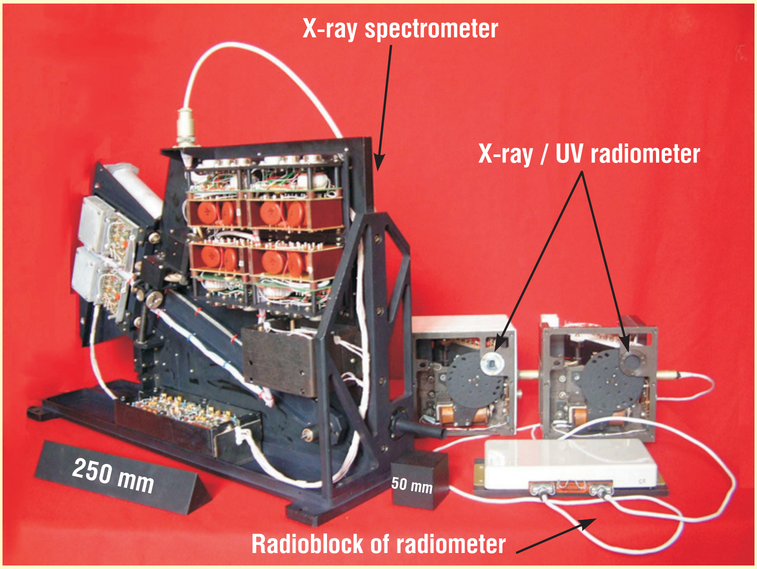


Figure 3: Optical-electronics instrumentation of SSP: view at the radioelectronics of X/EUV spectrometer

spacecraft at the sun-synchronized orbit. ROSCOSMOS has an intention to launch SSP at the board of one of the spacecraft built in the framework of the Federal Space Program of Russia in 2006–2015.

Requirements TM-system equipment for the SSP:

• the total number of TM-sensors for two Radiometer and X/EUV spectrometers — 42;

• maximum flow of information from the task two Radiometer and EUV spectrometers — 565 Byte/s; and

• the maximum amount of information per 24 h for the SSP devices — 46.7 MB.

The SSP project is supported by resolutions of the main profile international organizations:
1. Committee on Space Research (COSPAR), the General Assembly 1996: Commission C ("Space studies of the upper atmospheres of the Earth and planets"), Commission D ("Space plasmas in the solar system), and Commission E ("Research in astrophysics from space").

2. International Union of Radio Science (URSI), the General Assembly 1996: Scientific Commission G ("Ionospheric Radio and Propagation").

3. International Association of Geomagnetism and Aeronomy (IAGA) 1999, Division II "Aeronomic Phenomena" and Conference of official delegates of IAGA.

4. International Symposium on the Programme of the Thermospheric, Ionospheric and Geospheric Research (TIGER), 1999.

5. Science and Technology Advisory Council under Rosaviacosmos and Russian Academy of Sciences (Sections # 2 и 9.2), 2000.

6. International Organization for Standardization (ISO), WG4 "Space Environment," Skobeltsyn D.V. INP of Moscow State University, 2004.

7. International seminar "Biological effects of solar activity," SRI RAS, 2004.

8. All-Armenia Life Science Congress, 2008.

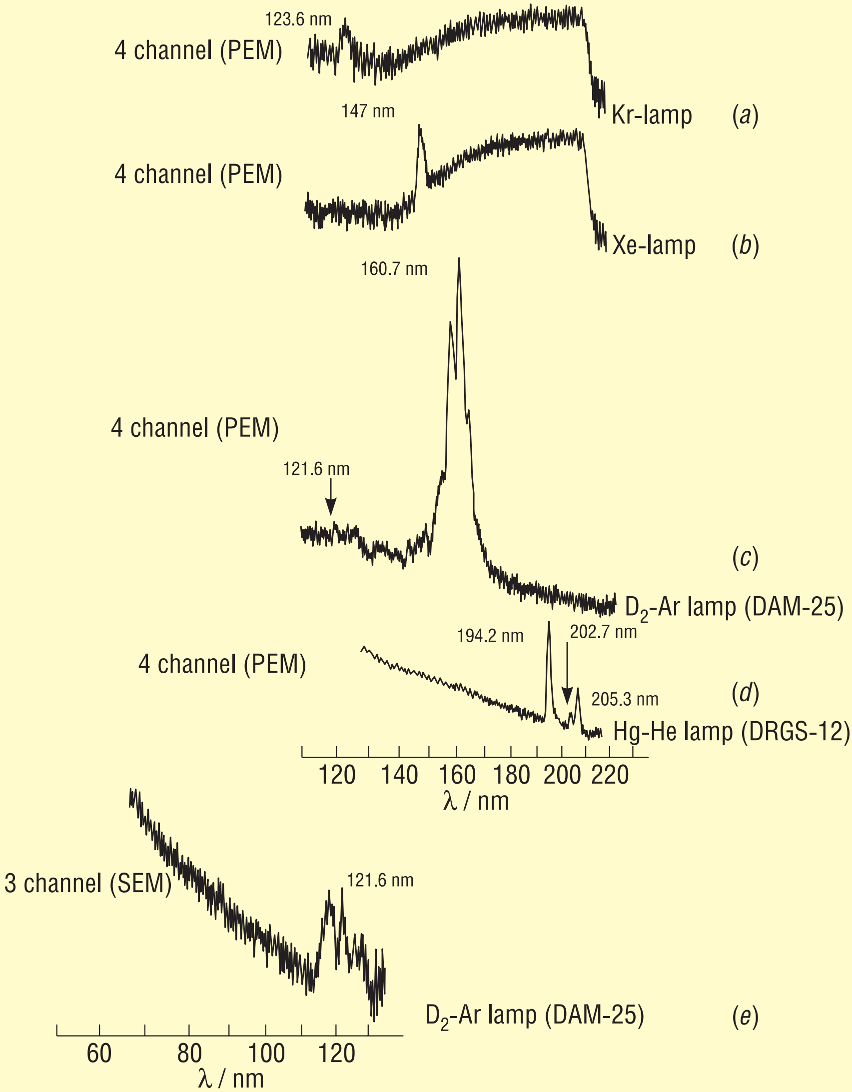


Figure 4: Calibration of Space Solar Patrol: X/EUV spectrometer

Project Number:	#1917
Full and Short Title:	Development of the Design Technology of the Lightweight Shielding Protection for the Pressurized Hulls of Spacecraft and its Theoretical, Experimental and Computational Justification **Shield Protection for Spacecraft**
Tech Code / Area / Field:	SAT-SAF / Space, Aircraft and Surface Transportation / Space Safety
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	$300,000 (EU)
Commencement date:	September 1, 2002
Duration:	21 months, extended by 3 months
Leading Institute:	Federal State Unitary Enterprise “State Research Institute of Aviation Systems” (GosNIIAS)Moscow, Russia
Contact Information:	Phone: +7 (499) 943 30 19 Fax: +7 (495) 943 86 05 E-mail: info@gosniias.ru Website: http://www.gosniias.ru
Supporting Institutes:	Institute of Applied Mechanics, Moscow, Russia Institute of Advanced Study, Moscow, Russia Central Research Institute of Machine Building (TsNIIMash), Korolev, Moscow Region, Russia
Collaborators:	DaimlerChrysler Aerospace, Bremen, Germany (Hoffmann J.-P.) Lyndon B. Johnson Space Center, National Aeronautics and Space Administration, Houston, TX, USA (Christiansen E.)
Project Manager:	SEMENOV Andrej Sergeevich
Contact Information:	Phone: +7 (499) 157 91 97
ISTC Senior Project Manager:	KULIKOV Gennady Genrikhovich
Contact Information:	Phone: +7 (495) 982 31 54 Fax: +7 (499) 978 46 37 E-mail: kulikov@istc.ru
ISTC Website:	http://www.istc.ru

Background

The safety of spacecraft at a long-term space flight requires creation of special protection from damage by meteoroids and orbital debris. As of now, this danger is the most important problem of spacecraft survivability. The known principles of protection design demand the use of very massive shields. With an overall outer surface of a pressurized cabin exceeding 100 m^2, the shielding mass becomes a critical characteristics in spacecraft design. For example, the specific mass of an International Space Station (ISS) Module shielding is about 10 kg/m^2, its delivering cost to the orbit is more than 10,000 USD for each kilogram. Evidently even saving of 1 kg/m^2 in the shielding weight leads to a considerable reduction of space mission cost.

Project Objectives

The Project objective was to elaborate the protection construction technology as logicality of actions and calculations which are necessary to perform in order to reduce the used mass for the meteoroids and orbital debris protection of spaceships in Near Earth Space. Moreover, some physical characteristics of high-velocity impacts of projectiles on bumpers had to be investigated for producing light-weight protection samples.

According to the Project objectives, the following two problems have been considered.

Problem 1:

• to establish the most important physical characteristics of high-velocity impacts which could be used to increase antistrike durability of protection samples; and

• to design the protection samples (geometrical and physical parameters of bumpers displayed in protection sample design) meeting the requirements of high efficiency at low cost.

Problem 2:

• to divide the hermetic hull into zones where the protection scheme is kept fixed; and

• to minimize the spacecraft protection mass by means of optimal mass distribution in the spacecraft zones for the given probability of non-penetration of the spacecraft hermetic hull.

Description of the Works

For the solution of the first problem, the following investigations have been carried out:

1. Projectile fragmentation processes during high-velocity interaction with spaced bumpers were analyzed theoretically and experimentally based on the known data and own experiments.

2. Computer programs were developed; numerical simulation of fragmentation processes was performed and analyzed.

3. A possibility of creating "semi-active" protection was studied theoretically and experimentally.

4. Projectile fragmentation on mesh bumpers was studied experimentally.

All experimental investigations were carried out at the light-gas (helium) ballistic gun in GosNIIAS (Fig. 1). Balls 6.35 mm in diameter made of aluminum alloys AD-1 and 2017 were accelerated in the main to the velocity of 2.7–3.7 km/s. A target (protection shield model) with sizes of 150 × 150 × 100 mm – 200 mm or 150 × 250 × 100 mm – 200 mm was placed in a camera where the air pressure was 80–90 mm Hg. The experiments were made with normally incident impactors only (impact angle 0°).

Figure 2 shows a schematic of experiments, whereas Fig. 3 presents the scheme of grid protection constructions. A witness plate

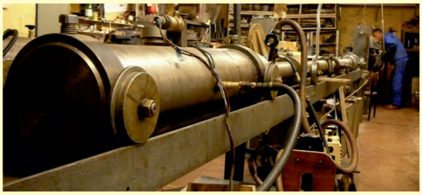


Figure 1: Light-gas (helium) ballistic gun in GosNIIAS

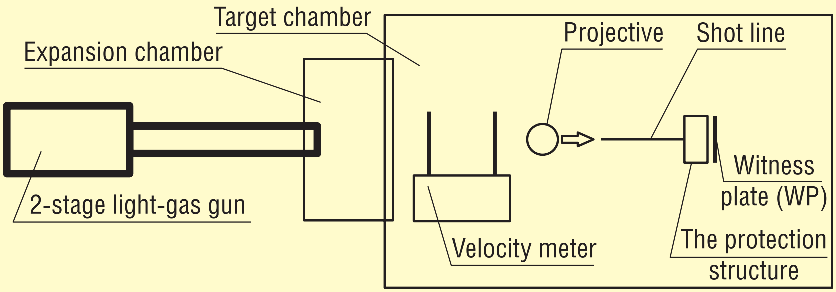


Figure 2: Schematic of the experiments of grid protection constructions

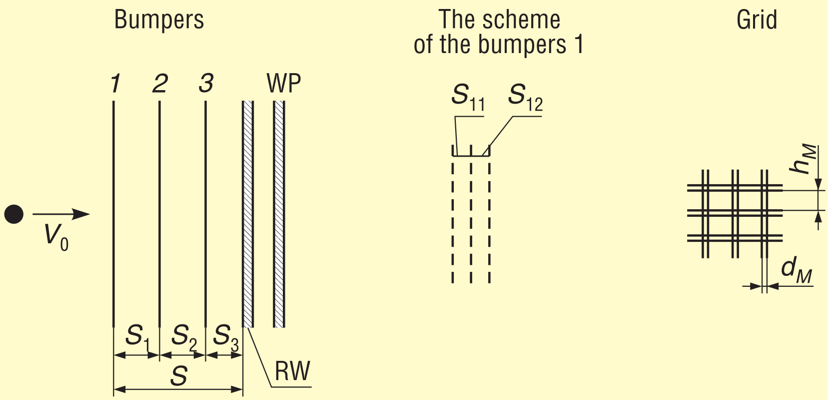


Figure 3: Scheme of the protective structure

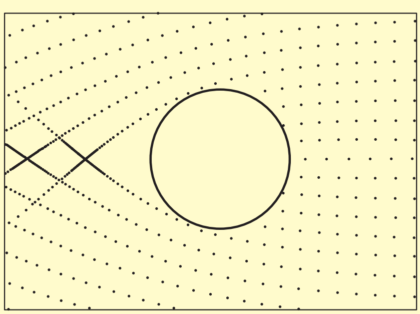


Figure 4: Steady flow of a meteoroid stream near the Earth if the velocity of the particles at infinity is 10 km/s

made of aluminum alloy AMG6 or D16 1 mm thick is located at 30–50 mm distance behind the rear wall of the protection structure.

Solution of the second problem generalizes experience gained during developing the first protection module of the ISS (module FGB). It concerns the optimization of protection construction mass needed for the FGB taking into account the module geometrical characteristics and orbital debris flow zoning. For this purpose, the problem of steady flows of interplanetary meteoroids near the Earth was solved with due regard for the effects of shadowing by the Earth and its atmosphere (Fig. 4). The application of the method of generalized functions allowed analytical formulas for the

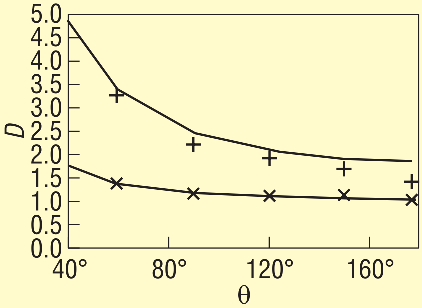


Figure 5: Azimuthal distribution of interstellar dust near the Sun

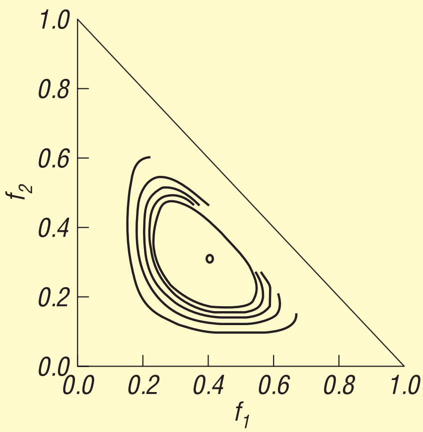


Figure 6: Graphical illustration of a model optimization problem for a spacecraft

dust density to be derived. The formulas derived have many other applications including classical astronomical problems (Fig. 5).

The optimal protection was treated as the protection which minimizes risks (risk is defined as the probability of loss multiplied by the cost). A new method to solve the relevant optimization problems has been proposed. The method applies finite hyberbolic elements. The software for evaluating spacecraft protection has been developed. The software inludes Grafic User Interface (GUI) and appropriate codes to solve direct and inverse problems with different methods. The codes were tested within the frame of the Working Group 3 of the Interagency Committee on Space Debris (Fig. 6).

Obtained results

The main results of the Project are:

1. The mechanisms of projectile fragmentation at high-velocity impact and the fragmentation characteristics after impact on a mesh bumper have been obtained.

2. Benefits of using grid shields were confirmed experimentally. Several designs of light-mass protection constructions have been developed.

3. The concept of “semiactive” protection based on using a mechanochemical effect under intense shear deformations was put forward.

4. The problem of steady flows of interplanetary dust near the Earth was solved taking into account the shadowing effects by the Earth and its atmosphere.

5. The new method to solve the optimization problems of spacecraft protection, using finite hyberbolic elements, has been developed.

The results were presented at the 4th European Conference on Space Debris (Darmstadt, Germany, 2005) and at the International Conference “Near-Earth Astronomy 2009” (Kazan, Russia, 2009).

Project Number:	#2128
Full and Short Title:	The Development and Creation of Unified Shielding Construction for the Protection of Spacecraft from Meteoroid and Space Debris Impacts **Meteorite Protection of Spacecraft**
Tech Code / Area / Field:	SAT-SAF / Space, Aircraft and Surface Transportation / Space Safety
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	$300,000 (US)
Commencement date:	September 1, 2002
Duration:	36 months, extended by 3 months
Leading Institute:	Central Research Institute of Machine Building (TsNIIMash), Korolev, Moscow Region, Russia
Contact Information:	Phone: +7 (495) 513 59 51 Fax: +7 (495) 512 21 00 E-mail: corp@tsniimash.ru Website: http://www.tsniimash.ru
Supporting Institutes:	NPO Energia, Korolev, Moscow Region, Russia Research Production Center DIPROK, Korolev, Moscow Region, Russia
Collaborators:	European Space Agency / European Space and Technology Center, Noordwijk, The Netherlands NASA Johnson Space Center/ Space Debris Laboratories and Technical Assistant for the Earth Science and Solar System Exploration Division, Houston, TX, USA (Crews J. L.) National Aerospace Laboratory, Tokyo, Japan (Kibe S.)
Project Manager:	FELDSTEIN Valery Adolfovich
Contact Information:	Phone: +7 (495) 513 55 57 (56 06) Fax: +7 (495) 513 53 53 (56 06) E-mail: feld.v@ru.net, anfimov@mcc.rsa.ru
ISTC Senior Project Manager:	RUDNEVA Valentina Yakovlevna
Contact Information:	Phone: +7 (495) 982 32 06 Fax: +7 (499) 978 46 37 E-mail: rudneva@istc.ru
ISTC Website:	http://www.istc.ru

Background

Protection of spacecraft from meteoroid debris, and especially protection of the International Space Station (ISS), is one of the most challenging problems of manned space exploration.

The main threat comes from debris with particle mass in the range of ~ 1 g and with relative velocity in the range of 10 km/s. Only special shields can protect spacecraft from the impact of such particles. Different kinds of shields have to be used for different spacecraft and missions. In spite of considerable progress, made recently in this field, the shielding protection of some ISS modules does not satisfy design requirements and does not possess optimal technological suitability. So, uniform shielding constructions must be developed to guarantee the high level of spacecraft protection from any meteoroid and debris environment.

Shield effectiveness is characterized by ballistic limit equation, which determines the dependence of impacting particle size on impact velocity. This equation is used to calculate the probability of no penetration (PNP), which is a design parameter for a given spacecraft's mission duration. Several analytical codes for PNP calculations have been developed, the "BUMPER" code of NASA being the most widely used. However, the "BUMPER" code has certain disadvantages, connected with spacecraft shielding on the basis of deployable thin construction elements (radiators, solar panels, and so on). Russian organizations (TsNIImash and RSC "Energia") worked to create the basis for solving the above problems.

Rational shielding construction has to consist of two bumpers, the functions of which are different. The first is intended for the effective destruction of impacting particles and the spread of destruction products. The latter requires that the bumper shell must have a spatial structure, which increases the time of interaction. The second bumper has to be easily destroyed, so as to decrease the destruction products' cloud velocity and to reduce the pressure on the protected wall. However, these are the general rules, which have been established during investigations, and realizations of this idea can be varied. It can be stated that shielding design principles that combine the properties of universal application and optimal structure (in terms of mass penalties, technological simplicity, ecology, etc.) are not yet known. The complexity of the problem lays in the fact that the destruction mechanisms are different for various ranges of impact velocity (low, medium, and high velocity ranges); so, a special model has to be constructed in every velocity range to describe the impact interaction. Reliable experimental data have been obtained for impact velocities less than 7 km/s.

Analysis of preliminary obtained results has shown that a database is in place for the creation of a unified two-bumper structure, capable of protecting any spacecraft.

Project Objectives

The Project objective was development and creation of unified protection shielding with high ballistic limit for protecting pressurized compartments of space vehicles from impacts of meteoric particles and space debris.

Description of the Works

The following experimental, theoretical, computational, and designing works have been carried out:

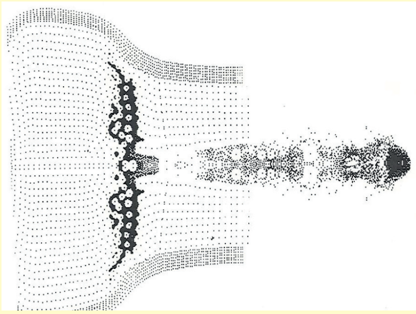


Figure 1: Thrown particle form obtained from cylindrical installation operation simulation (V = 4.6 km/s)

1. Maintenance and improvement of test facilities for shielding verification

The blast throwing facility (BTF) has been improved to extend the range of throwing velocities of particles/space debris models. The particles may be accelerated using ballistic light-gas facility to velocities ≈ 6 km/s (Fig. 1). Further increase of velocity requires application of facilities, which use energy of explosion. The blast ballistic installation was improved for accelerating particles with mass about 1 g to velocities up to 8–9 km/s (Fig. 2).

Blast throwing facility for generation of nocalibrated particles

The BTF scheme was suggested and examined when a particle was formed from a billet (round plate) through its acceleration under action of pressure in a detonation wave of explosive. Final shape of this particle is not known beforehand and is determined by mathematical modeling of the acceleration process, that is why such particles are called noncalibrated. It is necessary to have compact particles, i. e., their dimensions in all directions have to be close.

Blast throwing facility for generation of calibrated particles

Investigations were carried out in order to determine a possibility of creating a blast throwing facility intended for acceleration of particles with initially given compact shape.

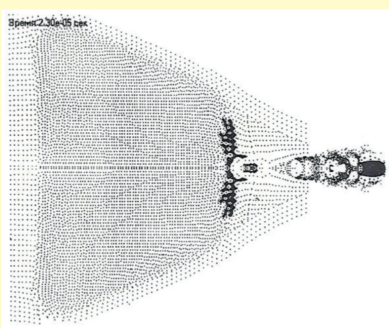


Figure 2: Thrown particle form obtained from conical installation operation simulation (explosive weight = 1.4 kg, V = 9.2 km/s)

This problem is complicated as the particle is effected by high pressure (which destroys the particle); the temperature of explosion products is low and sound speed in them equals $c_R \approx 6$ km/s; and since the speed of explosion products at expansion to vacuum $V_{max} \approx 2c_R/(\gamma - 1)$ and $\gamma \approx 3$, the maximal speed of striker is $V_{max} \approx c_R$. Thus, in order to accelerate a particle with conserved shape to higher velocities, it is required to increase the temperature and sound speed in the pushing gas and at the same time to decrease pressure in it.

Mathematical models have been developed for two blast ballistic installation types intended for mechanical particle acceleration up to velocity ≈ 6…8 km/s:

– type 1, forming compact particles from plane blank in the process of its acceleration under pressure loading caused by explosive detonation (not calibrated particle); and

– type 2, accelerating given particle without a significant change in its initial form shape (calibrated particle).

Simulation of particle acceleration process (in the BTF of type 1) has confirmed the basic idea about a possibility to form a compact particle from a blank constituted spherically-curved cycle plate during its acceleration by the pressure of explosive detonation wave. Main ballistic installation parameters have been identified, which determine particle acceleration.

Numerical modeling of the BTF of type 2 has shown that it is possible to reduce loads acting on the particle and increase the particle speed with the help of the gap between the particle and explosive.

2. Search of protection-shielding first screen rational structure

2.1. The definition of the first screen structure potential variants that satisfies technology limitations requirements and compatibility with protected structure specifications

The best already designed structures were taken into account during new shielding protection development, namely, such as developed for ISS: MOD2, JEM, and Columbus. The minimum diameter (min do) of spherical particles with impact velocity $V \approx 6.5$ km/s that can penetrate the protection of the ISS modules in normal direction is correspondingly 12.9, 13.2, and 14.5 mm.

The first screen plays the main role in particle destruction. Recommendations were formulated for choice on material and structure of the first screen (bumper) of the protection shielding that provide efficient protection with the minimum weight.

Two principal concepts of screen construction and potential variants for their realization were developed, namely:

(1) concept of nonuniform screen, which provides shock interaction with a particle in several points (regions), therefore intensifying the process of particle destruction; and

(2) concept of screen based on conglomerate of powder metal material and polymer sticker.

The structure of the first type is more practically feasible; therefore, special attention was paid to spatially nonuniform front screens.

2.2. Analytical study of debris impact on the screens of defined configurations. Comparison of screen effectiveness in terms of fragmentation cloud structure. Search for the best variants of experimental investigations

Two promising types of front screens were analyzed using numerical simulation:

(1) type A with heterogeneous pattern (plate with relief surface); and

(2) type B based on powders of heavy metals (wolfram, zinc) coated on close-meshed steel nets.

Obtained results showed that the use of front screens with relief surface may increase efficiency of fragmentation of impinging particles due to appearance of complex spatial configurations of shock and depression waves in the particles. Recommendations were formulated on the choice of geometry of pyramids, which form a relief of screen front surface.

It was found by calculations that the front screens of porous structure from heavy metals are more efficient comparing with flat monolith sheet screen.

2.3. Experimental research of the best types of specimens with the purpose to confirm or correct analytical results. Investigation of the fragmentation rule

Theoretical and experimental investigations were carried out with prototypes of two general types of front screens (types A and B).

Advantages and disadvantages of these design schemes were stated and quantitative estimations of their effectiveness were found. Levels of resistance of screen protection shielding for both types were close to each other. The screen of type A was more practically feasible and satisfied better the requirements of operation in space conditions. There are theoretical data to suppose that at higher impact velocities (up to 10 km/s) the screen of type B will possess advantage, but this supposition cannot be verified experimentally.

3. Search for protection-shielding second screen rational structure

The task of the second screen is to reduce levels of heat (especially, at high-velocity collision), local and distributed impulse effect of large and fine-dispersed particle of behind-screen cloud of destruction products. At the same time, the destruction mass of the second screen adds to behind-screen cloud and produces additional effect on the protected wall.

Studies have shown that the second screen has to meet the following requirements:

- the upper layers of the screen must be heat-resistant and easy destructible, and the lower layers must consist of high-strength and easy vaporizable materials;
- the second screen materials should not generate large fragments and must possess low densities; and
- it is undesirable to use metals, because petals appearing at puncture may break through the protected wall.

Experimental investigations with prototypes of intermediate screens were carried out. Results have shown that effectiveness of the intermediate screen may be obtained by the following ways:

• use of fabrics with high melting temperature and low specific energy of destruction;

• use of honeycomb panels of carbon plastics with honeycombs filled by fine-dispersed powders of heatproof materials; and

• use of Kevlar, technical (armored) fabric TT.

Prototypes of two-screen shielding structure were tested. Experiments have confirmed efficiency of suggested construction approach.

4. Development of numerical methods for impact processes simulation and engineering method for ballistic limit curves determination.

4.1. Numerical simulation of debris impact to the first screen.

The numerical technique was developed for modeling a process of high-speed impact between particles – space debris – with protection shielding. The technique is based on general equations of mechanics of continua and numerical procedure for their integration.

4.2. Development of engineering method for ballistic limit curves determination.

Ballistic limiting dependency (BLD) is a main characteristic defining resistance of a construction effected by impact of compact mechanical particles and efficiency of protection shielding. Ballistic limiting dependency is a dependency of minimum size $d(V)$ of a particle puncturing shielding with screen protection against impact velocity V.

Ballistic limiting dependency has three specific ranges with respect to velocity of impact of a particle with front screen: low-, medium-, and high-speed. On the plane "impact velocity – particle size" these ranges are divided by lines of critical velocities V_{1k} and V_{2k}.

1. Low-speed range ($V < V_{1k}$). The particle punctures the first screen (without destruction); screen and protection wall may be punched (craters, scabbings, etc.) depending on structure peculiarities and condition of impact (Fig. 3).

2. Medium-speed range ($V_{1k} \leq V \leq V_{2k}$). The particle is destroying intensively while punching the first screen: from large fragment near the boundary between the first and second ranges to a state of fine-dispersed melt when it is approaching to the boundary between the medium- and high-speed ranges; mechanism of puncture in this range is noted by the greatest uncertainty; the protected wall is effected by two factors: impact of a large fragment (leader), and distributed load from fine-dispersed cloud of products of the particle and screen dispersion.

3. High-speed range ($V > V_{2k}$). Material of the particle and first screen undergo developed phase transformations (melting and vaporization). In this range the protected wall is subjected to spaced impulse load in a cone of dispersion of primary fine-dispersed cloud of fragments, which are shielded partially by intermediate screen of the protection shielding.

Engineering method and procedure for calculation of BLD were developed as well as specific techniques for these calculations. Some of them are:

1. Methods for calculating boundaries of specific velocity ranges of impact, where main mechanisms of the particle destruction are realized: flattening, fragmentation and dispersion.

2. Methods for determining parameters of the secondary particles' cloud: calculation of irreversible heat losses of the particle energy, estimation of parameters of "the leading fragment," calculation of the angle of dispersion of

Figure 3: Craters from particle with foam layer (alloy AD-1, V_{exp} = 6.4 km/s, V_{cal} = 6.6 km/s)

the particle and screen fragments after puncture, modeling distributions of the cloud mass, momentum and energy based on the model of spherically symmetric dispersion.

3. Methods for calculating strength of pressurized compartment under effect of distributed impulse of particle and screens destruction products (numerical and approximate engineering calculation).

The technique was developed for determination of ballistic limit curves for unified protection shielding. The techniques were refined taking into consideration the technical suggestions on protection screens' structure that were stated during finding structure of unified screen protection shielding. In course of works particular techniques were tested, specified basing on experimental data and combined into united engineering technique for BLC determination.

The techniques include peculiarities of protection screens developed for UPS. Calculation results obtained by these techniques are in a good agreement with experimental data.

5. Search of two-screen Unified protection shielding scheme.

5.1. Choice of protection shielding scheme and its ballistic limit curves analytical determination.

Ballistic limit curves for UPS with porous front screen of wolfram and UPS with the front screen of aluminum alloy with relief surface were calculated, using developed engineering technique. UPS have the same unit weight as MOD-1 protection. It follows from comparison of estimated data with BLC for MOD-1 protection with similar unit weight that the protection with suggested promising front screen exceeds in resistance MOD-1 protection, and it was also confirmed by experimental results. Developed Unified protection shielding has ballistic limit at 25% higher than level for MOD-1.

5.2. Experimental investigation of two-screen Unified shielding protection parameters.

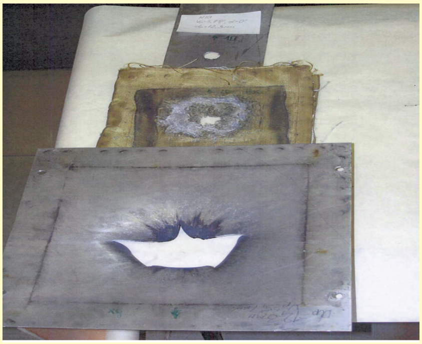


Figure 4: An experimental model with the flat shield after test

Experimental investigations were carried out:

• on efficiency of protection shielding with various fronts screens (relief in forms of truncated pyramids, blind holes and stamped hemispheres, screen pressed from powder metals with polymer impregnation);

Analysis of the results has shown that the most advisable is to use in UPS construction the screens with stamped hemispheres commensurable with dimensions of impinging particle;

• to estimate the influence of a distance between intermediate screen and protected wall on UPS efficiency. It was demonstrated that the less is the distance the better is UPS efficiency; and

• to estimate the influence of specific mass of heat-shielding and load-bearing layers of intermediate screen on UPS efficiency. Heat-shielding layer must neutralize action of front part of destruction products' cloud and prevent this action on load-bearing layer (Fig. 4).

Comparative investigations were carried out

• on impact resistance for protection shielding type MOD (NASA) and UPS. At equal conditions of collision, UPS of the same mass permits to increase impact resistance at 25% and more;

• on weight efficiency for protection shielding of zone 11, FGB-1, and UPS. It was demon-

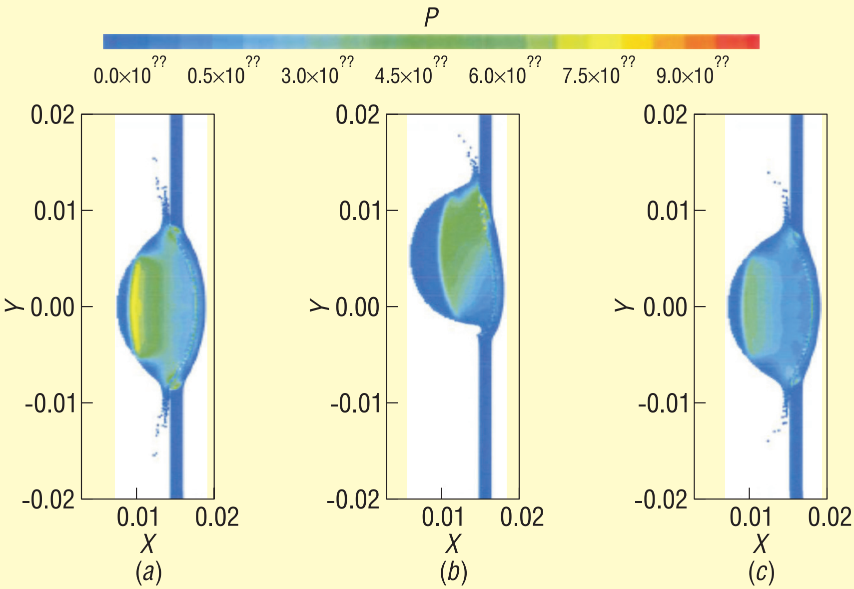


Figure 5: Results of simulation of two-dimensional aluminum cylinder impact on the porous tungsten plate

strated that UPS may have weight at 25%–30% less than protection shielding used for FGB-1.

Numerical technique was developed for estimating design parameters of UPS tentative variant (dimensions of first screen, number of linens in heat-shielding and load-bearing layers, etc) that is necessary for step-by-step calculations in order to refine probability of non-puncture and UPS parameters. Examples of determining dimensions and impact resistance are presented for various schemes of protection shielding (Fig. 5).

Obtained Results

• Initial data for UPS structure and construction of pressurized compartment for ISS standard module (FGU module analog) were elaborated.

• Construction of UPS sections in form of a set of similar rectangular or trapezoid segments, which dimensions are multiple to dimension of honeycomb cell of the module was validated.

• There were analyzed loads acted on structural components that appear at assembly, transportation as a component of a launch vehicle (LV), at LV ascent trajectory and operation at orbit. It was shown that the most loaded are situations at LV ascent when the elements are effected by linear longitudinal and transverse accelerations induced by LV engines' thrust and by low-frequency oscillations, and also by additional accelerations due resonance at low frequencies of structural components.

• A concept is presented for choice of construction of UPS mounting elements when UPS is assembled on the outside of ISS standard module, which pressurized compartment is done in form of a honeycomb structure with outside load-carrying construction.

• Design documentation was developed for mounting elements and a technique of UPS fastening to ISS standard module. It was shown that mounting elements of UPS segments may be fabricated and mounted on the module shell in such a way that load deformations of module shell due to pressure fall appeared at initial part of orbital motion and due to temperature deformations caused by nonuniform heating are damped.

• Integral mass of mounting elements' construction for UPS was evaluated and it was shown that it does not exceed 17% mass of protection for ISS standard module, which is ejected to orbit by medium-class launch vehicle (type "Proton").

• There were analyzed cases of loading for component of UPS construction and its mounting elements and it was shown that the ultimate load condition is a stage of launch vehicle flight when maximal linear and additional equivalent accelerations take place. Strength analysis was done for the most loaded UPS structural components and its mounting elements; it was verified that all structural components have sufficient strength margin at given operation conditions with given safety factors.

Demonstrative computations on effectiveness of application of the unified protection shielding created during the Project realization at ISS standard module were carried out.

The following results were obtained:

1. Geometrical model of ISS standard module (FGB analog) was developed.

2. Ballistic limit curves for standard protection shielding of ISS module and for Unified protection shielding were elaborated and included into "Zashchita KA" code.

3. Probability of no-penetration of ISS module was evaluated for two variants of the protection shielding: standard one used previously at FGB module and Unified one developed in the Project. It was shown that use of the Unified protection shielding reduces probability of no-penetration of the pressurized compartment in three times.

Project Number:	#3392
Full and Short Title:	Development of Means and Methods to Ensure Microbiological Safety of Long-Operating Space Equipment **Microbiological Safety of Space Equipment**
Tech Code / Area / Field:	SAT-SAF / Space, Aircraft and Surface Transportation / Space Safety
Status:	Project completed
Technology Development Phase:	Basic research
Allocated Funding:	244,684 € (EU)
Commencement date:	November 1, 2006
Duration:	30 months, extended by 3 months
Leading Institute:	Institute of Biomedical Problems, RAS, Moscow, Russia
Contact Information:	Phone: +7 (499) 195 23 63, 195 15 00 Fax: +7 (499) 195 22 53 E-mail: info@imbp.ru Website: http://www.imbp.ru
Supporting Institutes:	FEI (IPPE), Obninsk, Kaluga reg., Russia
Collaborators:	Bremen Institute for Materials Testing, Bremen, Germany (Kuever J.) SCK-CEN, Mol, Belgium (Mergeay M.) Universita degli studi della Tuscia / Dipartimento di Agrobiologia e Agrochimica, Viterbo, Italy (Canganella F.) Universitat Bremen / UFT, Bremen, Germany (Warrelmann J.) University of Groningen / University Medical Center Groningen, Groningen, The Netherlands (Harmsen H J. M.)
Project Manager:	NOVIKOVA Natalia Dmitrievna
Contact Information:	Phone: +7 (499) 195 65 59 E-mail: Novikova@imbp.ru
ISTC Senior Project Manager:	VISSER Hendrik
Contact Information:	Phone: +7 (495) 982 31 18 Fax: +7 (499) 978 02 27 E-mail: visser@istc.ru
ISTC Website:	http://www.istc.ru

Background

Russian experience in running long-term space objects evidences that as the flight duration gets longer the ecological problems of closed compartments, which are directly related to both the crew safety and reliability of the space equipment, become more and more important. Among these problems, the microbe factor is of the main concern

Processes of microbe contamination of orbital complexes proceed at a high intensity under conditions of continuous operation of taking-turns crews, freightflow (delivery from the Earth of replaceable equipment and consumable materials, and so on), and due to operation of a number of systems that regenerate the products of human being vital functions. Multiple-year duration of running the space equipment brings about prerequisites for realization of the selection and adaptation mechanisms as well as of manifestation of microbiota variability and progress of resident population wihth various microorganism groups of the space complex environment serving as a kind of an ecological niche.

Obviously, these processes can acquire a hazardous and irreversible character because they involve agents patogenic for a human being and microbes-biodestructors capable of damaging construction materials and resulting in failure or malfunction of various facilities and in virtually impossible realization of the total sterilization procedures under flight comditions. At present, microbiological purity of space objects is provided in the course of their preparation and running by means of disinfecting agents (biocydes) that have some drawbacks (Fig. 1).

Imparting of antimicrobe species in the materials themselves would be a more promising solution of the aforesaid problem. However, simple biocyde incorporation in the structure of a protected material at the stage of its manufacturing does not warrant its long-term antimicrobe protection because of the low biocyde concentration on the material surface and because a low-molecular biocyde fairly rapidly escapes (“sweats”) a high-molecular polymer. Within the ISTC Project #1346, we investigated the surface modification of materials to find efficient methods of their protection against microbe contamination and biologically induced damage. To this end, various methods (radiation grafting polymerization, chemical surface modification) that allow compounds containing biocyde groups to be immobilized on the material surface by chemical bonds, that is, biocydes to be chemically bonded to the material surface. High efficiency of this method for protection of fiber materials of various chemical composition was demonstrated with the use of the test bench manufactured within Project #1346 that imitates space flight conditions.

However, the surface modification method turned out to be insufficienty efficient when applied to materials with a smooth surface (polymer films, optical glasses, etc.) and metals. Moreover, this method is unsuitable for protecting ready-made items (instrumentation, equipment, interior items, and so on). Fabrication of film coatings based on polymers containing in their structure chemically bonded biocyde groups would be an optimal solution of the problem. This approach rules out aggregation and “sweating” of biocydes. Development and application of coatings containing immobilized biocydes would radically reduce the rate of processes leading to microbiological damage and microbiological corrosion of materials and devices, which would directly increase their operability duration. In addition, it would allow the ecological situation in compartments of manned space vehicles to be significantly improved.

At present, a number of physical methods are developed for removal of microorganisms from vatious objects (pulse ultraviolet (UV), electric field of an appropriate intensity and orientation, ultrasound sonication). However so far no such investigations were conducted for the needs of space industry.

In view of the aforesaid, it seems necessary to analyze the risk factors associated with bringing to ISS of microorganisms introduced during prelaunch preparation of modules and

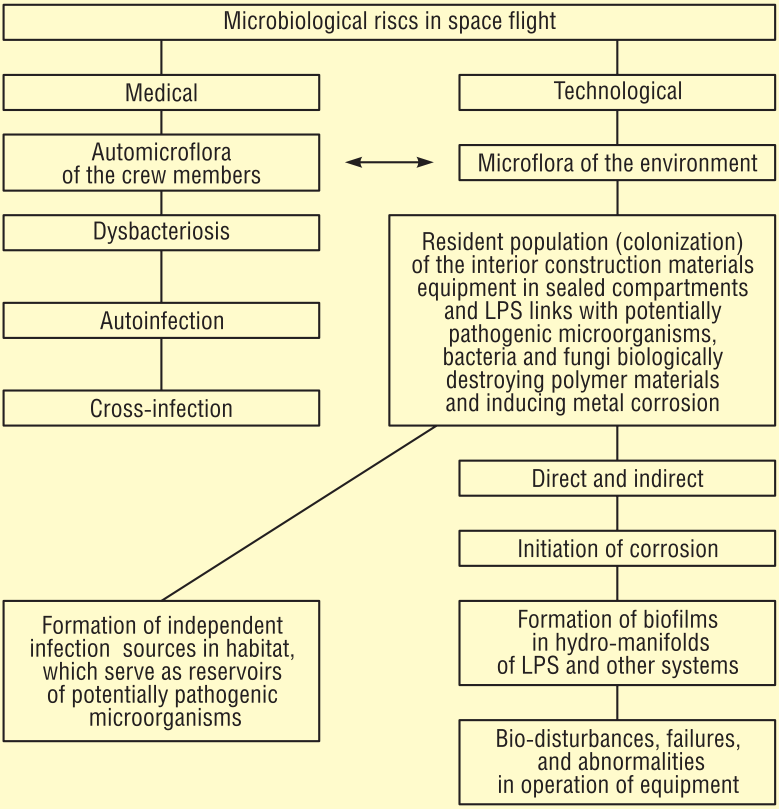


Figure 1: Microbiological riscs in space flight

transport vehicles and freightflow realization and to test new physical methods providing biological clearness at all stages of prelaunch woks.

Project Objectives

Objective of the Project is to find and develop efficient methods for long-term protection of the construction materials and equipment used in space objects against microbe colonization, biologically induced damage and biocorrosion, and to improve remedies that provide biological clearness at all stages of prelaunch works (Fig. 2).

Description of the Works

The Project includes the following tasks:

1. Creation of an imitation model of microorganism interaction with construction materials that ensures conditions with parameters as close as possible to those of the habitation medium at the International Space Station including possibility of emergency situations.

2. Development of receipts and technology of fabrication of antimicrobe film coatings based on polymers containing chemically immobilized biocydes.

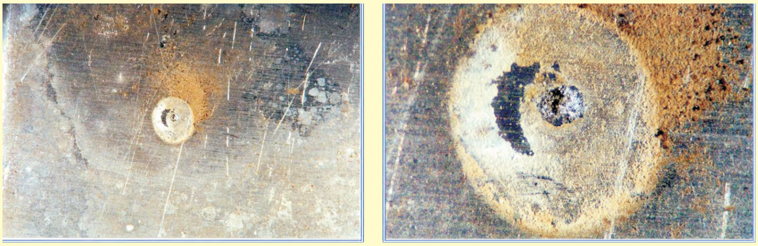


Figure 2: Microbiological damage of aluminum (cavern formation)

3. Validation of efficiency of the antimicrobe film coatings suggested.

4. Improvement of the methods and remedies that provide biological clearness of the modules, transport vehicles, and delivered freight at all stages of the prelaunch works.

Obtained Results

1. The test bench imitating climatic, radiation, and electromagnetic environment at a manned space orbital station is modified.

2. Antimicrobe film coatings with various biocyde concentrations are worked out and fabricated. Dimethylalkylbenzylammonium chloride complexes with a styrene – maleine anhydride copolymer are synthesized. The anhydride groups in the copolymer are converted into carboxylate and carboxyl groups by their interaction with sodium hydroxide. Compounds based on these complexes are synthesized and coatings on supports made of an aluminum alloy and polymethylmethacrylate (PMMA) are fabricated.

3. A comparative evaluation of the efficiency of antimicrobe coatings is carried out as a function of the microorganism type, chemical material structure, and operation conditions. Resource tests of antimicrobe coatings are conducted in standard, provicative, and extremal regimes.

4. The bactericide efficiency of pulse UV radiation emitted by a pulse xenon lamp is shown to be high. The reduction in the population of microorganisms varied from 96.35% to 99.99% of their initial number and depended

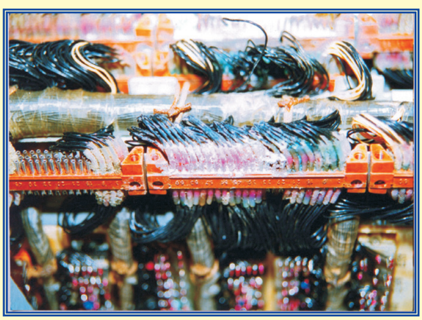


Figure 3: Growth of mould fungi on the insulation of communication device wires

Figure 4: Growth of mould fungi on insulating contacts of a communication device plugs

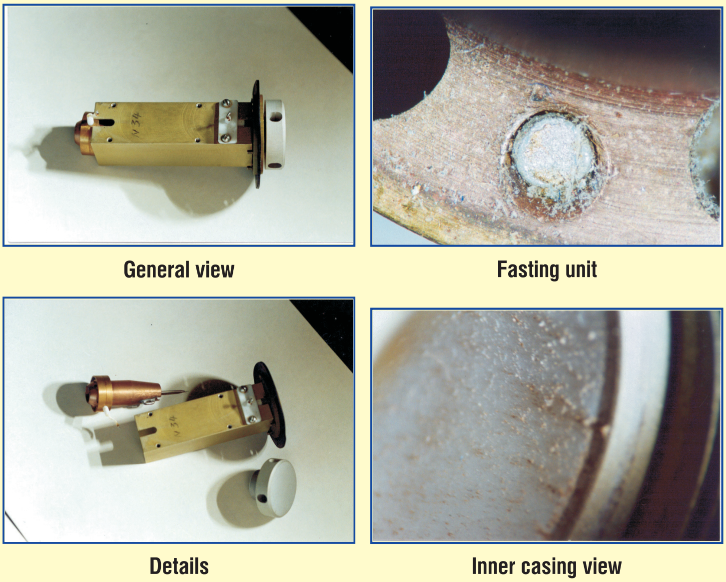


Figure 5: Growth of mould fungi on smoke indicator IDE-2

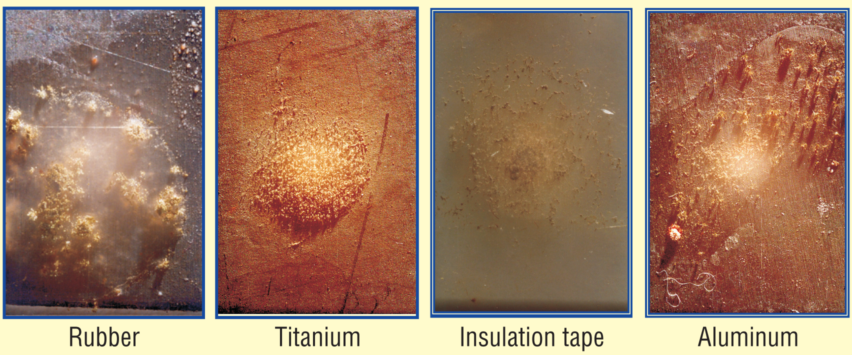


Figure 6: Growth of mould fungi on materials

on the distance from the UV source and irradiation time.

5. Antimicrobe effect of UV irradiation combined with hydrogen peroxide vapor is revealed. In addition, combined action of pulse UV and hydrogen peroxide vapor provides permeation of hydrogen peroxide vapor toward the material of items of a complicated geometry.

6. The efficiency of cleaning the gas medium from microorganisms with the aid of a "Potok-150M01" experimental apparatus is assessed; the tests support the feasibility of efficient supply of a horizontal weakly turbu-

lized laminar sterilized-air flow and its ability to clean the air medium from microorganisms at a high initial load. The “Potok-150M01” apparatus provides air decontamination in compartments not exceeding 96 or 130 m^3 within no more that 5 h daily. A schedule of the use of the air decontamination apparatus ´Potok-150M01” in production areas with the purpose of making clean zones is worked out.

7. The effect on microorganisms of ultrasound (US) of intensity consistent with or exceeding the highest acoustic oscillations existing at ISS is studied. It is found that U.S. can reduce the number of bacteria and fungi in liquids (Figs. 3–6). The spore forms of Bacillus sphaericus bacteria are the most resistant to sonication. .

8. The efficiency of combined ultrasound and “Potok-150M01” apparatus action in aluminum surface cleaning from microorganisms is confirmed. Addition of moist (water) on a surface makes microorganism removal more efficient. When U.S. and ´Potok-150M01” apparatus are used simultaneously the latter decontaminates air completely from bacteria and fungi that are produced by sonication of surfaces.

Project Number:	#3412
Full and Short Title:	Investigation of Astrosols in Near-Earth Space Using the Onboard Measurements and Computer Modeling. Analysis of Astrosol Effect on Components of a Spacecraft **Investigation of Astrosols in Near-Earth Space**
Tech Code / Area / Field:	SAT-SAF / Space, Aircraft and Surface Transportation / Space Safety
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	$300,000 (US)
Commencement date:	September 1, 2006
Duration:	39 months
Leading Institute:	Federal State Unitary Enterprise "State Research Institute of Aviation Systems" Moscow, Russia
Contact Information:	Phone: +7 (499) 943 30 19 Fax: +7 (495) 943 86 05 E-mail: info@gosniias.ru Website: http://www.gosniias.ru
Supporting Institutes:	Institute of Applied Mechanics of Russian Academy of Sciences (IAM RAS) Moscow, Russia Scientific Research Institute of Mechanics and Mathematics of St. Petersburg State University, St. Petersburg, Russia
Foreign Collaborators:	Frank K. Schafer Fraunhofer-Institute for High-Speed Dynamics Ernst-Mach-Institute, Germany Jean-Claude Mandeville ONERA, Toulouse, France
Project Manager:	SHUTOV Vladimir Igorevich
Contact Information:	Phone: +7 (499) 157 91 97 Fax:+7 (499) 943 86 05 E-mail: vrebrikov@gosniias.ru
ISTC Senior Project Manager:	RYZHOVA Tatyana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (499) 978 36 03 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

A spacecraft in a near-earth orbit undergoes influence of many space factors including microparticles of sizes from fractions of a micron to hundreds microns of natural and man-caused origin. With growth of anthropogenic pollution of the Near Earth Space (NES) the concentration of the man-caused microparticles increases, and they already dominate in Low Earth Orbits in some size ranges now. As onboard measurements show man-caused particles form clouds with sizes from hundreds to thousands kilometers (the so-called "astrosols"). Existence of such populations with inhomogeneous distributions in space and time (not concerning Poisson one) is verified experimentally. Such distributions are not considered in the modern space debris models. Astrosol clouds can have density in 2–3 orders of magnitude greater than background, and due to high relative impact velocities of ~10 km /s can seriously influence on functioning of spacecraft components (solar panels, windows, optic reflectors).

Project objectives

The Project was aimed at investigation of astrosol distributions in Near Earth Space (NES) using onboard experiments and mathematical modeling, as well as analysis of their effect on exposed devices and construction elements of spacecraft.

Description of the Works

Three tasks were carried out within the frame of the Project:

Task 1: the data processing from onboard measurements collected during experiments on "Salyut" and "Mir" orbital stations and the analysis of the influence of micrometeoroids and space debris (MM/SD) particles on the retrieved sets particularly solar cells. As a result of solving this problem we expected to obtain new information on astrosol cloud distribution in the NES, penetrating effects of the MM/SD particles, and damage morphology of the solar cells that have been working in the space station "Mir" over 10 years.

Task 2: the computer modeling of evolution of fine space debris due to space engineering exploitation and forming of man-made astrosols in NES. Solution of this problem is necessary for development of new forecast tools for space distribution of astrosol debris in NES and mitigation measures in NES to minimize pollution with man-caused particles of different origin.

Task 3: investigation of influence of astrosol particles impact on the spacecraft components. The outcomes of experiments and codes suppose to be used for analysis of space particle effect on different spacecraft components and for solution of problems of protection optimization.

Obtained results

• Statistical analysis of the time sequence of MM/SD impacts was performed using onboard measurements data obtained at station "Salyut - 3, 4, 7" by means of the condenser censors. A conclusion about non-Poisson behavior of the stream of registrations of particles was done. The analysis of the registration data has shown (a) pronounced nonstationarity in the form of intensity discontinuities is observed in the registration stream; and (b) part of registered particles appear in groups with close times of registrations within the group. The obtained results are in qualitative agreement with the results obtained in experiment LDEF.

• The damage morphology of samples of the solar cells that have been working in the space station "Mir" over 10 years was investigated. Nanostructures formed on a surface of these samples have been visualized by means of atomic force microscopy. By a nanoindentation method it was showed that the exposed surface at nanodepth has higher value of plastic deformation and irreversible deformation but smaller value of hardness and reduced modulus in comparison with the nonexposed one.

The results were reported at the 5th European Conference on Space Debris in Darmstadt in 2009.

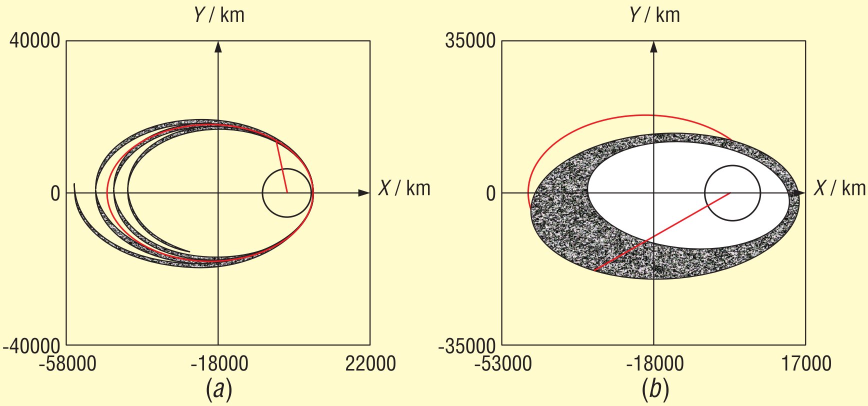


Figure 1: Spatial distribution of cloud particles for 100 (a) and 7000 h (b) after moment of injection of aluminum oxide particles in a perigee of "Molniya" orbit

• The dynamic models describing the movement of single microparticles and microparticles clouds of aluminum, aluminum oxide and carbon with radii from 0.01 to 100 μm in the NES for various levels of solar and geomagnetic activity are developed and realized as computer programs. As a result of carrying out of corresponding numerical experiments it has been established that:

– the astrosol clouds observed by low-orbit spacecrafts (LDEF, Salut and Mir) should consist of particles which move in the NES on the oblong elliptic orbits with a low perigee point; and

– possible sources of long-term astrosol clouds in near space are objects moving in the NES on the oblong elliptic orbits similar Molniya orbit, and also fine-dispersed products of exhaust of solid rocket motors (SRM) of space vehicles. The obtained calculated data are conformed to available experimental data about orbital characteristics of astrosol clouds particles and their possible sources received as result of natural measurements.

Data of numerical simulation of the process of formation of a cloud from aluminum oxide particles with radius 10 microns, which were ejected with velocities of 100 km/s in a perigee of "Molniya" orbit for the conditions of low activity, has confirmed an opportunity of formation of long-living clouds of microparticles in the NES if their source moves on the oblong elliptic orbit (Fig. 1).

The principle opportunity of formation of astrosol clouds in the NES for which source are fine-dispersed products of SRM exhaust is confirmed by numerical simulation results of the process of evolution of a cloud from fine-dispersed aluminum oxide particles which were ejected in the NES during the correction of an low spacecraft WESTAR 6 orbit (Fig. 2).

• The results of the numerical simulation of secondary particle generation process on ISS solar panels under the impacts of MM/SD particles have formed the database that can be used in the process of updating space debris model in the particle size range 0.1–10 μm.

The results were reported at the 5th European Conference on Space Debris in Darmstadt in 2009.

• Comparative experimental investigations of qualitative characteristics of back ejecta arising at high-speed interaction of an aluminium projectile with solid and discrete metal target, and composit target have been fulfilled (Fig. 3). Reliable estimates of ejecta particle masses were obtained. For instance, for aluminium targets about 80% of these particles

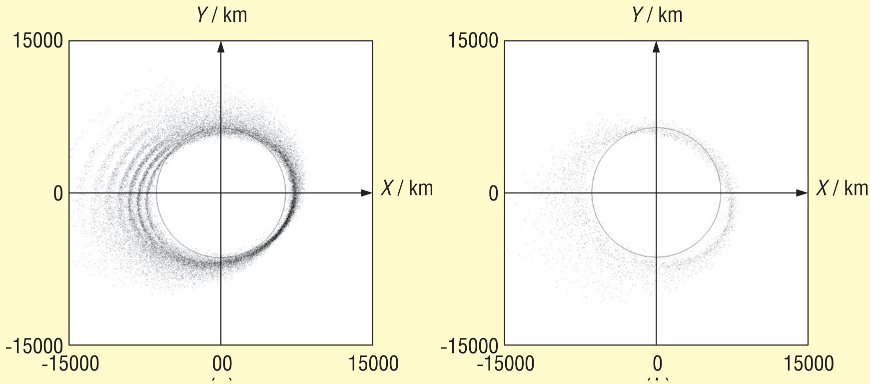


Figure 2: Spatial distribution of cloud particles for 1 (a) and 10 (b) days after moment of injection of aluminum oxide particles during the correction of an low spacecraft WESTAR 6 orbit

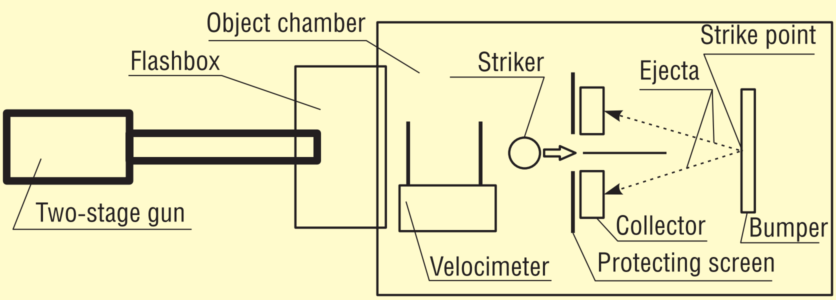


Figure 3: The scheme of the experiments studying the ejecta generated by impact on the bumpers made of metallic materials

have masses no more than 10^{-6} g, for composite (glass-fiber) targets about 90%–95% have masses within 10^{-7}–10^{-8} g.

Recommendations on use of these materials for shield protection of spacecraft are given.

The result of work, being considered from the point of view aiming the eliminating of the pollution of the outer space with ejecta particles generated at hypervelocity impacts, clearly suggests against the usage of metallic plates as first (outer) bumper in spacecraft shield protection systems (Figs. 4 and 5). In this case, the better choice would be the bumpers consisting of 2–3 meshes (not only steel).

The results were reported at the 5th European Conference on Space Debris in Darmstadt in 2009.

• The problem of calculations of fluxes of space debris and meteoroids on partially shadowed SC‘s surfaces has been invesrigated (Fig. 6). The analytical formulas for calculations of the coefficients of shadowing and the tables and graphics for fast estimations are developed. The numerical calculations for models of space debris and meteoroids have been done.

The results were reported at the 26th Meeting of the Interagency Committee on Space Debris in Moscow in 2008.

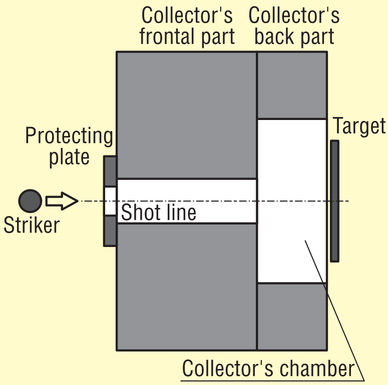


Figure 4: The cross section of the collector taken along the shot line

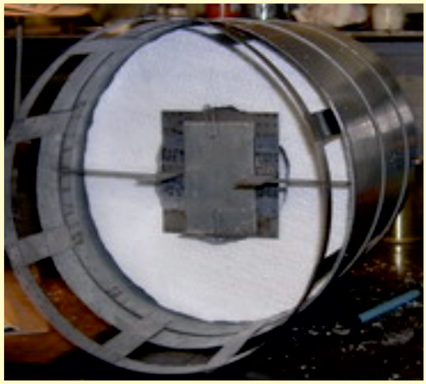


Figure 5: The view of the collector with the attached target

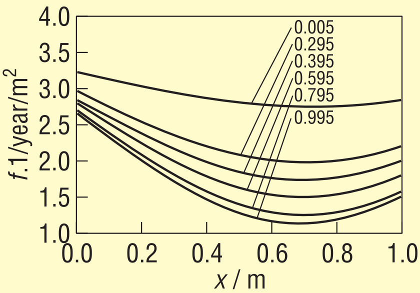


Figure 6: Meteoroid flux distributions on a partially shadowed surface

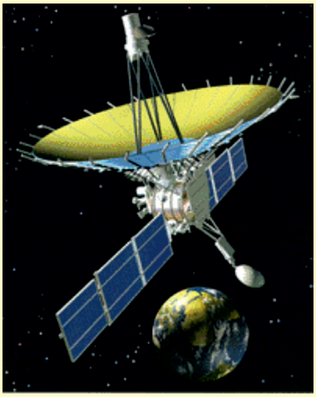


Figure 7: The spacecraft for the RadioAstron mission

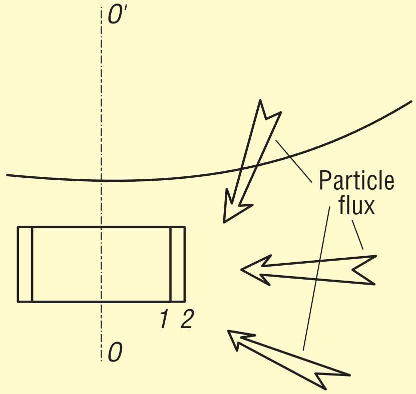


Figure 8: Scheme of the side element of thespacecraft in the mission RadioAstron

• The method of designing of optimal SC protection using estimations of risks distributed for a long-time is developed. As an example, the protection of the spacecraft “Spektr” (will be placed in a high elliptical orbit for the RadioAstron mission (Figs. 7 and 8)).

The results were reported at the 57th Congress of the International Aeronautical Federation (IAC57) in Valensia in 2006.

• The analytical solution of unsteady problem on the motion of gravitating body in a dust cloud (a linear prototype of the Chandrasekhar problem).

The solution can be used to analysis of an initial period of motion when self-gravitation can be neglected (Fig. 9).

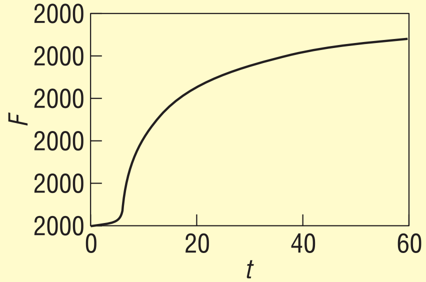


Figure 9: Temporary force exerted on a gravitating body moving in a dust cloud

The results were reported at the 5th European Conference on Space Debris in Darmstadt in 2009.

Project Number:	#3779
Full and Short Title:	Development of a Portable High-Energy Neutron Spectrometer for Active Diagnostics of Radiation Environment in Spacecraft **Neutron Spectrometer for Spacecraft**
Tech Code / Area / Field:	SAT-SAF: Space, Aircraft and Surface Transportation / Space Safety INS-MEA: Instrumentation / Measuring Instruments
Status:	Project underway
Technology Development Phase:	Applied research
Allocated Funding:	$300,000 (US)
Commencement date:	June 1, 2008
Duration:	36 months
Leading Institute:	V.G. Khlopin Radium Institute, St. Petersburg, Russia
Contact Information:	Phone: +7 (812) 297 56 41 Fax: +7 (812) 297 57 81 (57 00) E-mail: radium@khlopin.ru Website: http://www.khlopin.ru
Supporting Institutes:	No
Collaborators:	Canadian Space Agency / Operational Space Medicine Group, Canada Deutsches Zentrum fur Luft- und Raumfahrt e.V. / Institut fur Luft- und Raumfahrtmedizin, Germany University of Uppsala / Svedberg Laboratory, University of Uppsala / Department of Neutron Research, Sweden Bubble Technology Industries Inc., Canada Royal Military College of Canada, Canada
Project Manager:	RYZHOV Igor Vladimirovich
Contact Information:	Phone: +7 (812) 297 02 70 Fax: +7 (812) 297 02 70 E-mail: ryzhov@khlopin.ru
ISTC Senior Project Manager:	RYZHOVA Tatyana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (495) 978 36 03 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

Dosimetry measurements made aboard low-earth orbit (LEO) spacecrafts over the past 20 years revealed that neutrons could contribute significantly to astronaut radiation exposure. The neutron component is estimated to account for approximately 30% of the total dose equivalent in LEO spacecraft (and more than 50% — in space missions beyond the Earth's magnetosphere). The real numbers depend strongly on the solar cycle, spacecraft's shielding, orbital inclination, altitude, and, in fact, are not well understood. A large uncertainty in the neutron dose determination is due to a poor characterization of neutron fields inside a spacecraft. These fields are largely formed by secondary neutrons produced by high-energy charged particles of galactic and solar origin in their collisions with spacecraft structures. The neutron spectrum inside LEO spacecraft extends from thermal to the GeV energies, but for the accurate risk assessment of possible radiation effects on crewmembers, the neutron measurements over the energy range 0.2 eV – 200 MeV are necessary. Currently available instrumentation can provide reasonably good measurements of the neutron flux at energies below about 14 MeV, whereas the measurements at higher neutron energies remain a difficult problem.

Project Objectives

The present Project is aimed at the development of a portable, high-energy neutron spectrometer (PHENS) for real-time measurements aboard spacecraft.

Description of the Works

In PHENS, a stack of 5 mm thick lithium-drifted silicon detectors with an active area of about 2 cm^2 each will be used as a neutron-detecting element. The detecting element measures energy deposition spectrum of heavy recoils and light charged particles due to nuclear interactions (elastic and inelastic) between energetic neutrons and silicon nuclei. Having this spectrum, one can evaluate (using unfolding procedures) the incident neutron energy spectrum, provided that the detector response functions are known for a wide set of neutron energies. To separate neutrons from primary and secondary charged particles the silicon detector assembly is surrounded with an anti-coincidence shield fabricated from CsI(Tl) crystal with photodiode readouts. Geometry and physical characteristics of the detecting head components are determined making use of Monte-Carlo transport codes.

PHENS should meet the special technical demands, which are normally placed upon radiation detecting instruments in space. Experts from Institute of Biomedical Problems (IBMP) Russian Academy of Sciences, that is responsible for the crew radiation safety aboard the Russian Segment of the ISS, will draw up the corresponding requirements specification. The demands will be imposed on the detector portability, construction, power supply, safety, resistance to external action, etc.

A good "statistics" in the energy deposited spectrum can only be used if the response matrix is known with better accuracy. Thus, accurate determination of the response matrix at incident neutron energies from 10 to 200 MeV is of particular importance for the PHENS development. The calibration is expected to be carried out at the GNEIS facility of Petersburg Nuclear Physics Institute (PNPI).

A conceptual analysis of the PHENS design has been carried out. Attention has been paid to assessing the detector sensitivity in the neutron energy range from 10 to 200 MeV. For this purpose, the Monte-Carlo calculations have been accomplished with the use of the MCNPX code available in Uppsala University (Sweden). The spectrometer has been defined as a composition of cells of the cylindrical shape. The central (detecting) part of the spectrometer consisting of four thick lithium-drifted Si detectors is surrounded by the active shield, serves to separate neutrons from primary and secondary protons. Calculations were carried out for the active shields made from polystyrene (C_8H_8) and CsI. The VETO signals were considered to be gener-

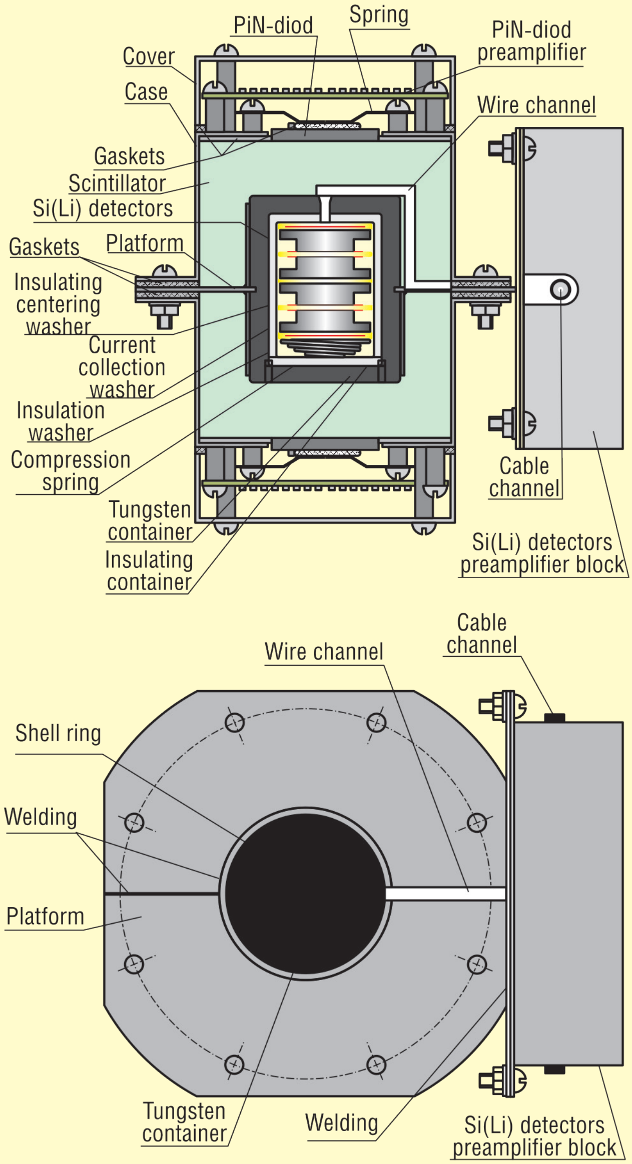


Figure 1: Design of the PHENS detecting head

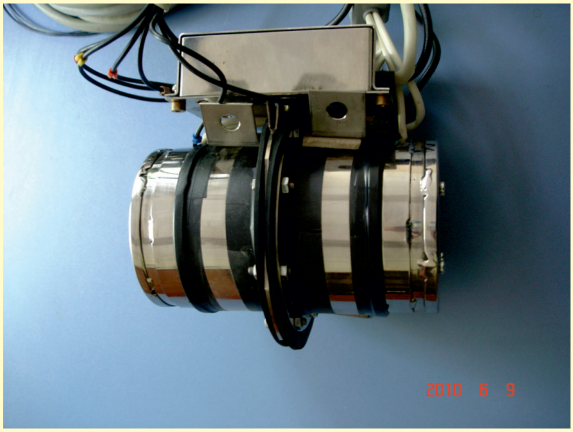


Figure 2: Photo of the PHENS detecting head

ated at energy depositions exceeding 2 MeV in polystyrene and 5 MeV in CsI. The calculation results have shown that the PHENS sensitivity depends slightly on neutron energy. The spectrometer having the active shield made of CsI has a higher sensitivity as compared to one with the polystyrene shield. Estimations have been carried out of the PHENS sensitivity to false events that could be induced by photons and protons. The Monte Carlo simulation results of the radiation environment aboard the Columbus module of the ISS obtained by T. Ersmark *et al.* have been used as inputs for our calculations. The calculation results have shown that probability P of the energy deposition above 3–5 MeV by photon in Si(Li) detector is low. In particular, this probability at E_R = 5 MeV is $4{\cdot}10^{-6}$ and $6{\cdot}10^{-6}$ for CsI and polystyrene, respectively.

Prototype of the detecting head has been designed and manufactured (Figs. 1 and 2). Si(Li) detectors (separated from each other with slip-ring contacts) are positioned coaxially inside an insulating cylindrical container. To provide tight electrical contacts the silicon detector assembly is pressed with a cone spring (applied to an insulating washer). The insulating container is mounted inside a tungsten container. Preamplifiers are connected with the slip-ring contacts by wirers passing along channels on the lateral surface of insulating container and then come out through the end of the tungsten container. For ensuring an operation control of the detectors and equalization of the preamplifier gain factors, each Si(Li)-detector is supplied by a reference sample of alpha-particles constituting from a layer of natural uranium with the activity of about 6 Bk, deposited on aluminum foil backing of 0.1 mm thick.

Cylindrical scintillator consists of two equal parts having the caves where the tungsten container is inserted. The PIN diodes manufactured by Hamamatsu (model S3584-08) are used for registration of the scintillations. In order to fasten the PIN diodes resilient tines are used. The outer casing prevents detectors from both mechanical failures and light effect. Test and calibration measurement at 14 MeV monoenergetic neutrons has been carried out. A D-T neutron generator produced by All-Russia Research Institute of Automatics has been used in the experiment. Figures 3 and 4 show an energy deposition spectrum produced by 14 MeV neutrons in the PHENS active volume (assembly of four Si(Li) detectors) and result of determination of the detection efficiency.

The general PHENS calibration will be carried out at the neutron time-of-flight (TOF) spec-

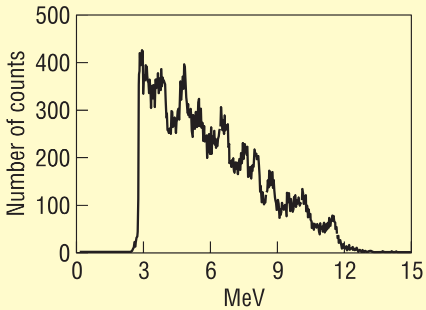


Figure 3: Energy deposition spectrum produced by 14 MeV neutrons in the PHENS active volume

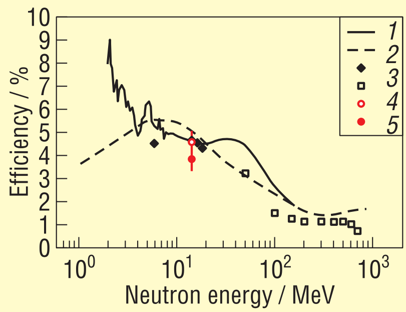


Figure 4: Measured efficiency of a thick silicon detector compared with efficiency calculated using common models of the neutron–silicon reaction cross section

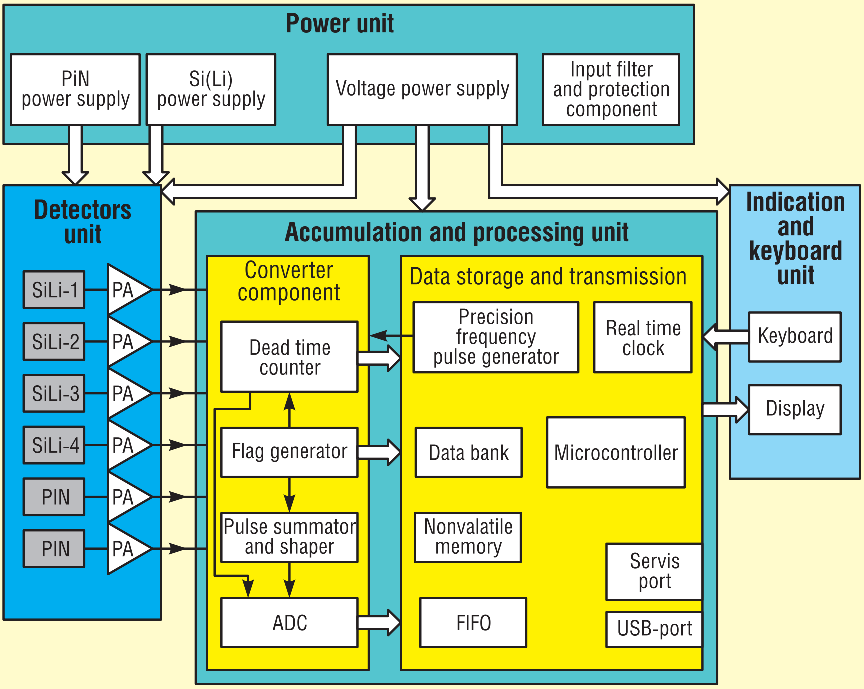


Figure 5: Functional scheme of the PHENS

trometer GNEIS based on the 1-gigaelectronvolt proton cyclotron of Petersburg Nuclear Physics Institute. At this facility, we plan to use waveform digitizers for TOF measurements in order to avoid problems related to gamma flesh. For this purpose, the CAEN electronic equipment (waveform digitizers CAEN V1721, crate CAEN VME8002 and PCI optical link CAEN A2818) has been purchased. The code WaveROOT has been developed to provide the data acquisition and processing.

Final concept of the PHENS outward appearance has been developed as well as the general arrangement of the detector components, functional scheme and the power supply circuit. Development of the functional scheme of the PHENS data acquisition system (DAc) has been completed. Interplay between amplitude to digital processor, data buffer and module of system control and data storage has been investigated in detail. The functional scheme is given in Fig. 5.

Obtained/Expected Results

1. A conceptual analysis of the PHENS design has been carried out.

2. Prototype of the detecting head has been designed and manufactured.

3. Experimental study of the detector characteristics and its calibration using monoenergetic 14 MeV neutron source have been carried out.

4. Development and manufacturing of the electronic modules are in progress:

• functional design of the DAc and power supply units;

• elaboration of electronic circuits and making of printed circuit boards; and

• assembling and testing of electronic modules

5. Assembling and testing of a prototype of PHENS will be performed:

• design study of the PHENS assembly and elaboration of working drawings;

• manufacturing and assembling of mechanical components, assembling, and debugging of PHENS; and

• testing of PHENS at the neutron beam with a continuous “white” spectrum (GNEIS Facility, PINP, Gatchina).

Space Vehicle and Support Equipment

List of projects

In total, 6 projects were funded by the ISTC Parties and 1 project by a Partner.

#0192

"Studies Relative to Creating Reaction Engine with Microwave Power Supply"

(Microwave Pumped Rocket Engine)

– Moscow Institute of Radioengineering and Electronics, Moscow, Russia

#0978

"Researches on Providing Interference Protection and Development of the Automatic Optical System to Check Rendezvous Parameters of Co-operating Space Vehicles"

(Cooperating Space Vehicles)

– NPO Geophysica / Special Design Bureau "GeoKos", Moscow, Russia

– NPO Energia, Korolev, Moscow Region, Russia

– GNPO Polyus, Moscow, Russia

#1171

"Testing of Feed System for Nuclear Propulsion Technology under Consideration for Development of Moon, Exploration of Mars and Far Planets"

(Testing of Propulsion Feed System)

– Keldysh Research Center, Moscow, Russia

– Chemical Automatics Engineering Design Corp., Voronezh, Russia

– Research Institute for Chemical and Constructional Machine Building, Sergiev Posad, Russia

#1926

"Development and Creation of a Laser System for Fuel Components Ignition for Multiple Start of a Space Rocket Engine"

(Laser Ignition in Jet Engines)

– Chemical Automatics Engineering Design Corp., Voronezh, Russia

– Energomachtehnica, Moscow, Russia

– Keldysh Research Center, Moscow, Russia

#2260

"Theoretical and Experimental Investigations of Problems of Creation of Rocket Laser Engine"

(Laser Rocket Engine)

– Chemical Automatics Engineering Design Corp., Voronezh, Russia

– Energomachtehnica, Moscow, Russia

– Keldysh Research Center, Moscow, Russia

#3236

"Adaptation of System Laser Ignition Components for the Chamber of Combustion of the Rocket Engine"

(Laser Start for Rocket Engine)

– Chemical Automatics Engineering Design Corp., Voronezh, Russia

– Keldysh Research Center, Moscow, Russia

Project Number:	#0192
Full and Short Title:	Studies Relative to Creating Reaction Engine with Microwave Power Supply **Microwave Pumped Rocket Engine)**
Tech Code / Area / Field:	SAT-VEC / Space, Aircraft and Surface Transportation / Space Vehicles and Support Equipment
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$470,000 (JP)
Commencement date:	January 1, 1995
Duration:	36 months, extended by 3 months
Leading Institute:	Moscow Institute of Radioengineering and Electronics, Moscow, Russia
Contact Information:	Phone: +7 (495) 626 23 13 Website: http://www.mnirti.ru
Supporting Institutes:	No
Collaborators:	NASDA, Tokyo, Japan
Project Manager:	NOVIKOV Aleksei Dmitrievich
Contact Information:	Phone: +7 (495) 926 25 17 Fax: +7 (495) 973 20 26
ISTC Senior Project Manager:	NOVOZHILOV Valery V.
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (499) 982 32 01 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

Nowadays, chemically driven engines, in which the rocket jet is generated with the use of chemical energy released only due to fuel burning, serve as cruise engines. However, the chemical reaction jet velocity cannot exceed 5 km/s. The jet velocity can be increased using an additional source of heat. Thus, an engine in which an atomic reactor supplies the energy and pure hydrogen serves as a working fluid that can provide a jet velocity amounting to about 12 km/s. The maximum velocity value is limited by thermal resistance of the construction materials.

Despite the concept of thermal nozzle suggested by L. A. Vulis has not been tested experimentally, it is of great technical interest and offers an opportunity of designing a rocket engine with a microwave energy supply and with a high jet velocity and resource.

An idea of creation of a cruise rocket engine with contact-free preheating by a microwave field, in which the vapor evolved from a solid material by microwave discharge is converted to a plasma can be realized applying well-known radiophysical methods. The plasma forms a jet under action of gasdynamic forces. Feasibility of operation of a thermal nozzle with microwave energy supply can be verified by mathematical simulation methods.

Project Objectives

The objective of the Project was to study experimentally microwave discharges and to ascertain the conditions under which microwave energy is absorbed efficiently.

Description of the Works

The following tasks were implemented in the course of investigations:

– Design and fabrication of the experimental setup;

– Investigations of plasma discharge;

– Solution of arising plasma-physical problems;

– Theoretical study of arising diagnostics problems; and

– Mathematical simulation of a thermal nozzle and development of computer codes.

The schematic of the selected engine design is shown in Fig. 1.

Rod (*1*) about 1 m in diameter is made of solid working material. The side rod surface can be covered with a copper layer (*2*) few micron thick. The rod in such a system must be radio-transparent and can be made of several discs. The microwave power source (*3*) is mounted behind the rod. An array antenna can serve as the power source. A magnet system (*4*), e. g., a superconducting solenoid operating at liquid nitrogen temperature, is arranged around the rod. The solenoid generates a magnetic field B that contains surface (*5*) at which the electron resonance conditions are met.

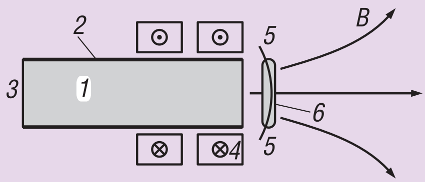


Figure 1: Schematic of engine design

The following issues relevant to the problem of thermal nozzle realization were addressed:

• investigation of steady flow in a one-dimensional (1D) jet;

• investigation of transition to a supersonic flow;

• investigation of flow stability and transient processes in the 1D flow; and

• numerical simulation of simple cases of quasi-1D and two-dimensional (2D) jet flow with a free boundary.

It has been found that in a 1D nozzle, there always exists a steady flow of a polytropic gas with transition through sonic velocity. This flow is stable with respect to small perturbations. The time of transition from one flow regime to another is of the order of few times of material flight through the nozzle. The analytical results were confirmed by numerical solutions of gasdynamic problems of qiasi-1D and 2D flows. The results obtained can serve as a basis for formulation of the approach to calculation of realistic engine dimensions.

It is noteworthy that radiofrequency heating is now used in practice, e. g., in nuclear fusion setups with magnetic confinement. This supports the feasibility of microwave preheating application in a rocket engine with allowance for the specific requirements imposed on plasma in it.

To prove experimentally that there are regimes in which the super high frequency (SHF) energy supplied is absorbed efficiently, a microwave setup for generating a discharge in a waveguide chamber was designed (Fig. 2).

The setup comprises two SHF energy sources: one operating continuously (based on a traveling wave tube 200 W in power operating at 6.2 GHz) and the other in a pulsed mode (based on a multiresonance klystron of a 20-kilowatt power in a pulse with an off-duty factor of 50 operating at 5.9 GHz).

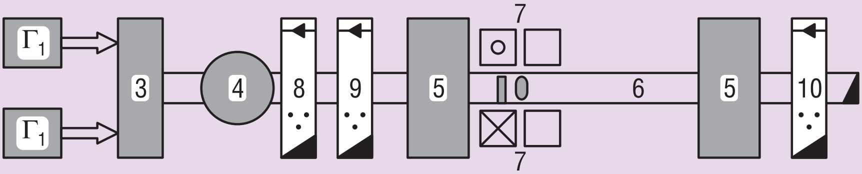


Figure 2: Microwave setup for generating a discharge in a wave-guide chamber

The continuous signal ensures initial conditions favoring discharge initiation by the pulse source.

Signal generators Γ1 and Γ2 serve as the sources of the continuous and pulse signals. The signals are summed up in a single wave-guide tract with the aid of balance filter device (3). The generators contain transistor amplifiers and semiconductor diode attenuators that can be controlled by automatics. The two signals are directed through a ferrite isolating device to polarization selector (5) consisting of two input rectangular waveguides, which excite a round wave-guide, each on its own polarization mode. Further on, the two signals enter polar converter (5) that converts linearly polarized waves into waves of round polarization. The polarization selector and converter are overlapped in the figure and are both referred to as No. 5. These devices are both located at the inlet and outlet of the working chamber. Transition to a wave of round polarization is necessitated by the fact that such a wave exhibits resonant absorption when spreads along the magnetic field.

Then the microwave signal comes to the chamber through a tightly sealed window. Chamber (6) is a round waveguide in which plasma forms. Several coils (7) are mounted on the chamber to induce the needed magnetic field. Each coil has its own power source, which is a stabilized electric current source. The current intensity is controlled by an automated system.

The energy absorbed by plasma is measured with the aid of couplers of the incident (8), reflected (9), and transmitted (10) waves.

Photos of the setup and working chamber are displayed in Figs. 3 and 4, respectively.

Absorption of microwave energy is measured in a configuration in which the wave vector of the incident wave is parallel to the magnetic field and microwave energy is fed from the strong-field side. Measurements are performed at a 6-gigahertz frequency in a round waveguide 40 mm in diameter, in which two waves differing in their polarization can spread. Experiments with a traveling wave tube at a level of the continuous radia-

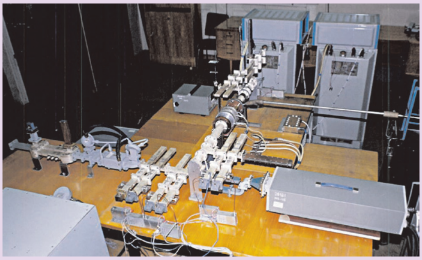


Figure 3: Photo of the experimental setup

Figure 4: Photo of the working chamber

tion power of 100 or 150 W showed that small energy losses for reflection could be attained in a wide range of initial pressures, between 0.001 and 1 Torr, and magnetic field intensity B (electric current of 110 A). No additional matching units were needed. Absorption exceeded 50% and its best values amounted to 80% or 90%.

If the pulse klystron power exceeds the power of the traveling wave tube by a factor of about 100, the pressure in the chamber can be increased. This circumstance is good for engine operation because a higher specific thrust value can be achieved.

Experiments show that an appropriate adjustment of the electric current in the coils allows the reflection coefficient to be increased to 95%–98%. To this end, a simple built-in reflectometer should be provided in the engine.

Reflection of a powerful signal occurs mostly with a change of polarization; hence, the plasma conserves its cylindrical symmetry. Cylindrical symmetry of the magnetic field, waveguide, and chamber is not violated by the plasma. Such a reflection mode can be reduced in a fixed regime by introducing units that adjust the cylindrical symmetry or by a dielectric diagram in the multimode waveguide. It is this approach which was planned to be applied in the existing setup in a new chamber when continuing the work. As a rule, the plasma was quiet in the majority of operation regimes, no relaxation was observed in oscilloscopic traces.

Approaches to measurement of the engine and jet parameters were analyzed only theoretically. The results of this analysis were included in the proposals concerning further development of the investigations.

When analyzing the physical processes attending plasma generation and acceleration in a thermal nozzle, a mixture of three gases (rather than a polytropic gas, which was considered in authors' previous investigations) was considered as the jet material. The mixture components were neutral atoms, electron gas, and positive ions; they could be converted into each other. In this case, the quasineutrality condition must be met, i. e., the charge of all electrons in any volume should equal the charge of positively charged ions in the same volume.

The mechanisms of acceleration and ionization of the gas mixture were considered and appropriate simplified models were formulated; the models were amenable to mathematical simulation.

The physics of preheating zone formation was considered tentatively. Simple mathematical models were formulated; they allowed parameters of the microwave preheating zone to be assessed after development of the appropriate computer programs.

Gas flow in a jet with a free boundary with account taken of mass sources and heat input was simulated numerically.

A quasi-1D gasdynamic model of a gas flow in a jet with a free boundary was developed and examined both analytically and numerically (several computation codes were developed).

The results have demonstrated that

– the gas flow accelerated from zero velocity to its supersonic values even in a jet with a constant cross section within a wide range of parameters of thermal-energy sources. Gas acceleration was stable in time;

– an unsteady process at arbitrary initial data with a fixed sufficiently low pressure at the outlet cross section yielded a supersonic steady solution with a smooth transition through the cross section where Mach number M attained unity. A sufficiently high pressure value at the outlet cross section yielded a subsonic steady flow; and

– the results of calculations with the use of the model of a jet with expanding cross section supported the conclusions drawn from the calculations performed for a jet of a constant cross section. Nonetheless, acceleration of the gas in the supersonic portion of an expanding flow required a lesser cooling rate than that in the case of the purely 1D model of a jet with a constant cross section. In a jet with expanding cross section, gas could be accelerated from subsonic to supersonic velocities with no cooling as well. Jet expansion served as cooling in this case.

An axially symmetric 2D gasdynamic model of a gaseous jet with a free boundary was also suggested and investigated numerically. A digitized mathematical model approximating the gasdynamic model was developed based on the finite-difference Godunov scheme, and an appropriate 2D code was created.

The results have shown that

– the jet with a free boundary reliably attained a steady supersonic regime within a wide range of the parameters characterizing localization of the energy sources and of initial conditions;

– the main parameter affecting the thrust value and jet expansion in the model considered was the thickness of the preheated zone in the longitudinal direction. When the preheated zone was sufficiently thin the thrust value attained its maximum and only insignificantly depended on concavity of the solid evaporation surface and on the distribution of thermal energy sources within the zone of preheating; and

– mathematical modeling of the cooling zone (energy loss) showed that, as in the case of a quasi-1D flow, jet expansion was responsible for cooling.

The results of mathematical simulation favor the possibility of creation of a low-thrust rocket engine based on the thermal nozzle principle.

Obtained Results

1. An experimental radioengineering setup was designed and fabricated.

2. Plasma discharge was investigated and conditions for efficient microwave energy absorption were ascertained.

3. Problems of diagnostics were investigated and relevant plasma-physical problems were solved.

4. Operability of a thermal nozzle with microwave power supply was demonstrated.

5. A prospective plan of the next stage of investigations into creation of a laboratory-scale model rocket engine has been put forward.

Project Number:	#0978 PDG (Project Development Grant)
Full and Short Title:	Researches on Providing Interference Protection and Development of the Automatic Optical System to Check Rendezvous Parameters of Co-operating Space Vehicles **Cooperating Space Vehicles**
Tech Code / Area / Field:	SAT-VEC / Space, Aircraft and Surface Transportation / Space Vehicles and Support Equipment
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$10,000 (EU)
Commencement date:	January 1, 1998
Duration:	6 months
Leading Institute:	NPO Geophysica / Special Design Bureau "GeoKos," Moscow, Russia
Contact Information:	Phone: +7 (495) 462 03 43 Fax: +7 (495) 462 13 14 E-mail: info@geofizika-cosmos.ru Website: http://www.geofizika-cosmos.ru
Supporting Institutes:	NPO Energia, Korolev, Moscow Region, Russia GNPO Polyus, Moscow, Russia
Collaborators:	European Space Agency / European Space and Technology Center, Noordwijk, The Netherlands Jena Optronik GmbH, Jena, Germany (Skarus W.)
Project Manager:	KOUZMIN Vladimir
Contact Information:	Phone: +7 (495) 462 03 43 Fax: +7 (495) 462 15 06
ISTC Senior Project Manager:	NIETZOLD Dieter
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (499) 982 32 01 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

When manned and unmanned space vehicles (SV) approach each other and dock on an orbit, monitoring devices are used which control the parameters of their relative positions: their separation, angular orientation of one vehicle with respect to the other, and displacement velocity. Preliminary investigations have shown that application of optical facilities for the aforesaid purposes would significantly improve the size–weight characteristics of the monitoring devices and the precision of measurements. One of the factors impeding development of such instruments is a high level of light jamming existing in an SV (owing mostly to Solar radiation).

NPO Geofizika/SDB "GeoKos" together with Rocket-Cosmic Corporation "Energia" and Research Institute "Polyus" have submitted to ISTC a Project Proposal the objective of which was to develop an automated optical system for monitoring rendezvous of both manned and unmanned SV which is capable of operating under real light-jamming conditions.

The major efforts was planned to be focused on investigations of the jam-protection problem, namely, to systemize the available and obtain new data on characteristics of light jamming in SV that affect performance of apparatus of the type considered and on development of techniques that permit the instruments to operate under action of light jamming. The Project was also planned to include studies of the SV rendezvous dynamics and of the effect of dynamic impacts on the equipment characteristics.

Based on the investigations performed, it was intended to implement design assessment, mathematical simulation, laboratory modeling of the most important units, to prepare design documents, to manufacture a dummy sample of the apparatus, and to test it.

A well-known scheme, in which special reference marks (light reflectors or responders) are mounted on a passive, nonmaneuvering SV and an angle–distance meter is mounted on the active SV, has been suggested as a basis for designing the system. The angle–distance meter detects coordinates of these reference marks and calculates parameters of the relative SV positions based on the data of measurements; it also scans the space with a narrow laser beam and with a small field of vision of its receiving device, searching, thereby, for the object of interest (a group of reference marks), detecting and tracing it.

A Grant has been allotted to the authors of the Project on creation of an automated optical system that controls the rendezvous parameters. The Grant was allotted for development and updating of the Project. It was proposed to perform technical and economic assessment of the Project and coordinate the technical requirements to the system with the European collaborators.

Project Objectives

The objective of the Project first stage was to work out its technical and economic substantiation and to coordinate the performance specification with the European collaborators.

Description of the Works

During the Project first stage (Project No. 0978, 6 months), three meetings with the European collaborators (EKA and "Jena-Optronic") were organized. At the meetings, additional materials concerning the systems controlling SV rendezvous parameters were discussed and the required parameters of instrumentation for controlling SV (RVS and ATV) rendezvous were analyzed.

The following documents were worked out for the Project second stage (Project No. 0978-2) after analyzing the documents provided by EKA and "Jena-Optronics:"

• List of system problems to be solved in the course of Project implementation.

• The plan of cooperative research to be performed by the organizations and enterprises involved.

• Refined version of the "Results expected" Section of the Project.

- Refined calendar plan of works.
- Estimated cost of the work within Project No. 0978-2 with amendments in the calendar plan taken into account.

The “Expected results” and “Technical calendar plan of works” Sections of the Project were coordinated with the European collaborators. The estimated cost of works was recognized reasonable.

It was recommended to continue discussion of the Plan of cooperative works after the problem of Project No. 0978-2 funding is solved.

Obtained Results

As a result of three meetings with the collaborators, the following documents concerning the second stage of Project No. 0978-2 were worked out. The documents were coordinated with the collaborators.

- List of problems to be solved in the course of Project implementation.
- The tentative plan of work.

The European collaborators were interested in Project No. 0978-2. The Project now expects its funding.

Project Number:	#1171
Full and Short Title:	Testing of Feed System for Nuclear Propulsion Technology under Consideration for Development of Moon, Exploration of Mars and Far Planets **Testing of Propulsion Feed System**
Tech Code / Area / Field:	SAT-VEC / Space, Aircraft and Surface Transportation / Space Vehicles and Support Equipment
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	362,614 € (EU)
Commencement date:	June 1, 2000
Duration:	24 months
Leading Institute:	Keldysh Research Center, Moscow, Russia
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
Supporting Institutes:	Chemical Automatics Engineering Design Corp., Voronezh, Russia
Collaborators:	Research Institute for Chemical and Constructional Machine Building, Sergiev Posad, Moscow Region, Russia SEP (Société Européenne de Propulsion), Vernon, France
Project Manager:	SEMYONOV Vitali Felixovich
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
ISTC Senior Project Manager:	TOCHENY Lev Vasil'evich
Contact Information:	Phone: +7 (495) 982 31 13 Fax: +7 (499) 978 46 37 E-mail: tocheny@istc.ru
ISTC Website:	http://www.istc.ru

Background

When designing a nuclear engine to be used in space flights intended to develop and explore Mars and other planets, one has to improve the technologies applied in previous test programs and the methods of designing appropriate feeding systems. A feeding system was designed with allowance for specific features of booster turbopump aggregates (BTPA) operating at a low flow rate of supercooled hydrogen, and for dynamic characteristics of BTPA operating in unsteady regimes.

Project Objectives

The basic objective of the Project was to develop approaches to designing feed systems for prospective space engines, including a nuclear rocket engine (NRE) equipped with a naturally aspirating pumping system, and to test some units of the feeding system of promising space engines, including NRE. The Project continued the works accomplished within Project No. 092 and furnished new experimental data on the characteristics of booster BTPA-2 operating in the regime of cavitation start at low liquid hydrogen flow rates ranging from 4 to 8 kg/s and at a temperature of pumped overcooled hydrogen of 17 K. The goal of the investigations was to create a feeding system with loss-free hydrogen storage.

Description of the Works

In compliance with the Work Plan, cavitation tests with the BTPA pumping overcooled hydrogen were performed. The data obtained supplemented the BTPA-2 cavitation characteristics obtained previously. Three specific regimes of BTPA-2 operation were reproduced. The vapor content in hydrogen arriving at the pump inlet in the regimes considered increased with the rotor rotation frequency in the booster turbopump. Such regimes of

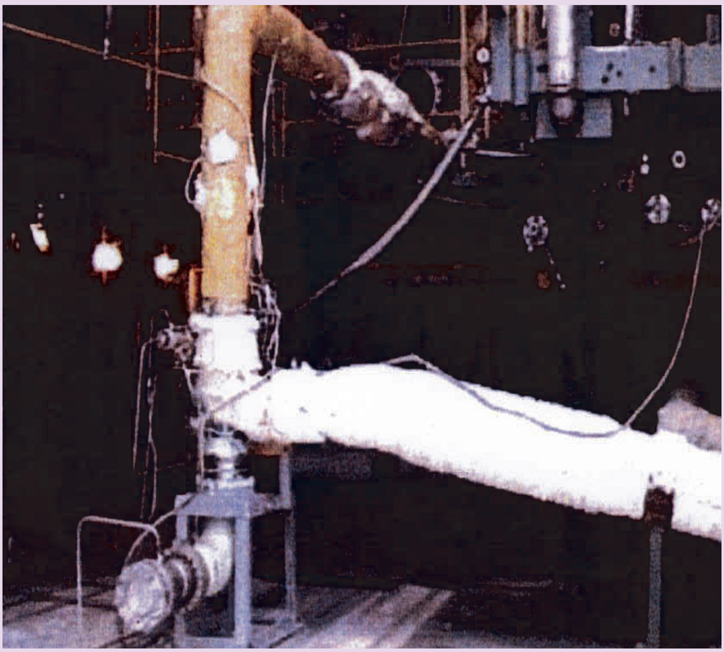


Figure 1: General view of setup 1 SU-M mounted on the test facility V-2A

booster pump operation are inherent in starting rocket engines; therefore, the pump characteristics revealed are of interest. The parameters of booster turbopump operation in three regimes with varied hydrogen flow rate and in three regimes with varied hydrogen temperature were measured and calculated.

Workability of the tested aggregate in the flow rate range of 4–8 kg/s at temperatures between 17.5 and 21 K was confirmed by the experiments (Fig. 1). The experiments also confirmed deterioration of the pump anticavitation properties as the hydrogen temperature decreased.

The parameters obtained were compared with the data of all previous tests with this particular BTPA; the available experimental data were summed up and a regressive dependence of the relative reduced thrust of the pump on vapor phase content, specific regime parameter, hydrogen temperature at the inlet, and rotor rotation frequency was derived.

The basic aspects of the new technology suggested for cavitation tests of BTPA pumps pumping two-phase hydrogen were developed and analyzed. The technology allows the tests to be conducted both in steady and unsteady regimes, i. e., BTPA operation under conditions of the so-called naturally aspirated feeding scheme (when the difference between the hydrogen pressure at the BTPA inlet and the saturated hydrogen pressure equals zero) during rocket engine start to be imitated.

The technology applied improved the value and quality of the empirical data and provided shorter test duration and cost, the other parameters being equal. When working out this technology, new schematic and design solutions facilitating a clear quantitative description of the physical phenomena attending cavitation tests were suggested.

Obtained Results

A computational algorithm depicting time histories of some physical parameters of the modulus and some systems of the test bench has been developed. The algorithm was realized in the form of a computer program. Mathematical simulation is to be applied when developing a test cyclogram, calculating the debugging parameters, and formulating the requirements imposed on the telemetry instruments and test bench systems.

The new developments are listed below:

– new principles of organizing the cavitation tests have been suggested; they are aimed at improving information value and diminishing the cost of tests; and

– general schematic of the algorithm for numerical simulation of cavitation tests of the aggregate pumping two-phase hydrogen in both quasi-steady and unsteady regimes has been developed.

Project Number:	#1926
Full and Short Title:	Development and Creation of a Laser System for Fuel Components Ignition for Multiple Start of a Space Rocket Engine **Laser Ignition in Jet Engines**
Tech Code / Area / Field:	SAT-VEC / Space, Aircraft and Surface Transportation / Space Vehicles and Support Equipment PHY-OPL/Physics/Optics and Lasers
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	335,000 € (EU)
Commencement date:	June 1, 2002
Duration:	24 months, extended by 3 months
Leading Institute:	Chemical Automatics Engineering Design Corp., Voronezh, Russia
Contact Information:	Phone: +7 (4732) 63 36 73 (34 65 65) Fax: +7 (4732) 34 65 71 (76 84 40) E-mail: cadb@comch.ruWebsite: http://www.kbkha.ru/
Supporting Institutes:	Energomachtehnica, Moscow, RussiaKeldysh Research Center, Moscow, Russia
Collaborators:	Cranfield University / School of Engineering, Cranfield, Beds, UK (Greenhalgh D. A.) Los Alamos National Laboratory (M. S. E535, Group CST-6), Los-Alamos, NM, USA (Sze R. C.)Los Alamos National Laboratory, Los-Alamos, NM, USA Stork Group/Stork Product Engineering B. V., Amsterdam, The Netherlands Tohoku University/Institute of Fluid Science / Shock Wave Research Center, Sendai, Japan (Takayama K.)
Project Manager:	GUTERMAN Vitaly Yurievich
Contact Information:	Phone: +7 (80732) 33 08 02 Fax: +7 (80732) 33 81 55 E-mail: guterman@vitaly.vsi.ru
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 31 57 Fax: +7 (499) 978 46 37 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

At present, intense investigations aimed at reducing the cost of payload launching to the orbit are going on in developed countries all over the world. These investigations are mainly conducted in the following directions:

- Multiple use of vehicles; and
- Increase of the number of payload displacements on orbit by multiply starting the engine.

This, in turn, imposes certain requirements on the new generation of space rocket engines in terms of multiple utilization of a round-trip engine, provision for several engine starts in space, and high reliability of all propulsion systems.

Huge experience accumulated at CADB and Keldysh Research Center shows that development of a reliable multiple ignition system of nonhypergolic propellant components (among them are virtually all nonpolluting components) is one of the chief technical problems to be solved when creating such rocket engines.

Search for new approaches to propellant ignition in liquid rocket engines is of great importance nowadays; therefore, creation of a reliable system of laser ignition of the propellant components used in space engines would be a breakthrough in this search.

Project Objectives

The Project was aimed at creation of a system of laser ignition of propellant components for multiple starts of space rocket engines.

Description of the Works

At present, the system of laser ignition of propellant components in multiple starts of a space rocket engine has no analogues; it must, in principle, include a pulse solid industrially produced laser, parameters of which are sufficiently high to ignite the propellant components, and a system of light-guides and devices directing the laser beam into the combustion chamber of a rocket engine.

The following tasks were solved in the course of Project implementation:

- theoretical investigations of laser beam interaction with propellant components;
- preparation to experimental studies;
- experimental testing of model setups; and
- designing and testing the laser igniter.

Available Russian and foreign materials concerning the level of development of lasers of various types in the world industry have been analyzed; authors' experience in computational assessment of the basic laser characteristics was used.

The energy and time parameters of laser radiation needed to ignite a working mixture in the combustion chamber of a rocket engine were evaluated both theoretically and computationally.

Investigations were carried out for two versions of physical schemes:

(1) generation of optical gas discharge; and

(2) initiation of a plasma jet on a metal surface.

The studies showed that the threshold electric field intensity needed to initiate discharge was about $E \sim 2 \cdot 10^5$ V/cm. The radiation power density corresponding to this value of the electric field intensity was $J \sim 1.4 \cdot 10^9$ W/cm^2. Assuming (for an estimate) that the laser focal spot area was equal to $F = 10^{-4}$ cm^2 (a realistic value that can be achieved with the use of short-focus lenses), the energy of a laser pulse absorbed by the medium amounting to $Q_{abs} \sim 1.4$ mJ was obtained.

The threshold energy value in the case of plasma generation at the target surface was about an order lower than the aforesaid value.

Computations were performed to explore the feasibility of discharge initiation and to ascertain the conditions under which the propellant components could be ignited with a laser beam in combustion chambers of various design versions. A comparative analysis of the two ignition techniques of the mixture, namely, laser beam focusing on a target and laser spark, showed that the two techniques could be successfully realized. Each of them has its own advantages and drawbacks. Laser beam focusing on a target leads to a high plasma temperature; the ignition zone is definitely localized in this case (at the target). However, this techniques necessitates introduction of an additional thermally resistant body in the combustion chamber. Laser spark (discharge) does not necessitate additional changes in the combustion chamber design; however, generation of the discharge in a medium containing fine particles is poorly studied.

The results of analysis provided a theoretical basis for designing experimental setups in which ignition of the propellant components with a laser beam could be studied and to make up a program of experimental studies.

Two experimental bench setups were fabricated at the Keldysh Research Center:

(1) setup SDS (Fig. 1) designed for investigation of ignition of an oxygen + alcohol and kerosene + oxygen mixtures with optical discharge in ambient atmosphere under normal conditions. The optical discharge was ignited 10 mm away from the prechamber wall. A solid laser with resonator Q-factor modulation was used in the setup. It operated in a pulse-periodical generation regime; the wavelength of radiation λ = 1.06 μm, pulse duration τ = 10^{-8} s, pulse energy E = 150 J, and pulse repetition frequency f = 10 Hz. The above parameters of the laser provided initiation of optical discharge in the atmosphere under normal conditions; and

(2) setup KVU (Fig. 2) in which ignition of a hydrogen + oxygen mixture with a laser beam interacting with a target was studied. The solid target can be preheated to produce a plasma cloud nearby it at a laser radiation power of about 10^5 W, which is significantly less than the power needed to ignite discharge in the gas phase. A phosphate–glass GLS-24 solid laser was used in the setup. The remarkable feature of this laser is high reliability of its operation and insensitivity to small perturbations of resonator adjustment.

Trial experiments in which various combustible mixtures were ignited with a laser beam were performed on both test benches. Figure 3 displays a schematic of the model combustion chamber (with side-wise introduction of the laser beam and target) in which laser ignition of mixtures was studied.

An analysis of the experimental results led to the following conclusions:

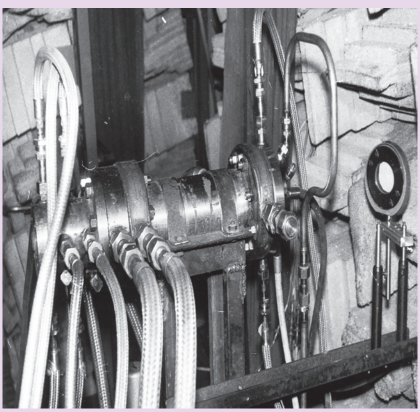


Figure 1: Experimental setup at the SDS test bench

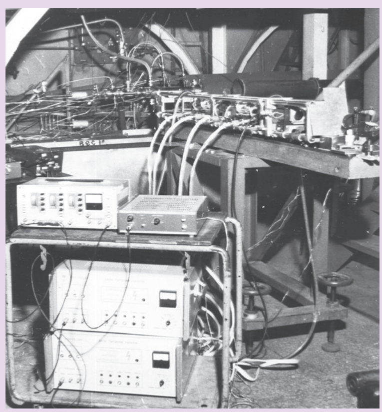


Figure 2: Combustion chamber at the KVU test bench

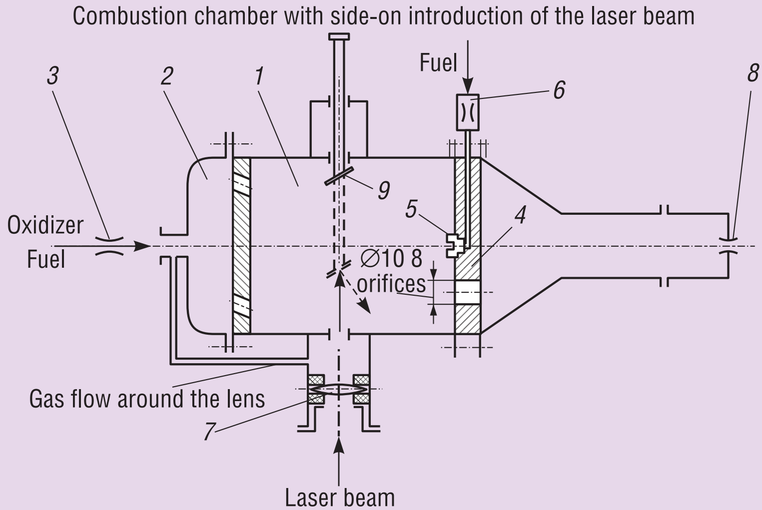


Figure 3: Model combustion chamber designed for studying laser ignition of combustible mixtures: 1 — combustion chamber; 2 — oxidizer nozzle block; 3 — flow meter nozzle; 4 — fuel injector head; 5 — worm fuel injector; 6 — orifice plug of the fuel main; 7 — focusing lens; 8 — replaceable outlet nozzle; and 9 — displaceable target with the rod

– feasibility of ignition of various propellant component pairs with a laser beam was demonstrated experimentally both in the optical gas-phase discharge mode and in the mode of plasma cloud generation at the target surface; and

– the minimum laser pulse energies needed to warrant mixture ignition were assessed experimentally.

A device to be incorporated in the standard system of propellant mixture ignition was fabricated, mounted, and tested on the KVU and SDS benches. The basic units of this device are:

• solid small-size 20-W YLF1/100/20 laser produced by "IRE-Polyus" and supplied by ISTC for implementation of this work;

• small-size pilot-light device with various designs of injectors of hydrogen–oxygen and kerosene–oxygen mixtures; and

• system of laser energy supply into the pilot-light device through light-guide.

The igniter device was tested on the KVU bench (with hydrogen–oxygen components) and on SDS bench (with kerosene–oxygen components). Both hydrogen–oxygen and kerosene–oxygen mixtures were successfully ignited in the ignition devices with a laser radiation source. The results of tests indicated that:

• oxygen–kerosene propellant is reliably ignited with a laser beam in a standard kerosene–oxygen pilot-light device (Fig. 4) at a minimum laser beam energy of 100 mJ / 0.6 ms, the optimal ignition site is a spot at the bevel edge of the sudden contraction surface of the pilot lighter located 120° away from the kerosene injector along the circle on the side, where the oxygen supply orifice is positioned. The aforesaid energy emitted by the multiple-prism grating laser exceeds energy capability of the small-size YLP laser;

• oxygen–kerosene propellant is reliably ignited with a YLP laser beam in the experimental oxygen–kerosene pilot lighter when the propellant flow rate is about 3 times as low as that in the standard pilot light device;

• the glass window (or lens) of the optical unit in the pilot lighter remains clear (is not sprinkled with kerosene, no condensed combustion products are found on the glass surface), so that there is no necessity of wiping the window before the next start; and

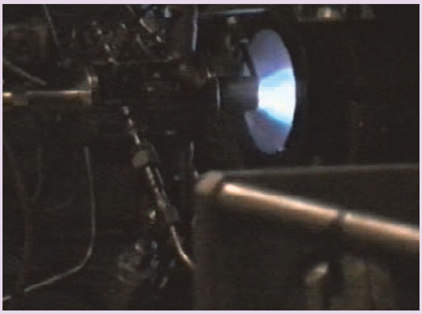


Figure 4: Standard oxygen–kerosene pilot light device operating after mixture ignition with a laser beam at the SDS test bench

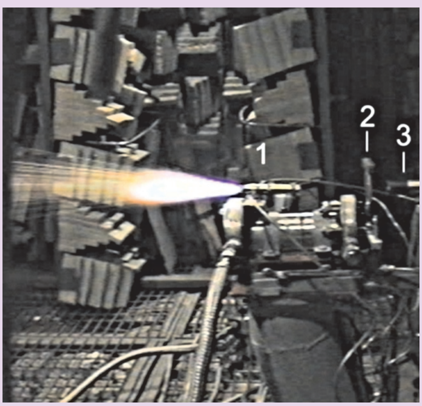


Figure 5: Oxygen–hydrogen pilot light device operating after mixture ignition with an YLP laser beam at the KVU test bench: 1 — primer; 2 — lens with an adjusting unit; and 3 — YLP laser collimator

• hydrogen–oxygen propellant is reliably ignited with an YLP laser beam both in the experimental pilot lighter and in the standard hydrogen–oxygen pilot light device (Fig. 5). The results indicate that the device tested can be used in designing the standard system of propellant ignition in full-scale space rocket engines.

The following products were designed, manufactured, and mounted on the test bench at the Keldysh Research Center:

• a special device for introducing laser radiation in the combustion chamber;

• an experimental laser ignition system based on a solid-state laser; and

• a laser device based on a phased diode matrix.

Ignition of various propellant pairs (hydrogen + oxygen, methane + oxygen, and kerosene + oxygen) that are predominantly used in space rocket engines was studied experimentally at various values of duration and energy of laser pulses.

The engineering requirements imposed on the device designed for laser ignition of propellant components were elaborated and a comparative analysis of various pulse laser types was performed to provide a correct selection of the optimum laser type for a laser propellant-ignition device.

A standard laser ignition device was manufactured and mounted at the test benches of Keldysh Research Center. Ignition of propellant components was studied experimentally with the use of the standard laser device. A design scheme specifying how the device of propellant ignition with a laser beam can be applied in a space rocket engine was developed.

An analysis of a great number of tests permitted the conditions warranting reliable propellant ignition in the pilot lighter to be optimized, and the basic specifications to be fulfilled in designing the system of laser ignition in a rocket engine were formulated.

All the above indicated findings resulted in a preliminary engineering prognosis of the future general design scheme and of design units of a liquid propellant rocket engine with laser ignition, in the confirmation of feasibility of this approach, and in suggesting the way along which the problem considered can be successfully solved.

Obtained Results

• A device of the standard system of propellant components ignition in a rocket engine was manufactured, mounted, and tested at the KVU and SDS test benches. The basic units of the device are:

– solid-phase small-size 20-W YLF1/100/0 laser produced by “IRE-Polyus” and supplied by ISRC for implementation of the work within the Project;

– small-size pilot lighter with various designs of the injectors of the components (hydrogen–oxygen and kerosene–oxygen); and

– a system supplying the laser energy to the pilot light device via light guide.

• The device manufactured was tested to ignite kerosene–oxygen (bench KVU) and hydrogen–oxygen (bench SDS) mixtures. The two mixtures were successfully ignited in the pilot light devices with laser radiation sources.

• Database depicting the design features of the device of laser ignition of propellant components was compiled.

• Array of data furnished by experimental investigations of laser ignition of propellant components was obtained.

Project Number:	#2260
Full and Short Title:	Theoretical and Experimental Investigations of Problems of Creation of Rocket Laser Engine **Laser Rocket Engine**
Tech Code / Area / Field:	SAT-VEC / Space, Aircraft and Surface Transportation / Space Vehicles and Support Equipment PHY-OPL / Physics / Optics and Lasers
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	$300,000 (US)
Commencement date:	September 1, 2003
Duration:	24 months, extended by 3 months
Leading Institute:	Chemical Automatics Engineering Design Corp., Voronezh, Russia
Contact Information:	Phone: +7 (4732) 63 36 73, 34 65 65 Fax: +7 (4732) 34 65 71, 76 84 40 E-mail: cadb@comch.ru Website: http://www.kbkha.ru
Supporting Institutes:	Energomachtehnica, Moscow, Russia Keldysh Research Center, Moscow, Russia
Collaborators:	Astrium GmbH/ Space Infrastructure Division Ottobrunn, Munich, Germany (Langel G.) Schafer Corporation, Albuquerque, NM, USA (Walter R. F.) Tohoku University/Institute of Fluid Science / Shock Wave Research Center, Sendai, Japan (Takayama K.)
Project Manager:	GUTERMAN Vitaly Yurievich
Contact Information:	Phone: +7 (80732) 33 08 02 Fax: +7 (80732) 33 81 55 E-mail: guterman@vitaly.vsi.ru
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 31 57 Fax: +7 (499) 978 46 37 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

The concepts of prospective propulsion systems include the use of energy of a beam bundle generated by ground-based lasers to provide thrust in a space vehicle propelled by a blast wave induced by the lasers.

The importance of this problem stems from the fact that a laser propelling system is much cheaper than the traditional engines using chemical energy. At the initial flight stage, the atmospheric air serves as a working fluid, while outside the atmosphere, a relatively small amount of liquid hydrogen stored onboard can be used in the engine. In this case, the specific cost of payload transport to space can be reduced to 200–1000 USD/kg, i. e., approximately 20- or 100-fold as compared to the present-day level.

According to numerous experimental data, gasdynamic CO_2 lasers (GDL) are the most promising energy sources to be used for launching vehicles to orbit. Firstly, this type of lasers is ecologically pure and well developed technologically. Gasdynamic CO_2 lasers provide stable radiation for a quite long time. Secondly, radiation of CO_2-lasers can be transmitted through the atmosphere with minimum losses. Furthermore, specificity of operation of laser rocket engines necessitates the use of pulse lasers in order to preclude laser radiation absorption by a plasma that would inevitably arise in the case of continuous laser irradiation of a gas flow.

The areas in which laser-induced thrust can be applied in solving space exploration problems are diverse:

• correction of orbits of near-Earth satellites, in particular, those on a geostationary orbit because transport of propellant to such orbits is very costly;

• maneuvers of orbital stations and vehicles to avoid collisions with space debris which causes a lot of troubles in space exploration; and

• a reserve system for final approach of a vehicle to the space station that does not require considerable propellant expenditure and is used in emergency situations.

Significant experience in creation of powerful GDL is accumulated in CAEDC and Keldysh Center, while the team at "Energomashtekhnika" performed successful experiments on adaptation of an optical section of a GDL to a pulse-periodic laser operation. CAEDC and Keldysh Center were involved during many years in development of liquid propellant rocket engines. Engines designed by CAEDC have been applied in the majority of space rockets in Russian Federation and former Soviet Union.

Project Objectives

Objectives of the Project was to design, manufacture, and test an experimental version of a laser rocket engine (LRE).

Description of the Works

To achieve the goals of the Project, the following work was performed:

– development of a design of a gasdynamic CO2 laser operating in a pulse-periodic regime;

– development of design model versions of a flying vehicle propelled by a laser-induced blast wave; and

– bench tests of experimental model laser rocket engines mounted on a specially designed and manufactured device that measures the engine thrust.

A physical model of laser beam interaction with a gas flow issuing from the engine in continuous and pulse laser operation regimes was developed. The results of calculations by the procedure suggested were shown to be consistent with the experimental data. Feasibility of laser engine operation both in continuous and pulse-periodic regimes was predicted and grounded theoretically.

In designing GDL, Russian and foreign materials characterizing the level of gasdynamic-laser development achieved in industry all over the world were analyzed; the experience accumulated in computational prediction of laser parameters was also used.

The possibility of CO_2 GDL operation in the pulse-periodic regime at megawatt levels of the mean radiation power was explored. It has been found that there are some aspects restricting this possibility. In the first place, they are associated with the problems of Q-factor modulation of the driving generator and with insufficient durability of power optics.

The basic parameters of an LRE were assessed based on computational and theoretical considerations.

Feasibility and arrangement of pulse-periodical impact of a laser beam on a gas flow in LARE in the case of continuous GDL operation were grounded theoretically. Such an impact mechanism was provided by a proper choice of the optimal flow rates of gas components arriving at the zone of optical discharge in the LARE chamber. A schematic LARE design with pulse injection of components into the optical discharge zone was suggested.

A special device for the pulse-periodical operation regime (PPR) was designed and fabricated at the test bench in Keldysh center. The device was finalized experimentally.

GDL was equipped with an auxiliary resonator and modulator. The PPR device was used in investigations of a GDL operating in the PPR. The tests have shown that the device used to change GDL operation from the continuous to pulse-periodic regime functioned quite well.

Four versions of model LRE were designed and fabricated. Their photographs and schematic drawings are presented in Figs. 1 to 6.

Two devices measuring LRE thrust were designed, manufactured, and calibrated. One of them was based on a ballistic pendulum and the other used a tensometric gauge attached to the butt end of an LRE model.

Adjusting tests of a system comprising GDL with PPR mounted on it and the thrust measuring device were performed. Video frames of these tests are displayed in Fig. 7.

The LRE models with GDL operating in the PPR were tested experimentally. Air flow was used in the tests. Radiation intensity was the same as that in tests with continuous laser operation. The thrust levels obtained were comparable in value with their counterparts measured in tests with continuous laser generation.

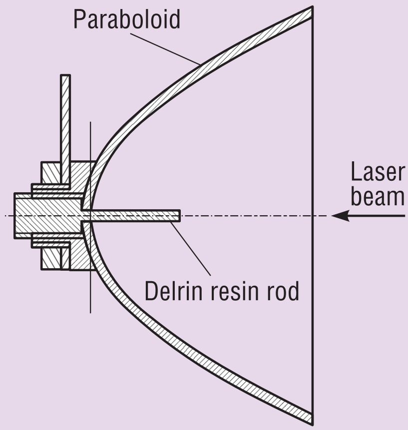


Figure 1: Laser rocket engine with laser beam focused on a delrin resin rod

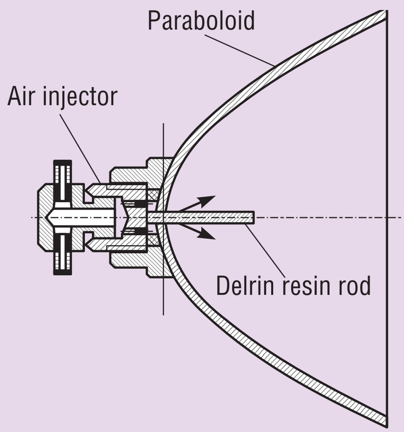


Figure 2: Laser rocket engine with laser beam focused on a delrin resin rod and with a flow system

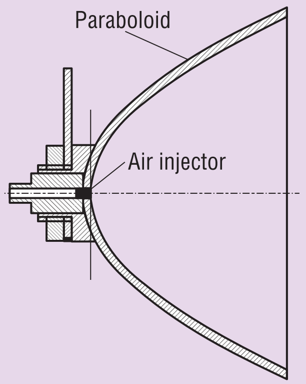


Figure 3: Laser rocket engine with laser beam focused on the injected liquid

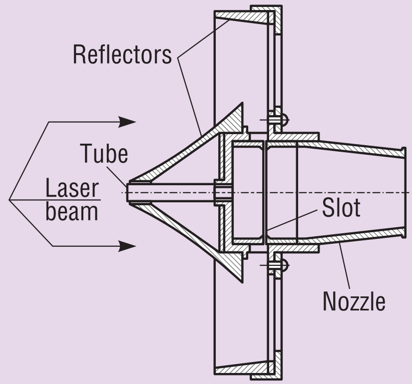


Figure 4: Laser rocket engine with laser beam focused in the nozzle with the aid of two reflectors

Figure 5: Laser rocket engine model with a delrin resin rod

Figure 6: Laser rocket engine model with liquid injection in the paraboloid focus

The results of experiments were analyzed and systematized. Based on them, a computational method for assessment of the main parameters of a laser driven engine was developed.

Obtained Results

• A physical model of laser beam interaction with a gas flow issuing from the engine has been developed for continuous and pulse-periodical laser operation regimes.

• A device providing pulse-periodical radiation regime has been designed and tested.

• Four model LREs were designed and manufactured.

• Two devices measuring the LRE thrust were designed and manufactured; they were based

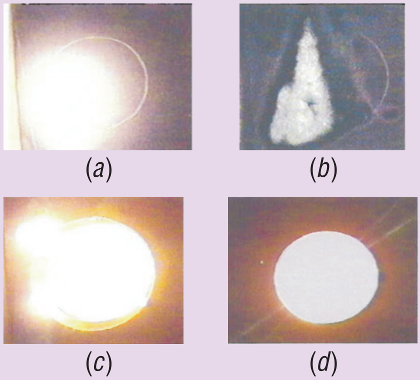


Figure 7: Video frames taken in the course of adjustment tests of GDL and model LRE

on a ballistic pendulum and tensometric gauge attached to the LRE model butt end.

• The computational and theoretical investigations performed permitted the main laser rocket engine parameters to be assessed.

• Arrangement of pulse-periodical laser beam impact on a gas flow in LARE when GDL operated in the continuous regime was grounded theoretically. The impact mechanism suggested was provided by a proper choice of the optimum flow rate of the gas components coming to the optical discharge zone in LARE.

• The experimental results proving correctness of the approach suggested have been demonstrated.

• Opportunities offered by application of a laser driven engine to put payloads into space orbit were analyzed.

Project Number:	#3236
Full and Short Title:	Adaptation of System Laser Ignition Components for the Chamber of Combustion of the Rocket Engine **Laser Start for Rocket Engine**
Tech Code / Area / Field:	SAT-VEC / Space, Aircraft and Surface Transportation / Space Vehicles and Support Equipment
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	330,579 € (EU)
Commencement date:	February 1, 2006
Duration:	24 months, extended by 3 months
Leading Institute:	Chemical Automatics Engineering Design Corp., Voronezh, Russia
Contact Information:	Phone: +7 (4732) 63 36 73, (4732) 34 65 65 Fax: +7 (4732) 34 65 71, (4732) 76 84 40 E-mail: cadb@comch.ru Website: http://www.kbkha.ru
Supporting Institutes:	Keldysh Research Center, Moscow, Russia
Collaborators:	Aerospace Propulsion Products B. V., (Vermeulen E.) Cranfield University / School of Engineering, Cranfield, Beds, UK (Greenhalgh D. A.) European Space Agency / European Space and Technology Center, Noordwijk, The Netherlands (Marraffa L.) Snecma Moteurs, Paris, France (Pouliquen M.)
Project Manager:	GUTERMAN Vitaly Yurievich
Contact Information:	Phone: +7 (80732) 33 08 02 Fax: +7 (80732) 33 81 55 E-mail: guterman@vitaly.vsi.ru
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 31 57 Fax: +7 (499) 978 46 37 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

The rocket-propellant laser ignition system for multiple start of the space rocket engine was developed by OSC CADB and Keldysh Research Center during the accomplishment of ISTC Project #1926.

The system main elements are:

• small size solid state laser produced in Russia

• small size ignition device with different inlet design for supply of O_2–H_2 and kerosene–O_2 propellant components; and

• a system of the laser energy input to ignition device through a light guide.

The developed device has been tested using the O_2–H_2 and kerosene–O_2 propellant components.

The ignition of O_2–H_2 and kerosene–O_2 propellant mixture has been realized by the laser light source in laser ignition devices.

There exist no similar systems as an operative equipment in the world.

The prolongation of this work on research, design development and an adaptation of the rocket propellant laser ignition system for rocket engine combustion chamber is the sequence of two conditions:

(1) As a result of the investigations, it has been shown that there is a principle capability to ignite rocket propellant mixtures and the real engineering solution has been suggested.

(2) Space industry is now searching, mainly, for the development of multiuse rocket launchers and small-thrust multistart rocket engines of space object positioning and control systems for the ultimate goal to cut down the flight costs. The traditional start propellant-ignition methods do not satisfy the requirements for rocket engines of a new generation.

Project Objectives

The Project was aimed at adaptation of the developed laser propellant-mixture ignition system to combustion chambers of Liquid Rocket Engines (LRE).

Description of the Works

Three main tasks were solved during Project implementation:

(1) development of a modified rocket propellant laser-ignition device operable in rocket-engine combustion chamber;

(2) development of a rocket-engine combustion chamber design schematic with rocket propellant laser ignition system;

(3) testing of the experimental rocket-engine combustion chambers including the rocket propellant laser ignition system; and

(4) theoretical and experimental determination of combustion chamber ignition conditions from igniter operation and influence of the conditions of engine start and combustion chamber operation on igniter functioning.

A physical model of laser beam interaction with gas flow in LRE igniters was developed. The influence of engine start conditions and combustion chamber operation on igniter functioning was evaluated analytically. Conditions under which LRE combustion chambers were ignited by igniters, i. e., pressure, temperature, mass flow rate, composition and mixture ratio of propellant components supplied to the igniter, the timing diagram of supplying these components into the igniter, these conditions' connections with the igniter design, as well as with the combustion chamber's design and operating conditions were analyzed. Directions of improving the LRE laser igniters, developed within ISTC project #1926, as well as their lasers, were selected.

A method for investigating effects of acoustic and vibration loads from operating LRE combustion chamber on laser ignition system was developed. The method included investigation of an operating combustion chamber's effects on a laser ignition system's optical-mechanical devices and tests of this system on a vibrating table (Fig. 1). The acoustic and vibration effects of a functioning combustion chamber on laser operation was evaluated experimentally.
The following technical reports were issued:

– "Development of the physical model of laser beam – gas flow interaction;"

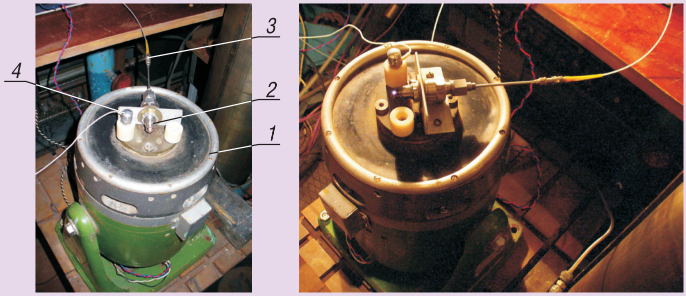


Figure 1: Photograph of the VED-10 vibration table with a vibration gauge attached to it and the laser ignition plug with the optical connector (a) and VED-10 vibration table with the switched-on laser ignition plug and a vibration gauge(b): 1 — VED-10 vibration table; 2 — laser ignition plug; 3 — optical connector; and 4 — vibration gauge

– "Analytical evaluation of influence of the conditions of engine start and combustion chamber operation on igniter functioning;" and

– "Experimental evaluation of the acoustic and vibration effects of a functioning combustion chamber on laser operation."

Development of a modified rocket-propellant laser ignition system operable in rocket-engine combustion chamber. Experimental studies

The experimental system for laser ignition was created and prepared for experimental studies.

In the experimental development and maturation of the laser ignition system on the NDF facility with oxygen/kerosene igniters under atmospheric ambient pressure, the following units of the laser ignition system have been developed and matured experimentally (Fig. 2):

– a device for inputting the laser radiation from the laser's collimator into a fiber going into the laser igniter;

– an optical connector on the fiber;

– a device for inserting the fiber into the igniter; and

– a universal device for multiple ignitions of gas/liquid (oxygen/kerosene, oxygen/ethanol, etc.) and gas/gas (oxygen/hydrogen, oxygen/methane, etc.) propellants from the fiber into the igniter.

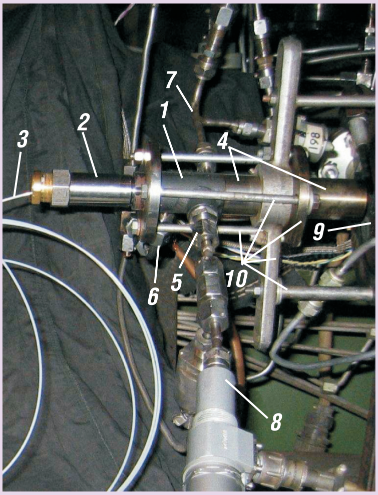


Figure 2: The experimental oxygen/kerosene igniter with the fiber laser plug on the NDF facility: 1 — igniter; 2 — igniter's fiber laser plug; 3 — fiber; 4 — exhaust tube for supplying the diluting nitrogen; 5 — kerosene injector's connecting pipe; 6 — oxygen supply pipe; 7 — igniter pressure measurement tube; 8 — gauge for measuring pressure in the kerosene supply tube; 9 — exhaust tube inserted into the facility exhaust column; and 10 — system of fastening the igniter to the exhaust tube

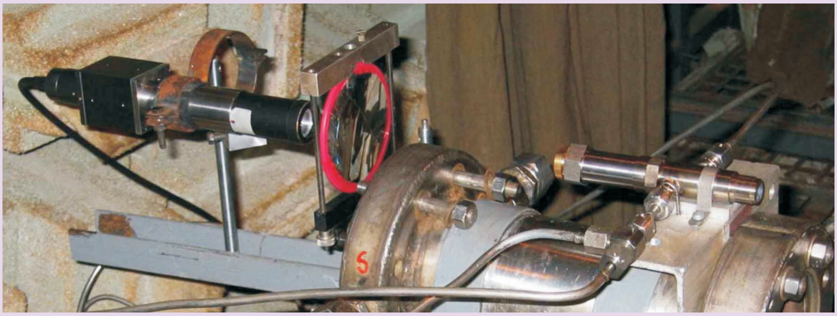


Figure 3: Inputting the laser beam from the compact YLP-1/100/20 pulsed ytterbium fiber laser into an oxygen/hydrogen igniter on the Keldysh Center's KVU facility: the laser collimator (at the left) is installed before a lens (with red edges) focusing the laser beam into the igniter (at the right)

During maturation of this system, a stable operation of an oxygen/kerosene laser igniter with ~ 120 ignitions per 1 h without any technical maintenance was reached.

During experimental maturation of the laser ignition system on the KVU (Fig. 3) facility with the developed oxygen/hydrogen laser igniter under the atmospheric ambient pressure, the following results have been obtained:

– serviceability of the developed universal device for multiple ignition of gas/liquid and gas/gas propellants in a fiber igniter has been verified on an oxygen/hydrogen propellant; and

– a stable multiple operation of the developed oxygen/hydrogen laser igniter without any technical maintenance (replacing parts, wiping, etc.) has been demonstrated.

Conditions and methodology for experimental investigations were determined.

The experimental laser ignition system was fabricated and installed on an experimental bench of Keldysh Center. Experimental tests of the laser device were performed.

Testing of experimental rocket-engine combustion chambers with the rocket-propellant laser ignition system.

At the first stage of experimental studies, the modeling combustion chamber together with the device for laser ignition was installed on the 5ST-04 stand (Fig. 4) and debugging tests of the mounted systems were performed.

Experimental investigations of the combustion chamber's start-up and operation with the adapted laser ignition system were conducted on the NDF facility under the following conditions:

– kerosene was the igniter's fuel;

– gaseous oxygen was the igniter's oxidizer;

– ethanol was the combustion chamber's fuel;

– air was the combustion chamber's oxidizer;

– the combustion chamber pressure was 100 kgf/cm^2;

– the combustion chamber propellant mass flow rate was 0.70–0.77 kg/s;

– the combustion chamber oxidizer excess coefficient was α = 0.3…0.6 (the combustion products temperature was 1200–1700 K); and

– the duration of combustion chamber operation was 5–20 s.

Experimental investigations of the thruster's start-up and operation with the adapted laser ignition system have been conducted on the 5ST-04 facility under the following conditions:

– ethanol was the thruster's fuel;

– gaseous oxygen was the thruster's oxidizer;

– the combustion chamber pressure was 6–8 kgf/cm^2;

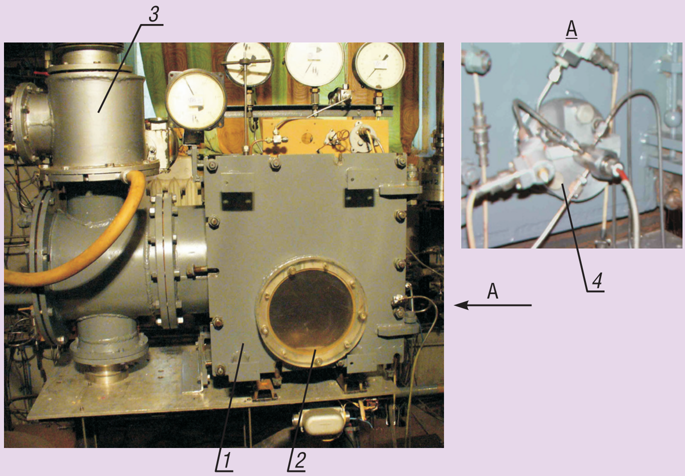


Figure 4: The 5ST-04 facility's altitude chamber with the installed igniter: 1 — altitude chamber; 2 — window; 3 — vacuum valve; and 4 — igniter

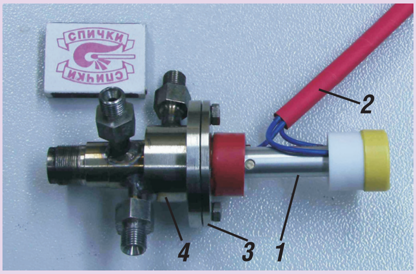


Figure 5: Ignition device on a base of LTI 200/18 laser: 1 — laser LTI 200/18; 2 — cable for connection to the supply unit; and 3 — laser plug case, 3-ID case

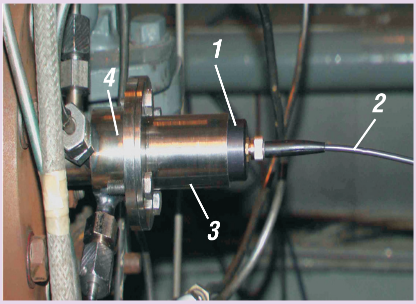


Figure 6: Ignition device on a base of RL- 1,0Q laser: 1 — laser; 2 — optical cable; and 3 — laser plug case, 4-ID case

– the combustion chamber propellant mass flow rate was 13.5–16.5 g/s;

– the combustion chamber oxidizer excess coefficient was α = 0.3…0.34 (the combustion products temperature was 1200–1500 K); and

– the duration of thruster operation was 1–3 s.

Scientific and technical report “Experimental studies of laser ignition system built in the combustion chamber” was issued.

Technical requirements to laser ignition systems with improved mass-size and power characteristics were formulated. According to these requirements, different variants of such systems were manufactured (Figs. 5 and 6).

At the second stage of experimental studies, the modernized laser ignition system was adapted to combustion chambers of rocket engines. As a result of this work, the modernized laser ignition system was created and adapted to various variants of LRE combustion chambers.

Obtained Results

• The research on an opportunity of creating a reliable and compact laser ignition system for rocket-engine combustion chambers has been reviewed.

• Conditions under which LRE combustion chambers are ignited by laser igniters, i. e., pressures, temperatures, mass flow rates, compositions and mixture ratios of propellant components supplied to the igniter, the timing diagram of supplying these components into the igniter, these conditions’ connections with the igniter design, as well as with the combustion chamber’s design and operating conditions have been analyzed. Igniters’ operation after ignition in combustion chambers, which provides serviceability of both the combustion chambers (with no leakage) and the igniters for the next ignitions of multiple-start-up LREs has been analyzed. Igniters’ operating conditions related to the combustion chamber of Keldysh Center NDF facility have been also analyzed.

• The vibrations which can influence the laser-ignition system operation in LREs have been analyzed. It was concluded that the laser ignition system must be capable of operating under the nominal vibrations of about 400*g* and the maximum vibrations of 1000*g*.

• The technique of studying the influence of acoustic and vibrating loadings from the operating combustion chamber on the optical-mechanical devices of the laser ignition system has been developed. This technique included investigation of the effect of the operating combustion chamber on laser-ignition system and tests of this system on a vibrating table.

• In the experiments with acoustic and vibration loading of the laser ignition system, a combustion chamber operating on gaseous O_2/H_2 propellant and having ~ 110 N thrust has been employed. The acoustic loads at the places of fastening the laser-ignition system’s optical-mechanical devices were equal to ~ 160–180 dB, and the vibration loads were equal to ~ (8–10)*g* for the action time of 5 s. The O_2/H_2 igniter successfully passed these loads and successfully operated after these loads; so, this laser-ignition system’ optical-mechanical devices were shown to be capable of successfully withstanding such loads.

• Technical requirements to laser ignition systems with improved mass-size and power characteristics were formulated. According to these requirements different variants of such systems were manufactured.

• A combustion chamber operating under pressure of up to 100 kgf/cm^2 and combustion products’ temperature of up to 2000 K, its pneumohydraulic system, computer measuring system, control system, and the adapted igniter-based laser-propellant ignition system have been mounted on the Keldysh Center’s NDF facility and prepared for tests.

• Experimental investigations of the combustion chamber’s start-up and operation with the adapted laser ignition system have been conducted on the NDF facility. The laser ignition system’s serviceability in multiple combustion chamber operations has been demonstrated.

• A low-thrust oxygen/ethanol thruster of 50 N thrust, its pneumohydraulic system, computer measuring and control system, and the adapted igniter-free laser-propellant ignition system have been mounted on the Keldysh Center's 5ST-04 facility and prepared for tests.

• Experimental investigations of the thruster's start-up and operation with the adapted laser ignition system have been conducted on the 5ST-04 facility under the conditions described above.

• The laser's operating conditions, the laser switching-on and propellant components supply timing diagrams have been optimized. The laser ignition system's serviceability in multiple thruster operations has been demonstrated.

• As a result of this work, the modernized laser ignition system was created and adapted to various variants of LRE combustion chambers.

Spacecraft Trajectories and Mechanics

List of Projects

In total, 9 projects were funded by the ISTC Parties.

#0277
"The Elaboration of High Precision Measurement System on the Basis of the CCD-Sensors"
(Earth and Sun Location Sensors)
– Scientific Industrial Association "ELAS," Zelenograd, Moscow, Russia
– SPC Astrosystems, Zelenograd, Moscow, Russia

#0360
"Flanged Connection with a Static Spherical Bearing"
(Flanged Connection for Space Launchers)
– NPO EnergoMash, Khimki, Moscow Region, Russia

#0473
"Design and Manufacturing of Loop Heat Pipes and Capillary Pumps for Advanced Thermal Control System of Space Apparatus"
(Pumps for Space Control Systems)
– Ural Branch of RAS / Institute of Thermal Physics, Ekaterinburg, Sverdlovsk Region, Russia

#0751
"Review of Space Mechanisms and Components"
(Space Mechanism and Components)
– Lavochkin Association, Khimki, Moscow Region, Russia

#0936
"Research on Fundamental Problems of Heat Transfer Intensification in Air–Hydrogen Heat Exchanger" **(Air–Hydrogen Heat Exchanger)**
– TsIAM (Aviation Motors), Moscow, Russia

#1165
"Development and Research of an Experimental Model of Electric Propulsion Based on Accelerator with Closed Electron Drift"
(Electric Rocket Propulsion)
– Keldysh Research Center, Moscow, Russia

#1214
"Technological Problems of the Long Life Lubricating Technology for Space Mechanisms"
(Lubricating Technology for Space Mechanisms)
– All-Russian Scientific Research Institute for Mobile Vehicle Engineering, St Petersburg, Russia

#3151
"Experimental and Numerical Study of Critical Aerothermodynamic Phenomena on the EXPERT Reentry Demonstrator for Preparing In-Flight Tests"
(Demonstrator for Flight Tests)
– Siberian Branch of RAS / Institute of Theoretical and Applied Mechanics (ITAM), Novosibirsk, Russia
– Russian Academy of Sciences / Institute for Problems in Mechanics, Moscow, Russia
– Makeyev Design Bureau of State Rocket Center, Miass, Chelyabinsk Region, Russia

#K-035
"Operating Process Investigation of Supersonic Combustion Ramjet as Applied to Promising Aerospace Planes"
(Hydrogen Hypersonic Flow for Air-Cosmic Crafts)
– Kazakh National University, Almaty, Kazakstan
– TsIAM (Aviation Motors), Moscow, Russia
– Almaty Institute of Energy and Communication, Almaty, Kazakstan

Project Number:	#0277
Full and Short Title:	The Elaboration of High Precision Measurement System on the Basis of the CCD-Sensors **Earth and Sun Location Sensors**
Tech Code / Area / Field:	SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$350,000 (EU)
Commencement date:	March 1, 1996
Duration:	24 months, extended by 9 months
Leading Institute:	Scientifics Industrial Association “ELAS,” Zelenograd, Moscow, Russia
Contact Information:	Phone: +7 (495) 531 17 49 Fax: +7 (495) 531 32 13
Supporting Institutes:	SPC Astrosystems, Zelenograd, Moscow, Russia
Collaborators:	DaimlerChrysler Aerospace (Satellites), Friedrichshafen, Germany (Skarus W.) Jena Optronik GmbH, Jena, Germany
Project Manager:	ZAKHARCHUK Oleg Tarasovich
Contact Information:	Phone: +7 (495) 534 93 95 Fax: +7 (495) 534 93 95 E-mail: asys@orgland.ru
ISTC Senior Project Manager:	MEYER Uwe
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (499) 982 32 01 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

Solution of contemporary space problems with the aid of satellites necessitates their very precise orientation or arrival at a preset point in space. An orientation and navigation system on board of a space vehicle (SV) serves for this purpose. Sensors measuring angular positions of astromarks are the basic units of this system.

Because of continuously increasing requirements imposed on the characteristics of SV and development of small SV, the requirements imposed on the characteristics of sensors used in orientation and navigation systems become more rigid. First of all, these requirements concern the manufacturing cost, weight and size characteristics, duration of service, and precision.

Project Objectives

The Project was aimed at development of astrosensors (star and solar sensors) that meet the modern requirements.

Description of the Works

An analysis of literature sources, foreign Collaborator recommendations, and demands of potential customers has shown that two sensor modifications, "rough" and "precise," are claimed at the market. The engineering specifications of the sensors are listed in Tables 1 and 2.

Table 1: Technical specifications of star sensors

Sensor type	Sensitivity	Field of vision (sq. deg)	Random error (1σ)	Systematic error (2σ)	Weight, kg	Energy consumption, W
STS-01 (high-precision)	$+6^m...+7^m$	50…100	≤ 4"	≤7"	5	10
STS-02 (low-precision)	$+6^m...+7^m$	50…100	≤20"	≤30"	2	3

Table 2: Technical specifications of solar sensors

Sensor type	Field of vision (sq. deg)	Random error (3σ)	Systematic error (3σ)	Weight, kg	Energy consumption, W
SUSEN-01 (high-precision)	±64°	≤ 10"	≤ 20"	1	1
SUSEN-02 (low-precision)	±64°	≤ 60"	≤ 120"	0.4	0.5

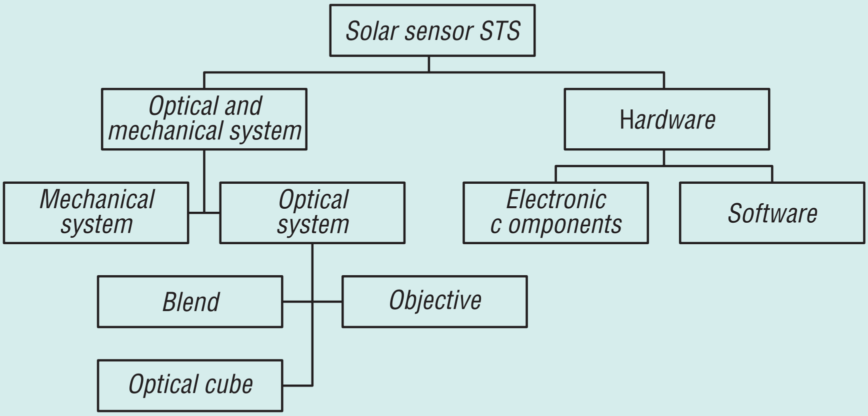


Figure 1: Schematic of a solar sensor STS

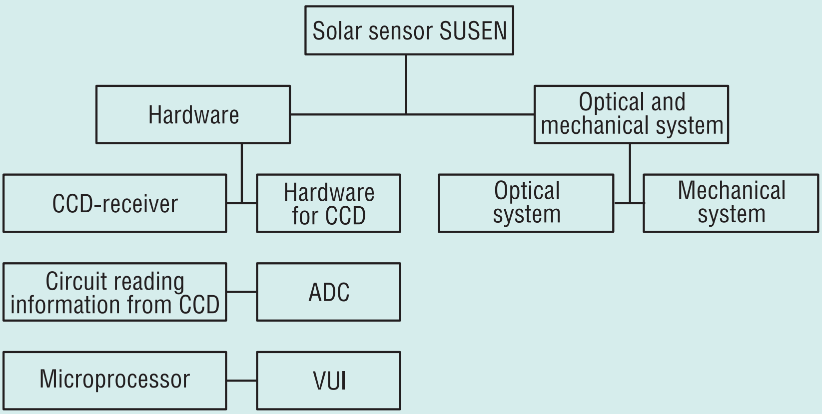


Figure 2: Schematic of solar sensor SUSEN

The indicated technical sensor characteristics (see Tables 1 and 2) can be provided with the use of a fully static design scheme.

The structural sensor schemes are shown in Figs. 1 and 2. Figures 3 and 4 display design schemes of a solar and star sensors, respectively.

A mathematical apparatus was elaborated for computation-theoretical predictions of the precision characteristics of the solar and star sensors. Based on the mathematical apparatus, theoretical dependences of the technical sensor characteristics on various factors were derived; methods and the following software for computer modeling were worked out:

– codes for calculating background-target setting of STS and SUSEN;

– program modules for optical and electric modeling of STS and SUSEN; and

– programs for geometric and thermal modeling of STS and SUSEN.

Figures 5 to 12 display the most interesting results of a theoretical analysis of the sensor characteristics.

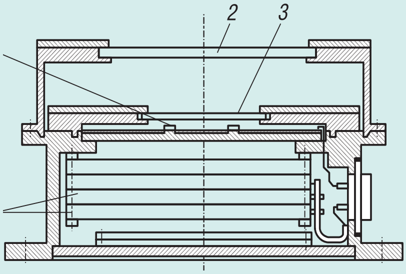


Figure 3: Design schematic of solar sensor SUSEN. Solar radiation passes through a slit system with filter 2 and falls onto linear CCD receiver 1. A CCD strip comprising 2048 elements 13 x 13 µm in size is used (3). Hardware modules 4 are used for processing the results of measurements

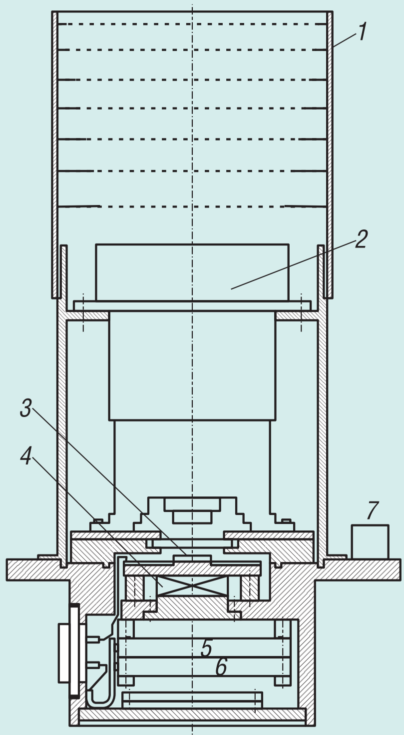


Figure 4: Design schematic of STS: 1 — blend; 2 — objective; 3 — CCD; 4 — Peltier-refrigerator; 5 and 6 — hardware components; and 7 — optical cube

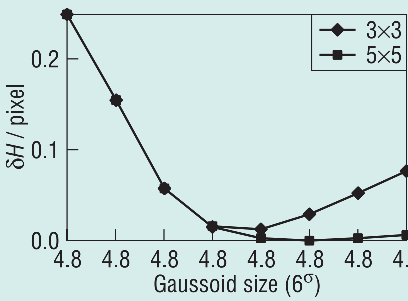


Figure 5: Distribution of a signal from a star in the radiation receiver units

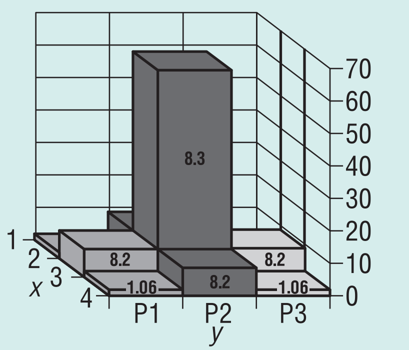


Figure 6: Discretization error versus the size of star image

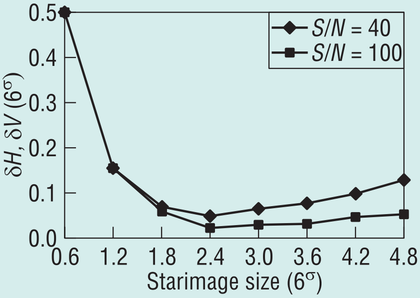


Figure 7: Results of statistic modeling of the error in detecting the position of a star image center with an adaptive integration window size

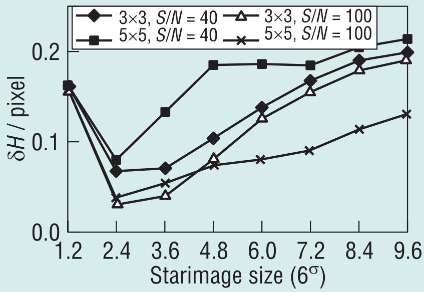


Figure 8: Results of statistic modeling of the error in detecting the position of a star image center with an adaptive integration window size

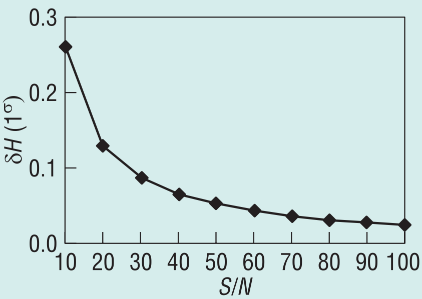


Figure 9: Error in detecting the star image center (in portions of the receiver element size) versus the S/N ratio at I = J = I

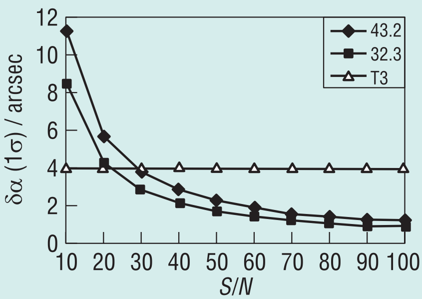


Figure 10: Error in detecting the angular position of the star image center as a function of the S/N ratio at I = J = I and two values of the angular size of the receiver element 32.3 arcsec and 43.2 arcsec

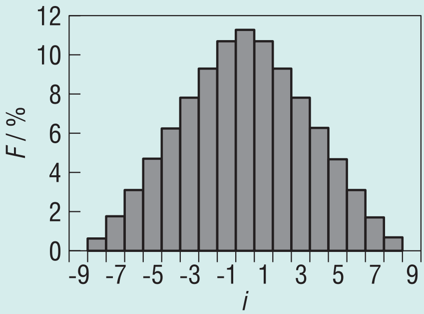


Figure 11: Signal distribution within the central slit image for a solar sensor

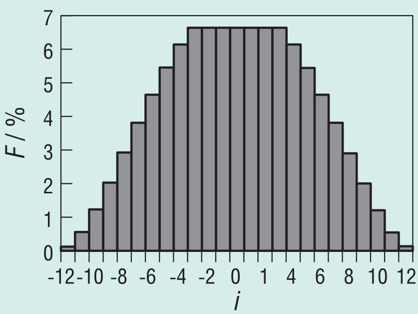


Figure 12: Signal distribution within the image of an oblique slit for a solar sensor

Obtained Results

In the course of Project implementation, the following results were obtained:

– performance specifications on star and solar sensors were worked out;

– schemes of sensor splitting into elements were developed;

– functional sensor schematics were elaborated;

– mathematical models of astrosensors and their functional units, the appropriate computer codes were developed;

– prototypes of the functional units were created and reports about their testing were delivered;

– technical documentation on astrosensors (schematic, design, program, engineering, and textual documents) was prepared;

– technological sensor models were fabricated and reports about their tests were delivered; and

– the engineering approaches to fabricating filters, slit system, and thermal compensation of the optical system of a solar sensor were proposed.

The mathematical models of astrosensors and computer programs apply new approaches to solving a number of problems, such as optimization of the optical system and sensor design with application of the methods for solving inverse optical and thermal problems developed by the scientists from the ‘Astrosistemy” enterprise.

Algorithms and codes simulating filtration and segmentation of images and correcting systematic sensor errors have been developed.

The astrosensors created within the Project have technical characteristics that are not inferior to those of foreign analogs, and are competitive in the world marked owing to their tentative lower cost.

Project Number:	#0360
Full and Short Title:	Flanged Connection with a Static Spherical Bearing **Flanged Connection for Space Launchers**
Tech Code / Area / Field:	SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics
Status:	Project completed
Technology Development Phase:	Technology demonstration
Allocated Funding:	$400,000 (EU)
Commencement date:	November 1, 1995
Duration:	18 months
Leading Institute:	NPO EnergoMash, Khimki, Moscow Region, Russia
Contact Information:	Phone: +7 (495) 777 02 71 Fax: +7 (495) 777 21 36, 777 21 37 E-mail: energo@online.ru Website: http://www.npoenergomash.ru
Supporting Institutes:	No
Collaborators:	European Space Agency / European Space and Technology Center / YMM, Noordwijk, The Netherlands SEP (Société Européenne de Propulsion), Vernon, France (Fiorentino C.)
Project Manager:	GROMYKO Boris Mikhailovich
Contact Information:	Phone: +7 (495) 777 21 65 Fax: +7 (495) 251 75 04
ISTC Senior Project Manager:	UREZCHENKO Vladimir Makarovich
Contact Information:	Phone: +7 (495) 982 31 21 Fax: +7 (499) 978 36 03 E-mail: urezchenko@istc.ru
ISTC Website:	http://www.istc.ru

Background

Increasing of reliability and improving of characteristics of the existent and advanced liquid propellant rocket engines with reusability is very important problem.

The availability in rocket engines of a large number of rigid ducts, connected between each other and with units by means of tight connections requires for engine mounting the implementation of complicated in terms of design and technology, bulky, and heavy expansion joints, making the engine design more sophisticated and its characteristics worse. In the first place, it is disposed to high-pressure large-size connections through which highly flammable liquids are conveyed and slight leakage of which may result in fire or explosion.

The SEP and NPO Energomash proposed to develop a new kind of fluid and gas connections which exhibit high-pressure tightness, reliability and allow assembling the engine with numerous rigid lines without the help of heavy and unreliable expansion joints.

These connections are supposed to use spherical contact surfaces and specific seals with double sealing barriers; in this case, the first barrier will be a self-sealing with elastic elements and the second one will be in a form of a tight thrust bearing. It will eliminate almost any risk of leakage as well as any risk of overheating and fretting-wear of surfaces that is most important to eliminate the connection fire hazard.

Such connection allows its operability diagnostics, leakage monitoring between the two sealing barriers and organized leakage drain at all stages of engine manufacturing, assembly, and operation (these procedures could be possible without engine pressurization).

The developed connection units may be usefully implemented not only in space transportation, but in other fields of activity like chemical or oil industry, nuclear power plants, air or sea transportation (mainly, submarines), and other engineering fields, in which operability diagnostics and the line flange connections reliability increasing leads to the important improvement of human and environmental protection, and decreasing of metal capacity provides the mass and overall dimensions decreasing.

Project Objectives

The Project was aimed at designing and development of the detachable flanged connections with the static spherical bearing for the liquid and gas pipelines of liquid propellant rocket engines.

Description of the Works

Activity under the Project included theoretical analysis, design-technological and material-science justification, designing, documentation issue, as well as preliminary and qualification tests.

The manufacturing process was developed taking into consideration advanced procedures of the manufacturing operation control at the various manufacturing stages, including radiographic method of material blanks and leak check of finished connectors by helium leak detectors. When investigating the materials, the various methods were applied, including the X-ray microstructural analysis that enables to determine the phase transitions in materials.

The connection units were tested on the stand making it possible to conduct experiments with the hot gas flow and working pressure, providing the leakage measurement during testing by various methods, including the use of a leak detector.

In accordance with requirements specifications agreed with SEP, three connection versions were designed and simulators of one chosen version were manufactured to carry out tests. Review and choice of materials for the developed connections, investigations of the chosen materials, development of the design and technological documentation for manufacturing of the chosen connection simulator, hardware manufacturing, initial and qualification vibro and hot dynamic tests of these simulators have been done.

The following project milestones have been completed:

– The Statement of work for the development of three connections “60-GG,” “110-LH_2,” and “110-LOx” was released and concurred with SEP;

– The material review and choice for these three connections were conducted (see sketches in Figs. 1 to 3);

– The design and strength analysis for the mentioned connections were performed;

– The Test Plan for the “60-GG” connection was released and concurred with SEP;

– Material scientific investigations of the chosen material characteristics in operational temperature and pressure ranges were conducted;

– Mechanical properties characteristics of the EP741NP alloy without coating were investigated on smooth specimens and notched ones

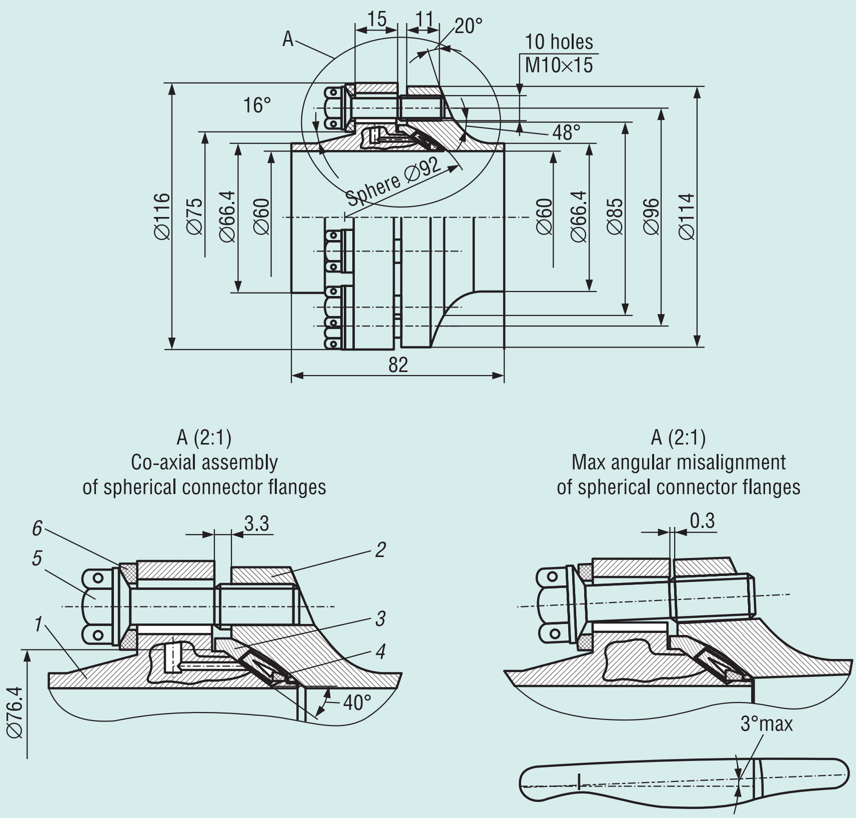


Figure 1: Static separable bolted flange of connector with spherical joint for hot hydrogen-rich gas

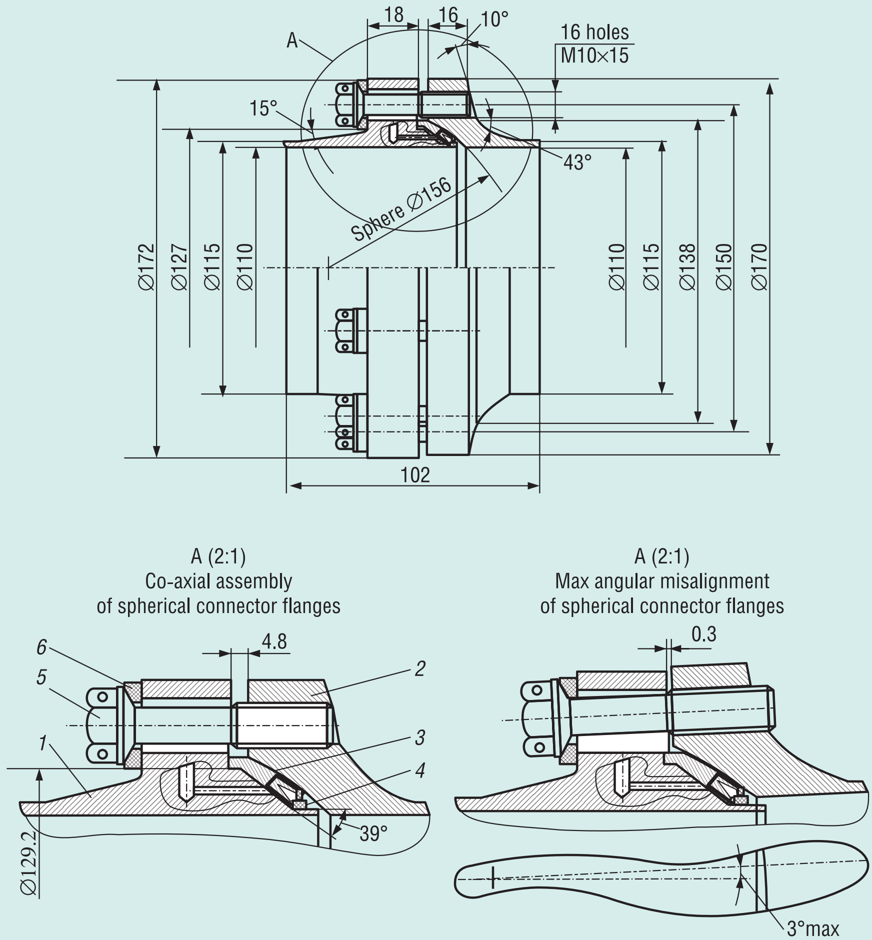


Figure 2: Static separable bolted flange of connector with spherical joint for LOx

under hydrogen and helium pressures at temperature of 460 °C (the choice of the stated temperature is explained by the fact that the curve of the hydrogen penetrability has a point of inflection at this temperature);

– The mechanical properties characteristics of the EP741NP alloy with electroplating (Ni + Ag) were investigated at temperatures 20, 460, 700, and 800 °C under hydrogen pressure;

– The hydrogen resistance of the EP741NP alloy (with and without coating)) and the EP99ID alloy was investigated under conditions of the strained-stress state;

– Equivalent stresses in the tube-type specimens made of the stated alloys in hydrogen and helium were determined;

– Long-term strength of the EP99ID alloy in air (700 °C, 3.3 h) was investigated to confirm the alloy usage for the fastening parts;

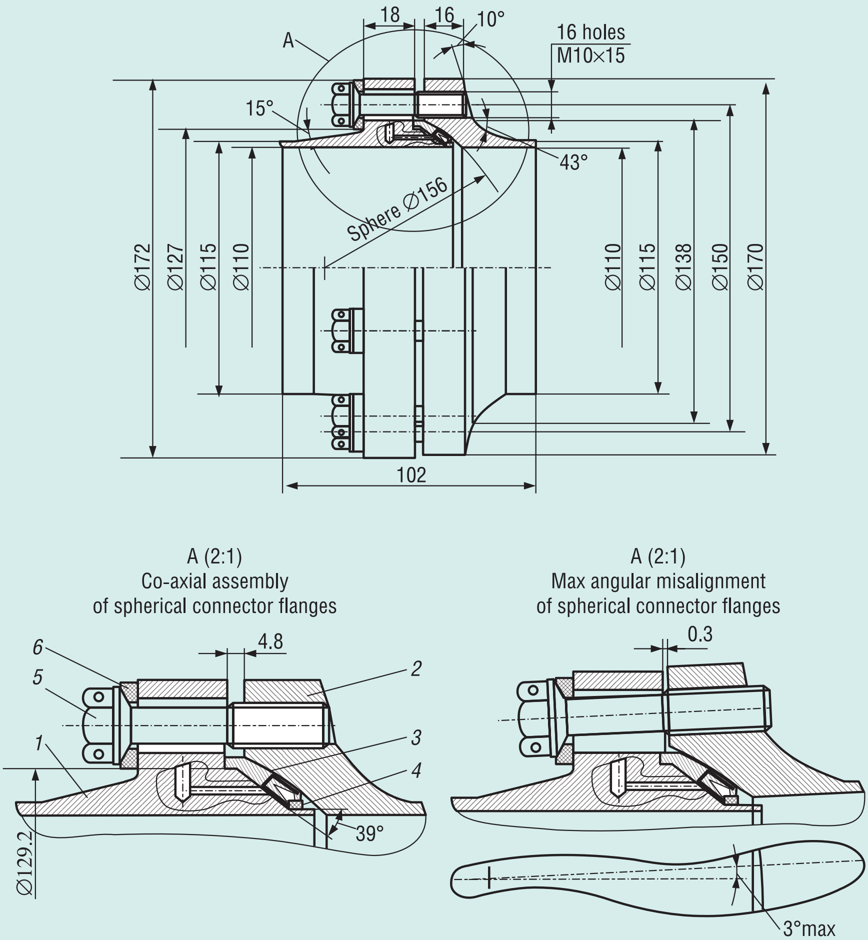


Figure 3: Static separable bolted flange of connector with spherical joint for LH_2

– Design and the strength analysis of the “60-GG” connection simulators (alignment and misalignment) for vibrotests were performed;

– Design and the strength analysis of the complex simulator for the hot dynamic tests of these simulators were performed (Fig. 4);

– Vibrotest plan, provided 3 types of vibrotests in three mutually perpendicular directions (along the chosen coordinate system) when water was fed under 15-megapascal pressure into the inner cavity of the simulator, was developed and concurred with SEP; the following vibrotests were conducted:

(1) investigating the resonance properties of the flange connection with uniform spectral density of 0,001 g^2/Hz in frequency range 5...2000 Hz. If there was no connection resonance in the range up to 2000 Hz (along the

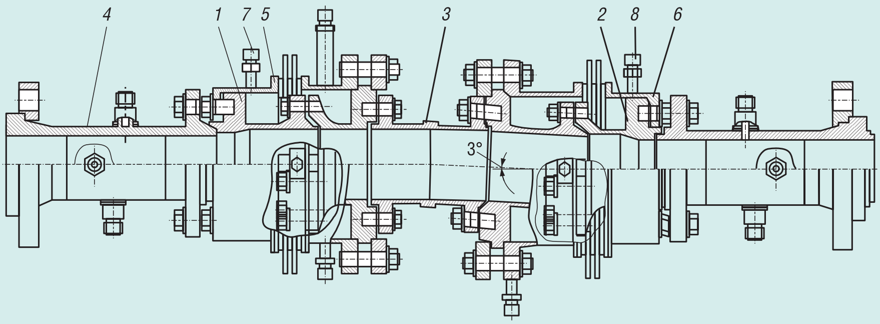


Figure 4: Complex simulator for hot tests: 1 — PHC3 simulator (with alignment); 2 — simulator (with misalignment); 3 and 4 — distance piece; 5 and 6 — housing; 7 and 8 — union for checkout of working medium leakage through the PHC3 simulator

X-axis), the vibrostrength tests of this connection with the vibroaction along the X-axis were not carried out;

(2) vibrostrength tests with the vibroaction of sine type included two modes:

(a) frequency range 5...70 Hz (scanning speed of 1/3 oct/min) and frequency range 70...2000 Hz (scanning speed of 2 oct/min). Amplitude was up to 22.5*g* in the both modes; and

(b) vibrostrength tests with the action of noise in frequency range 20...2000 Hz.

Plan of hot dynamic tests was developed and concurred with the SEP. The hot gas (products of alcohol combustion in air) at temperature T = 760 ± 30 °C, pressure P = 13 ± 0.75 MPa and with flow rate of 1.51–1.61 kg/s was fed to the complex simulator (the mode transient time was less than 50 s). The complex simulator was held at these parameters for the following time: 900 s for the first cycle; 600 s for other cycles; total test duration 12 000 s; number of cycles 20.

To provide the feasibility of leak check (determination of the hot gas leakage through the connection) during the experiment, gaseous helium was fed into the gas passage of the stand. The point of helium feed was chosen to provide the uniform gas mixture at the simulator inlet. Helium flow rate of 2% (by volume) of the hot gas flow rate was provided by control valve and made it possible to control the leakage with the use of helium leak detectors and mechanical vacuum pumps. The actual leakage was determined:

• along the first seal barrier for simulator No. 1;

• along the second seal barrier for simulator No. 2;

• the total connection leakage for simulator No. 3 (qualification); and

• along the first seal barrier for simulator No. 4 (added);

– Tooling was designed to provide the vibrostand and hot dynamic test stand adjustment and its preparation for experimental work;

– The test tooling, two simulators Nos. 1 and 2 (alignment and misalignment) for the initial tests, and the parts included in the complex simulator for the hot dynamic tests were produced;

– The initial vibrotests of two simulators according to the vibrotest plan were performed;

– The initial vibrotest results were analyzed and showed that simulators were successful in the all initial vibrotests according to the vibrotest plan;

– The complex simulator with the alignment and misalignment simulators for the initial hot dynamic tests was assembled;

– Twenty cycles of the initial hot dynamic tests of this complex simulator according to the hot dynamic test plan were completed;

– The test results were analyzed and the design and technological documentation were corrected;

– Two simulators Nos. 3 and 4 (additional) for qualification tests and the simulators included in the complex simulator for the qualification hot dynamic tests were produced;

– The qualification vibrotest results were analyzed and showed that the all qualification vibrotests of the simulator in accordance with the vibrotest plan were successful;

– The complex simulator for the qualification hot dynamic tests with simulators Nos.3 and 4 was assembled;

– Twenty cycles of the qualification hot dynamic tests of this complex simulator in accordance with the hot dynamic test plan were completed.

Obtained Results

• Three types of the flanged spherical connections: "60-GG," "110-LH_2," and "110-LOx" were designed.

• "60-GG" type was chosen for further verification and its test samples were manufactured.

• The samples successfully underwent vibro and hot dynamic tests. Results of the tests confirmed that the chosen "60-GG" connection design and geometry were correct and the chosen material grades and coating were operable.

• The results of the pneumo tests of complex simulators (after the initial and qualification tests) as well as the results of the checks of the simulators tightness were positive; the connections leakage met the Specification retirements.

• The hardware inspection for defect which was performed after the hot dynamic tests did not reveal the defect formation on the connection parts. The metallographic investigations did not reveal the material structure changes.

As a result, the flanged spherical connection for the hot gas line of liquid propellant rocket engines has been designed for the conditions specified in the Specification.

Project Number:	#0473
Full and Short Title:	Design and Manufacturing of Loop Heat Pipes and Capillary Pumps for Advanced Thermal Control System of Space Apparatus **Pumps for Space Control Systems**
Tech Code / Area / Field:	SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics
Status:	Project completed
Technology Development Phase:	3/Technology development
Allocated Funding:	$55,000 (EU: $27,500, US: $27,500)
Commencement date:	February 1, 1997
Duration:	12 months
Leading Institute:	Ural Branch of RAS/Institute of Thermal Physics, Ekaterinburg, Sverdlovsk Region, Russia
Contact Information:	Phone: +7 (343) 267 88 01 Fax: +7 (343) 267 88 00 E-mail: itp@itp.uran.ru Website: http://www.uran.ru
Supporting Institutes:	No
Collaborators:	Deutsches Zentrum fur Luft- und Raumfahrt e. V. / Institut fur Technische Thermodynamik Stuttgart, Stuttgart, Germany (Sprengel) Phillips Laboratory, Albuquerque, NM, USA (Gluck D.)
Project Manager:	MAIDANIK Yury Foilevich
Contact Information:	Phone: +7 (343) 249 32 93 Fax: +7 (343) 244 54 50 E-mail: maidanik@etel.ru
ISTC Senior Project Manager:	BUNYATOV Karen Stepanovich
Contact Information:	Phone: +7 (495) 982 31 99 Fax: +7 (499) 978 46 37 E-mail: bunyatov@istc.ru
ISTC Website:	http://www.istc.ru

Background

Scientific and technical problems relevant to heat transport by high-density fluxes at low temperature differences, to arrangement of efficient thermal exchange in high-heat areas, and to provision of optimal thermal regimes in various objects belong to the most representative and complicated ones in technical progress. This is true in full for the space technologies where the operation conditions impose additional restrictions on the solution of thermal problems. In this connection, development of two-phase heat-transfer devices with capillary heat-carrier pumping, considered to be a main thermal regulation link in space apparatus, are at present very promising. These devices require no additional equipment for mechanical heat-carrier pumping, possess a low thermal resistance, are reliable, have a small size, and are readily amenable to control. They are actively worked out in all the countries that have space programs.

The present Project was based on the original designs elaborated at the Institute of Thermal Physics UrB RAS in this area, namely, loop heat pipes (LHPs) and high-head capillary pumps-evaporators (CPEs). Unlike heat pipes of other types, LHPs are more efficient and compact devices that allow heat to be transferred through distances of up to few meters not only under microgravitation conditions but at various orientations in a gravitational field as well; they provide a flexible link between heat sources and sinks. These advantages are of great importance for optimal arrangement of equipment on board of a space apparatus, for providing ground tests, and for increasing reliability and operation resource.

High-head CPEs are the basic components of two-phase loops with capillary pumping. The technology developed permits CPEs from 10 to 40 mm in diameter to be manufactured; they generate a pumping pressure of up to 45 kPa at 20 °C when pumping ammonia and of up to 120 kPa at 100 °C when pumping water. These values are more than an order of magnitude higher than that produced by other known analogous devices. Moreover, the suggested pumps serve concurrently as efficient evaporation heat exchangers that provide heat transfer coefficient of about 10,000–20,000 $W/(m^2 \cdot K)$.

The technological solutions used in developing LHPs and CPEs are patented in Russia as well as in USA (patent No. 4.515.209), France (patent No. 2.540.613), Germany (patent No. DE 3301998c2), and Japan (patent No. 62-42236).

Project Objectives

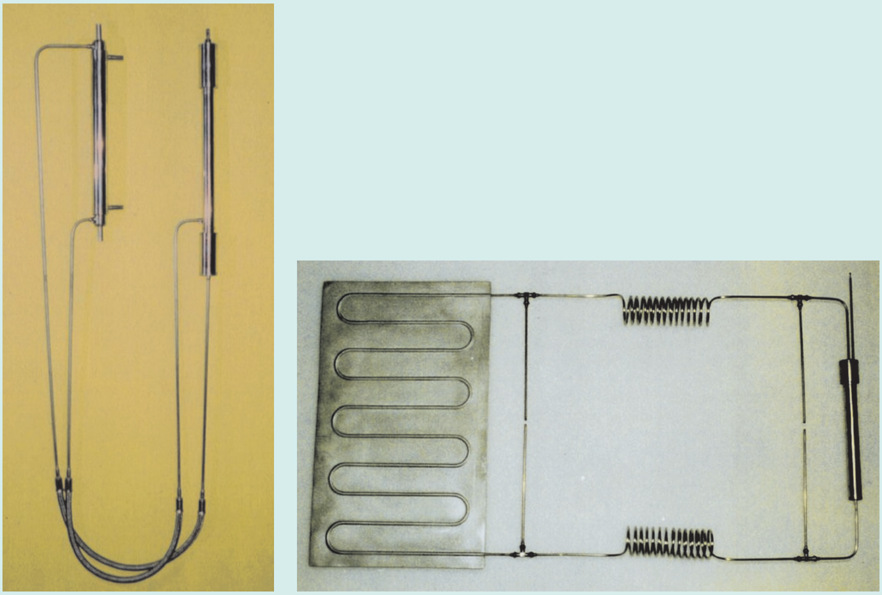
The Project was aimed at creation of high-efficiency two-phase heat transfer devices with a capillary heat-carrier pumping: LHPs and high-head CPEs with an increased active zone length to be incorporated in prospective systems of thermal control in space apparatus.

Description of the Works

The following investigations were accomplished in the course of Project implementation:

• Engineering calculations were performed and technical designs of LHPs with ammonia and propylene serving as heat-carriers were developed based on the calculation results;

• Loop heat pipes were manufactured; they were made of stainless steel and equipped with wicks made of a sintered fine nickel powder. The first LHP (LHP-1) was equipped with a cylindrical evaporator 24 mm in diameter with an active zone length of 200 mm. The total device length was 2030 mm. The liquid and vapor lines 6 mm in diameter had flexible insets 500 mm in length. Ammonia was used as a heat-carrier in LHP-1. The second LHP (LHP-2) was equipped with a cylindrical evaporator 24 mm in diameter with an active zone length of 177 mm. The effective device length was 4320 mm. The liquid and vapor lines 4 mm in diameter had flexible insets fabricated in the form of tubular multiple-turn spirals;



(*a*) (*b*)

Figure 1: Photos of loop heat pipes LHP-1 (a) and LHP-2 (b)

• LHP-1 and LHP-2 were tested under normal conditions at their various orientations;

• Two CPEs with a nickel wick of 70 percent porosity (with pore diameter of 8.6 μm) and three CPEs with a titanium wick of 50 percent porosity (with pore radius of 1.1 μm) were designed and manufactured. The evaporator diameter was 24 mm and the length of the active zone amounted to 300 mm; and

• The CPEs were incorporated in an experimental two-phase ammonia loop 5 m in length and tested.

Photos of LHP-1 and LHP-2 are shown in Fig. 1.

Obtained Results

• Tests of LHP-1 have demonstrated its working capability at any orientations in a 1g gravitation field. The maximum power of 1500 W at a vapor temperature of 47.7 °C was achieved in all cases. The thermal resistance of the device was 0.02 °C/W at a nominal heat load.

• In tests of LHP-2, the maximum power was 140 W at the horizontal orientation and 100 or 120 W at all orientations under 1g conditions. The maximum temperature did not exceed 51.3 °C.

• The maximum power was 2000 W in tests of the CPEs with a nickel wick while in tests of CPEs with a titanium wick it was 1700 W.

Project Number:	#0751
Full and Short Title:	Review of Space Mechanisms and Components **Space Mechanism and Components**
Tech Code / Area / Field:	SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics MAN-TRI / Manufacturing Technology / Tribology
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	$150,000 (JP)
Commencement date:	February 1, 1997
Duration:	12 months
Leading Institute:	Lavochkin Association, Khimki, Moscow Region, Russia
Contact Information:	Phone: +7 (495) 251 67 44 Fax: +7 (495) 573 35 95, 556 43 37 Website: http://www.laspace.ru
Supporting Institutes:	No
Collaborators:	NASDA, Tokyo, Japan
Project Manager:	KOZLOV Oleg Evgenievich
Contact Information:	Phone: +7 (495) 575 59 53 Fax: +7 (495) 573 25 84 E-mail: npol@laspace.ru, o-kozlov@yandex.ru
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 3157 Fax: +7 (499) 978 4637 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

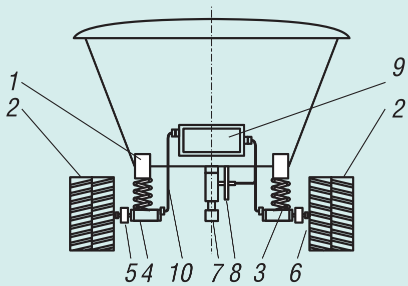
The flight of the first man-made satellite around the Earth in 1957 engendered new engineering branches, such as space machine-building and space material science. This is because the items produced operate in space under conditions that drastically differ from those on Earth. When escaping the Earth atmosphere, a space apparatus (SA) gets into a world which is alien to Earth materials.

The factors that govern the space impact on materials are high vacuum, wide range of temperature variation, and radiation. These factors when acting on materials change their surface properties and, hence, alter the conditions of interactions in friction pairs of mechanical SA units.

Virtually, all SA have friction units: joints, valves, and driving gears. Figure 1 shows a schematic of a moon robot ("Lunokhod-1) with indication of the friction units.

Implementation of the Project coincides with the forty-year anniversary of the space exploration era beginning. During 40 years, a tribological school was created in Russia, the result of its work is development of a great number of diverse antifriction materials, lubricants, and coatings.

Lavochkin Association has conducted unique tribological investigations of the effect of an-



(*a*)

(*b*)

Figure 1: Schematic (a) and photograph (b) of a moon robot ("Lunokhod-1") with indication of friction units: 1 — bearing structure (bracket); 2 — driver; 3 — elastic suspension bracket; 4 — electric motor with a brake; 5 — reducer; 6 — unblocking mechanism; 7 — penetrometer; 8 — ninth wheel; 9 — block of chassis automatics; and 10 — cable circuit

tifriction coatings and parameters of the ambient medium under conditions of an actual space flight. A set of vacuum setups and test benches were designed based on up-to-date knowledge of the external friction nature under conditions of deep vacuum and on an analysis of the mechanical units of SA and their service regimes. Techniques of thermal and vacuum tribological exploration of antifriction materials and coatings were worked out. The test bench basis permits tests to be conducted under conditions close to realistic ones.

Experience accumulated in Lavochkin Association in designing various mechanisms, driving gears, and mechanical systems functioning long time under extreme space conditions allowed reliable operation of automated interplanetary stations of the "Luna," "Venera," and "Mars" series and man-made Earth satellites of the "Prognoz" and "Granat" series to be provided. Experience shows that the use of modern vacuum lubricating agents retaining their properties within a vide temperature range allows one to design all the mechanical units, including precision electric and mechanical driving gears, without tight sealing or with partial sealing, which reduces the construction weight and improves dynamic SA characteristics.

Project Objectives

The Project was aimed at systematization of the available materials on designing, testing, and running mechanical units of SA and space buggies (joints, driving gears, mechanisms, and landing legs).

Provision of reliable functioning of mechanical units of SA with explanation of the working conditions, techniques of and approaches to tests by way of examples of main design solutions suggested for mechanical units and of materials used for their manufacturing are the major tasks of the Project. The results of investigations are presented in the form of a scientific and technical report.

Description of the Works

The data from the practical experience acquired at Lavochkin Association in designing mechanical units of space apparatus, the mechanisms of "Lunokhod-1" in the first place, were systematized in the Report.

For the first time in the practice of space machine building, specific features of operation of the mechanisms of SA were analyzed and the experience gained in designing, selection of materials, and conducting ground-based tests of friction units was summarized, the results of functioning in space of diverse mechanisms of automated interplanet stations of the "Luna," Venera," "Mars" series and man-made Earth satellites of the "Prognoz" and "Granat" series were presented.

The major sections of the report were:

• Specific features of functioning of mechanical units of SA.

• Survey and appraisal of the methodology of designing mechanical units.

• Survey and appraisal of the methods for providing working capability of mechanical units of SA.

• Experience in creation and operation of mechanical units of SA.

• Experience in creation and application of special techniques and devices to be used in testing mechanical units and lubricants applied in SA.

• Survey and appraisal of the lubricating materials applied in mechanical units of SA.

Obtained Results

The data furnished by practical experience of Lavochkin Association on development of mechanical units of SA were surveyed and systematized.

The results of the work were presented in the report that would be helpful for designers and material science specialists working in the rocket-space area.

The report issued in the form of a text book could also be helpful for students of technical universities being educated in the "space flying apparatus" specialty.

Project Number:	#0936
Full and Short Title:	Research on Fundamental Problems of Heat Transfer Intensification in Air–Hydrogen Heat Exchanger **Air–Hydrogen Heat Exchanger**
Tech Code / Area / Field:	SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics
Status:	Project completed
Technology Development Phase:	Applied research, technology demonstration
Allocated Funding:	142,614 € (EU)
Commencement date:	November 1, 1998
Duration:	24 months, extended by 3 months
Leading Institute:	Baranov Central Institute of Aviation Motors, Moscow, Russia
Contact Information:	Phone: +7 (499) 763 57 47 Fax: +7 (499) 763 61 10 E-mail: avim@ciam.ru Website: http://www.ciam.ru
Supporting Institutes:	No
Collaborators:	AIRBUS Industrie, Blagnac, France (Price D.) Iber Espacio Tecnologia Aerospacial, Madrid, Spain (Bigand H.)
Project Manager:	FOLOMEEV E. A.
Contact Information:	Phone: 7 (495) 362 13 81 Fax: +7 (495) 267 13 54
ISTC Senior Project Manager:	KULIKOV Gennady Genrikhovich
Contact Information:	Phone: 7 (495) 982 31 54 Fax: +7 (499) 978 46 37 E-mail: kulikov@istc.ru
ISTC Website:	http://www.istc.ru

Background

Pollution and economy requirements, such as reduction of the detrimental effect of combustion products of aviation fuel on the atmosphere and decrease in the specific fuel consumption (i. e., lowering the shipping cost) significantly affect the progress in aviation technologies. Because of this, fundamental investigations are conducted all over the world aimed at change over to an ecologically pure and high-efficiency fuel, e. g., to hydrogen.

An increase in the efficiency of the thermodynamic cycle of hydrogen-fueled aviation engines necessitates the use of heat exchanging devices in them. In particular, cooling of the compressed atmospheric air by the cold (stored in liquid) hydrogen allows the work spent for air compression in the compressor and the specific fuel consumption to be reduced.

Competing capability of hydrogen aviation engines is increased due to a decrease in both specific fuel consumption and construction weight. These two tasks are directly related to development of a high-efficiency system for cooling compressed atmospheric air, which is based on heat exchangers with thin-walled tubes of small diameter with intensifying construction elements.

Solution of the problem calls for additional basic and experimental investigations, such as experimental ascertaining of thermal and hydrodynamic features stemming from the use of a promising method of heat exchange intensifications (knurled tubes), as development of the basic technology for manufacturing tubes with such intensification, as designing and testing of a model hydrogen–air heat exchanger (HE) that demonstrates opportunities offered by the suggested intensification techniques, and improvement of the precision of the software used to optimize the appropriate devices.

The major requirements imposed on hydrogen–air HEs to be used in civil aviation and their specific features can be formulated based on the previously performed research. They are: high thermal efficiency and presence of areas where the temperature heads are small (ΔT of up to 5...8 K); minimization of the HE weight; high pressures of the cooling agent — hydrogen (of up to 300 atm); perfect sealing and enhanced reliability; and stringent requirements imposed on pressure losses in air being cooled at a moderate absolute pressure level.

Project Objectives

The goal of the Project was obtaining, summarizing, and experimental verification of scientific and technological data needed to develop high-efficiency and light hydrogen–air HEs with intensified heat exchange.

Description of the Works

The method, which is most promising for hydrogen–air HEs and is associated with knurling of small-diameter thin-walled tubes, was considered. The approach with tube knurling on flat plates, implementation of which is very simple under laboratory conditions, was chosen.

The laboratory-scale technology of knurling of thin-walled small-diameter tubes was developed and the appropriate device was designed, fabricated, and finished. The distinction of the physical processes inherent in the technology developed from the traditional ones applied to knurle thick-walled tubes consisted in formation of grooves in the course of bend-plastic deformation with no thinning of the tube wall.

A set of steel tubes (Kh18N9T material analogous to 316L) of an initial size 2 x 0.1 mm and with knurling parameters that varied in the following ranges: depth H of up to 0.15 mm, intergroove pitch t = 1.4…2 mm, groove with width b ~ 0.6...0.85 mm, and the length of the knurled zone L = 200 mm. The photo of a bundle of knurled tubes is shown in Fig. 1.

An air–air HE of the “tube-in-tube” type with a “hot” outer channel and “cool” inner-tube channel was designed and manufactured for studying local thermal and hydraulic charac-

Figure 1: Bundle of knurled tubes

teristics of the knurled tubes. Test bench systems including the system of measurements were prepared. The general view of the setup is displayed in Fig. 2. A technique of experimental data treatment meeting the requirements of similarity theory and allowing the results obtained to be transferred to an arbitrary working fluid (including hydrogen) and to multiple tube HE constructions with the bundle oriented longitudinally was developed.

The Reynolds number Re (flow turbulization), Mach number M (flow compressibility), Nusselt number Nu (heat conduction), and hydraulic drag coefficient ζ (pressure losses) were the basic similarity criteria used. The data acquisition and processing system was worked out and verified by way of comparison of the theoretical predictions with the experimental characteristics of smooth, not rolled-up, tubes. This permitted the authors to assess the mean square root error value at no more than 12%, which is typical of heat engineering experiments.

Measurements of the mean integral temperature of the tube wall based on its electric resistance, which produces no flow perturbations nearby small-size grooves, and integration of the full set of one-dimensional (1D) continuity, motion, and energy equations when treating the data were the important features of the measurement and data processing technique used. This made it possible to take into account the distribution of parameters over the tube length. The representative parameters of heat exchange intensification Nu/Nu_0 and of hydraulic drag increase ζ/ζ_0 as compared to those measured in a nonrolled-up tube were assessed based on the results of tests on knurled tubes at Reynolds numbers Re = $4{\cdot}10^4...3{\cdot}10^5$. The aforesaid parameters amounted at Re ~ 10^5 to:

– within the tube Nu/Nu_0 = 1...1.5 and ζ/ζ_0 = 1...6.5; and

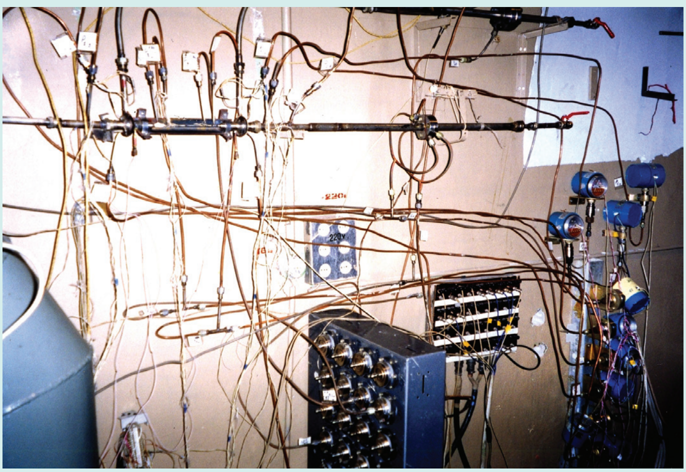


Figure 2: General view of the setup

– outside the tube Nu/Nu_0 = 1.5...2.3 and ζ/ζ_0 = 1...5.6

depending on the knurling parameters.

The behavior of the Nu number dependence on the Re number appeared to be depicted by highly different power functions, although the general trend of Nu increase with Re was retained. The power exponent *n* in the approximating $Nu = aRe^n$ dependences varied between 0.6 and 0.9. The hydraulic drag coefficient vs. Reynolds number dependences exhibited both a typical behavior with attaining a self-similar portion as Reynolds number increased or a more complicated nonmonotonic behavior. In some cases, a significant scatter of the data was observed in $\zeta = f(Re)$ and $Nu = f(Re)$ dependences which was ascribed to the effect of Mach number. Excitation of resonant sound-eddy self-sustaining oscillations in the channel that arose when the frequency of eddy shedding from the rear edges of profiles mounted at the channel center was identical to one of the frequencies of natural acoustic oscillations of the “channel + profile” system was one of the methods for heat exchange intensification that is characterized by strong dependence of the Nusselt number on the Mach number. A comparison of the $Nu/Nu_0 = f(M)$ dependences for the acoustic-eddy intensification and for intensification caused by knurling of a tube in which the intensification effect was manifested most clearly demonstrated that the two methods were similar. The Mach number effect on the acoustic-eddy intensification was controlled mostly by the conditions of resonance onset and by the appropriate oscillation amplitude level. Some acoustic-eddy interactions were supposed to arise in a rolled-up tube, because it is well known that a flow around protrusions and grooves at a surface generates periodical emission of eddies, like it does in a channel with a profile.

Different heat transfer coefficients in tests with co-flow and counter-flow arrangement of the working-fluid flows was another factor that complicated an analysis of the test results. The tentative explanation of this observation is that there are local changes in the heat transfer coefficients in the separation zone areas. In thin-walled tubes, both local heat transfer coefficients and their values averaged over the tube length would change in this case.

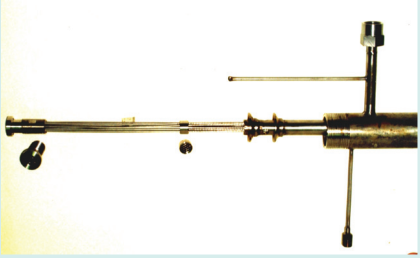


Figure 3: Units of the model HE

A multiple-tube full-scale HE with knurled tubes was designed and manufactured to test the knurled tubes under realistic conditions. The knurled tubes with the best characteristics were chosen from those tested.

The basic technical solutions, typical of cryogenic hydrogen–air HEs, were included in the HE design (Fig. 3):

– compensation for temperature-caused stresses with no additional devices, which became possible because of the extended range of elastic deformations of knurled tubes revealed in experiments (the Jung modulus of knurled thin-walled tubes was about twice as low as that of smooth tubes);

– soldered joints to provide perfect sealing of the hollows containing working fluids, special solder alloy found for the fluids tested, and a fairy complicated soldering technique;

– separation of the tubes in a bundle with provision of necessary intertube distances with long bushes that precludes the knurling effect on gaps between the tubes; and

– the use of materials compatible with hydrogen, etc.

A special setup was designed and manufactured at test bench Ts-16 in CIAM to conduct testing of a model HE under real cryogenic conditions with a model (nitrogen) and real cooling (hydrogen) agents with the cryogenic cooling agent temperatures of down to 80 K,

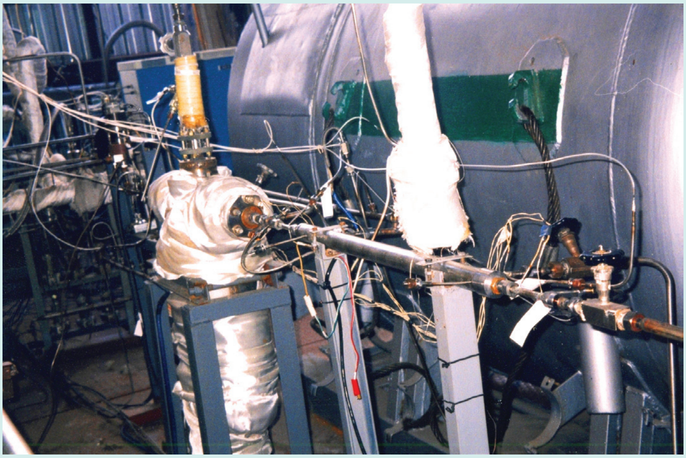


Figure 4: General view of the setup used for tests under real conditions with cryogenic components at test bench Ts-16

the required levels of flow rates of the components (expressed in Reynolds numbers) through both tracts of up to $(2–3)\cdot10^5$, and pressures of up to 50–80 atm. Figure 4 demonstrates the general view of the setup.

The tests performed yielded a more than 90-minute overall duration of HE operation in a cooled and pressurized regime with cryogenic components, the number of cooling–warming cycles was no less than 12. The HE remained operable after these tests, that is, saved, in the first place, its tight sealing, which provided evidence of reliability of the technical solutions applied.

Apart from static pressurizing of the HE to 60 atm in both directions (from inside and outside with periodical hot and cool pressurizing to 120 atm), the HE was subjected to a dynamic loading with a hydropercussion level of up to 180 atm at every primary start. All the above indicated heat exchanger pressurizing tests both under cryogenic conditions and at a normal temperature level, did not cause a failure of sealing between the tracts. This is evidence of efficient operation of the knurled tubes serving as thermal compensators, which is an important positive result.

Thermal and hydraulic HE characteristics were qualitatively and quantitatively consistent with the findings inferred from the studies of local characteristics of an individual tube from the tube bundle.

We extended the range of Mach numbers in tests of the outer HE tract, which allowed us to make some important observations. A diversity of the behavior of the performance diagram as a function of Mach number (existence of both ascending and descending dependences) was observed in the outer tract of the model HE, as well as in a single-tube HE.

In the course of exploring the effect of ultrasonic irradiation on *ortho*-para conversion of hydrogen, an ultrasonic reactor was designed and examined. No positive effect was revealed when hydrogen was sonicated at the applied frequencies (up to 60 kHz) and amplitudes (up to 178 dB); however, due to these experiments, a valuable experience was accumulated in excitation of self-sustaining oscillations under cryogenic conditions, this phenomenon was not investigated previously. In particular, specific features of the external heal flux on the level of excited self-sustaining oscillations were disclosed. These specific features led to a significant reduction of the excited oscillation amplitude. Possible approaches to modernization of the technique of ultrasonic action on hydrogen conversion were considered.

After accomplishing the mathematical model of a tube bundle flown around in the longitudinal direction, theoretical dependences of the optimal intertube pitch in a HE on the representative regime parameters were derived.

A flat minimum of the tube bundle mass was observed in a wide range around the optimum pitch, which permitted the necessary hydraulic losses in the inner tube tract of the HE to be provided with no significant increase in its weight. The dependences derived permitted also the efficiency of heat exchange intensification (a decrease in the tube bundle weight) to be evaluated. The heat exchange surface area (the tube bundle mass) was reduced by a factor of about 2 (at a maximum) with application of the above considered knurled small-diameter (2 × 0.1 mm) tubes flown around longitudinally at the experimentally studied nonoptimal relative pitch of the bundle (compact heat exchanger). The tube bundle weight could be reduced further with the aid of the observed Mach number effect on the thermal and hydraulic characteristics of knurled tubes. Tubes that showed up this effect most notably exhibited an additional 40 percent decrease even with the nonoptimized pitch. This phenomenon can be used, in particular, in order to ascertain optimal knurling geometry and heat exchanger pitch, only after its physical mechanism is well understood and the appropriate general dependences taking it into account are derived. This calls for an independent thorough physical investigation.

Obtained Results

• A laboratory-scale technology of knurling thin-walled small-diameter (2 × 0.1 mm) tubes was developed. An appropriate laboratory-scale device was designed and manufactured.

• A workplace for studies of local thermal and hydraulic characteristics of small-diameter knurled tubes was designed and arranged.

• The test and data acquisition systems (including wall temperature measurements based on changes in electric resistance of the tube) were developed and validated. The representative dependences of heat exchange intensification Nu/Nu_0 vs. Re and increase of the hydraulic drag ζ/ζ_0 vs. Re are derived from the results of tests of 10 different knurled tubes at Reynolds numbers ranging between $4{\cdot}10^4$ and $3{\cdot}10^5$. The values of the above parameters at $Re \sim 10^5$ are:

– inside the tube: Nu/Nu_0 = 1...1.5 and ζ/ζ_0 = 1...6.5; and

– outside the tube: Nu/Nu_0 = 1.5...2.3 and ζ/ζ_0 = 1...5.6 depending on the knurling parameters.

• Experiments revealed a number of unusual phenomena, including the effect on heat transfer characteristics of the flow Mach number and arrangement of the working fluid flow (co- or counterflow).

• A model multiple-tube full-scale HE equipped with knurled tubes was designed and fabricated. Experiments carried out with real cryogenic working fluids (hydrogen–air) confirmed the characteristics measured in single-tube tests and demonstrated the reliability of the technical solutions applied, including compensation for temperature strains at the expense of elastic properties of the knurled tubes.

• Computational and theoretical analysis performed with modified mathematical models of heat exchangers with a longitudinal flow around the tube bundle has demonstrated that the use of knurled tubes of the geometry studied could allow one to make the HE twice as light. The tube bundle weight can be decreased further by applying purposefully the new phenomena observed in the tests; however, this calls for their detailed studies and physical understanding (some physical hypotheses concerning the phenomena have been suggested).

Project Number:	#1165
Full and Short Title:	Development and Research of an Experimental Model of Electric Propulsion Based on Accelerator with Closed Electron DriftElectric **Rocket Propulsion**
Tech Code / Area / Field:	SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$200,000 (JP)
Commencement date:	January 1, 1999
Duration:	24 months
Leading Institute:	Keldysh Research Center, Moscow, Russia
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
Supporting Institutes:	No
Collaborators:	Marubeni Utility Services, Ltd., Tokyo, Japan (Sakamoto Takeshi) NASDA, Tokyo, Japan (Konno Akira, Hattori Akito, Saito Nariyoshi, Kajiwara Kenichi)
Project Manager:	GORSHKOV Oleg Anatolievich
Contact Information:	Phone: +7 (495) 459 95 23 (64 65) Fax: +7 (495) 456 82 28 E-mail: kercgor@dol.ru
ISTC Senior Project Manager:	KARABASHEV Sergey
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (495) 982 32 01
ISTC Website:	http://www.istc.ru

Background

Electrically driven rocket systems based on accelerators with closed electron drift exhibit a high level of output characteristics in combination with relative simplicity of their design. Reliability of electrically driven rocket engines (ERE) designed on the basis of Hall engines 600–1500 W in power is confirmed by their long-term operation at Russian geostationary communications satellites. This fact allows the Hall engines to be considered as candidates to be used in small-scale satellites of a new generation with low-power ERE.

Hall engine consists of an accelerator block (AB) and cathode-compensator (CC). Electric discharge in crossed electric and magnetic fields is ignited in AB and ions are accelerated in the electric field. Electrons move along Larmore orbits and predominantly generate, thereby, an azimuth current. The magnetic field virtually locks electrons and affects ion motion only insignificantly. Electrons are displaced to the anode owing to their collisions with atoms of the working fluid, ions, and walls of the discharge channel and also because of plasma oscillations. Electrons emitted by the CC neutralize the ion flow come to the discharge channel and support the discharge.

The available data furnished by investigations of Hall engines indicate that a decrease in the power of an engine deteriorates its characteristics, namely, its efficiency factor and specific impulse drop. This is caused by both an increase of the relative fraction of working-fluid losses in the CC and a decrease in the efficiency of the AB.

Project Objectives

The Project was aimed at development of an engine model with closed electron drift of a 100–300-watt power and at exploring the possibility of provision of a high level of its output characteristics.

Description of the Works

At the initial stage of the work a preliminary model of the engine AB was designed and manufactured. According to the physical principles laid in the design, the AB occupied an intermediate position between stationary plasma engines and engines with an anode layer. The main specific features of the AB distinguishing it from the existing analogs were: nontraditional geometry of the accelerator channel; a set of electromagnets that admitted a more flexible variation of the magnetic field in the accelerator channel; and the flexible accelerating channel design that permitted its geometry to be readily changed. The working fluid in the engine was Xenon; its power ranged between 100 and 300 W and its thrust varied from 5 to 15 mN. The power supply system of the AB included power sources feeding the magnets, an electric source generating the discharge, and a system that provided supply of the working fluid to the anode and CC. A set of tests was performed to investigate the effect of the discharge channel height and of the material of discharge channel walls on engine operation. Investigated was also the dependence of the engine characteristics on the flow rate of the working fluid at various power levels. Divergence of the plasma flow and the energy distribution of ions were thoroughly studied. High-efficiency operation regimes were explored at various discharge voltage.

The CC was designed and manufactured. It is one of the basic units of a Hall engine. It affects significantly the reliability of engine start, stability of its output characteristics, and overall operation resource. Two versions of the cathode design were considered, with LaB_6 and W + BaO emitters. Acceptable emissivity values of tungsten–barium cathodes and of LaB_6-cathodes were attained at about 1400 and 1900 K, respectively. Therefore, from the point of view of operation resource, the tungsten–barium cathodes seem to be more preferable; however, this emitter was more sensitive to poisoning by active species than was the LaB_6-cathode. This circumstance brought a lot of difficulties in conducting laboratory-scale engine tests with a W + Ba emitter. LaB_6-cathodes are intensely used as CCs in Hall engines because they are highly resistant to action of oxygen and other active species.

Therefore, it was more reasonable to use, at the stage of AB development, a hollow cathode with a LaB_6 emitter and to run the device at 1900 K. A LaB_8 pellet 9 mm in diameter and 2 mm thick was used as an emitter in the cathode device. A flat spiral tungsten heater was mounted at its rear end. The heater was placed in a ceramic alumina insulator. To reduce heat losses, a vacuum screen insulator made of a tantalum foil was installed at the pellet side and front. The whole construction was placed in a stainless steel casing. An orifice 1.5 mm in diameter was drilled in the face thermal insulation screen in front of the pellet.

The working fluid, Xenon, was fed through this orifice during cathode operation. The igniting electrode made of a tungsten wire 0.5 mm in diameter was mounted on the cathode casing. Preliminary tests of the cathode with the AB have shown that the cathode was capable of supporting gas discharge and providing engine operation at a discharge current in the 0.5–2.0 A range. This made it possible to test the AB at a low power (100–300 W).

At the third investigation stage, an automated system for measurements and control of engine operation was created. The system provided input of 32 analog and 16 digital measurement signals and 8 analog and 32 digital control signals. The data acquisition system was connected with a commercial personal computer. The PC controlled and processed the experimental data. In creating the main program and all subroutines, the “Lab View” software developed by National Instruments company was used. The basic functions of the system are: recording the parameters measured on a data carrier both in an automatic regime and by a user command, online processing of the experimental data with demonstration of necessary information on a monitor; and delivery of the control signals at needed time instants. Testing and adjustment of the system were performed first separately and then in combination with the measurement system of the routine (PC plus information processing system).

A new system of working fluid feeding to the anode and cathode was designed and debugged in the course of work. Its schematic was distinguished, first of all, by a more convenient and precise system of measurements and control of the working fluid flow rate due to the use of an automated control and measurement system.

Based on the results obtained a model engine KM-37 was designed and manufactured (Figs. 1 and 2) that was not inferior in its output characteristics to the KM-32 engine but had a higher mechanical strength and simpler manufacturing technology.

The basic distinctions of the new model were:

– Magnetic system. In order to preclude saturation of the magnetic conductor units the core diameter was increased by 25% while its length was reduced by 30%. The number of magnet coils was reduced to 2, while the number of winds in them was increased;

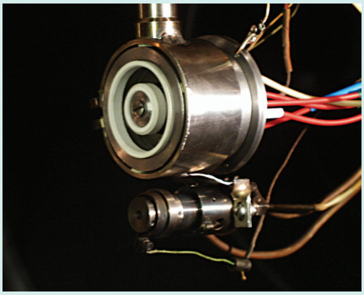


Figure1: Photo of the KM-37 engine

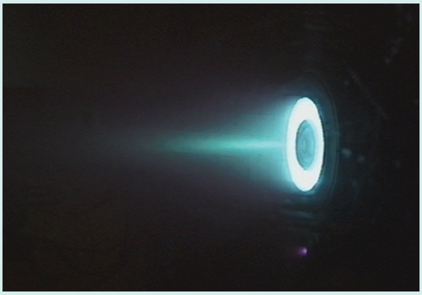


Figure 2: Operating KM-37 engine

– Anode-gas distributor. The number of internal chambers was increased to 3 in order to increase azimuthal homogeneity of the gas flow. At the same time, the mechanical strength of the internal chamber was enhanced;

– Accelerator channel. The thickness of the accelerating-channel walls near the outlet was increased by 50% and the average accelerating-channel diameter was increased by 15% to increase the engine resource. Furthermore, the parts of the accelerator channel outlet were fixed on high-voltage electrodes and had neither electric nor thermal contact with the engine casing.

Engine operation was examined at a power value ranging between 100 and 300 W at rates of the Xenon flow to the anode varying from 0.6 to 1.4 mg/s. A considerable improvement of the output characteristics compared to the KM-32 engine model was achieved. The KM-37 engine is superior in its characteristics to the known analogs of similar power.

Obtained Results

• An AB for KM-32 engine has been worked out and tested in the following range of parameters: gas flow rate through the anode of 0.7 or 1.2 mg/s, discharge voltage of 130 or 300 V, discharge current of 0.7 or 1.1 A, and discharge power of 115 or 250 W.

• A CC for the accelerator block 100 or 300 W in power has been manufactured and tested. It has been shown that all regimes of the AB operation can be provided at the following cathode operation parameters: Xenon flow rate of 0.05 mg/s and standby power of up to 15 W. Stable operation was observed at discharge voltage values of up to 450 V.

• A new KM-37 modulus possessing, along with the high characteristics attained in KM-32, higher strength, and technological characteristics has been developed based on optimization of the AB for the KM-32 engine. The KM-37 engine is superior in its characteristics to the analogs available in the world.

• An automated system of measurements and control of engine operation has been worked out based on a computer, L-Card crate system, LEM gauges, and Analog devices, and National Instruments Software. The system had 32 analog and 16 digital input channels and 8 analog and 32 discrete output channels. A system of gas supply to AB and CC controlled by a computer has been designed and manufactured. The system comprised also a convenient calibration mechanism.

Project Number:	#1214
Full and Short Title:	Technological Problems of the Long Life Lubricating Technology for Space Mechanisms **Lubricating Technology for Space Mechanisms**
Tech Code / Area / Field:	SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics
Status:	Project completed
Technology Development Phase:	Technological Problems of the Long Life Lubricating Technology for Space Mechanisms
Allocated Funding:	$60,000 (JP)
Commencement date:	October 1, 1998
Duration:	12 months
Leading Institute:	All-Russian Scientific Research Institute for Mobile Vehicle Engineering, St Petersburg, Russia
Contact Information:	Phone: +7 (812) 749 69 42 Fax: +7 (812) 746 16 18 E-mail: tm@vniitransmash.ru Website: http://www.vniitransmash.ru
Supporting Institutes:	No
Collaborators:	JAXA / Tsukuba Space Center, Tokyo, Japan
Project Manager:	TARASOV Vyacheslav Mikhailovich
Contact Information:	Phone: +7 (812) 135 99 25 Fax: +7 (812) 146 18 51
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 31 57 Fax: +7 (499) 978 46 37 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

Since 1963, the team working at All-Russian Scientific Research Institute for Mobile Vehicle Engineering accumulated great experience in providing operation efficiency of friction units and mechanisms of various space apparatus (SA). The techniques and test bench facilities were developed which allow tribotechnical investigations of construction and lubricating materials to be performed in a wide range of negative and positive temperatures, loads, and slip velocities in vacuum and various non-aggressive gases. A number of self-lubricating materials, antifriction coatings, plastic lubricants, and methods for increasing wear resistance of construction materials were worked out in cooperation with other organizations. An analysis and systematization of this experience furnished valuable information about methods that provide operation efficiency; techniques and setups to be used in tribotechnical tests of construction and lubricating materials, mechanisms, and devices; about properties of lubricating materials; and about solution of the problem of operation efficiency provision in particular spacecraft devices.

Project Objectives

Objective of the Project was to analyze and systematize the results of scientific and engineering investigations into provision of operation capability of friction units in spacecraft with the aid of long-life lubricating materials and to issue an integrating report.

Description of the Works

The analysis and systematization of the data on provision of operation efficiency of friction units was predominantly based on the results of research work performed at the Institute.

The conditions of running space mechanisms on the Moon, Mars, and in near space were analyzed. It was shown that vacuum, rarified carbon dioxide gas, low temperatures, and vibrational overloads exert the worst effect on operation efficiency of friction pairs. Operability of friction pairs under such conditions can be provided by application of solid lubricating coatings, various lubricants, and self-lubricating materials.

A methodology was suggested for solving the problem of provision of operation efficiency of friction units in space apparatus. It was based on development and analysis of friction pairs (Fig. 1). The analysis permitted the authors:

– to find optimal construction and lubricating materials;

– to assess needed minimum number of tests and test bench equipment;

– to appraise the necessity of searching for and working-out of new materials and technologies,

– to modernize the available equipment and to develop a new one; and

– to perform, in accord with the scheme chosen, the set of tests needed to investigate every friction pair as applied to the conditions of its operation in a SA.

The techniques and test bench equipment available in the Institute were considered from the point of view of their use in stage-by-stage finalizing, on model specimens, of construction and lubricating materials in friction pairs and units and in electric mechanisms, as well as in design-finalizing and acceptance tests of ready items and their parts. The equipment permitted the composition of medium, temperature, load and velocity parameters of the friction units of SA to be imitated.

The test benches permitted operation efficiency of gear sets, sleeve and frictionless bearings made of various construction and self-lubricating materials with coatings and lubricants to be assessed with allowance for construction, load, and specific kinematic features of the friction units in SA operating in vacuum, rarified carbon dioxide and air, at negative and positive temperatures.

Friction machines made it possible to perform quick selection tests of construction and lubricating materials on model specimens under conditions close to those in which the friction units of concentrated and distributed contacts

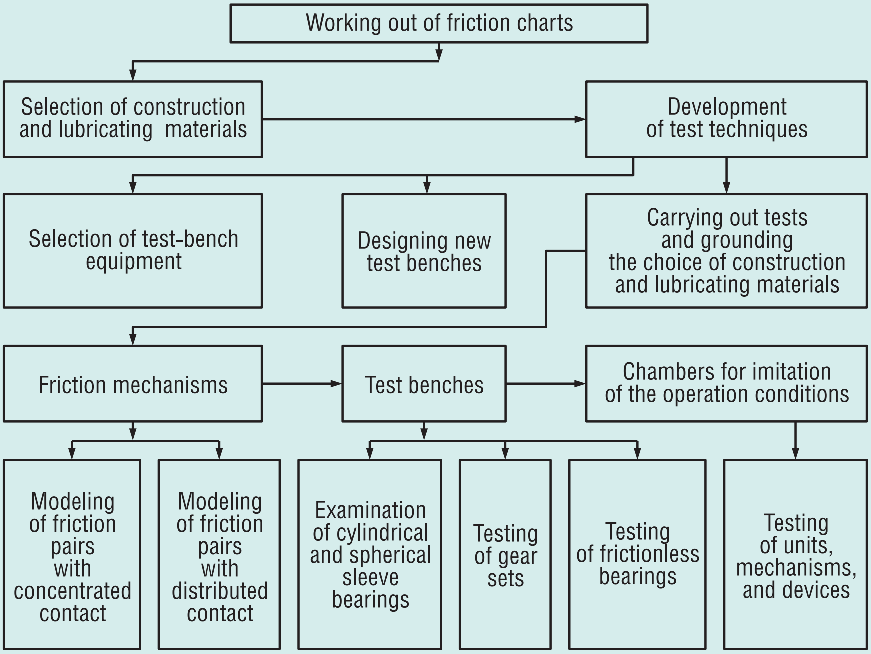


Figure 1: The technique providing operation efficiency of friction units

were actually run within a wide range of loads, velocities, and positive or negative temperatures.

Vacuum chambers provided conditions under which the design-finalizing and acceptance tests of the manufactured articles, mechanisms, and their fragments were performed that allowed the operation efficiency of both a manufactured article as a whole and its individual systems to be assessed.

Characteristics of the construction and lubricating materials available at the Institute and the methods used to improve their operation efficiency as applied to the conditions of friction unit operation in space apparatus were analyzed.

The list of construction materials (steels, titanium and aluminum alloys, metal-glass materials, and methods of their strengthening) for friction units in space mechanisms was composed.

The results of the following investigations and working-out of materials performed at the Institute and in cooperation with other organizations were considered:

– modifying (in cooperation with Central Research Institute of Materials) the anodic coating technology that permitted the antifriction properties of aluminum V95T alloy with solid anodic coating to be improved at the expense of impregnation with lubricating materials;

– creating (in cooperation with Russian Research Institute of Petroleum Industry) a number of plastic lubricants based on polyperfluoroethers, that permitted the low-temperature range of their application to be extended to –100...–130 °C and the load resistance and resource of mechanisms in their operation in vacuum, rarified carbon dioxide, and in air to be increased;

– working-out (in cooperation with contractors) a number of anti-friction coatings for steels, titanium and aluminum alloys and investigation of their functionality in friction pairs of concentrated and distributed contact as applied to items used in space;

– exploring tribotechnical properties of some self-lubricating materials on metal and polymer basis in pairs with construction materials. Their use in sliding friction pairs and in gear drives of reducers in vacuum, rarified carbon dioxide, and in air was tested;

– testing the magneto-powder technique of lubrication of gear drives in vacuum and carbon dioxide. A magneto-powder lubricant based on lithium ferrite allowed the resource of "dry" heavily loaded planetary gearboxes in vacuum and rarified carbon dioxide atmosphere to be significantly increased;

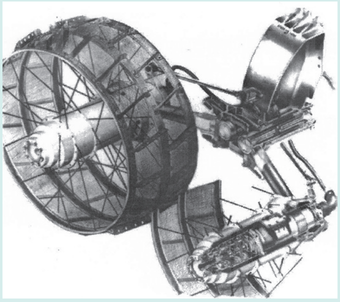
– investigating the effect of fluorine-containing surfactants on operation efficiency of friction pairs both with dry friction and in the presence of plastic lubricants. Experiments proved that the use of fluorine-containing surfactants in friction pairs increased their workability in air, vacuum, and rarified carbon dioxide;

– developing a nuclear space power installation on the "Red Star" (Krasnaya Zvezda) state enterprise. Workability of friction pairs under heavy conditions of their running (temperature ranging from 150 to 800 °C and high radiation dozes) was provided by application of heat-resistant construction and metal-ceramic materials and coatings based on molybdenum and nickel disulfides. The product kept working for a time period as long as its double resource both in ground-based and natural space tests.

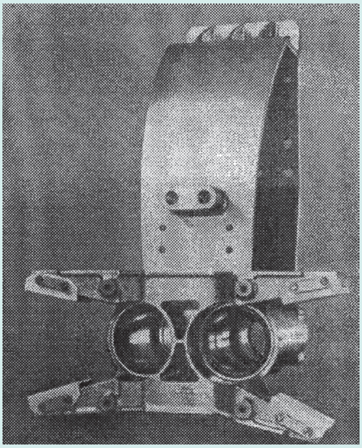
The analysis was performed of:

– technical characteristics of rovers designed for exploration of Moon and Mars, of the construction and lubricating materials incorporated in them, and of the techniques used to predict the operation regimes; and

– methods for providing workability and long-life of friction pairs in the motor vehicle chassis of "Lunokhod-1" and "Lunokhod-2" (Figs. 2 and 3), "dry" motor-



(*a*)



(*b*)

Figure 2: Tool-carrier wheel block in "Lunokhod-1" (a) and Corbel — a part of the bearing structure of "Lunokhod-1" (b)

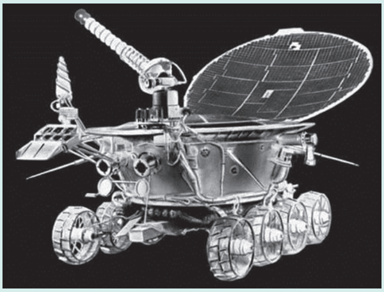


Figure 3: Moon buggy-1 ("Lunokhod-1")

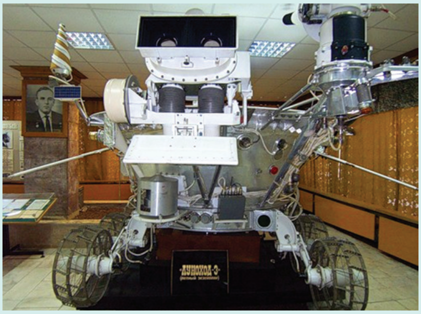


Figure 4: Moon buggy-3 (“Lunokhod-3”)

wheel of “Lunokhod-3” (Fig. 4), minirover PrOP-M for Soviet missions “Mars-2” and “Mars-3” (Fig. 5), and Mars-rover — project 4M (Fig. 6);

The following friction pairs of the aforesaid rovers were finalized:

– cylindrical gear drives;

– cylindrical and spherical plain bearings;

– frictionless bearings of various types and sizes;

– friction-disc brake; and

– bellows and labyrinth seals.

The methods developed and construction and lubricating materials selected provided stability of the friction characteristics of friction units throughout the duration of “Lunokhod-1” and “Lunokhod-2” operation on the Moon surface. The comprehensive ground tests confirmed operation efficiency and long-duration resource of the “dry” motor-reducer of “Lunokhod-3” as well as of friction pairs of the mobile vehicles designed for traveling on Mars surface.

Obtained Results

Based on the analysis and systematization of the data furnished by investigations aimed at provision of operation efficiency of friction units in space workpieces with the aid of long-life lubricating materials, a technical report “Technical aspects of application of long-life lubricating materials in space mechanisms” was issued.

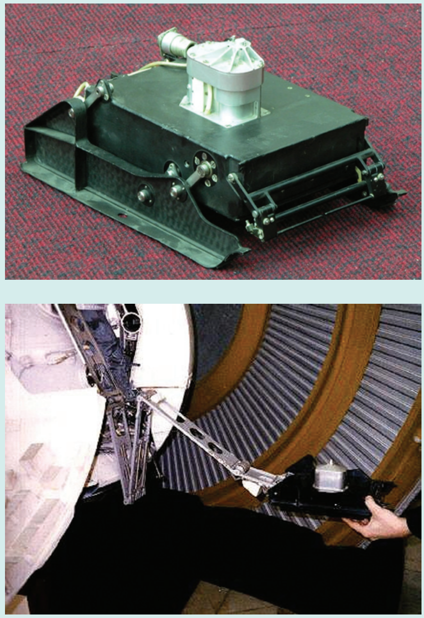


Figure 5: Minirover PrOP-M

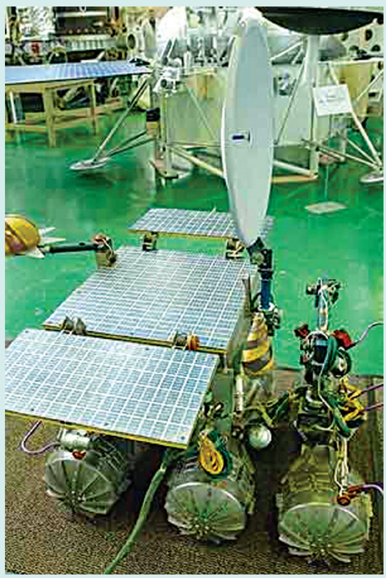


Figure 6: Soviet Mars buggy (Marsokhod)

The report consisted of four Chapters that were supplemented with concluding remarks:

Chapter 1. Methods for provision of workability of friction units in space mechanisms;

Chapter 2. Techniques and setups developed for studies of operability of friction units and mechanisms;

Chapter 3. Construction and lubricating materials for friction units of space manufactures; and

Chapter 4. Technical solutions applied to provide operation efficiency of friction units in motor vehicle chassis of planetokhods (planet buggies).

Working out of friction charts, Selection of construction and lubricating materials, Development of test techniques, Selection of test-bench equipment, Designing new test benches, Carrying out tests and grounding the choice of construction and lubricating materials, Friction mechanisms, Test benches, Chambers for imitation of operation conditions, Modeling of friction pairs with concentrated contact, Modeling of friction pairs with distributed contact, Examination of cylindrical and spherical sleeve bearings, Testing of gear sets, Testing of frictionless bearings, Testing of units, mechanisms, and devices

Project Number:	#3151
Full and Short Title:	Experimental and numerical study of critical aerothermodynamic phenomena on the EXPERT reentry demonstrator for preparing in-flight tests **Demonstrator for Flight Tests**
Tech Code / Area / Field:	SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics
Status:	Project underway
Technology Development Phase:	Basic and applied research
Allocated Funding:	$500,000 (EU)
Commencement date:	April 1, 2006
Duration:	57 months
Leading Institute:	Khristianovich Institute of Theoretical and Applied Mechanics, Siberian Branch, Russian Academy of Sciences (ITAM SB RAS), Novosibirsk, Russia
Contact Information:	Phone: +7 (383) 330 81 63 Fax: +7 (383) 330 72 68 Website: http://www.itam.nsc.ru
Supporting Institutes:	Institute for Problems in Mechanics, Russian Academy of Sciences, Moscow, Russia State Rocket Center “Makeyev Design Bureau,” Miass, Russia
Collaborators:	ESA ESTEC (The Netherlands)CIRA (Italy) Von Karman Institute for Fluid Dynamics (Belgium)
Project Manager:	IVANOV Mikhail Samuilovich
Contact Information:	Phone: +7 (383) 330 81 63 Fax: +7 (383) 330 72 68 E-mail: ivanov@itam.nsc.ru
ISTC Senior Project Manager:	RYZHOVA Tatiana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (499) 978 46 37 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

In recognition of the importance of an independent European access to the International Space Station (ISS), in preparation for the future needs of exploration missions as well as future launcher technology programs, ESA is conducting in flight research programs with the objectives to generate flight data associated with critical aerothermodynamic phenomena for design tool validation. The EXPERT (European eXPErimental Re-entry Test-bed) vehicle is a ballistic generic configuration featuring a blunted nose and a conical body on which 4 generic flaps are mounted (Fig. 1). The objective of EXPERT is to provide a test-bed for the validation of aerothermodynamics models, codes and ground test facilities in a representative flight environment, to improve the understanding of critical issues related to analysis, testing and extrapolation to flight.

The EXPERT concept is based on a symmetrical re-entry capsule whose shape is composed of simple geometrical elements. The suborbital trajectory will reach 150 km altitude and a reentry velocity of 5 to 6 km/s (Fig. 2). The dimensions of the capsule are 1.6 m high and 1.3 m diameter; the overall mass is in the range of 300–400 kg, depending upon the mission parameters and the payload/instrumentation complement. The EXPERT vehicle will be launched on a suborbital trajectory using the Russian Volna launcher (RSM-50 adapted to civil applications), which is rather flexible and can be adjusted to prescribed flight conditions.

The goal of EXPERT is to achieve low cost reentry experiments focused on flying "problems for design"; that is, hypersonic fluid dynamic phenomena such as boundary layer/shear layer transition, viscous interactions, flow separation-reattachment, shock-boundary layer interactions, surface catalysis, blackout, and plume-flow field interactions. The approach is to conduct several suborbital flights using a partly reusable generic vehicle with high priority on accurate flight measurements and a high fidelity air data system (ADS).

Project Objectives

This project deals with applied research aimed at the development of novel technologies for studying aerothermodynamics of space vehicles under real flight conditions. For this purpose, the European Space Research and Technology Center (ESTEC) proposed a geometric shape of the EXPERT flight demonstrator, its reentry conditions, and thermoprotection system. The project includes three research directions related to:

(1) numerical and experimental research of aerothermodynamics of the EXPERT demonstrator model along the descent trajectory (altitudes of 130–80 km);

(2) numerical and experimental (laboratory or ground-based) modeling of heat loads on the surface of the EXPERT demonstrator and de-

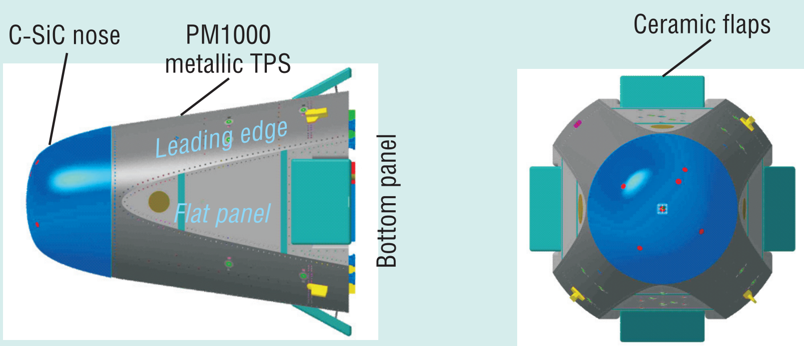


Figure 1: EXPERT configuration

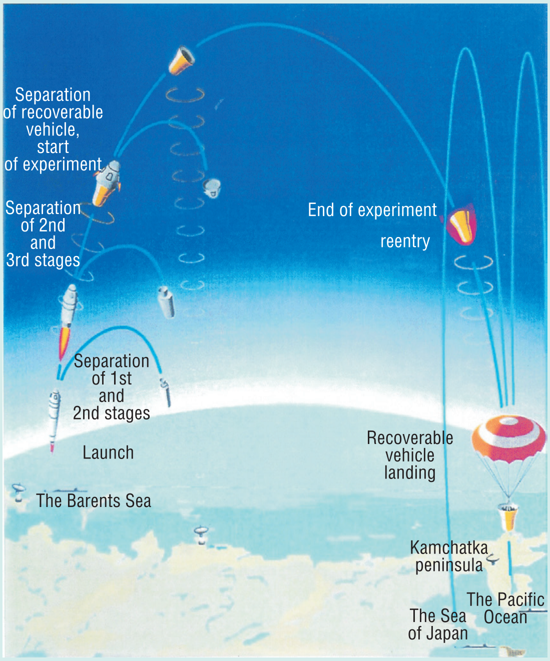


Figure 2: EXPERT trajectory

termination of the coefficients of catalytic activity of the thermoprotective material surface with respect to heterogeneous recombination of oxygen and nitrogen atoms; and

(3) design activities aimed at mutual adaptation of the EXPERT capsule and VOLNA launcher, preparing launch scenarios, determining mechanical and electrical interfaces of the launcher and EXPERT capsule, including the separation system, determining the parachute system parameters for providing required conditions of the flight experiment, analysis of the optimal set of onboard equipment of the VOLNA launcher, as applied to experimental launches of the EXPERT demonstrator, determining the optimal schemes of using the measurement equipment along the flight trajectory, acquisition, processing, and presentation of information, based on results of flight tests.

Description of the Works

A database management system was created for the aerodynamic database of the EXPERT vehicle. Numerical and experimental data on aerothermodynamics of the EXPERT vehicle obtained in the course of the present project were inserted into the database.

The planned calculations of aerothermodynamic parameters of the EXPERT demonstrator were performed by the Direct Simulation Monte Carlo (DSMC) method in the free-molecular and transitional flight regimes. Drag coefficients, lift and side force coefficients, and aerodynamic moments were obtained as functions of the flight altitude and angles of attack and sideslip. Critical phenomena of local heating near the flaps were analyzed. Distributions of the heat-transfer coefficients and heat fluxes on the vehicle surface were obtained for various flight altitudes and angles of attack and sideslip. Regimes with critical aerothermodynamic loads that require particular attention in design of the thermal protection system for the vehicle and in choosing the surface material were identified.

The influence of surface temperature on the values of aerodynamic characteristics along the descent trajectory was studied. With increasing surface temperature, the coefficients of aerodynamic forces were found to increase mainly at flight altitudes greater than 95 km.

The proposed engineering method of estimating the heat-transfer coefficient on bodies in hypersonic flow allows rapid calculations with sufficient accuracy in a wide range of Reynolds numbers. The error of the method depends on the body geometry and increases in the transitional regime (in the worst case, the error of the integral value of C_h is approximately 20% in the range $5 < Re_\infty < 200$). As a whole, this method can be used for rapid analysis of thermodynamic loads on bodies in hypersonic flow with subsequent refinement of critical issues by more accurate methods, for example, by the DSMC method.

Diagnostics of high-enthalpy flows in the plasmatron (air, air–oxygen mixture, nitrogen) was performed, and samples of thermoprotective materials were tested (analogs of C/SiC and PM1000 materials). The surface temperature and stagnation-point heat fluxes in two new regimes of subsonic flow were measured.

In these two regimes, heat transfer tests with a 50-millimeter diameter euromodel equipped with a sample made of tile material with a standard borosilicate coating were performed. The surface temperature of the borosilicate coating and the heat flux at the stagnation point were measured.

Flow fields, fields of thermophysical parameters, and heat flux maps for new TPM testing regimes were obtained through CFD modeling of subsonic reacting air flows.

For an EXPERT trajectory point at an altitude of 52.6 km and entry velocity 5 km/s, complete simulation of the stagnation-point heat transfer was realized on the IPG-4 plasmatron. The stagnation-point heat flux, temperature, and SiC surface catalycity were predicted for the EXPERT entry conditions. For the same conditions, calculations of subsonic air free-stream parameters were performed by a newly developed numerical algorithm.

Aimed at further estimation of the border of active/passive oxidation of the C/SiC thermal protection material in terms of “pressure – surface temperature,” diagnostics of the IPG-4 subsonic air test regimes providing heating of SiC samples in the temperature range 1600–2100 K and in the pressure range 170–540 hPa was performed.

In order to approach the border of active/passive oxidation of the SiC material in terms of “pressure – surface temperature,” heat transfer tests with SiC samples and diagnostics of the IPG-4 subsonic air test regimes providing heating of SiC samples in the temperature range 1600–2100 K and in the pressure 540 hPa were carried out. Diagnostics of the air free-stream conditions and heat transfer was performed.

A prototype model of the reentry vehicle was developed for testing launcher/vehicle separation. The mass-centering and inertial characteristics, as well as the rigidity characteristics of the prototype seat affecting the magnitude of perturbations during the separation process correspond to those of the standard vehicle.

A mockup of the parachute landing system was formed. The technology of operations with the parachute landing system of the EXPERT vehicle on the preparation area was developed. The list of tests of the parachute landing system included into the vehicle system was developed, which includes mockup testing of the parachute system, testing of the system for shroud cutting, and autonomous testing of the cap jettisoning velocity.

The time diagram of commands and the EXPERT/VOLNA electric interface were developed and agreed with collaborators.

The composition of the board instrumentation complex (BIC) was determined, as applied to launching of the EXPERT vehicle. Documentation was developed for supplying the BIC instruments for the launch considered and their certification. Zones for sensors of high-frequency vibrational and shock accelerations and low-frequency shock accelerations were determined. A set of check-out equipment of the preparation area was developed to ensure electrical verification of the launcher BIC in the course of launch preparation.

For trajectory parameters refined in accordance with the specification for the parachute system, the gasdynamic pattern of the flow in the base region of the vehicle and in the wake region was calculated. The aerodynamic characteristics of the EXPERT vehicle were estimated for the case of its descent on the parachute with velocities $M_\infty = 0.44$, 0.85, 1.1, and 1.5. The calculations showed that the descent velocity of 60–85 m/s for main parachute actuation can be ensured by the braking parachute with an area from 1.5 to 4.0 m^2.

The set and characteristics of the on-board system for rapid detection of the vehicle were determined. Various scenarios of ground-based operations on preparing, launching, detection, and evacuation of the EXPERT vehicle were analyzed.

The issues associated with preparing sets of ground-based support and control-test equip-

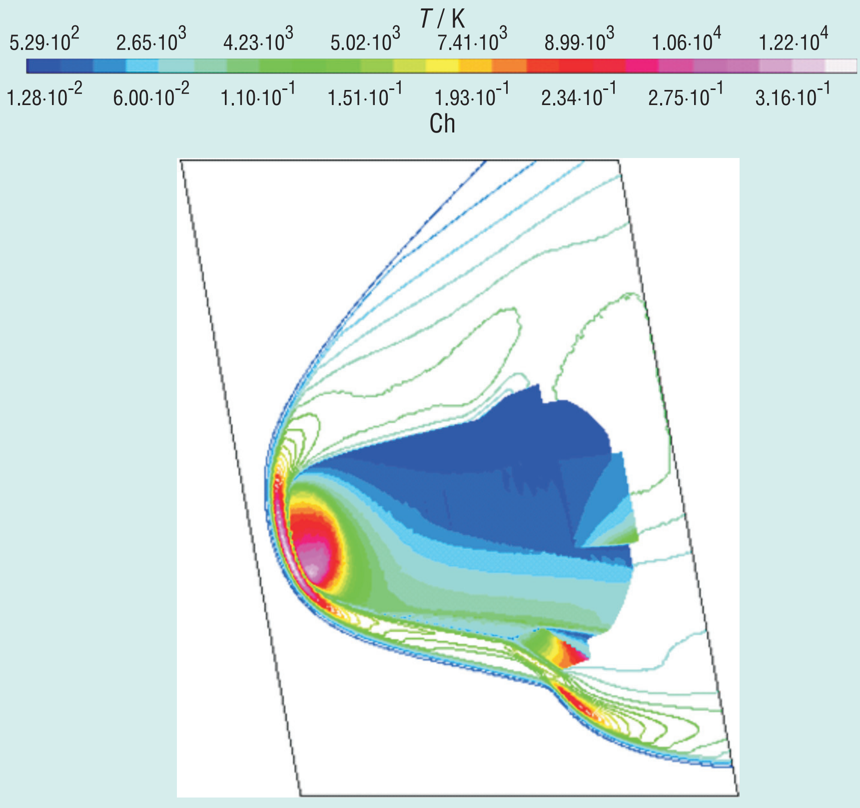


Figure 3: Temperature field and surface distribution of the heat-transfer coefficient of the EXPERT vehicle

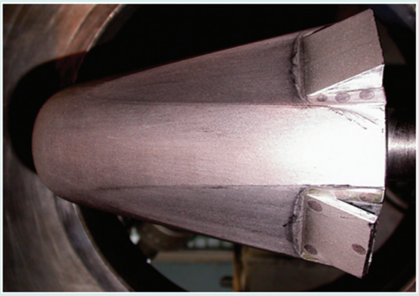


Figure 4: Oil-film visualization of the flow on the EXPERT model surface in the T-313 wind tunnel

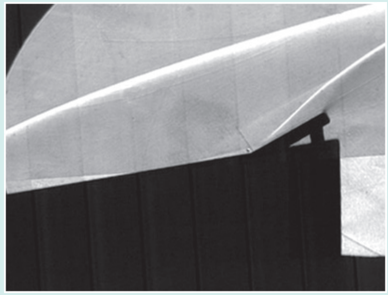


Figure 5: Schlieren pictures of the flow around the EXPERT model (Mach number 13.8)

ment were discussed. Technological plans for operations with the adapted launcher and vehicle in preparing and conducting the launch and in the region of vehicle landing were developed.

Numerical and theoretical estimates were obtained, and conditions of information acquisition and transfer during the launch were determined. Optimal schemes of ground-based telemetry systems over the flight trajectory and in the landing region were chosen. Various organizational issues of search and rescue of the demonstrator in the landing region and its evacuation were considered.

Obtained/Expected Results

– An aerothermodynamic database of the EXPERT capsule was generated and filled with numerical and wind-tunnel data (Fig. 3).

– The aerodynamic characteristics of the EXPERT capsule were calculated from free-molecular to continuum flow regimes.

– The aerodynamic characteristics of the EXPERT model were measured in ITAM SB RAS wind tunnels in a wide range of angles of attack (Fig. 4); schlieren pictures were also obtained (Fig. 5).

– The flow structure and positions of local separation regions in the vicinity of flaps were determined.

– Surface catalycity relevant to TPM, geometry and trajectory of the EXPERT capsule was studied in the IPMech plasmatron as close as possible to flight conditions.

– The shape and parameters (including energy parameters) of the RSM-50 launcher adapted for mounting a test capsule for trajectories with the minimum reentry angles were determined.

– The mechanical and electrical interfaces between the launcher and capsule, including the separation system, were determined.

– The parachute system parameters providing necessary test conditions were obtained.

– The optimal set of on-board measurement tools on the launcher, as applied to flight tests, was analyzed.

– Optimal schemes of using the measurement tools along the flight trajectory, acquisition, processing, and representation of experimental information were developed.

– After the EXPERT vehicle is launched, it is planned to compare the predictions with the real flight data and to perform a postflight analysis.

Project Number:	#K-035
Full and Short Title:	Operating Process Investigation of Supersonic Combustion Ramjet as Applied to Promising Aerospace Planes **Hydrogen Hypersonic Flow for Air-Cosmic Craft**
Tech Code / Area / Field:	SAT-STM / Space, Aircraft and Surface Transportation / Spacecraft Trajectories and Mechanics
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding:	$320,000 (EU)
Commencement date:	September 1, 1998
Duration:	36 months
Leading Institute:	Kazakh National University, Almaty, Kazakstan
Contact Information:	Phone: +7 (3272) 67 54 59 (63 88 52) Fax: +7 (3272) 47 26 09 Website: http://www.kaznu.kz
Supporting Institutes:	CIAM (Aviation Motors), Moscow, Russia Almaty Institute of Energy and Communication, Almaty, Kazakstan
Collaborators:	Aérospatiale Missile, Chatillon, France (Falempin F.)
Project Manager:	YERSHIN Shakhbar Alimgyreevich SEMENOV Vyacheslav L'vovich
Contact Information:	Phone: +7(495) 362 49 50 Fax: +7 (495) 362 03 73 E-mail: semenov@ciam.ru
ISTC Senior Project Manager:	TYURIN Igor Alekseevich
Contact Information:	Phone: +7(495) 982 31 96 Fax: +7(499) 978 36 03 E-mail: tyurin@istc.ru
ISTC Website:	http://www.istc.ru

Background

Further Space exploration requires new technologies leading to essential reduction of flight cost and impact on environment. Creation of Aero-Space Plane (ASP) to replace rocket launch systems in orbital transport operation is a way to meet today's requirements.

Almost all national space agencies are involved in ASP research affiliated into national or international space programs. The main problem of developing ASP and aircraft space launch systems is a creation and experimental development of a propulsion system based on supersonic combustion ramjet (scramjet). The core problem of scramjet creation is a combustor, in which efficient combustion of hydrogen in supersonic air flow has to be achieved. Complex theoretical and experimental investigations, including study of features of fuel mixing processes and combustion in supersonic air flow, is needed for solving the problem.

Project Objectives

The Project objective was to develop a mathematical model of hydrogen burning and experimentally determine the main relationships describing physical processes accompanying burning of a single hydrogen jet in supersonic air flow in a model combustor.

Description of the Works

Investigation of combustion processes in supersonic flow included small-scale physical experiments and tests of a combustor model containing hydrogen injectors, which were close in size to real injectors, as well as computational studies throughout the entire range of operational parameters using high-level mathematical models. It allowed reliability of results obtained to be increased and ensured deeper insight into the operation process of supersonic combustors.

Along with conventional measurements of pressure and temperature in gas flow, methods of determining local concentrations and burning rates were used in the experimental study. Television recording of ultraviolet (UV) radiation of OH radicals with automated image processing allowed reconstruction of the detailed burning process in the combustor.

Mathematical models of hydrogen burning were improved and a detailed mathematical model of supersonic combustion in a two-dimensional planar flow was developed.

Disturbance waves initiated by hydrogen combustion were shown to interact with disturbance waves caused by off-design jet flow and to generate new wave structures in the combustor with nonpremixed combustion of flat hydrogen jets in a co-flow with air. This structure enhances mixing of fuel with oxidizer and intensifies chemical reactions.

Flat supersonic hydrogen jets were shown to form two combustion zones. Intense chemical reactions with heat release occur in the first zone, whereas the second zone exhibits slow hydrogen burning with the rate limited by mixing of fuel with oxidizer. Ignition delay can be reduced by directing fuel jets at some angle to the supersonic flow. The presence of water vapor or OH radicals in air promotes chemical reactions and reduces ignition delay. This should be taken into account when conducting experiments with the air of realistic composition.

A set of computer codes developed previously in CIAM for numerical simulations of supersonic turbulent flows of hydrogen–air mixture in channels was modified. The codes capabilities were extended to account for three-dimensional (3D) effects, wall boundary layer, and shock – boundary layer interaction. At present, the developed computational fluid dynamics (CFD) tools allow simulating the influence of the shape of fuel strut afterbody as well as the base region and recirculation zone behind the strut on mixing and combustion.

The set of computer codes is based on the averaged full Navier–Stokes equations or on their parabolized version. The problem formulation is completed by a differential equation for turbulent viscosity. The detailed schemes of chemical kinetics were used for simulating combustion processes. Numerical solutions are obtained using special finite-volume schemes, which are the modifications of S.K. Godunov scheme and its steady analog for supersonic flow. The modifications were focused on achieving a higher accuracy, providing a capability of working with multispecies flows and chemical reactions, and on developing implicit schemes. The latter issue is of particular importance for numerical simulation of viscous flows with chemical reactions.

For validating the mathematical models published experimental results were used. Experimental data obtained for simple experimental models were also invoked. Furthermore, the experimental research on CIAM test facility C-16 (Fig. 1) was performed with specially designed model injectors, struts and ducts.

Hydrogen ignition and flame stabilization in the base region and in the wake of fuel strut were investigated taking into account the detailed structure of the flow field. Particular attention was paid to the role of shock system in jet ignition and combustion in the duct. The detailed flow structure was studied and the conditions of oblique detonation shock generation were investigated taking into account the finite rates of chemical reactions. Flow structure at the entrance of the duct with combustion was analyzed. The influence of duct thermal throttling due to combustion and wall thermal conditions on the flow structure was studied. The main effects found in CFD investigations were confirmed by existing experimental data and by the results of experimental research performed in CIAM.

The presented direct comparison of computational and experimental results allowed to make the conclusion on the adequacy of mathematical models and on the sufficient accuracy of numerical methods.

Experimental investigations of supersonic hydrogen jet combustion with recording OH-radical radiation were performed in AIPEC. In the investigated range of parameters (flow Mach number from 1.2 to 1.6, total temperature from 1700 to 2100 K, hydrogen jet Mach number from 0.5 to 1.4), the equality of absolute velocities of fuel and oxidizer flows was found to be required for the most efficient combustion at co-flow injection. Temperature increase in disturbance waves enhances combustion. The dimensions, shape and location of the hydrogen flame front in the supersonic flow as well as dynamic factors influencing these parameters were determined. Due to significant turbulence in mixing layers the flame front was not distinctive. Artificial creation of disturbances in the flow through the use of non-symmetrical nozzles results in reduction of the ignition zone length and in increase of combustion efficiency in initial duct sections. The growth of co-flow air tempera-

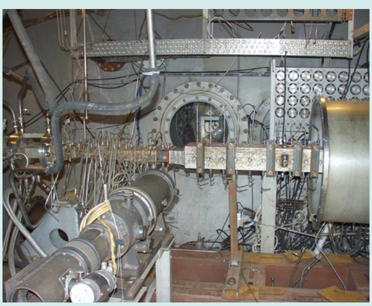


Figure 1: CIAM test facility C16V/K

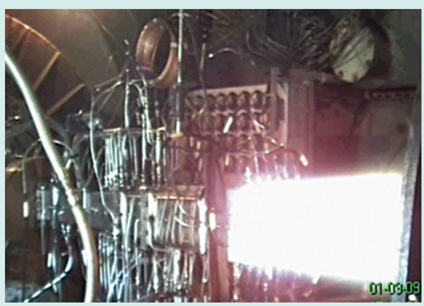


Figure 2: Experimental investigation of model chamber (combustor): flow Mach number 3–4; pressure 2,4 MPa; and temperature 1670 K

ture results in enhanced combustion intensity and reduced ignition zone length. When flow temperature increases from 1700 to 2100 K, ignition zone length decreases by 8*d*, where *d* is the hydrogen jet diameter.

Temperature fields in various regimes were studied in detail using optical method. The investigation of radial profiles of temperature has shown that hydrogen jet decreases the co-flow temperature by 14% on the length of 1*d*. In this regime, the length of the zone before beginning of intense burning was 21*d* from the nozzle location. In case when combustion does not occur at 40*d* intense cooling of the flow begins due to mixing with cold atmospheric air. Hydrogen combustion was shown to increase flow temperature even at a distance of 55*d*. The experiments have shown that the ignition delay attained a minimal value when velocities of hydrogen jet and co-flow air were close to each other. The temperature integral over duct cross section was shown to be similar for all three combustion regimes. The quantitative determination of temperature based on the measured integral radiation was not possible. It was only possible to perform qualitative estimation of temperature variation.

Experimental investigations of hydrogen burning in a model combustor with an individual strut have been carried out (Fig. 2). The model combustor has been developed. Combustor cross-section was a rectangle 40 × 100 mm at its entrance. After the strut, combustor cross-section increased; it became a rectangle 60 × 100 mm at exit. In so doing, the first version of fuel strut previously tested in free supersonic high-enthalpy stream was used. Sufficiently good ignition was obtained in the combustor at the operation mode with flow throttling at nozzle entrance.

A series of fire tests on the model combustor equipped with a single modified strut has been carried out. The purpose of the investigation was to determine hydrogen combustion characteristics at hydrogen feed through the strut.

As a result of the tests fulfilled, pressure distributions along the model combustor flow passage have been obtained. It followed from these distributions that pressure sharply increased just after the strut and then reduced as the flow-passage cross-section area increased.

The tests showed that the hydraulic resistance of leading-edge cooling channel was above the design value, and hydrogen flow rate in this channel was not sufficient for reliable operation of strut at the total temperature of incoming flow of 1650 K. The results obtained were taken into account when manufacturing a new lot of struts for the model combustor assembly.

The model combustor with strut lattice was updated: its cross section was modified to fulfill experimental investigations of strut lattice, and the number of model combustor sections has been increased.

The total area of injectors intended for hydrogen feed for impingement-jet cooling of strut leading edge was increased by a factor of 1.42. As computations showed, hydrogen flow rate for leading edge cooling is to be increased by 7%. To check the efficiency of taken measures, hydraulic tests of manufactured struts have been conducted. Gas dynamic computation of strut lattice inclination angle was carried out. The main requirement was that the front of oblique shock generated by the first strut hitting the subsequent ones had to be excluded. It was found that the struts had to be positioned symmetrically within the angle of 44°. The first strut had to be positioned in the vertex of this angle. With taking into account these data, the new section of the model combustor with 3 struts has been designed.

Technology tests showed that all updated systems operated normally. As a result, all test facility systems provided the required values of pressure, temperature and gas content at model combustor entrance. Experimental investigations of the model combustor with three struts were launched. The tests of strut lattice showed that good stabilization of burning in the combustor was achieved with the new strut design. Fuel struts of modified construction ensured normal operating process of the combustor in investigated range of total

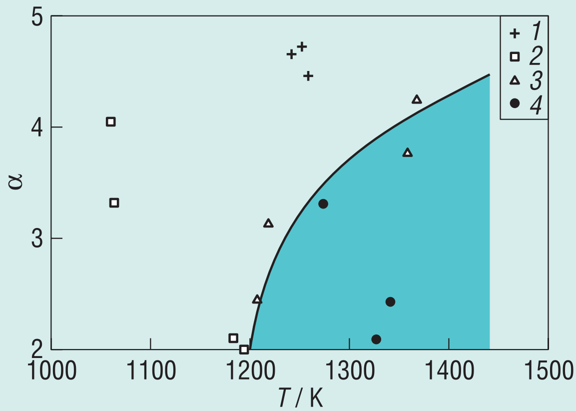


Figure 3: Example of steady burning area of hydrogen in model combustor in coordinates "total flow temperature – air-to-fuel equivalence ratio" (shown in blue): 1 — ignition and burning in subsonic flow; 2 — ignition absence in supersonic flow; 3 — ignition and burning along fuel jets boundaries in supersonic flow; and 4 — ignition and burning across the combustor in supersonic flow

temperature of air at combustor entrance from 1260 to 1629 K and air-to-fuel equivalence ratio from α = 2 to 7.74.

In addition, experimental investigations of the influence of supersonic-injector design parameters on combustion stabilization and ignition zone length have been carried out in CIAM. A set of experimental investigations of individual supersonic hydrogen jet burning in co-flow air were performed.

Self-ignition and flame stabilization conditions were determined. An example of steady burning area of hydrogen in coordinates "total flow temperature – ait-to-fuel equivalence ratio" is presented in the Fig. 3 by blue color.

Flame stabilization in a free flow downstream from the strut rather than at the strut edge was obtained experimentally. The comparison of the two variants of supersonic hydrogen injectors has shown the undeniable advantage of the injector with elliptical nozzle. This injector ensured hydrogen jet separation into two jets resulting in mixing and combustion enhancement. As a result, the elliptical nozzle ensured ignition zone length reduction by a factor of 1.5–2, and about twofold increase in the combustion zone width as compared to the variant with circular nozzle.

These experimental data agreed well with the data of computer simulations.

Obtained Results

– Mathematical models of hydrogen burning in scramjet-combustor supersonic flow were refined and verified by comparing with experimental data;

– Main relationships describing physical processes accompanying combustion of a single hydrogen jet were developed based on the results of experimental investigations;

– Experimental results of hydrogen burning in scramjet-combustor supersonic flow were obtained, which can be used for a real scramjet design;

– Experimental and theoretical investigations were generalized and recommendations for real scramjet design were developed.

Unmanned Spacecraft

List of Projects

In total, 11 projects were funded including 6 projects funded by ISTC Funding Parties and 5 projects funded by ISTC Partners.

#2513

"Designing of the Lander for Mars Landing"

(Mars Lander)

– Lavochkin Association, Khimki, Moscow reg., Russia

#2447

"Investigation of Lifetime Capabilities of Low-Power Hall Thruster"

(Lifetime for Low-Power Hall Thruster)

– Keldysh Research Center, Moscow, Russia

#0190

"Research to provide creation of recoverable vehicles with scientific and technological equipment for production of high-effective materials and preparations under zero-g conditions, derived from warheads and to be launched by RSM-40, RSM-50 rockets"

(Design of Recoverable Vehicles for Zero-g Experiments)

– Makeyev Design Bureau of State Rocket Center, Miass, Chelyabinsk reg., Russia

– NIIA (Automatics), Ekaterinburg, Sverdlovsk reg., Russia

– NPO Agat, Miass, Chelyabinsk reg., Russia

– Rudin Vladimir Nikolaevich

#1469

"Advanced Inflatable Re-entry Descent Development Technology (IRDT)"

(Inflatable Re-entry Technology)

– Lavochkin Association, Khimki, Moscow reg., Russia

#1469.2

"Advanced Inflatable Re-Entry and Descent Technology (IRDT) — Part 2"

(Inflatable Re-entry and Descent Technology- Part 2)

– Babakin Science and Research Space Center, Khimki, Moscow reg., Russia

#2836

"In-Orbit Demonstration Experiment with Inflatable and Rigidizable Structure"

(In-Orbit Experiment with Inflatable Solar Generator)

– Lavochkin Association, Khimki, Moscow reg., Russia (AEF)

Project Number:	#2513
Full and Short Title:	Designing of the Lander for Mars Landing **Mars Lander**
Tech Code / Area / Field:	SAT-UNM / Space, Aircraft and Surface Transportation / Unmanned Spacecraft
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding :	262,000 € (EU)
Commencement date:	October 1, 2004
Duration:	24 months, extended by 6 months
Leading Institute:	Lavochkin Association, Khimki, Moscow reg., Russia
Contact Information:	Phone: +7(495) 251-6744 Fax: +7 (495) 573-3595, 556 43 37 E-mail: npol@laspace.ru Website: http://www.laspace.ru
Supporting Institutes:	no
Collaborators:	Deutsches Zentrum für Luft- und Raumfahrt e. V. / Institut für Physik der Atmosphare, Wessling, Germany EADS Space Transportation (EADS ST GmbH), Bremen, Germany (Walther S.) EADS Space Transportation, Les Mureaux, France (Plotard P.)
Project Manager:	KONSTANTINOV Sergey Borisovich
Contact Information:	Phone: +7 (495) 573 9138 Fax: +7 (495) 573 9138 E-mail: konstantinov@laspace.ru
ISTC Senior Project Manager:	OSIPOV Evgeny
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (499) 978 01 10 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

Unmanned space vehicles are advanced guards, pioneers in exploration of near-Earth space and Solar System planets. No doubt, Solar System planets would be explored for a long time period mostly by means of unmanned space stations-laboratories, while the planets themselves would some time remain "a hard-to-reach area" for astronauts.

Landing Apparatus (LA) and the Mars Surface Station (MSS) are among the key space apparatus components in the "Small Mission to Mars with a Lander." According to the block of technical solutions imputed in them, creation of LA and MSS is one of the most complicated problems to be solved in the area of interplanetary space investigations.

Taking into account diversity of facilities worked up for launching and delivery of research stations to Mars this problem can be solved at lowest cost and with the maximum efficiency.

Project Objectives

The main objectives of the Project were:

• grounding of technical practicability of LA and MSS creation within the "Small Mission to Mars with a Lander" Project;

• formulation of the tentative design of LA–MSS specifying its functioning starting from its detachment from space ship and finishing with mission accomplishment;

• summing-up of requirements imposed on the LA–MSS systems and interfaces;

• defining technologies needed to implement the LA–MSS mission and appraisal of their accessibility; and

• investigations and elaboration of critical technologies at the modeling level.

Description of the Works

In investigations within the Project the experience based on technical solutions that have been elaborated in previous Soviet and Russian interplanetary missions were used.

The following basic tasks of the Project were formulated:

– development of the initial mission project and of the corresponding systems on the basis of payload model;

– specification of LA configuration and basic characteristics;

– specification of the entry, descent and landing system;

– specification of MSS and its subsystems;

– assessment of accompanying risks and critical technologies;

– formulation of the test program;

formulation of the work schedule; and

- assessment of Project cost.

Obtained Results

Accomplishment of the Project yielded the following results:

1. Mission analysis was performed (Tables 1 and 2).

2. The LA architecture was specified and grounded; among other things considered were various schemes of apparatus entry and descent in the atmosphere and landing systems (Figs. 1–8):

– the shape and sizes of the aerodynamic screen designed for braking in the atmosphere that provide the optimal weight ratio between the LA and MSS (the goal payload) were determined;

– parachute system parameters providing safe descent in the atmosphere were specified;

– the basic characteristics of the Inflatable Damper Device (IDD) ensuring the necessary conditions of apparatus landing on the surface were assessed; and

– the composition of basic systems and equipment of the MSS was specified; they comprised:

– thermal control system;

– power supply system;

Table 1: Results of an analysis of the "Demolander" mission (to be launched in 2011)

Parameter	Variants					
Launching concept	Target launching				Concurrent launching	
Launcher rocket	"Dnepr"		"Soyuz-2/Fregat"		"Arian-5"	
Main orbit	Low Reference Orbit(LRO) (H_{cr} = 300 km, i = 51.8°)		LRO (H_{cr} = 300 km, i = 51.8°)		Geo Stationary Launch Vehicle Transfer Orbit (GSTO)	
Intermediate orbit	High Elliptical Orbit (HEO) (H_α =50 000 km, i = 51.8°)		HEO (H_α =200 000 km, i = 51.8°)		HEO (H_α = 200 000 km, $i \approx 90°$)	
SA mass, kg	3 700		2 180		4 000	
Mass of concurrent payload (PL), kg	—		—		3 575	
SA mass at the Mars gravisphere, kg	911		1 727		2 420	
Prelanding trajectory	Transiting-Mars trajectory (TT)	Three-day orbit of Mars (MO)	TT	MO	TT	MO
SA mass on MO (T = 3 days), kg	410	679	750	1 282	1 020	1 803
Mass of LA at its entry in the atmosphere, kg	360	360	720	720	1 050	1 050
Velocity of entry in the atmosphere, m/s	5 700	5 000	5 700	5 000	5 700	5 000
AS diameter of LA, m	2.68	2.68	3.8	3.8	4.56	4.56
Mass of the orbital apparatus (OA) on MO (T = 3 days), kg	410	319	750	562	1 020	753
OA mass on MO (T = 1 day), kg	384	298	702	526	955	705
Mass of SI in OA, kg	64	—	300	190	500	300

Note: The data listed in the Table are calculated with no account taken of the possible aeromaneuver.

Table 2: Results of analysis of the mission variants (LA #2, to be launched in 2013 or 2014)

Parameter	Variants							
Launching concept	Target launching				Concurrent launching			
Launcher rocket	"Soyuz-2/Fregat"				"Arian-5"			
Main orbit	LRO (H_{cr} = 300 km, i = 51.8°)				GSTO			
Intermediate orbit	HEO (H_{α} = 200 000 km, i = 51.8°)				HEO (H_{α} = 200 000 км, $i \approx 90°$)			
SA mass, kg	2 180				4 500			
PL mass, kg	—				3 075			
Year of launch	2014		2013		2014		2013	
Transfer trajectory type	1st half-circuit (arrival two weeks before the dust storms)		2nd half-circuit (dust storms at the arrival)		1st half-circuit (arrival two weeks before dust storms)		2nd circuit (dust storms at the arrival)	
SA mass at the Mars gravisphere, kg	1 680		1 688		2638		2 655	
Prelanding trajectory	TT	MO	TT	MO	TT	MO	TT	MO
SA mass on the MO (T = 3 days), kg	458	—	575	1 172	536	—	727	1 643
Mass of LA at its detachment, kg	860	—	860	860	1 320	—	1 320	1 320
Mass of LA at its entry in the atmosphere, kg	850	—	850	850	1 300	—	1 300	1 300
Velocity of entry into the atmosphere, m/s	6 550	—	6 020	5 000	6 550	—	6 020	5 000
AS diameter in LA, m	3.8	—	3.8	3.8	4.56	—	4.56	4.56
OA mass on the MO (T = 3 days), kg	458	—	575	312	536	—	727	323
OA mass on the MO (T = 1 day), kg	428	—	538	292	501	—	680	302
SI mass in the OA, kg	76	—	139	– 60	100	—	260	– 50

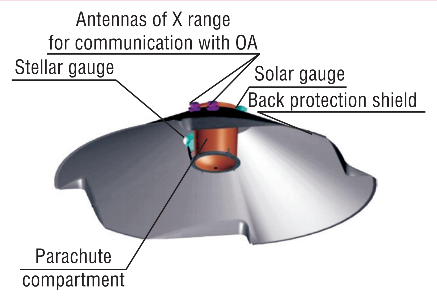


Figure 1: Launch apparatus configuration

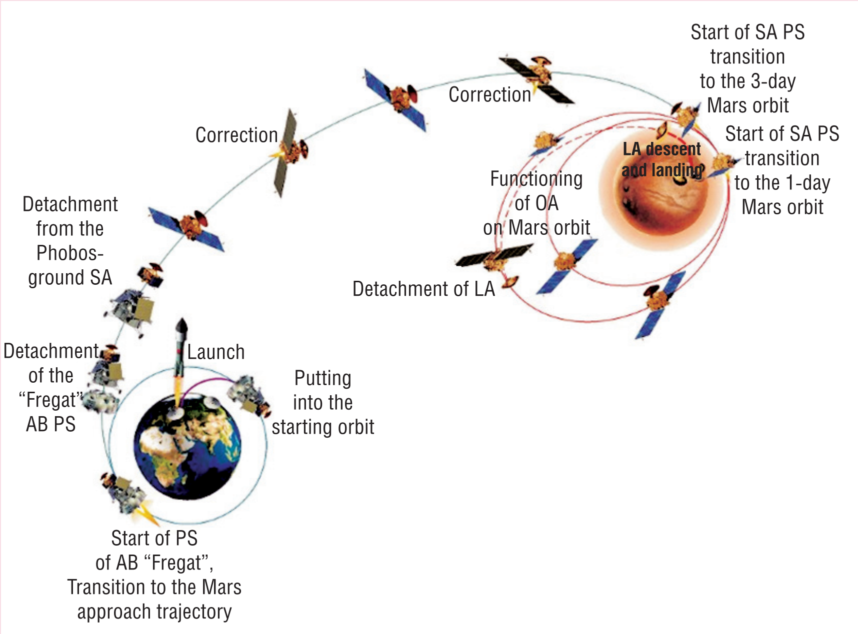


Figure 2: Mission scheme: EMT–MO variant

– radio complex;

– governing block/onboard computer;

– construction and mechanisms; and

– scientific instruments (SI).

– parameters of the parachute system used in LA–MSS descent in the atmosphere were assessed;

– basic characteristics of the IDD that warrants the needed conditions at landing on the surface were evaluated.

The basic systems and equipment of the MSS were analyzed and their composition was determined; it included:

– thermal control system;

– power supply system;

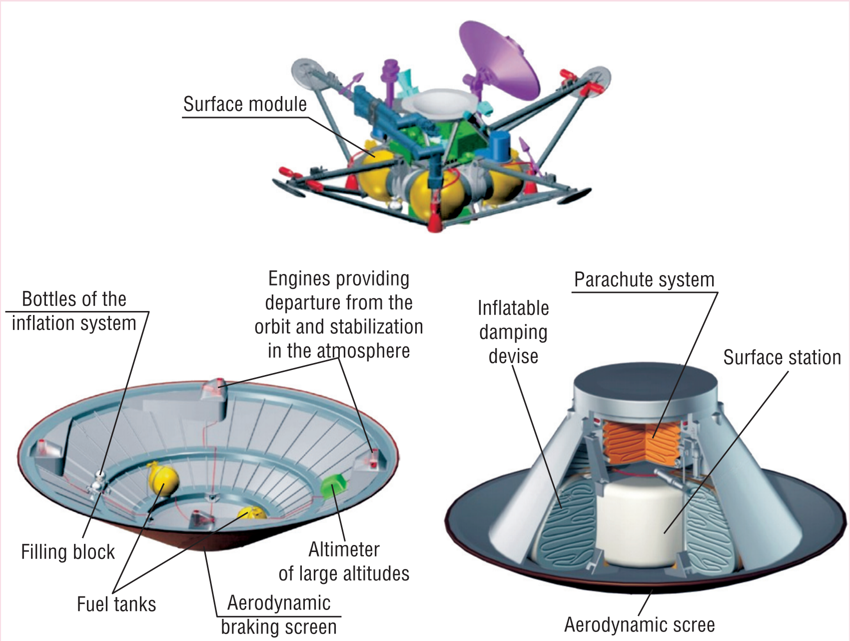


Figure 3: Demolander configuration

– radio complex;

– control block/ Onboard Computer;

– construction and Mechanisms; and

– scientific instruments.

2. The Mars LA architecture was specified and grounded, various schemes of atmosphere entry and of descent and landing systems were considered and analyzed:

– The shape and sizes of the aerodynamic screen applied at the entry in atmosphere that provide the optimal weight ratio between the landing apparatus and surface station (desired payload) were determined;

– Parachute system parameters used in descent in the atmosphere were assessed;

– The basic characteristics of the IDD that provides the conditions needed to safely land the apparatus on the ground were evaluated;

– The composition of the basic MSS systems and equipment were analyzed, they included:

– thermal control system;

– power supply system;

– radio complex;

– control block / onboard computer;

– construction and mechanisms; and

– scientific Instruments.

3. The basic parameters the LA–MSS subsystems (including information about the prototypes and succession of the equipment used) were assessed.

4. The loads acting on LA at all stages of its functioning were analyzed:

– analysis of mechanical loads; and

– analysis of heat loads

5. Interfaces were specified for:

– Surface Station / Entry System and Landing System; and

– MSS / Orbital Apparatus.

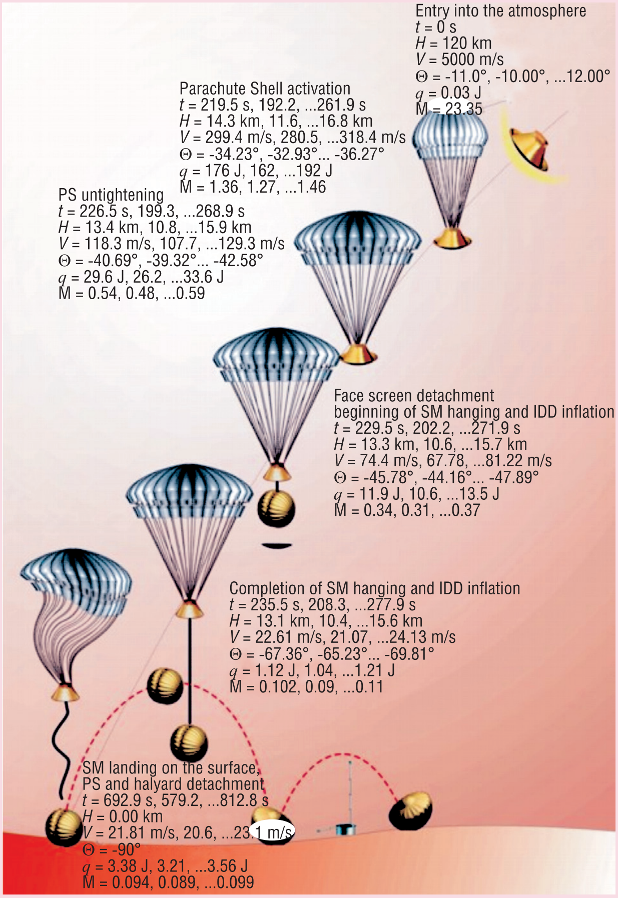


Figure 4: Scheme of MSS descent on the Mars ground

6. The major drawings of LA–MSS were elaborated for:

– configuration at launching;

– configuration at atmosphere entry and descent; and

– landing configuration.

7. Summaries of the system operation parameters at all mission implementation stages were elaborated:

– mass summary;

– inertia characteristics;

– summary of electro- and power consumption; and

– the amount of transmitted/received information.

8. The schedule and methodology of the work performance were worked out; they included:

– general schedule;

– prototyping and testing philosophy; and

– formulation of the requirements imposed on the test and assembling facilities.

9. Preliminary analysis of the risks and philosophy of safety provision was performed.

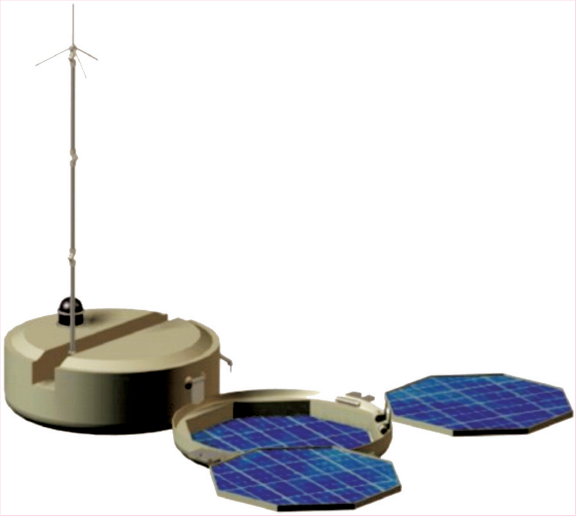


Figure 5: Mars surface station

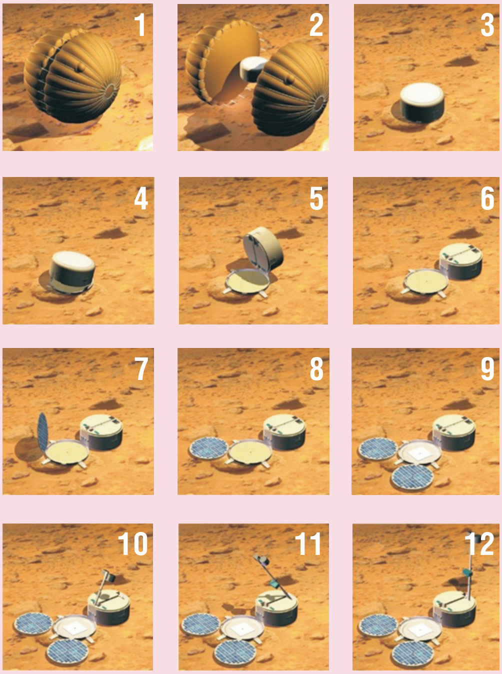


Figure 6: Putting of the MSS in its working position

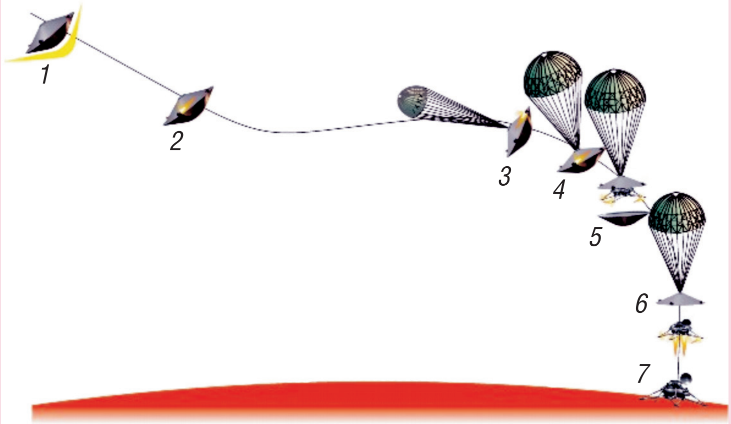


Figure 7: Scheme of LA descent

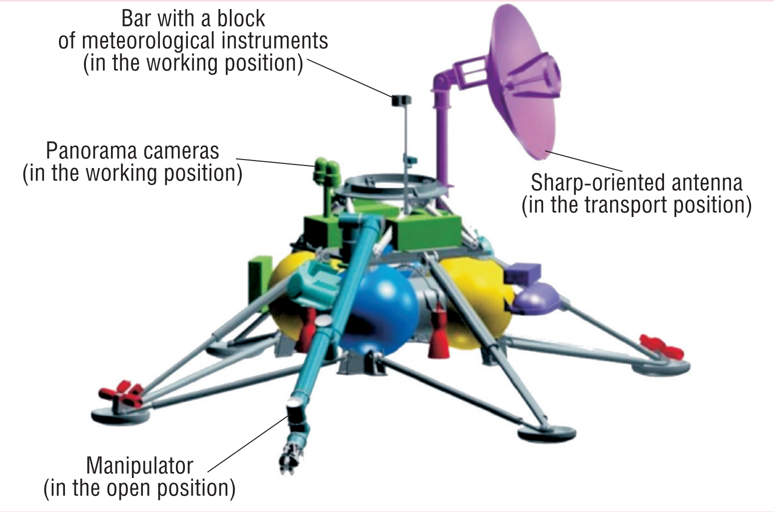


Figure 8: Demolander construction

10. Technologies needed to mission realization and their accessibility were ascertained. Critical technologies were developed at the modeling level.
All the tasks formulated in the Project were successfully accomplished completely. As a result, a tentative project of the Mars LA was elaborated. The experience gained in working out of unmanned space vehicles was intensely used in the course of Project implementation.

Most of the technical solutions applied were typical and checked in previous missions. Some technical solutions (aerodynamic screen detachment, variants of the construction of adapter fixing (or detaching) of the landing and orbital apparatus) were redesigned.

Project Number:	#2447
Full and Short Title:	Investigation of lifetime capabilities of low power Hall thruster **Lifetime for Low-Power Hall Thruster**
Tech Code / Area / Field:	SAT-UNM / Space, Aircraft and Surface Transportation / Unmanned Spacecraft
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$300,000 (US)
Commencement date:	August 1, 2004
Duration:	36 months
Leading Institute:	Federal State Unitary Enterprise "Keldysh Research Center", Moscow 125438, Onezhskaya 8, Russia
Contact Information:	Phone: +7 (495) 456 64 45 Fax: +7 (495) 456 82 28 E-mail: kerc@elnet.msk.ru Website: http://www.kerc.msk.ru
Supporting Institutes:	No
Collaborators:	NASA (National Aeronautics and Space Administration) John H. Glenn Research Center, Cleveland, OH 44135-3191, 21000 Brookpark Road, Mail Stop 86-15, USA
Project Manager:	GORSHKOV Oleg Anatol'evich
Contact Information:	Phone: +7 (495) 456 64 65 Fax: +7 (495) 456 82 28 E-mail: kercgor@dol.ru
ISTC Senior Project Manager:	RYZHOVA Tatiana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (499) 978 36 03 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

Nowadays electric propulsion systems (EPS) find wider application on-board spacecraft (SC). This tendency is connected with progress in development of on-board power systems and increased complexity of space missions. Such undoubted advantages as high level of output parameters (for example, specific impulse of EPS can be an order of magnitude higher than that of conventional low-thrust liquid propulsion systems (LPS)), small mass and overall characteristics as well as the simplicity of control make an actual EPS application perspective.

The forecasts indicate the increase of the share of small SC for scientific and commercial applications in the future. This circumstance arises from fast progress in the field of miniaturization of on-board electron equipment and stimulates the development of low-power electric propulsion (EP) with power from 100 to 300 W. The advantages of low-power EP are small mass and overall characteristics, as well as low power consumption.

Among the low-power EP, Hall effect thrusters (HET) are considered as the most advanced. The principle of HET operation is based on ionization and acceleration of working gas atoms in the crossed $E \times B$ fields. Ion flow neutralization is realized via the cathode-compensator that is a hollow cathode. Gas flow ionization is implemented by the electrons moving from cathode to anode along the complex quasi-closed cyclic trajectories. The simplicity of design and control, high output characteristics made it possible for HET to take an important place among the on-board equipment.

Such countries as USA, Russia, France, Italy, Germany, and Japan are actively involved in development and adoption of that kind of thrusters. One of the crucial problems of low-power HET is to ensure the required life. The task-oriented investigations of lifetime capabilities of low-power HET have not virtually been carried out in the world up to now, and published figures bear the estimated nature and do not exceed 1000 h.

Project Objectives

The Project objective was to solve the key problems of attaining long lifetime for low-power Hall thrusters and to develop a low-power HET (100–300 W) with the lifetime up to 3000 h. This objective should be achieved both by selection of wear-resistant materials consisting the walls of the discharge channel and optimization of thruster design, especially the magnetic field configuration.

Description of the Works

The most critical process from the point of view of HET lifetime restriction is sputtering of the discharge channel walls by the accelerated ions. At the initial stage of the Project, a data of sputtering of single-phase ceramics were collected. The list of observed materials includes: pyrolytic boron nitride; hot-pressed boron nitride and multiphase ceramics, formed in systems boron nitride – silicon dioxide; boron nitride – zirconium dioxide; silicon nitride – silicon dioxide; boron nitride – silicon nitride, and some other materials. The conclusion was made that materials with high contents of boron nitride are most perspective and materials on the basis of a composition boron nitride – silicon nitride and boron nitride – boron oxide are more perspective for practical use, rather than compositions from boron nitride and silicon dioxide.

The method and experimental installation for investigation of material sputtering at ion bombardment in plasma plume of HET was designed. The investigation of sputtering rate of eight different samples was carried out: alumina and titanium carbide composite, alumina, boron carbide, boron nitride, silicon nitride, boron nitride and silicon oxide composite, silicon carbide and silicon nitride composite, and molybdenum.

The existing approaches to low-power HET development were critically analyzed. With taking into account the specific features of magnetic field topology, the approach to HET scaling was developed which provides the highest level of lifetime characteristics. On the base of calculations of the magnetic system, the requirements specification was created and thruster model was manufactured.

Preliminary investigations of the output parameters of the HET model were conducted. During these experiments, the map of main parameters was taken at different propellant mass flow rates and discharge voltages. Then, a set of thruster modifications was manufactured and tested to improve the thruster performance. The most progress of the performance characteristics was achieved after optimizing the magnetic system and the length of the discharge chamber. In discharge power range 150–300 W, the anode efficiency was increased from 20%–28% to 25%–36% and the anode specific impulse was increased on average by 100–150 s. The most effective thruster work was achieved at discharge power 100–350 W.

The set of experiments with the purpose of validating the applicability of the materials in the design of discharge chamber from the point of view of both providing the high thruster performance and resistance to thermal impact of discharge plasma was performed. As a part of discharge chamber, the following materials were tested: the composite of boron nitride and boron oxide, prepared using hot pressing technology; three materials prepared using the technology of self-propagating high-temperature synthesis: boron nitride; the composite of boron nitride and silicon oxide; and the composite of boron nitride and zirconium oxide. As a result of investigations, the two materials prepared using hot pressing technology, BGP-10 and boron nitride, were selected for further experiments.

The shortened life-test of the thruster model was conducted, the mathematical prediction of ceramic erosion was made, and the optimal material and operating modes were chosen. It was shown that among the investigated materials, the most perspective was the boron nitride prepared using hot pressing technology.

During experimental tests of different thruster modifications, there was a need to evaluate plasma plume characteristics both to discover the reasons of the performance modifications and to evaluate the wall sputtering rate. Thereto, development of system for diagnostics of structure and properties of a plasma plume was conducted.

The diagnostics subsystem intended to reveal the charge structure of the plume included the device of ions separation, which allowed measuring the relative shares of two- and three-fold ionized particles in the ion beam. The results of measurements allowed the influence of two- and three-charged ions on the thruster efficiency to be clarified.

Also, fabrication and tests of system for diagnostics of angular and energetic distribution of plasma plume ions were performed. It was shown that the sensitivity of the system was sufficient for investigations of the plasma flow with ion current density of 0.1 mA/cm2 typical for low-power Hall thrusters. A set of experiments with measurements of angular and energy ion distributions in the plasma flow was conducted during thruster design modifications. The analysis of experimental results has shown that the strongest distinction of the optimized thruster was the narrower ion energy distribution. The conclusion was made that this was the consequence of the increase of the factor of ion acceleration efficiency.

Both the experiments with magnetic mass-analyzer and retarding potential analyzer showed that relative content of two- and three-charged Xenon ions at discharge voltage 200–400 V was not high enough to influence the thruster's output performance. More important information could be obtained from the analysis of sputtered atoms and ions in the plasma plume. It was noted that relative content of these atoms and ions may become a criterion that characterizes the sputtering rate of discharge chamber interior. The spectrographic diagnostic system containing optical and registration systems was created for conducting these investigations. Experiments showed that the most intense radiation was from Boron doublet at 249.68, 249.77 nm wavelength. Measurements of sputtered materials lines intensities showed that resolution and sensitivity of spectrographic diagnostic system optical subsystem were enough for investigation of dependence of the sputtering rate on discharge power and voltage. A set of experiments, devoted to systematic investigation of ceramic sputtering rate at different thruster operation modes was conducted. These experiments helped choosing the optimum operation modes and magnetic field topologies to provide long lifetime of Hall thrusters. As a result, the optimal operation mode at nominal discharge power of 200 W was found and works of thruster model preparation for 500-hour life-test were finished.

As a final step, the works on experimental evaluation of thruster lifetime characteristics were performed. The total thruster operation time was 507 h. To the moment of life test ending, the thrust was 11 ± 0.5 mN, anode specific impulse 1200 ± 50 s, and anode efficiency 34% ± 5%. In the course of periodical measurements of the ceramic surface profiles, the data were obtained necessary for mathematical prediction of the thruster lifetime and forecast of ceramic profiles were made for periods of 1000, 2000, and 3000 h. As a result of conducted tests and predictions, the conclusion was made that the predicted thruster-model lifetime was not less than 3000 h.

Obtained Results

• The installation for an experimental research of material resistance to ion-beam sputtering has been created. The most perspective ceramic materials for use in the structure of low-power Hall thrusters with long lifetime were determined. These are ceramics with the high contents of boron manufactured using hot pressing technologies. Among the investigated materials, the best characteristics were shown by ceramics BN05 representing a composite of boron nitride and boron oxide.

• The spectroscopic method was developed and experimental installation for investigations of sputtering rate of ceramic walls of the HET discharge chamber was created. The main advantage of the method is the opportunity of prompt estimation of the sputtering rate and choosing of the optimum operation

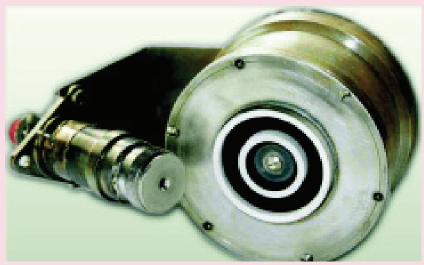


Figure 1: The HET KM-32 appearance

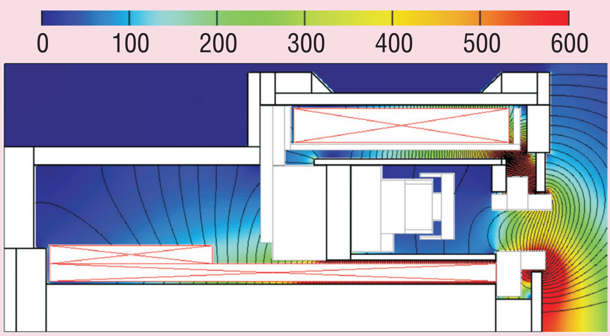


Figure 2: The HET KM-32 magnetic field configuration

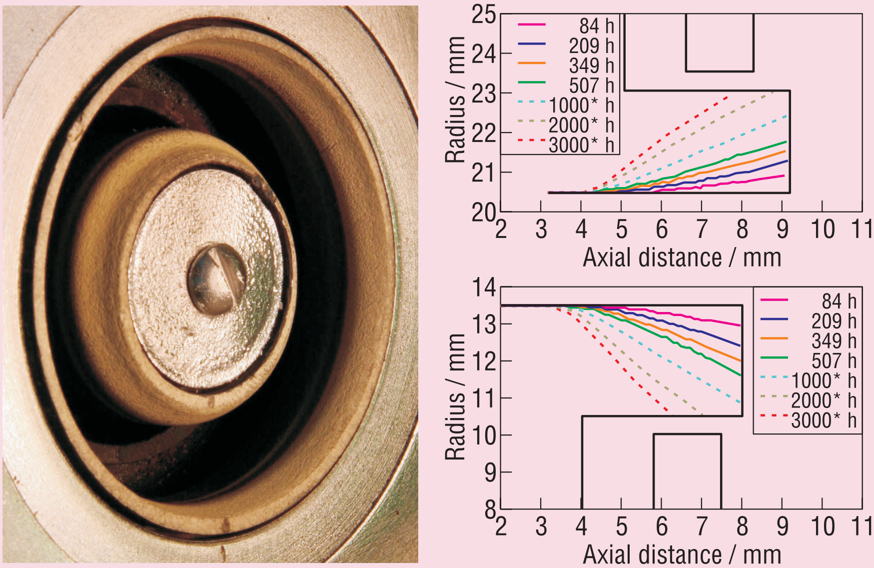


Figure 3: Measured and predicted surface profiles of the discharge channel walls

mode from the point of view of maintenance of the maximal lifetime.

• The HET laboratory model with nominal power of 200 W, thrust of 11 mN, anode specific impulse of 1200 s, and anode efficiency of 34% has been developed (Figs. 1 to 3).

• The 500-hour life test of the low-power HET was carried out. During the test, the Hall thruster has shown steady work. By results of the carried out tests, the settlement-theoretical analysis was performed. It has shown that the full predicted lifetime of the thruster makes 3000 h.

Project Number:	#0190
Full and Short Title:	Research to provide creation of recoverable vehicles with scientific and technological equipment for production of high-effective materials and preparations under zero-g conditions, derived from warheads and to be launched by RSM-40, RSM-50 rockets **Design of Recoverable Vehicles for Zero-g Experiments**
Tech Code / Area / Field:	SAT-UNM / Space, Aircraft and Surface Transportation / Unmanned Spacecraft
Status:	Project completed
Technology Development Phase:	Technology demonstration
Allocated Funding:	$498,000 (JP)
Commencement date:	July 1, 1995
Duration:	12 months
Leading Institute:	Makeyev Design Bureau of State Rocket Center, Miass, Chelyabinsk reg., Russia
Contact Information:	Phone: +7 (3513) 28 63 33 Fax: +7 (3513) 56 61 91, 24 12 33 E-mail: src@makeyev.ru Website: http://www.makeyev.ru
Supporting Institutes:	NIIA (Automatics), Ekaterinburg, Sverdlovsk reg., Russia NPO Agat, Miass, Chelyabinsk reg., Russia
Collaborators:	NASDA, Tokyo, Japan Rocket System Corporation (RSC), Tokyo, Japan
Project Manager:	RUDIN Vladimir Nikolaevich
Contact Information:	Phone: +7 (3513) 52 61 05, 52 63 70 Fax: +7 (3513) 55 22 91
ISTC Senior Project Manager:	NAGAI H.
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (495) 982 32 01 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

Design and production of round-trip space vehicles would make it possible to perform, with the aid of scientific and technological equipment, experiments, synthesize high-efficiency medications, make superpure semiconductor crystals, special alloys, etc. under conditions of zero gravity, that is, to implement the work which cannot be done so far under ground Earth conditions. The problem is solved in the Project with the use of the available developments and technologies incorporated in Navy RSM-40 and RSM-50 missiles which no longer serve as launchers for warheads.

Project Objectives

The Project objectives concerned elaboration of a recoverable space apparatus (RSA) to be used in production of materials under microgravity conditions and launched with modified ballistic RSM-40 and RSM-50 missiles.

Description of the Works

The work performed in the course of Project implementation included:

• investigations aimed at RSA development based on the warhead casings taken out of armament; they are performed with the purpose of arranging in the casings scientific and technology equipment with as large as possible weight and volume, provided that instruments of each particular type are mounted so that the rearrangement of a recoverable space vehicle is insignificant;

• development of the onboard measurement complex intended to provide control of the scientific instrument equipment and continuous monitoring of telemetric information during the flight in amount sufficient to analyze the conditions under which the experiment is conducted, including parameters of detachment from the launcher, microgravity level and time of its onset, temperature regimes, and loads at the atmospheric flight stage during descent;

• exploration of the possibility of incorporating in the onboard measurement complex a control radio-system that provides governing of the scientific equipment operation in the course of flight from Earth and also a television system to transmit videoinformation (if the scientific instrumentation is equipped with a videocamera);

• modification of the “Volna” launcher and submarine systems to provide trajectories with a time duration allotted to experiment of 15 or 30 min and microgravity level of $(10^{-4}–10^{-5})g$, and elaboration of RSA with provision of its workability on any of its possible trajectories;

• modification of the rocket and submarine systems to provide their minimum alterations which would allow all the work to be done directly at the technical position with no their transfer back to the producer-factory; and

• design of the recovery system with allowance for “soft” flying apparatus landing to save integrity of the RSA systems after the flight, including the scientific equipment, for their possible use in subsequent launches.

Obtained Results

The investigations performed furnished the following main results that pertain to the basic RSA version and ensure short duration of and low expenditures for its creation and preparation to launch:

• an RSA construction was designed on the basis of the warhead casings taken out of exploitation and passed the full processing cycle;

• RSA admits arrangement of scientific and technological equipment in the form of a single module of up to 200 kg in weight and 250 dm^3 in volume;

• microgravity duration in the course of experiment is of up to 30 min, microgravity level is up to $(10^{-4}–10^{-5})g$ for the flight trajectories: Pacific Ocean – Kamchatka Peninsula and Barents Sea – Kamchatka Peninsula;

• the onboard RSA measurement complex provides telemetric on-line monitoring of the experiment conditions, including the microgravity level and onset time, temperature regimes, and overloads;

• a control instrumentation complex was elaborated to control operation of the RSA systems and scientific and technological equipment. The complex functions in the automated regime;

• temperature regimes of the scientific and technology equipment is provided with a thermal stabilization system that supports the needed temperature level to within 5 ^{o}C;

• the RSA safe landing system was elaborated; it is based on a parachute system with the start devices and warrants safe RSA landing at descent velocity not exceeding 10 m/s and possible use of a number of its components, including scientific instrumentation, in subsequent launches;

• the search scheme, which uses radio-beacons and ensures quick (up to 3 h) finding of the apparatus after its landing, was worked out;

• the order and conditions of launch preparation and implementation with the use of the existing facilities of the producing factory and of the specially designed technology equipment and a set of control and measurement instruments were elaborated; and

• the project documentation on the RSA design and its systems and on rocket modification was issued. It allows one to proceed with the development of technical design documentation and realization of a launch with particular scientific and technology equipment.

Project Number:	#1469
Full and Short Title:	Advanced Inflatable Re-entry Descent Development Technology (IRDT) **Inflatable Re-entry Technology**
Tech Code / Area / Field:	SAT-UNM / Space, Aircraft and Surface Transportation / Unmanned Spacecraft
Status:	Project completed
Technology Development Phase:	3/Technology development, 4/Technology demonstration
Allocated Funding:	$750,000 + 543,922 € (EU: 543,922 €, Other Funding Sources: $750,000)
Commencement date:	May 1, 1999
Duration:	21 months
Leading Institute:	Lavochkin Association, Khimki, Moscow region
Contact Information:	Phone: +7 (495) 251 67 44 Fax: +7 (495) 573-35 95, 556 43 37 Website: http://www.laspace.ru
Supporting Institutes:	No
Collaborators:	DaimlerChrysler Aerospace, Bremen, Germany European Space Agency / European Space and Technology Center, Noordwijk, Netherlands

Project Number:	#1469.2
Full and Short Title:	Advanced Inflatable Re-Entry and Descent Technology (IRDT) – Part 2 **Inflatable Re-entry and Descent Technology- Part 2**
Tech Code / Area / Field:	SAT-UNM / Space, Aircraft and Surface Transportation / Unmanned Spacecraft
Status:	Project completed
Technology Development Phase:	Applied research
Allocated Funding :	$90,000 + 516,760 € (EU: 516,760 €, Other Funding Sources: $90,000)
Commencement date:	December 1, 2000
Duration:	15 months, extended by 12 months
Leading Institute:	Lavochkin Association, Khimki, Moscow region
Contact Information:	Phone: +7 (495) 251 67 44 Fax: +7 (495) 573-35 95, 556 43 37 Website: http://www.laspace.ru

Supporting Institutes:	No
Collaborators:	Astrium Space Infrastructure, Bremen, Germany European Space Agency / European Space and Technology Center, Noordwijk, The Netherlands
Project Manager:	ALEXASHKIN Sergey Nikolaevich
Contact Information:	Phone: +7 (495) 575 52 12 Fax: +7 (495) 573 25 84 E-mail: alexashkin@berc.rssi.ru, tatall@berc.rci.ru
ISTC Senior Project Manager:	NIETZOLD Dieter
Contact Information:	Phone: +7 (495) 982 32 00 Fax: +7 (499) 982 32 01 E-mail: istcinfo@istc.ru
ISTC Website:	http://www.istc.ru

Background

Round trips of space vehicles and payloads from space necessitate the use of complicated and expansive technologies of apparatus descent in the atmosphere, such as thermal shielding and specially elaborated parachutes. Traditional systems of reentry into atmosphere are in most cases too heavy and expensive for launchers that put into orbit mostly satellites and other payload. Moreover, a low weight, reasonable cost, and high efficiency of the reentry systems are necessary requirements in developing multiple-start launchers.

The atmosphere entry problem can be solved with the aid of inflatable constructions, specifically, by means of the Inflatable Reentry Descent Technology (IRDT).

The IRDT system is in a folded state and inactive at the launch stage. It opens only immediately before the reentry into the atmosphere in order to protect the descending payload against burning in the atmosphere and destruction at impingement on the Earth surface.

The Inflatable Reentry Descent Device (IRDD) replaces the thermal shield, parachute system, and the landing shock damper.

The inflatable device cushion is inflated after the orbit escape maneuver is accomplished, the vehicle enters the atmosphere, decelerates aerodynamically, and lands at the preset area.

Construction materials of thermal IRDT protection were developed by Russian scientists for the Mars exploration program.

Project Objectives

The objective of the Project was to confirm the feasibility of application of pneumatic decelerating reentry devices with flexible thermal protection to descend payloads from space to Earth.

The main task of the mission was demonstration of the technologies that pertain to the use of inflatable reentry system to descend space objects in the Earth atmosphere (Figs. 1 and 2). The following opportunities were demonstrated:

– placing IRDD in a compact volume;

– operation of the system of opening and inflating the IRDD cushion in space;

– preservation of the IRDD integrity after storing in the folded state;

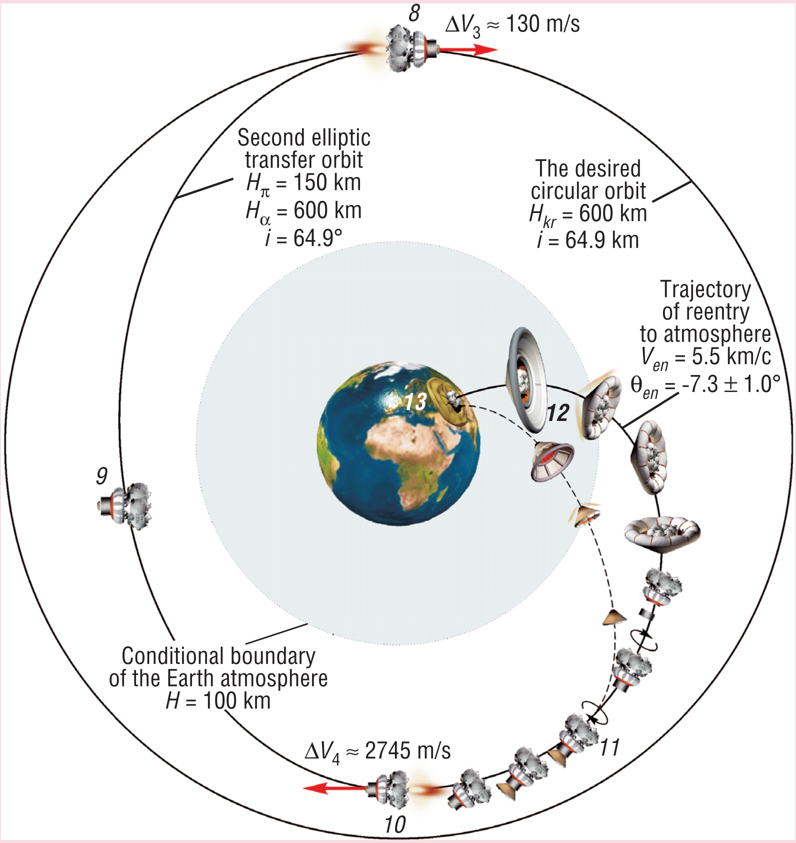


Figure 1: Descent schematic: 8 — displacement of the head block (HB) with the aid of the three-dimensional (3D) start of the propulsion system (PS) to the second transfer orbit with the perigee altitude of about 160 km, that makes it possible further on to perform reentry to atmosphere at a velocity not exceeding 5.5 km/s, the representative velocity of about 130 m/s is attained after the 3D PS start; 9 — passive flight along the second transfer orbit for about 45 min; 10 — booster PS start to form the reentry orbit with preset object velocity and entry angle, the process lasts about 490 s, the representative velocity of ~ 2745 m/s is attained during this period of time; 11 — quieting and spinning of booster; 12 — reentry of the demonstrator and booster into atmosphere, booster deceleration; and 13 — IRDD actuating, landing

– efficiency of thermal IRDD protection under the highest heat fluxes;

– preservation of the shape of a descending apparatus with the IRDD affected by the highest trajectory velocity heads;

– proper operation of the IRDD inflation system throughout the time period of apparatus descent in the atmosphere;

– proper functioning of the shock damper system that provides a preset level of shock

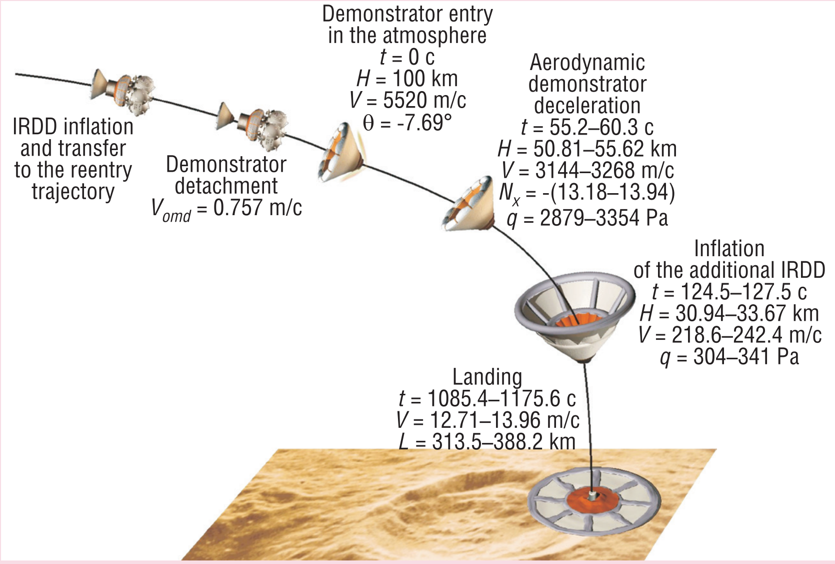


Figure 2: Descent and landing schematic

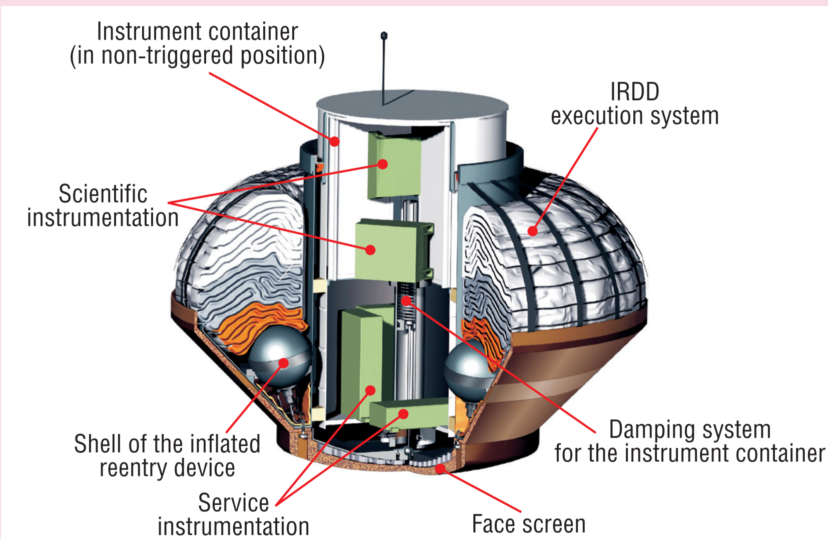


Figure 3: Demonstrator in the folded state

Figure 4: Open demonstrator

loads at impingement on the Earth surface; and

– efficiency of the system used to search for the apparatus after its landing.

Description of the Works

All the design operations formulated in the Project and needed to create the device were completed. One specimen to be used in flight and several experimental devices were fabricated. The thermal protection shielding was tested both on the experimental models and on a full-scale model (Fig. 3). Full-scale aerodynamic tests and ground experiments needed to qualify the device and its components were accomplished (Figs. 4–6), the certificates necessary for the flight test were obtained.

Obtained Results

Launcher rocket "Soyuz" with booster "Fregat" and payload imitator onboard was launched on February 9, 2000 from the cosmodrom "Baikonur" (Fig. 7). The European Space Agency and International Company DASA have used this flight as a first trial of practical IRDT application (Fig. 8). The booster "Fregat" was also equipped with an IRDD which demonstrated opportunities offered by IRDT.

"Demonstrator" and "Fregat" descent was monitored to a certain time instant with ground watching facilities (Figs. 9–11). Their own transmitting devices were to be on after the maximum heat fluxes were passed over, while radio-beacons should be activated after the objects touched the ground. No signals from the transmitting devices and radio-beacons were detected. The search for the returned objects was worsened by snow fall in the precalculated landing area in Kazakhstan (Fig. 12). The "Demonstrator" was found on the 8th day only. Its landing was abnormal (the second IRDD cascade lost its tightness), the descending apparatus dropped onto the Earth surface at a velocity of 60 m/s. Nonetheless, it luckily appeared possible to read and process the onboard recorded information.

Indirect data provided evidence of successful inflation of the first and second IRDD cascades at "Fregate" at the calculated trajectory points. Thus, feasibility of payload descent from space with the use of IRDD was confirmed. This new technology is expected to be successfully applied in space programs in which cheap reentry and return from space and landing are needed. For example, they can be used for payload return from the International Space Station (ISS), reentry of the operable upper rocket stages, and landing at planets with atmosphere.

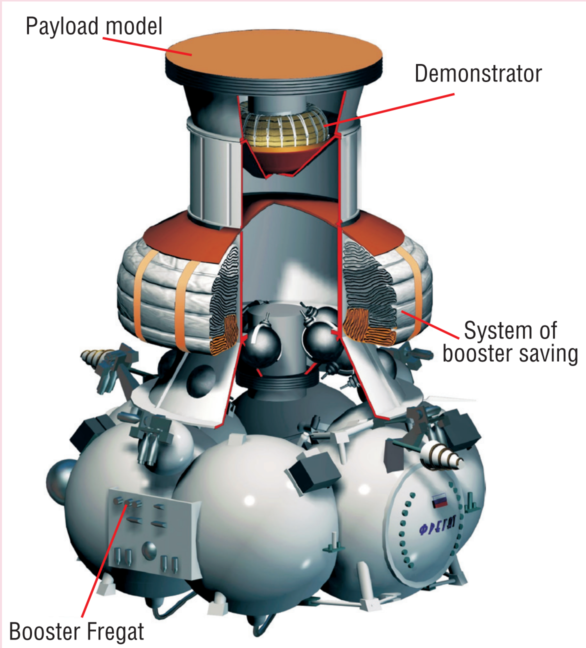


Figure 5: Start position

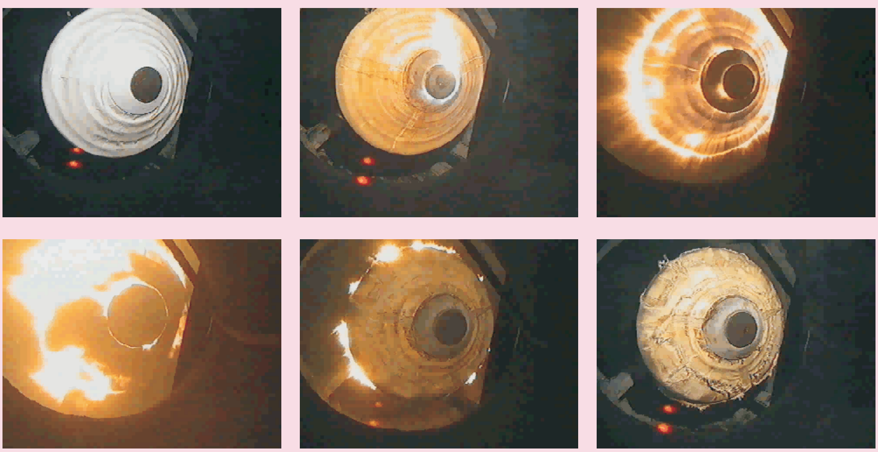


Figure 6: Thermal tests

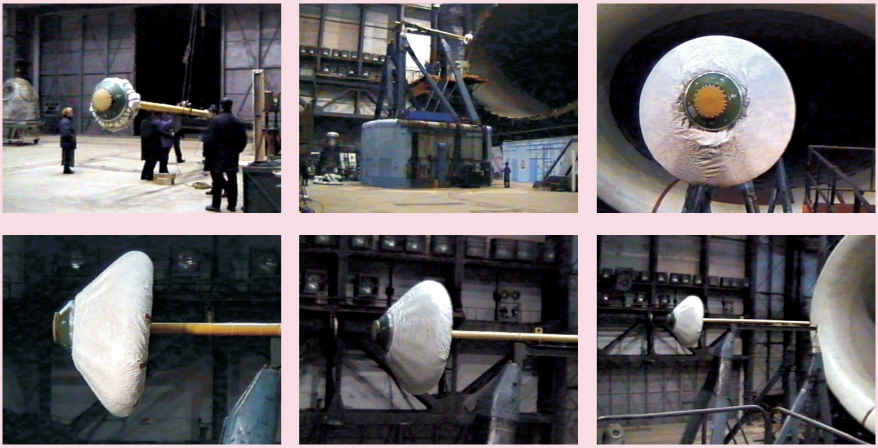
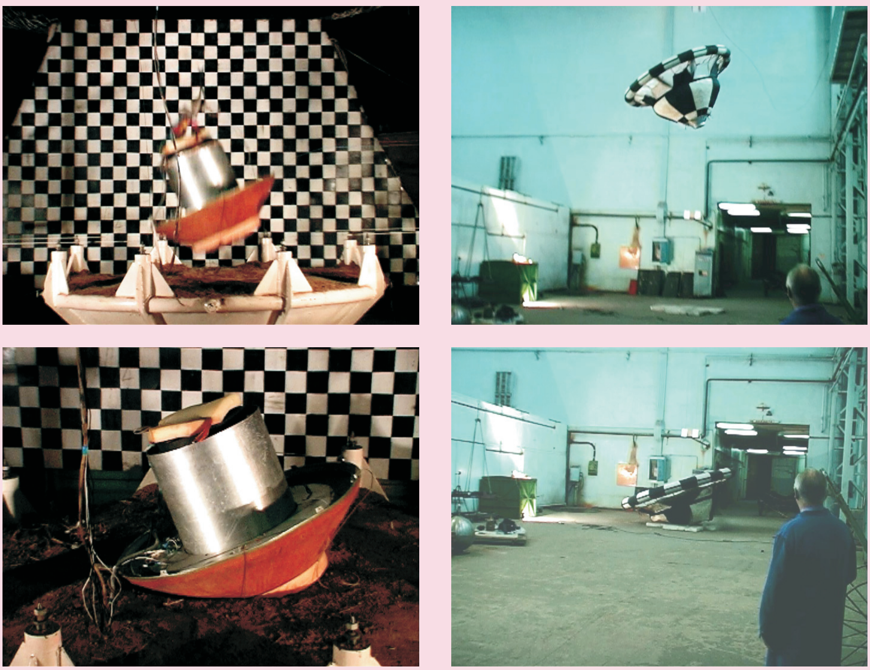


Figure 7: Tests in a wind tunnel. Shell stability studies



(*a*) (*b*)

Figure 8: Damping system studies (a) and drop tests (b)

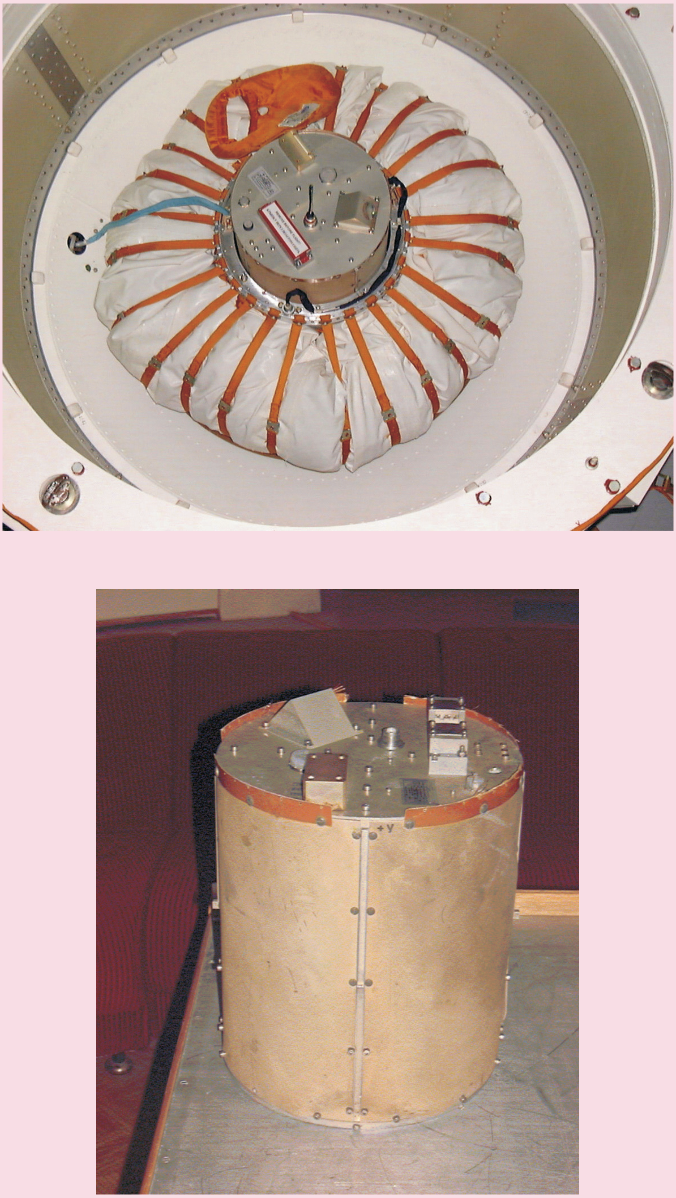


Figure 9: The DASA scientific instrument block extracted

Figure 10: Preparation of the launch, launch at Baikonur

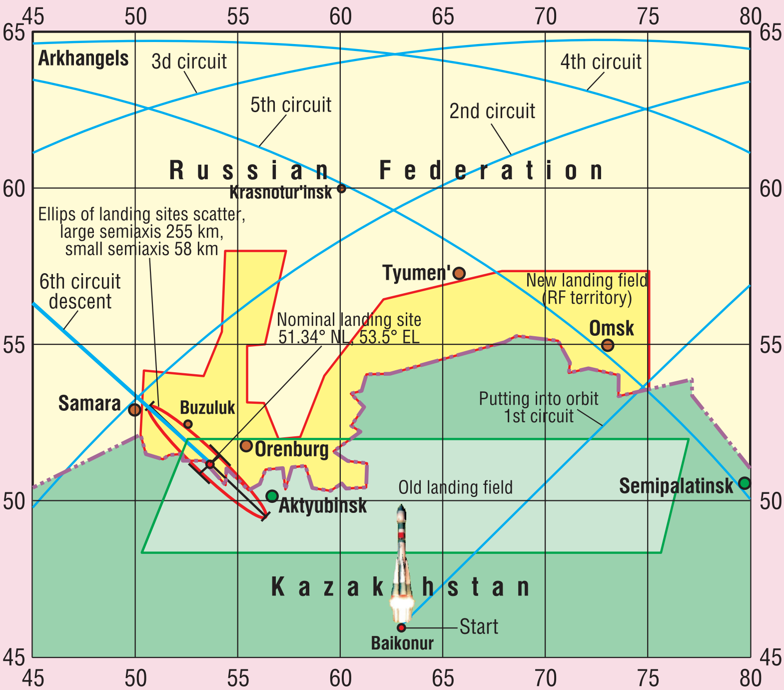


Figure 11: Landing area, the apparatus landed at south-east of Samara city (50 degrees 56 min NL, 053 degrees 43 min EL, about 50 km away from the nominal site)

The IRDT can be used to:

– deliver payloads from ISS;

– save the upper launcher rocket stages and boosters;

– deliver man-made Earth satellites (ES) from their orbits to the Earth;

– deliver to the Earth of ES modules from their orbits and other blocks of orbital stations and transport modules;

– deliver planet rovers and research stations to planets and their satellites; and

– rescue crews of orbital stations and other space objects.

Payload

Scientific facilities:

weight: 13 kg

designed, assembled, and tested DASA-RI

Scientific instruments:

3 fiber-optic gyroscopes (LITEF m-FORS 6)

1 triple-axes accelerometer (LITEF Triade)

oxygen gauge FIPEX (Stuttgart)

microcamera was not supplied because of the shortened schedule.

Onboard systems:

T*MC, BUM, power source, construction (DASA-RI)*

Stone:

Basalt, dolomite, and sand stone samples mounted at the Demonstrater forebody part CIMT:

Temperature measurements with crystalline sensors

81 units at the Demonstrator forebody

Project Number:	#2836
Full and Short Title:	In-orbit demonstration experiment with Inflatable and RIgidizable Structure **IRIS Experiment**
Tech Code / Area / Field:	SAT-UNM / Space, Aircraft and Surface Transportation / Unmanned Spacecraft
Status:	Project underway
Technology Development Phase:	SAT-UNM / Space, Aircraft and Surface Transportation / Unmanned Spacecraft
Allocated Funding:	595,812 € (EU)
Commencement date:	February 1, 2004
Duration:	36 months, extended by 47 months
Leading Institute:	Lavochkin Association, Khimki, Moscow reg., Russia
Contact Information:	Phone: +7 (495) 251 67 44 Fax: +7 (495) 573 35 95, 556 43 37 Website: http://www.laspace.ru
Supporting Institutes:	No
Collaborators:	EADS ASTRIUM Space Transportation, Saint Medard-en-Jalees, France (Thierry BONNEFOND)
Project Manager:	IVANOV Sergey Veniaminovich
Contact Information:	Phone: +7 (495) 575 51 41 Fax: +7 (495) 575 51 41 E-mail: s_ivanov@laspace.ru
ISTC Senior Project Manager:	RYZHOVA Tatiana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (499) 978 36 03 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

Last technological achievements in space inflatable structures, in areas of material rigidization and deployment technique, have presented a new possibility to the spacecraft developers with a low cost, lightweight alternative to mechanically deployed structures, such as the arrays of Solar Generators (SG). They can become an adequate alternative to the mechanical panels of solar arrays, which are widely used at present. In order to confirm the correctness of the developed technological solutions, it is expedient to carry out the demonstration experiment of the inflatable rigidizable array of SG in conditions of the orbital flight.

Flight Demonstrator of inflatable arrays of the Solar Generator (SGD) will consist of two main parts:

(i) an orbital platform allowing to integrate all equipment and associated harness required to fulfill the mission objectives; and

(ii) SG experimental inflatable solar arrays.

Project Objectives

The objective of the Inflatable RIgidizable Structures (IRIS) in-orbit demonstration experiment is in validation of development of structures rigidizable under affect of the space factors.

The main tasks of the in-orbit experiment are as follows:

• working out procedures of deployment of the rigidizable structures;

• working out procedures of the structures rigidization in the space flight conditions;

• acquisition of images of the IRIS and their transmission to the Earth; and

• determination of features of the hardened structures.

The IRIS Demonstrator is intended for provision of fulfillment of the in-orbit qualification experiment with the IRIS (Fig. 1).

Description of the Works

• Design of inflatable arrays of the SGD (engineering drawings, resources budget, dynamic, thermal and strength analysis).

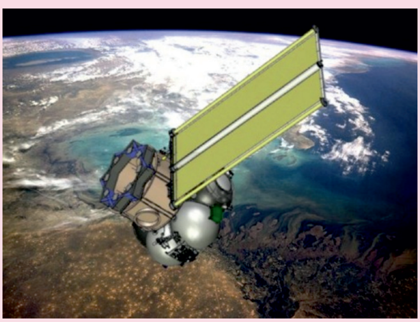


Figure 1: IRIS Experiment

• Test models of inflatable arrays of the SGD.

• Flight model of the Orbital Boost Platform and inflatable arrays of the SGD.

• Reports on results of the ground developmental testing.

• Launcher/spacecraft adapter.

• Ground support equipment.

• Insertion and flight program.

• Report about launch fulfillment.

• Injection into orbit.

• In-orbit measurements analysis.

The objective of the Demonstrator IRIS qualification tests was experimental verification of serviceability and durability of IRIS product as well as separate elements of its structure.

In the process of qualification tests, it was planned to solve the following tasks:

• verification of IRIS durability at the action of operating loads;

• determination of eigenfrequencies of the item and its subsystems;

• verification of IRIS serviceability in the conditions maximally close to operating ones;

• leakage testing after the action of dynamic loads; and

• evaluation of possibility of IRIS manufacturing and application to standard products.

In the process of IRIS Qualification Model (QM) ground testing, the following tests were performed:

• IRIS testing for the “Transportation” case;

• vibration testing of IRIS for the case of flight (Fig. 2);

• IRIS centrifuge testing on linear g-loads (Fig. 3);

• dynamic testing for the “Separation of Stages” case; and

• container internal pressure testing.

In the process of IRIS Flight Model preparation for launch at processing facility (PF) of Baikonur launch site, the following works were fulfilled:

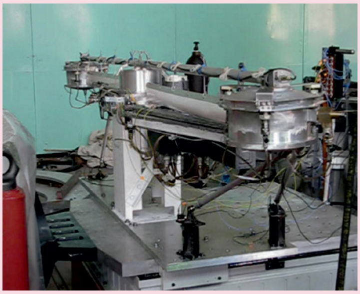


Figure 2: IRIS Demonstrator testing on vibration testing machine

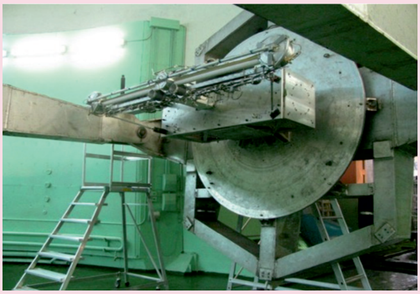


Figure 3: IRIS centrifuge testing

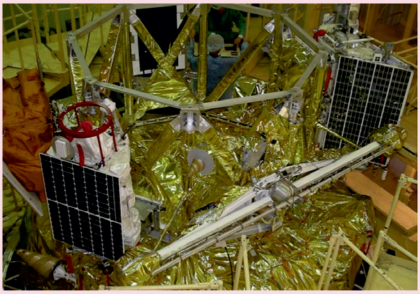


Figure 4: IRIS at upper composite technical complex

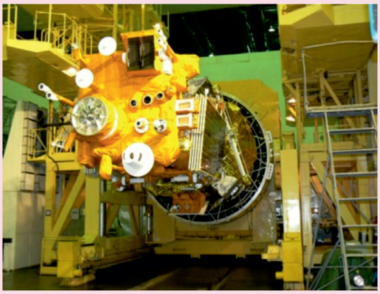


Figure 5: Mounting of FVST with IRIS Demonstrator onto SOYUZ-2 LV

• mounting of IRIS Demonstrator onto "Fregat" Versatile Space Tug (FVST);

• verification of flight software of IRIS Demonstrator and FVST;

• electrical testing of IRIS Demonstrator;

• integration electrical testing of IRIS Demonstrator and FVST; and

• mounting of FVST with IRIS Demonstrator onto SOYUZ-2 LV (Figs. 4 and 5).

The works performed at PF of Baikonur launch site permitted to provide successful launch and injection of IRIS Demonstrator into operating orbit.

FVST with IRIS Demonstrator was launched on September 17, 2009 at 18:55:07.4 of SMT. It was launched from Baikonur launch site by Soyuz-2-1b (Figs. 6 and 7).

Figure 6: "Soyuz-2" LV with IRIS at the launch site

Obtained Results

• Technical project on orbital experiment with IRIS was completed including resource budget, ballistic analysis, dynamic, thermal, and strength analysis. Design and operation

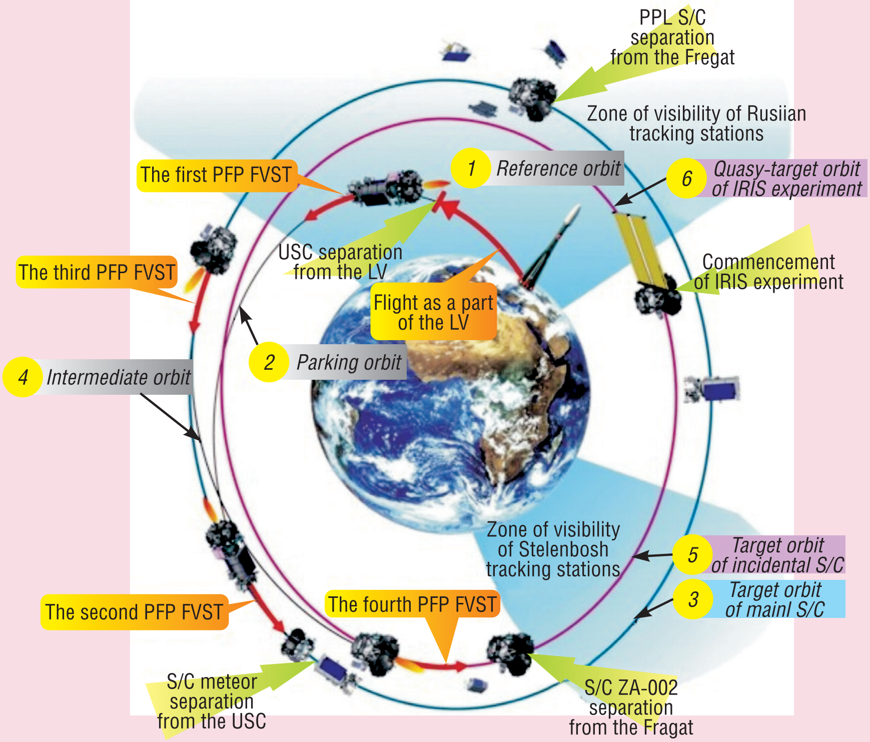


Figure 7: IRIS Demonstrator mission profile

documentation on IRIS Demonstrator was prepared.

• Experimental and QM of IRIS Demonstrator were manufactured.

• Flight model of IRIS demonstrator was manufactured.

• Ground testing equipment was manufactured.

• The complex of ground experimental tests of IRIS Demonstrator qualification and flight models was performed including strength and vibrodynamic tests, dynamic tests of IRIS panel, and electrical tests of On-Board Equipment Complement.

• FVST-IRIS Demonstrator adapter was manufactured.

• The program of IRIS Demonstrator launch and flight was developed. Integration electrical interface tests of flight SW were performed.

• The launch of IRIS Demonstrator on Soyuz-2 LV with FVST was implemented.

• Postflight analysis was made and IRIS Demonstrator tracking by ground stations was implemented.

Other

List of Projects

In total, 4 projects were funded by the ISTC Parties.

#0929

“Laser Beam Control by Means of Nonlinear and Coherent Optics Techniques”

(Energy Delivery Over Long Distances)

– Research Institute for Laser Physics, St. Petersburg, Russia

#3872

“Comprehensive Study of Shock Wave Interference with a Turbulent Boundary Layer, High-Enthalpy Layer, and Vortex Structure”

(Shock Wave and Vortex Interference with the Body Surface)

– Central Aerohydrodynamic Institute (TsAGI) Zhukovsky, Moscow Region, Russia

#A-1229

“Simulating Space Conditions and Their Effect of Materials and Devices Intended for Application in Space”

(Testing Materials for Application in Space)

– Yerevan Physics Institute, Yerevan, Armenia

#K-1482

“Development of Effective Methods of Analysis of Environmental Objects Contaminated with Rocket Fuel Components and Creation of a Scheme of High-Sensitive Biosensor Module for the Presence of Mutagens”

(Contamination with Components of Rocket Fuel)

– Kazakh National University / Center of Physical and Chemical Methods of Analysis, Almaty, Kazakstan

– National Biotechnology Center of Kazakstan / Research Institute for Biological Safety Problems, Gvardeiski, Kazakstan

Project Number:	0929
Full and Short Title:	Laser Beam Control by Means of Nonlinear and Coherent Optics Techniques **Energy Delivery Over Long Distances**
Tech Code / Area / Field:	SAT-OTH / Space, Aircraft and Surface Transportation / Other PHY-OPL / Physics / Optics and Lasers
Status:	Project completed
Technology Development Phase:	Technology development
Allocated Funding:	$450,000 (JP)
Commencement date:	April 1, 1998
Duration:	36 months
Leading Institute:	Research Institute for Laser Physics, St. Petersburg, Russia
Contact Information:	Phone: +7 (812) 331 75 50 Fax: +7 (812) 331 75 58 E-mail: leader@soi.spb.ru Website: http://www.npkgoi.ru
Supporting Institutes:	No
Collaborators:	NASDA, Tokyo, Japan (Itagaki Haruaki) National Aerospace Laboratory / Kakuda Research Center, Kakuda, Japan (Niino M.) National Aerospace Laboratory, Tokyo, Japan (Eguchi K.) Tohoku University, Sendai, Japan (Yugami Hiroo)
Project Manager:	MAK Arthur Afanasievich
Contact Information:	Phone: +7 (812) 328 57 34 Fax: +7 (812) 328 58 91 E-mail: mak@ilph.spb.su; lenzf@uni-bonn.de
ISTC Senior Project Manager:	MALAKHOV Yuri Ivanovich
Contact Information:	Phone: +7 (495) 982 31 57 Fax: +7 (499) 978 46 37 E-mail: malakhov@istc.ru
ISTC Website:	http://www.istc.ru

Background

Generation of high directivity laser beams is one of the key factors in solving such problems as superlong-distance space communications and space monitoring, utilization of the energy from space for Earth needs, e. g., energy delivery from Moon to Earth.

The approach suggested to develop optical systems is based on the use of contemporary methods for formation of wave fronts of laser beams, adaptive optics, and nonlinear-optical phase conjugation. Combination of these contemporary methods must allow one to design optical devices forming laser beams with extremely small aperture and with subdiffraction precision of propagation direction control suitable for lasers of various types differing in the generation wavelength as well as in operation regime.

Project Objectives

The basic objective of the Project was to develop methods for formation of the laser beam front with extremely small aperture and with subdiffraction precision of the propagation direction control which are needed when solving the problems of energy delivery through long distances by means of lasers.

Description of the Works

The project included the following tasks:
• Development of prospective architecture of optical schemes including a set of laser mod-

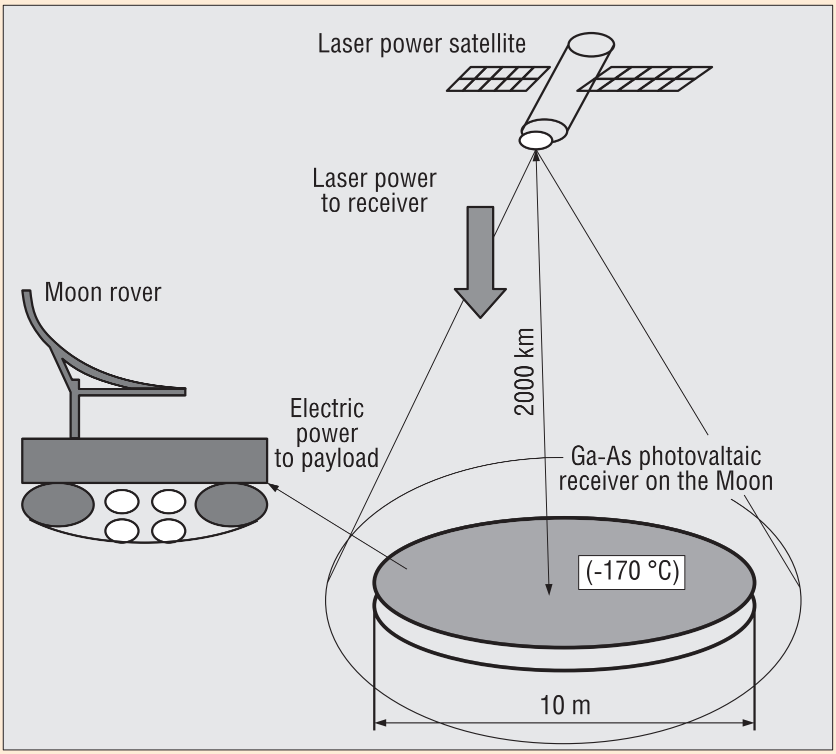


Figure 1: Concept of energy delivery from space to supply power to a Moon research vehicle during Moon night

ules and beam expanders with segmented mirrors, in which the problem of coherent beam channel summation, compensation of aberrations, and control of resulting beam direction is solved using adaptive and nonlinear-optical methods of laser wave front correction.

• Comparative analysis of the most promising laser types and opportunities of their scaling.

• Computational and theoretical analysis of attainable spatial and energetic laser beam characteristics for prospective optical devices.

• Conducting model, numerical, and full-scale experiments intended to demonstrate the efficiency of the approaches considered.

A number of original scientific and technical results of investigations performed at the Research Institute of Laser Physics in the area of energy delivery through long distances were used to solve the Project tasks, among them:

• an approach to designing optical schemes of lasers with sharp beam directivity based on a purely optical feedback, which is spread throughout the laser, and preclusion of mechanical displacements in the sites where the wave front is controlled; and

• schemes that autocompensate aberrations of the optical route, phase laser channels, and control the beam direction based on phase conjugation and the use of holographic diffraction units.

In the course of Project implementation, the key technologies of laser energy transportation have been thoroughly analyzed. The most promising approaches to designing optical schemes have been chosen to be used in solution of four problems of practical importance:

1. Power supply to a Moon research vehicle during Moon night by means of energy delivery from a satellite orbiting around Moon (Fig. 1).

2. Power supply to telecommunication zeppelins during night time by means of energy transport from a ground-based laser positioned underneath the zeppelin.

3. Power supply to Earth by delivering energy from a laser located on the Moon (Fig. 2).

4. Energy supply to zeppelins with the aid of a remote ground-based laser via a retranslating mirror launched to a geostationary orbit (Fig. 3). Three tests were performed at the final stage of Project implementation.

Test 1

This test was based on a pulse-periodic TEA CO_2 laser and demonstrated feasibility of the use of OWF (optical wave front) mirrors in systems designed to deliver radiation of a group of laser channels to a remote point-like transponder. The test was intended to demonstrate that the following tasks could be solved with the aid of controlled OWF mirrors:

• precise delivery of radiation generated by a matrix of telescopes (that imitate laser channels) to a point-like receiving transponder that moves side-ward through distances 5 or 7 times greater than the cross section of the receiver;

• coherent summation of radiation from a group of telescopes on a receiver-transponder;

• compensation of aberrations in laser channels (in optical channels of a telescope matrix);

• redirection of radiation emitted by a matrix of telescopes to a point positioned with a preset angular displacement with respect to the receiver-transponder, i.e., an operation similar to introduction of an anticipating angle when delivering radiation to rapidly moving receiver-transponder.

Test 2

This Test was intended to demonstrate the feasibility of precise addressing a laser beam to a low-power remote laser transponder with the use of a high-sensitivity hypersonic OWF mirror (SHOM) based on four-wave mixing. In this Test, aberrations in a laser system were experimentally corrected.

Test 3

This Test was intended to demonstrate efficiency of one of the key units of a laser system

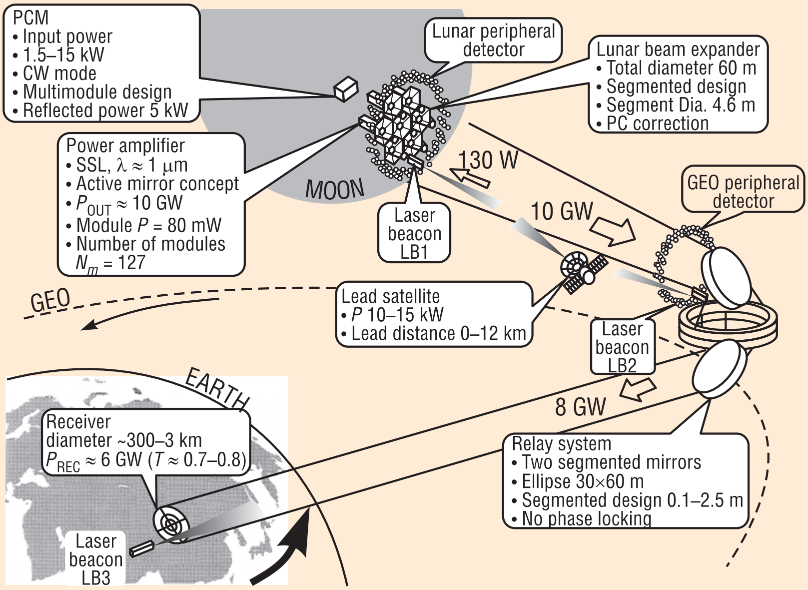


Figure 2: Nonlinear phase conjugation based laser system intended to transport power via "Moon-GEO-Earth" route

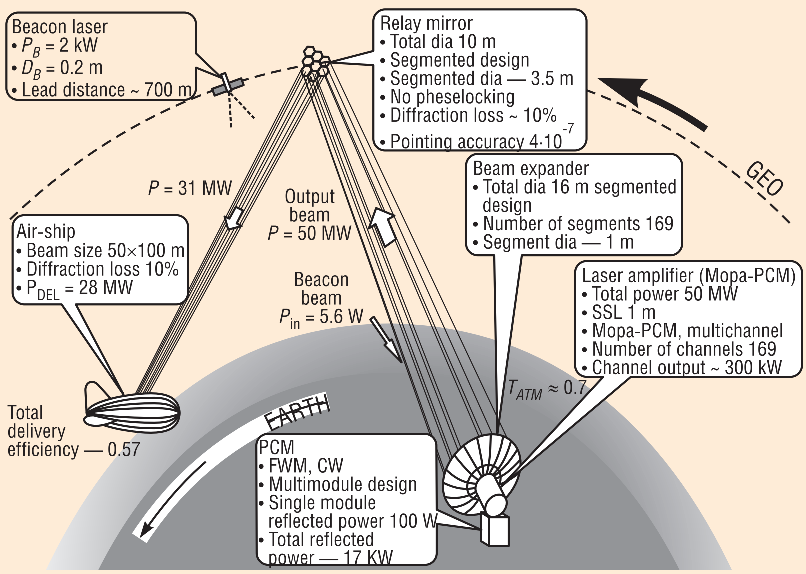


Figure 3: Nonlinear phase conjugation based laser system intended to transport power via "Earth-GEO-Zeppelin" route

with OWF, namely, an Yb:YAG-based amplifier whose efficiency is close to that of a generator, and that exhibits a high amplification factor and wide field of vision. A broad-field solid laser amplifier with diode pumping was tested experimentally.

Obtained Results

1. Various approaches to designing systems of laser energy transportation through distances ranging between 2000 and 400000 km with the use of contemporary methods developed to control laser beams and scale lasers in terms of their power were analyzed.

2. It has been shown that the nonlinear-optical techniques are a powerful tool in solving the following tasks relevant to the problem considered:

• scaling of lasers in terms of their power with the use of phased matrices comprising a great number of laser channels;

• correction of aberrations arising in an optical tract, including laser channels and transmitting telescope, and, if needed, of aberrations induced by atmospheric perturbations and transmitter vibrations;

• formation of a powerful radiation beam at the outlet of a transmitting telescope with a divergence close to 10^{-7} rad which suffices, e. g., to efficiently deliver radiation from the Earth surface to a receiver on a geostationary orbit whose size is as small as 10 m; and

• precise addressing of radiation to a remote receiver and its automated tracking when the transmitting and receiving systems are moving with respect to each other.

3. Analysis performed has demonstrated that both solid lasers (e. g., garnet–ytterbium) and gas lasers (such as fullerene–oxygen–iodine) can serve as powerful lasers capable of delivering energy through long distances. In both cases, it is expedient to use solar energy as the pumping source. Investigations the objective of which is creation of laser emitters based on diode lasers with 50%–60% efficiency are undoubtedly promising.

4. Design solutions for the basic units have been worked out. Numerical simulation of functioning of a surface system delivering radiation through up to 36 000 km and based on 164 solid laser channels and matrix comprising 164 telescopes about 16 m in overall diameter have been performed. The use of phase conjugation to correct all aberrations in the tract was shown to provide delivery of up to 44% of the power generated at the Earth surface to a receiver about 10 m in size situated on the geostationary orbit. This exceeds more than 10^3-fold the delivery efficiency that traditional optical systems can provide (Fig. 4).

5. Laboratory-scale demonstration experiments have supported the feasibility of realization of a number of the key technologies on which the suggested concepts of laser systems intended to deliver energy are based.

6. The concepts based on laser placing directly on the Earth orbit and on the use of solar radiation as the primary energy source was shown to be most promising for energy transportation through long distances in space with application of lasers. Prospective approaches to elaboration of such orbital laser systems were suggested.

7. Possibility of the use of dynamic correction of wave front aberrations by the nonlinear optics methods in designing light-weight orbital observation systems based on membrane mirrors was grounded.

On the whole, the results of investigations performed in the course of Project implementation indicate that the suggested approaches to designing laser energy transport systems based on application of the contemporary methods of coherent and nonlinear optics are quite efficient to be successfully used in practice.

Based on these results, it was suggested to expand the field of investigations and to use the principles of laser system design elaborated in solving a number of practical problems (ISTC Projects No. 1801 “Exploration of possibility of laser-driven propulsor application in space” and No. 2113 “Transmission

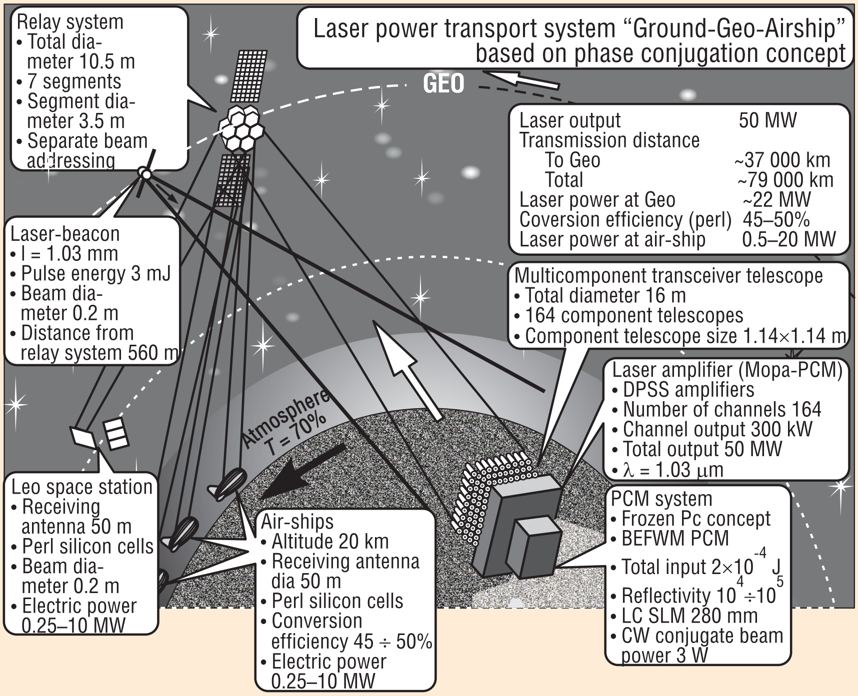


Figure 4: "Earth-GEO-Zeppelin" laser energy transmission system: ground-based multichannel power laser of an about 50-megawatt average power designed according to a scheme which includes amplifier, wave front phase conjugating mirror, and receiver–transmitter telescopic system in the form of a multiunit set of telescopes of about 16 m in the overall aperture diameter; segmented retranslator mirror about 10 m in overall diameter, laser transponder positioned 660 or 680 m away from the retranslator mirror; and Zeppelins located 20 km above the Earth surface, each of them carries a photovoltaic converter of laser radiation into electric current about 40–50 m in size

of solar energy with the aid of coherent radiation. Experimental simulation" supported financially).

Estimated trial cost-efficiency of the use of laser-driven propulsors and laser system for removal of space debris is available. The predicted cost-efficiency of debris removers is due to an increase in the satellite life-time, which will rapidly increase as the number of space objects rises. As follows from the estimates, the cost of launching of small satellites can be reduced tenfold, if they are launched sufficiently often, creation of such a system can be repaid within a few years.

Project Number:	#3872
Full and Short Title:	Comprehensive Study of Shock Wave Interference with a Turbulent Boundary Layer, High-Enthalpy Layer, and Vortex Structure **Shock Wave and Vortex Interference with the Body Surface**
Tech Code / Area / Field:	SAT-AER / Space, Aircraft and Surface Transportation
Status:	Project underway
Technology Development Phase:	Basic research
Allocated Funding:	222,250 € (EU)
Commencement date:	January 1, 2009
Duration:	36 months
Leading Institute:	Central Aerohydrodynamic Institute (TsAGI) Zhukovsky, Moscow reg., Russia
Contact Information:	Phone: +7 (495) 556 42 05 Fax: +7 (495) 777 63 32 Website: http://www.tsagi.ru
Supporting Institutes:	Siberian Branch of RAS / Institute of Theoretical and Applied Mechanics (ITPMech), Novosibirsk, Russia (AGU)
Collaborators:	ONERA, Chatillon, France (Chanetz B.) Rheinisch-Westfalische Technische Hochschule / Stoßwellenlabor, Aachen, Germany (Olivier H.) Université Libre de Bruxelles / Faculté des Sciences Appliquees, Brussels, Belgium (Degrez G.)
Project Manager:	SKURATOV Arkady Sergeevich
Contact Information:	Phone: +7 (495) 55 47 20 Fax: +7 (495) 777 63 32 E-mail: skuratov@progtech.ru
ISTC Senior Project Manager:	RYZHOVA Tatyana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (499) 978 36 03 Email: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

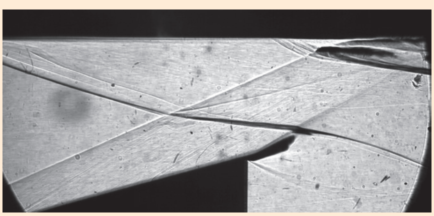
Interference regions are critical areas of the surface of supersonic flying vehicles because of extremely intense surface heating and manifold increase in pressure. In addition, vortices generated by various aerodynamic surfaces located in the frontal part of the flying vehicle can interfere with shock waves generated by other elements of the vehicle located further downstream.

Despite significant successes in computational fluid dynamics and computational methods, the flow in interference regions cannot be reliably calculated, in contrast to other segments of the vehicle surface. Particularly, severe difficulties are encountered in calculating turbulent interference flows. For the moment, experimental methods remain the basic source of obtaining principally new information in this field.

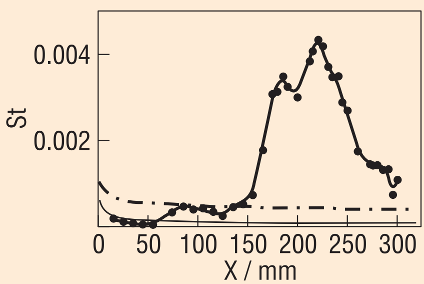
Shock wave/boundary layer interaction is one of the most urgent problems of today's aerodynamics (Fig. 1). Intense research in this field has been performed for 60 years. Fundamental properties of interference flows have been identified (formation of a separation region and a λ-shaped system of shocks, formation of heat-flux and pressure peaks, etc.). A vast volume of quantitative information has been obtained, and the dependence of the maximum heat-transfer coefficient on free-stream parameters and shock-wave strength has been found.

Research of interference flows has been intensified for the last two decades. Much attention is paid to three-dimensional (3D) flows near an isolated wedge (Fig. 2) and a pair of wedges generating intersecting shock waves. The main objective is the development of methods of numerical simulation of interference flows. Various approaches and various models of turbulence are used to calculate turbulent flows. Significant progress has been achieved on the basis of using advanced features of computational fluid dynamics. Yet, the heat-transfer and friction distributions in developed separation regions formed owing to incidence of strong shock waves on the body surface cannot be calculated with acceptable accuracy. It was recognized that solving this problem requires the volume of available experimental data to be increased.

Almost all activities aimed at studying interference flows deal with shock wave interaction with the boundary layer on a flat plate with a sharp leading edge (or a sharp cone). The effect of small bluntness of the body on the gas flow and heat transfer in the interference zone was ignored. At the same time, the leading edges are bound to have certain bluntness at high velocities. On the one hand, it is necessary to reduce the heat flux from the gas onto the leading edge and to restrict the maximum temperature. On the other hand, the radius of bluntness of the leading edges has also to be



(*a*)



(*b*)

Figure 1: Schlieren photo and Stanton number distribution along plate at 2D shock wave/turbulent boundary layer interaction (TSP); $M_\infty = 5$

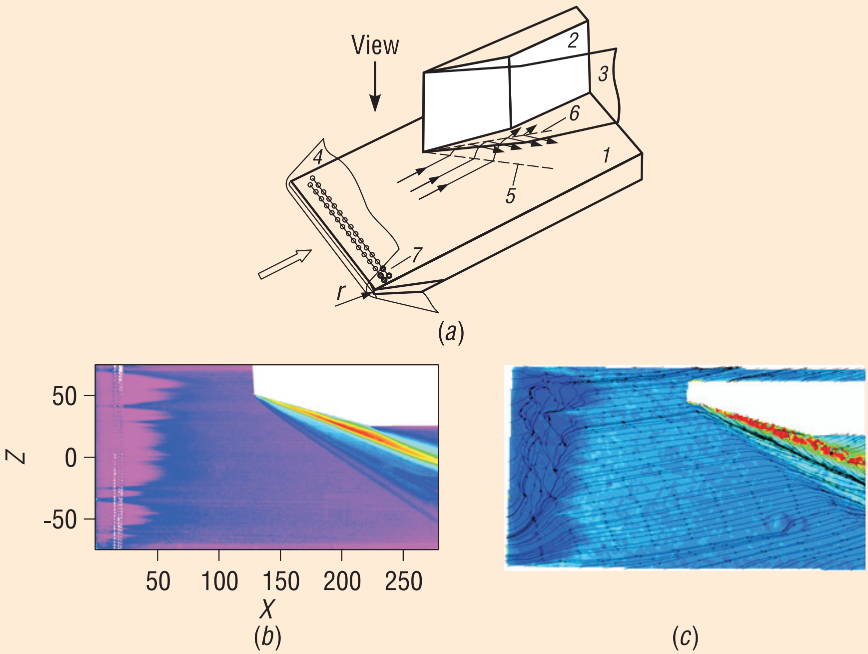


Figure 2: Heat transfer and flow structure at 3D shock wave/turbulent boundary layer interaction (TSP); $M_\infty = 5$

restricted to avoid deterioration of aerodynamic performance of the flying vehicle as a whole. Another important problem is the streamwise vortex/shock wave interaction (Figs. 3 and 4). Interference of the vortex with shock waves in the inlet or other elements of the flying vehicle located downstream often leads to vortex breakdown, which, in turn, can deteriorate the lifting capacity of aerodynamic surfaces, lead to inadequate regimes of engine operation and to a drastic increase in heat transfer. Despite the adverse features of this phenomenon, it can be used as one method for improving mixing in the combustor.

Project Objectives

The Project objective was to generalize the previous experience and provide new information about flow in the two-dimensional (2D) and 3D regions of shock wave/turbulent boundary layer interference on a plate surface in the presence of high-enthalpy layer generated by a plate leading-edge bluntness. Another object of the study was the streamwise vortex/shock wave interaction. Interference of the vortex with shock waves in the inlet or other elements of the flying vehicle located downstream often leads to vortex breakdown, which, in turn, can deteriorate the lifting capacity of aerodynamic surfaces, lead to inadequate regimes of engine operation and to a drastic increase in heat transfer. Despite the adverse features of this phenomenon, it can be used as one method for improving mixing in the combustor.

Description of the Works

1. It is planned to obtain a vast volume of experimental data on the problem considered, short-duration wind tunnels are used: UT-1

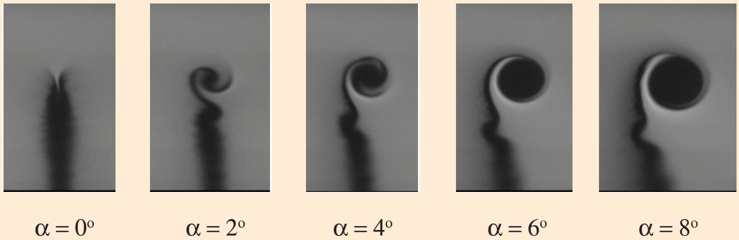


Figure 3: Vortex evolution at M = 6

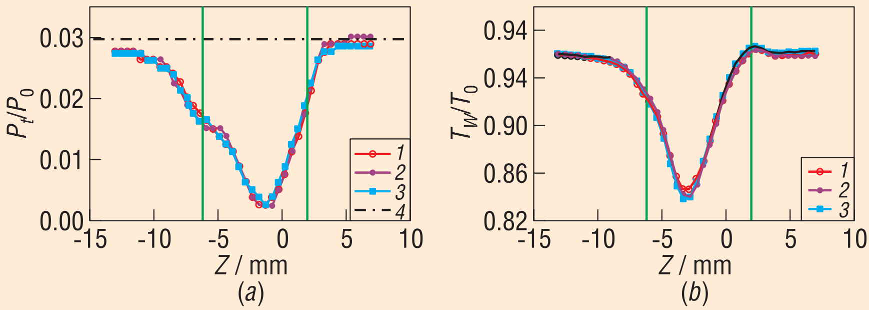


Figure 4: Total pressure (a) and recovery temperature (b) distributions in the streamwise vortex core at $M_\infty = 6$ and $\alpha = 8°$: 1 — Y = – 1.5 mm; 2 and 3 — Y = – 2 mm; and 4 — free stream

wind tunnel based at TsAGI and AT-303 wind tunnel based at ITAM SB RAS. They have the following advantages over other hypersonic tunnels:

- short-duration wind tunnels ensure high levels of the total pressure and, correspondingly, high Reynolds numbers at hypersonic velocities of the flow, which is of crucial importance for the problem considered; and
- because of the short duration of the experiment, these facilities consume small amounts of power and gas, which reduces the cost of experiments. Thus, it becomes possible to vary parameters affecting the flow under study within wide limits in terms of Reynolds number, Mach number, intensity of the incident shock, vortex intensity, radius of bluntness of the leading edge of the flat plate, location of the incident shock wave, etc.

The use of the AT-303 wind tunnel (ITAM SB RAS) in addition to the UT-1 tunnel (TsAGI) make it possible to increase the maximum Reynolds number from 10 million to 25 million. This is of principal importance, because these conditions ensure a natural transition of the laminar boundary layer to the turbulent state upstream of the region of interference with the incident shock wave. In addition, the range of the ratios of the entropy layer thickness to the turbulent boundary layer thickness will be substantially expanded (this ratio affects the “absorption” of the entropy layer by the boundary layer).

As a result, a database is to be composed, which will allow verification of numerical codes for different variants of the interference flow. This database can also be used to estimate flow characteristics in solving applied problems.

Some experiments aimed at studying vortex/shock wave interaction are to be performed in the T-326 hypersonic wind tunnel based at ITAM. This is a blowdown wind tunnel with gas exhaustion into the Eiffel chamber.

2. Two types of measurements are planned to be used: local measurements with the use of discrete gauges and global (panoramic) measurements with the use of temperature-sensitive (TSP) and pressure-sensitive (PSP) paints.

Gauges of the "thin-wall" type are used at TsAGI as discrete heat-flux sensors. They provide a high spatial resolution (about 0.5 mm) and a reasonable accuracy: the root-mean-square random error is about 6%. The systematic error is approximately of the same level (it depends on the properties of the setup used for calibrating the gauges). These gauges will also be used for studying shock-wave interference with the plate surface in the AT-303 wind tunnel.

Panoramic methods of measurement have obvious advantages over discrete measurements in studying complicated 3D flows, where an extremely large number of gauges would be needed to obtain full information.

Panoramic measurements of heat fluxes and pressure are to be performed with the use of luminescent coatings. Luminescent TSP have been used in NASA in long-duration wind tunnels for several years. TsAGI developed a variant of the method that can be effectively used in short-duration wind tunnels.

Luminescent PSPs are widely used in many laboratories to measure the pressure at subsonic and moderate supersonic velocities. The use of this method at hypersonic velocities is difficult because the paint temperature affects the measurement results. TsAGI managed to overcome these difficulties owing to the short time of the experiment, using a fast-response luminescent paint and a heat-conducting material for manufacturing the models.

3. The flow structure during interaction of a streamwise vortex with a shock wave is to be visualized by obtaining Schlieren pictures with an exposure time of 1 ms and recording of the video image by a high-speed camera. A new optical method of Schlieren visualization developed at ITAM will also be used, which allows flows with small inhomogeneities of density to be visualized.

Pressure fluctuations will be measured by fast-response pressure transducers with high natural frequency.

4. The planned research will be based on experience gained in previous activities and also unique experimental models designed for these activities.

5. Numerical simulations of turbulence interference flows are to be performed with the use of codes designed for solving averaged Reynolds equations.

Expected Results

The following basic results are expected to be obtained:

1. Database of experimental results on the flow structure, local characteristics of the flow, and distributions of the heat-transfer coefficient in regions of interference of an oblique shock wave and a streamwise vortex with the body surface.

2. Dependence of the maximum heat-transfer coefficient in the region of shock-wave incidence on the degree of bluntness of the leading edge of a flat plate for a turbulent state of an undisturbed boundary layer.

3. Conclusion on the hypothesis on the existence of a threshold value of bluntness in the case of interference of an oblique shock wave with a turbulent boundary layer on a blunted plate.

4. Laws of propagation of the vortex wake and its dissipation at hypersonic velocities.

5. Unsteady characteristics of the process and regimes of interaction of the vortex wake with the bow shock wave generated by a cylindrical obstacle.

6. Unsteady characteristics of the process and regimes of interaction of the vortex wake behind the wing with an oblique shock wave generated by an inclined flat plate.

7. Validated codes for numerical simulations of interference flows of the types considered.

Project Number:	#A-1229
Full and Short Title:	Simulating Space Conditions and Their Effect of Materials and Devices Intended for Application in Space **Testing Materials for Application in Space**
Tech Code / Area / Field:	SAT-OTH / Space, Aircraft and Surface Transportation / Other
Status:	Project underway
Technology Development Phase:	2/Applied research 3/Technology development
Allocated Funding:	$299,200 (US: $149,600, CA: $149,600)
Commencement date:	October 1, 2006
Duration:	36 months, extended by 12 months
Leading Institute:	Yerevan Physics Institute, Yerevan, Armenia (AWD)
Contact Information:	Phone: +7 (374) 10 34 47 36 Fax: +7 (374) 10 34 47 36 E-mail: chili@aragats.am Website: http://www.yerphi.am
Supporting Institutes:	No
Collaborators:	A. U. G. Signals LTD, Toronto, ON, Canada (Lampropoulos G) National Technical University of Athens / Laboratory of Microwave and Fiber Optics, Athens, Greece (Uzunoglu N.) Pacific Northwest National Laboratory, Richland, WA, USA (Johnson B. R.) School of Pharmacy and Chemistry, Liverpool John Moors University, Liverpool, UK (Rhodes C.) Spacecraft Engineering, Space Technologies Branch, Canadian Space Agency, Longueuil, QC, Canada (Nikanpour D.) University of California, Irvine, CA, USA (Collins P.)
Project Manager:	YERITYSAN Hrant Nikolaevich
Contact Information:	Phone: +7 (3741) 34 10 65 Fax: +7 (3741) 34 10 65 E-mail: Grant@uniphi.yerphi.am, grant@mail.yerphi.am, grant@Yerphi.am
ISTC Senior Project Manager:	RYZHOVA Tatiana Borisovna
Contact Information:	Phone: +7 (495) 982 32 80 Fax: +7 (499) 978 36 03 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

The advances in space technologies require modeling and study of materials and devices in the environment close to Space. Such numerical and experimental study can play an important role in research and technologies, in particular, as to create materials and devices with new or improved functions using the space conditions (for example, high irradiation of particles). Beyond its strong link with material science, it contributes to the development of new components, new systems for devices applicable in space and other fields ranging from production engineering to control system and measurement techniques. The use of irradiation methods allow to work out, for example, nanomaterials which are very important in this regard. The development of new technologies based on test results of space environment modeling equipment is an up-to-date problem.

Long term interplanetary missions, such as to Mars, cost-efficient satellite communication and other nowadays needs for space exploration require solving several problems including power engineering ones. For example, solar propulsion power system is among the most promising directions of research, but it needs creation of new materials for solar elements and arrays.

The unambiguous interpretation of the results of space factors influence is further complicated by the fact that under open space conditions along with ionizing radiation, there are other factors affecting defect formation in structural materials. These factors include but are not limited to Sun ultraviolet (UV) radiation, temperature differences (from 120 to 500 K), flows of various micrometeorite particles, ions, etc., which can cause photochemical or plasmochemical reactions on the surface of an object or induce formation of mini atmosphere. It is impossible to consider all of these factors, even by using theoretical approach; hence, the problem should be addressed empirically by using imitations and modeling of the specified phenomena and selecting most typical radiation and accompanying factors.

Project Objectives

The Project objective was to develop and construct a Cosmic Space Simulator Installation and to investigate the influence of Space Factors on the properties of semiconductors (currently one of the most widely applied materials in the space technology), High Temperature Superconductors (HTSC), which are new, but proved to be very promising in space applications.

Description of the Works

The Project work was carried out in two directions:

1. Construction of the vacuum chamber for simulating the factors of near Earth Space environment.

2. Study of material properties exposed to various doses and intensities of electron irradiation with measurement of electrophysical and optical parameters taking into account post radiation annealing and “aging.”

Chamber for space factors simulating Accelerated electron beam line: preparatory works were performed, needed upgrading was made, and operating accelerator system with high stability of electrical units in the low intensity beam regime (10 MeV, 10 μA/cm^2) was assembled.

Monitoring of outside bunker environment was implemented. The measurements have shown that the conditions correspond to radiation safety requirements (less than 60 μRh/h, RSS-99).

The following units were repaired and tested: high-voltage system and modulator system of the electron accelerator, cooling systems for accelerator and Small Vacuum Chamber (SVC).

A new experimental facility “Space Imitator Installation” (Vacuum Simulating Chamber (VSC)) for simulating the factors of near Earth Space environment and new special experimental hall for its location have been designed and constructed (Figs. 1 and 2).

Figure1: General view of the VSC

The following planned parameters have been attained in the VSC:

– solar UV radiation;

– electron beam (up to 10 MeV);

– vacuum (about 10^{-5} Torr); and

– cryogenic temperatures.

The useful VSC volume is 0.65 m^3. These conditions can simulate the environment in space up to the altitude of 50 000 km and may be applied separately or together with possibility to change their levels. Moreover, there is a possibility to measure the sample properties directly at the irradiation process and manage both mentioned VSC parameters and sample drive.

It makes this chamber unique and attractive for developers of new materials applicable for space.

A guide for VSC operation has been developed in 4 parts:

(1) Operation of Electron Accelerator;

(2) Vacuum Obtaining;

(3) Operation of UV Device; and

(4) Liquid Nitrogen Supply.

An additional experimental facility chamber — SVC with volume of 45 l was constructed to

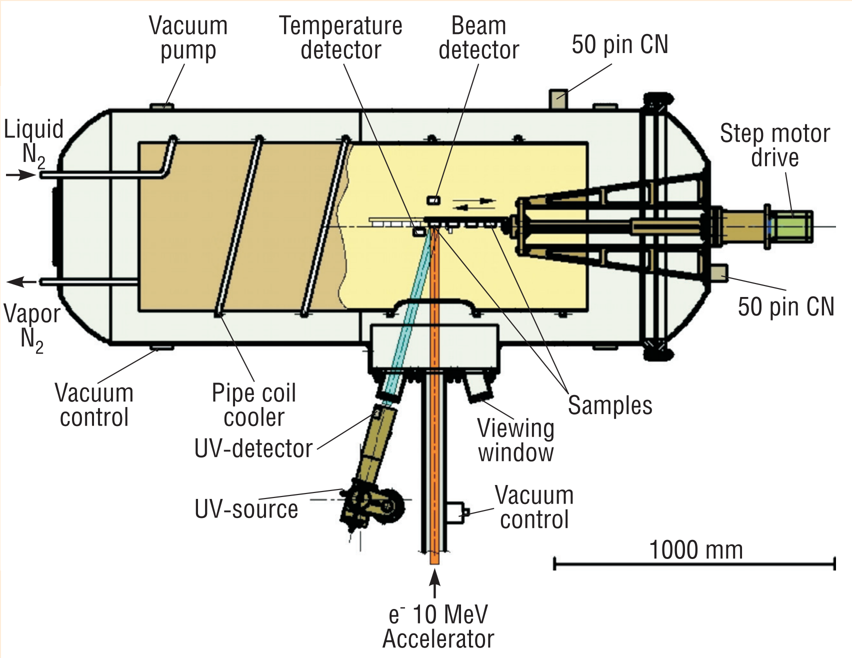


Figure 2: Horizontal section of VSC

reduce the cost of the experimental tests for small samples of materials and devices.

The accelerator exit vacuum tube was modified and a new tube was connected to the SVC. The SVC allows working with increased vacuum (better than 10^{-5} Torr).

Experimental investigation of materials

Investigation of the influence of space conditions on different properties of materials considered promising for space application were carried out on samples of semiconductors (currently widely used in space), and HTSC.

Natural Zeolites were studied as well in order to make radiation modification of the zeolite cage to obtain a new sorption or catalytic properties without changing zeolite stoichiometry. Radiation properties of mentioned materials were studied in air without VSC and in VSC after its construction.

Different experimental methods were applied to study silicon single crystals and HTS: Hall effect and electrical conductivity standard measurements (their temperature dependences), laboratory made AC magnetic susceptibility measurements, etc.

Silicon conductivity (the main property in many space applications) was measured directly under electron irradiation (*in situ* measurements). The specific conductivity of silicon samples measured during and after irradiation was found to exhibit different values; the first was much higher.

It was noted that radiation defects generated in the samples were stable and acted as both scattering and capture centers, i. e., they decrease the mobility and concentration of carriers. The analysis showed that the concentration of carriers decreased considerably more (by 3 orders of magnitude) than their mobility (tens percent).

Such testing is important for materials and devices applicable at Low (LEO) and Geostationary Earth Orbits (GEO). The results obtained (and data published) on silicon single crystals show nonmonotonous behavior of conductivity even at intensities lower than 10^7 el/(cm^2·s) and during yearly accumulated irradiation dose. So, a statement prevailing in some articles that the intensity of high-energy irradiations at LEO is low and does not need to be taken into consideration seems to be not correct.

In situ measurements of the electroconductivity (σ) of silicon single crystals (n-Si) were made under the following experimental conditions: temperature 177 K, vacuum $2{\cdot}10^{-5}$ Torr, electron irradiation with energy 8 MeV, solar UV radiation corresponding to near-Earth space conditions. The experiments were performed step-by-step with and without UV radiation at different temperatures; as an initial value of conductivity was the “dark” one without influence of mentioned conditions. Some results are presented in Table 1.

After preliminary measurements, the UV source was switched on, electron beam was conducted, and σ was measured depending on electron beam dose. The irradiation intensity was $1.6{\cdot}10^{10}$ el/(s·cm^2), which is higher than by a factor of 10 in comparison with the conditions at the near-Earth space satellite orbits. It was found that the “dark” (initial) value of σ decreases more than by 40% after switching UV on for 5 min. It increases again and reaches the equilibrium value which is lower than the “dark” value by about 30%.

Table 1: Results of in-situ measurements of silicon single crystal electro-conductivity

Type of irradiation	σ, (Ohm·см)$^{-1}$
Without irradiation	0.106
Immediately at UV radiation	0.061
Immediately at electron irradiation + UV	0.022

In order to elucidate the role of experimental conditions, the mentioned experiments were also carried out at room temperatures with gradual application of UV and electron irradiations. It was found that σ changes nonmonotonously with electron irradiation dose. Thus, when increasing electron irradiation under fixed UV irradiation, σ decreases by about 11% of the "dark" value at room temperature. Without UV radiation, the maximum decrease was 18% (at 217 K). These results indicate the importance of irradiation for the conductivity of silicon crystals which is closely connected to solar cells efficiency and can vary depending on the position at satellite orbit.

The postirradiation aging effect has been studied in the Bi-based HTSC materials. This effect depends essentially on the irradiation intensity at a fixed dose and on the concentration of doped atoms in the HTSC material. The results have shown that devices fabricated from Bi-based HTSC materials with high concentration of Pb atoms possess low postirradiation aging capacity. Hence, these devices can be recommended for space applications (as stable with respect to penetrating radiation) in view of their simple production technology.

The penetration of AC magnetic field (vortices) into Y-based HTSC materials ($YBa_2Cu_{3-x}M_xO_y$, $x = 0$; M = Fe; Ni; $x = 0.01$) before and after electron irradiation with energy 10 MeV in air has been investigated. The penetration of magnetic vortices into superconductors was found to depend on the initial properties of samples. The penetration rate of Josefson vortices after high-dose electron irradiation increased significantly with respect to Abrikosov vortices. The dependence of the penetration rate on the dose is nonmonotonous because it is also affected by the frequency of applied magnetic field.

Investigations of the effect of radiation on materials revealed that the results depend on both radiation itself and further storage conditions. The physical behavior of materials is affected by irradiation type, its intensity and dose, as well as by environmental conditions (temperature, vacuum, etc.). With radiation dose increase, the sample parameters were shown to exhibit the oscillatory behavior around their initial values which is indicative of multistage processes of radiation defect formation. This is explained by the behavior of radiation defects formed in extreme conditions of space environment.

Obtained results

At the Yerevan Physics Institute, unique facilities were constructed, namely:

– a large space-simulation chamber capable of imitating space conditions with low temperature, UV and ionizing radiation;

– a small chamber which is easier to use with a potential for a faster testing of samples.

Investigations of the influence of space conditions on the properties of materials considered promising for space applications were performed with samples of semiconductors and HTSC. Several interesting results were obtained:

– the conductivity of silicon semiconducting materials appeared to initially increase with increasing the radiation dose to a certain value and then decrease presumably due to modification and destruction of initial charge-carrying defect centers. Further irradiation increases again the conductivity of the material but later on it tends to decrease;

– Pb content was shown to affect the superconductivity of HTSC; and the magnetic field for these materials was proved to be dependent on T_c.

Reference

Yeritsyan, H. N., A. A. Sahakyan, S. K. Nikoghosyan, et al. 2009. Space environment model. Symposium (International) on Materials in a Space Environment. Aix in Provence, France.

Project Number:	#K-1482
Full and Short Title:	Development of effective methods of analysis of environmental objects contaminated with rocket fuel components and creation of a scheme of high-sensitive biosensor module for the presence of mutagens **Contamination with rocket fuel components**
Tech Code / Area / Field:	ENV-EHS: Environment / Environmental Health and Safety
Status:	Active
Technology Development Phase:	Under development
Allocated Funding:	$ 399 144.48 (EU)
Commencement date:	October 1, 2007
Duration:	36 months
Leading Institute:	The Affiliated State Enterprise "The Centre of Physico-Chemical Methods of Investigations and Analysis" of the Republic State Enterprise "al-Farabi Kazakh National University," Almaty, Kazakhstan
Contact Information:	Phone: +7 (727) 292 00 08 Fax: +7 (727) 292 37 31 Website: http://www.cfhma.kz
Supporting Institutes:	Research Institute of Problems of Biological Safety of the Republic State Enterprise "National Centre of Biotechnologies of the Republic of Kazakhstan," Gvardeiskyi, Almaty oblast, Kazakhstan
Collaborators:	Dr. Joao Fernando Pereira Gomes, Instituto Superior de Engenharia de Lisboa, Lisbon, Portugal; Dr. Lars Carlsen, Awareness Center, Roskilde, Denmark; Dr. Helge Egsgaard, Risoe National Laboratory, Roskilde, Denmark
Project Manager:	BATYRBEKOVA Svetlana
Contact Information:	Phone: +7 (727) 261 38 44 Fax: +7 (727) 292 37 31 E-mail: batyrbekova@cfhma.kz
ISTC Senior Project Manager:	RYZHOVA Tatiana
Contact Information:	Phone: +7 495 982 32 80 Fax: +7 499 978 46 37 E-mail: ryzhova@istc.ru
ISTC Website:	http://www.istc.ru

Background

A range of problems emerging in relation to the space rocket activity on the territories of cosmodromes is caused by both the frequency of space vehicles launches and the type of spacecraft launched. Space rocket activity on the territory of many countries (Russia, USA, France, Japan, China, Kazakhstan) is related to the use of unsymmetrical dimethylhydrazine(1,1-DMH) as fuel and nitrogen tetra oxide as its oxidant. In the course of launching "Proton" rocket-carrier, several hundred liters of unconsumed fuel may spill on the Earth's surface. Rockets of "Proton," "Cyclone," "Changen," "Kosmos," "Ariane," and "Titan" class refer to liquid-propellant space vehicles. Rocket-carriers separating stages contain unsymmetrical dimethylhydrazine (1,1-DMH, CAS 57-14-7) and oxidant (nitrogen tetra oxide). Fall of the first stages is known to be of greatest danger for flora and fauna. The problems of environmental pollution are mainly related to toxicity of 1,1-DMH itself and its transformation products. Of particular danger is accumulation of 1,1-DMH transformation products — N-nitrosodimethylamine(NDMA,CAS62-75-9), tetramethyltetrazene (TMT, CAS 6130-87-6), 1-methyl-1H-1,2,4-triazole(MT),1,3-dimethyl-1H-1,2,4-triazole (DMT) and others. The negative effect of pollution of soil, water, and air with rocket fuel components (RFC) in the regions of fall of rocket-carriers first stages may result in a considerable social and economic risk for health of people. It should be noted that emerging problems of ecological nature still remain unsolved and are caused by:

– the effect of RFC and their transformation products both at regular and accident launches directly in the vicinity of launching pads;

– contamination of environment with highly toxic RFC in the regions of fall of rocket-carrier separating parts;

– littering of the fall regions with fragments of metal constructions;

– the lack of effective methods of analysis of 1,1-DMH and its transformation products in field and laboratory conditions;

– the effect on the upper layers of atmosphere causing the change in its composition;

– possible accumulation of RFC transformation products in soil;

– the lack of efficient methods and technologies of neutralization and detoxication of RFC and its transformation products in the places of rocket-carriers fall.

The main problem in addressing the above listed issues is a lack of robust analytical methods and sampling techniques for analyzing environmental samples for the content of 1,1-DMH and its transformation products. This is primarily due to reactivity and ongoing chemical and biological processes in the samples. However, such analytical methods are needed as 1,1-DMH is known to be very reactive and readily converting to transformation products upon contact with air, water, and soil. Environmental factors driving these processes are only little known. Analytical methods should consider and minimize chemical transformations during sample preparation. During last 15 years, the research was mainly focused on the methods of detecting 1,1-DMH whereas there are no robust methods today for detecting its transformation products.

In view of the fact that regular and accident spills of RFC cover great territories of Kazakhstan, it appears necessary to solve the following tasks:

1. Develop physicochemical and biological methods of detecting RFC and its transformation products (N-nitrosodimethylamine, tetramethyltetrazene, 1-methyl-1H-1,2,4-triazole, 1,3-dimethyl-1H-1,2,4-triazole and others) in environmental and biological samples.

2. Develop biosensor-based test-systems and automated modules to accelerate the work of ecologists.

3. Develop measuring techniques for the concentration of 1,1-DMH and its transformation products in soils.

4. Reveal the locations of polluted zones and estimate the degree of their danger.

5. Study the seasonal dynamics of soil pollution, regularities of distribution and the con-

tent of RFC and its transformation products in a vertical soil profile.

6. Evaluate the mutagenic action of 1,1-DMH and its transformation products on the genome of a live cell.

7. Elucidate the distribution of components in a complex system 1,1-DMH- nitrosodimethylamine, tetramethyltetrazene, 1-methyl-1H-1,2,4-triazole, 1,3-dimethyl-1H-1,2,4-triazole, etc.

8. Evaluate the microbiological state of soils polluted with RFC; evaluate the immunity of plants; provide morphological indices of cultivated and pasturable plants; reveal plant species with heightened immunity to abiotic factors (RFC and its transformation products).

9. Evaluate the possible consequences of pollution with 1,1-DMH and its transformation products.

Project Objectives

The objective was to develop efficient methods for analysis of environmental objects contaminated with rocket fuel residuals and their toxic metabolites and create a scheme of highly-sensitive biosensor module for the presence of mutagens. It was implied that the implementation of the developed methods would make it possible to evaluate the fate and impact of rocket fuel residuals on the environment and population living in the regions located nearby the cosmodromes, and develop efficient remediation strategies.

Description of the Works

The objectives of the project were planned to be achieved by using modern approaches based on physicochemical (gas and liquid chromatography, mass spectrometry, headspace extraction, solid phase microextraction) and biochemical methods.

During the period of project performance, physicochemical and biological methods of detecting RFC and their transformation products (N-nitrosodimethylamine, tetramethyltetrazene, 1-methyl-1H-1,2,4-triazole, 1,3-dimethyl-1H-1,2,4-triazole, etc.) had to be developed. These methods will find application in decontaminating environmental objects polluted with RFC, at industrial enterprises for synthesis of 1,1-DMH and products on its basis, during RFC transportation, refueling, and accident spills. Biosensor test-systems had to be developed for detecting mutagens of chemical and physical nature in the environment. Such test-systems should allow for analysis of samples of water and aqueous extracts of soils for the presence of mutagens of chemical and physical nature. An automated biomodule could be widely used in chemical industry dealing with production of 1,1-dimethylhydrazine and products on its basis. Solution of these tasks could allow for evaluating the behavior of 1,1-DMH and its transformation products in polluted soils, water, and plants as well as revealing the effect of toxicants on the immunity of plants and investigating their effect on the genome of a live cell. The investigated test-systems will allow evaluating the efficiency of separate soil microorganisms and their combinations in the processes of soil decontamination.

Morphoanatomical study of the structure of plants and microbiological investigations of soils is directed towards the development of recommendations on remediation of soils polluted with 1,1-DMH and its transformation products. These investigations will provide the basis for solving the problems of choosing stable cultures and posturable plants. The study of the effect of RFC and its transformation products on the immunity of plants will reveal the species and sorts of cultures with high immunity to abiotic factors (RFC and its transformation products). The necessity of such works is caused by the fact that rocket-carrier trajectories often lie over the territories of grain farming. In a whole, it is implied that the implementation of the Project will provide the development of effective ways of solving of ecological problems associated with space rocket activity. The developed automated biosensor module may find wide applications in the industries related to synthesis of 1,1-DMH and products on its basis.

The project was planned to be implemented within three years (2007–2010). In the course of project implementation, the following works had to be solved:

1. Chromatographic methods of analysis of 1,1-DMH transformation products had to be developed and compared with each other:

1.1. GC/MS methods of detecting 1-methyl-1H-1,2,4-triazole and 1,3-dimethyl-1H-1,2,4-triazole in soils;

1.2. Universal GC/MS method of detecting 1,1-DMH transformation products in soil and water using solid-phase microextraction (SPME) as sample preparation; and

1.3. The results of evaluation of 1,1-DMH transformation products distribution in environmental objects by chromatographic methods and the method by biosensor modules had to be compared.

2. Mutagenic effect of 1,1-DMH and its transformation products on a genome of an alive cell had to be investigated. High-sensitivity biosensor test-systems for detecting mutagens of the chemical and physical nature in an environment had to be developed:

2.1. A pRAC vector providing inducible expression of cloned reporter genes under the control of regulatory region of recA Proteus mirabilis had to be designed;

2.2. Coding regions of gfp gene in designed (stage 2.1) expressive vector pRAC in E.coli had to be cloned;

2.3. Recombinant E.coli clone providing the greatest level of inducible expression of gfp gene which could serve as an indicated strain for studying of mutagenic influences of 1,1-DMH and products of its transformation on a cell genome had to be selected;

2.4. The influence of 1,1-DMH and its metabolites on a genome of indicator strain of E.coli had to be investigated;

2.5. A pRAD vector providing inducible expression of reporter genes under the control of regulator region of E.coli ada gene had to be designed; and

2.6. E.coli recombinant clone carrying pRAD plasmid and providing the greatest level of inducible expression of gfp gene after alkylating action of mutagens (1,1-DMH and its transformation products) on a cell genome had to be selected.

3. The technical documentation (a scheme) of the automated module for measurements of optical absorbance and fluorescence of the whole-cell biosensor had to be elaborated:

3.1. The technical requirements for designing the automated module had to be elaborated;

3.2. The engineering specifications of the temperature-controlled block for whole-cell biosensor cultivation in field conditions (–40...+50 ^{o}C) had to be developed;

3.3. The optical scheme for automatic measurement of the whole-cell biosensor absorbance had to be developed;

3.4. The optical scheme for automatic measurement of the whole-cell biosensor fluorescence had to be developed;

3.5. The setting-up scheme of the module assemblies for automated measurement of optical absorbance and fluorescence of whole-cell biosensor had to be optimized; and

3.6. The software for automated measurement of whole-cell biosensor absorbency and fluorescence had to be developed.

4. Distribution of 1,1-DMH and its transformation products in fall places of rocket-carriers 1st stages had to be investigated:

4.1. Rocket fuel components and their transformation products for a laboratory experiment had to be synthesized;

4.2. Physicochemical and chromatographic investigations of soil and water polluted with 1,1-DMH and its transformation products had to be performed;

4.3. Distribution of the main transformation products (triazoles) of 1,1-DMH in fall places of rocket-carriers 1st stages had to be investigated; and

4.4. The results had to be processed and the data base to be formed.

5. The processes of 1,1-DMH transformation in soil, water and plants had to be studied:

5.1. The processes of chemical transformation of 1,1-DMH in the basic types of soils, characteristic of rocket-carriers fall places had to be studied;

5.2. The behavior of 1,1-DMH in ground and water taking into account the mineral structure of soils had to be studied; and

5.3. The distribution of 1,1-DMH and its transformation products in plants had to be studied.

6. Microbiological investigations of the soils contaminated with 1,1-DMH and its transformation products had to be performed:

6.1. Model experiments on introduction of monocultures of microorganisms into soil polluted with 1,1-DMH and its transformation products had to be conducted;

6.2. Model experiments on introduction of complex cultures of microorganisms into soil polluted with 1,1-DMH and its transformation products had to be conducted;

6.3. Microbiological condition of soils had to be evaluated;

6.4. Chromatographic methods of determining 1,1-DMH and its transformation products in suspension medium had to be developed; and

6.5. The results had to be processed and the database of field investigations for GIS had to be formed.

7. The influence of RFC and products of its transformation on immunity of plants had to be studied:

7.1. The influence of RFC on morphological parameters of cultural and pasturable plants had to be studied;

7.2. The influence of RFC on vegetative and generative bodies of cultural and pasturable plants had to be studied. The control of the maintenance of 1,1-DMH using biosensor test-systems had to be implemented;

7.3. The influence of RFC on stability of grain crops to mushroom illnesses (kinds of a rust) had to be studied; and

7.4. The kinds and grades of grain crops with the increased immunity to abiotical factors (1,1-DMH and its transformation products) had to be revealed.

8. The final report had to be submitted and the generalized project results had to be prepared for publication.

Obtained/Expected Results

In the course of Project implementation, the following results were obtained:

• To study the transformation of 1,1-DMH in soils, the method of headspace extraction coupled with the GC/MS method was used for the first time which allowed detecting 15 volatile metabolites of 1,1-DMH (Fig. 1). The optimal parameters of headspace extraction for their detection were established.

• The use of the coupled methodology allowed revealing 12 new compounds forming as a result of 1,1-DMH transformation in soil. The total amount of the known 1,1-DMH metabolites increased to 27.

• Due to the absence of the data on toxicity of the main part of the detected transformation products of 1,1-DMH, the physical properties and toxicity of the detected metabolites were calculated together with collaborator, Dr. Lars Carlsen (Awareness Center). On the basis of the data obtained, the most toxic and persistent metabolites were revealed. The results have been published in journals Environmental Health Insights, Environmental Toxicology and Pharmacology and International Journal of Environmental Sciences.

• The method of detecting 1-methyl-1H-1,2,4-triazole in soils using GC/MS has been developed. The method detection limit is 5 µg/kg. The method has been described in the paper published in Chromatographia Journal.

• A method of simultaneous detection of 1-methyl-1H-1,2,4-triazole, 1-formyl-2,2-dimethylhydrazine (FDMH), acetaldehyde dimethylhydrazone (AADMH), nitrosodimethylamine and formaldehyde dimethylhydrazone (FADMH) in water samples has been devel-

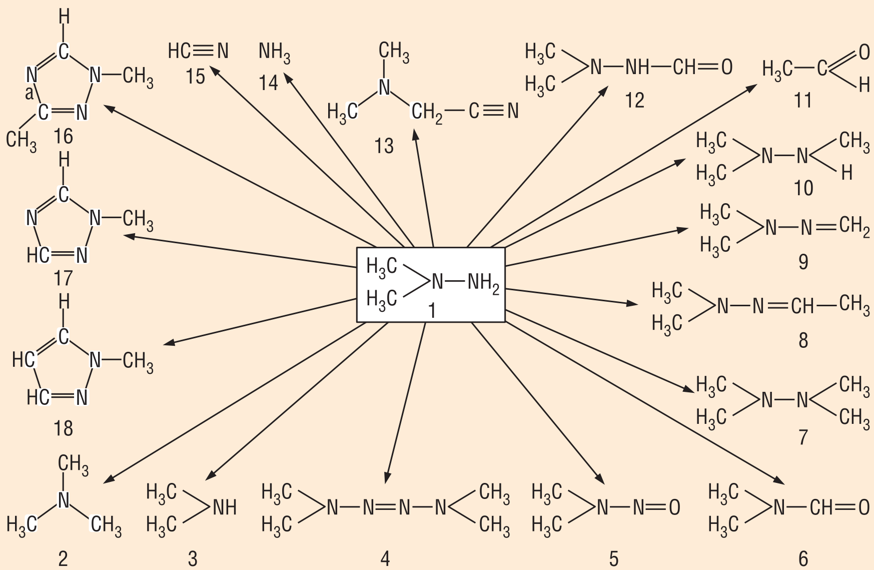


Figure 1: The main transformation products of 1,1-dimethylhydrazine detected using headspace extraction coupled with GC-MS

oped using the HPLC method with diode array detection. The total analysis time with this method was 2.5 min; the limit of detection is in the range of 0.2–1 mg/L. The method of detecting 1-methyl-1H-1,2,4-triazole in water samples based on HPLC/DAD was certified in Kazakhstan (certificate No.438 by State Standard).

• In collaboration with Dr. Jacek Koizel (Iowa State University, USA), Dr. Tim Grotenhuis (Wageningen University, Netherlands), and Dr. Lars Carlsen (Awareness Center, Denmark), a universal, fully automated method of screening 1,1-DMH transformation products in soils has been developed using the method of solid phase microextraction coupled with GC/MS (Fig. 2). The method was successfully applied for analysis of more than 500 soil samples taken from 2 fall places in fall region 25.15. The largest ever array of data was collected. The method was proved to be the most efficient tool for collecting the data about the level of pollution of environmental objects with transformation products of 1,1-DMH. The maps of distribution of 1,1-DMH transformation products in fall places have been obtained (Fig. 3). The method was described in the paper published in Analytica Chimica Acta Journal and is available online (http://dx.doi.org/10.1016/j.aca.2010.05.040).

• The method of quantitative determination of NDMA in water samples has been developed using SPME/GC/MS. The limit of detection is 1 µg/L.

• The method of quantitative determination of FADMH in water samples has been developed using GC/MS and GC/NPD coupled with SPME. The limit of detection is 1.5 µg/L and 0.5 µg/L for MS and NPD, respectively. The method was described in the paper submitted for publication in Chromatographia Journal.

• The main metabolite of 1,1-DMH in soils, 1-methyl-1H-1,2,4-triazole required for calibration of the equipment and for performing microbiological and biochemical studies has

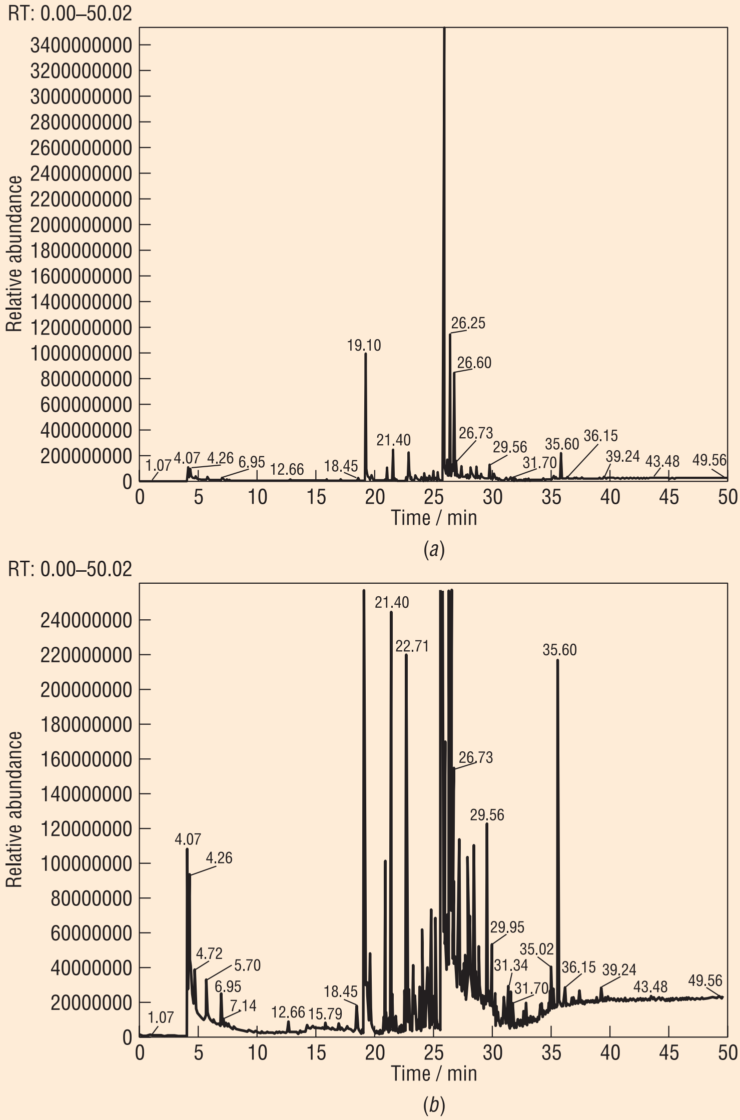


Figure 2: Total ion chromatogram of contaminated soil sample obtained by headspace SPME-GC-MS using 85-micron CAR/PDMS fiber: (a) full-scale chromatogram; (b) detailed chromatogram; conditions: soil incubation temperature 50 °C, headspace sampling time 18 h. Analyses were completed 6 months after spiking blank soil. Soil collected from the Fall Region 25,15 in Kazakhstan

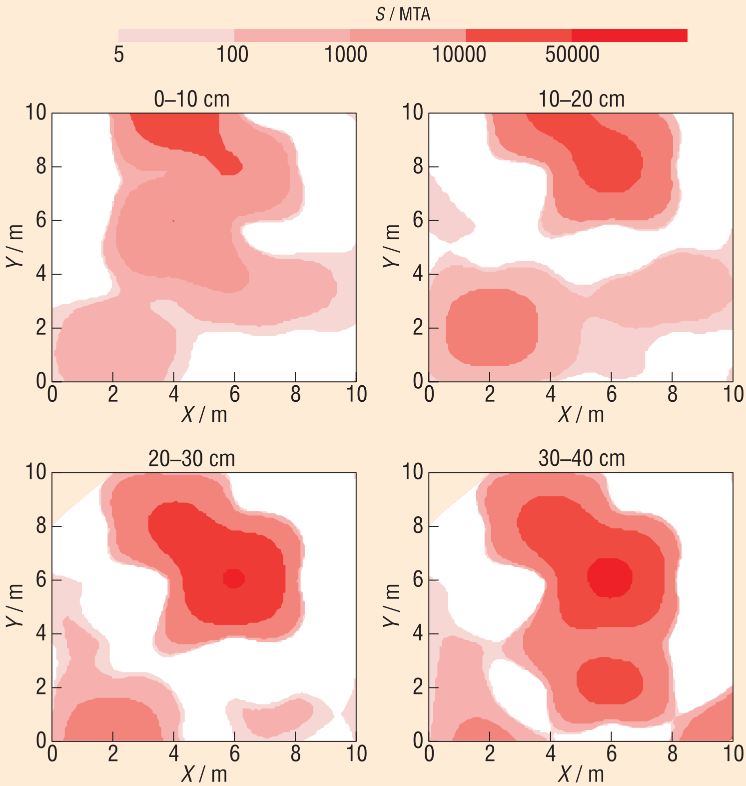


Figure 3: Horizontal distribution of 1-methyl-1H-1,2,4-triazole on different depths of fall place 2 (Fall region 25,15)

been synthesized (volume — 50 ml, 99% purity).

• Methods of synthesis of priority transformation products of 1,1-dimethylhydrazine: 1-formyl-2,2-dimethylhydrazine, formaldehyde dimethylhydrazone and acetaldehyde dimethylhydrazone were fine-tuned. The amount required for the development of analytical methods and performing experiments on 1,1-DMH transformation was synthesized.

• Kinetics of 1,1-DMH transformation in various types of soils was studied using the method of headspace extraction coupled with GC/MS. On the basis of the data obtained it was shown that in surface horizons the transformation of 1,1-DMH proceeded with a high rate according to the multistage mechanism combining consecutive and parallel reactions.

• Study of 1,1-DMH transformation in aqueous extracts from soil allowed revealing the accumulation of MT in them. It was stated that the main intermediate compound, formaldehyde dimethylhydrazone, is responsible for formation of the final products.

• Vector pRAC providing inducible expression of cloned reporter genes under the control of regulatory region of recA Proteus mirabilis gene has been constructed (Fig. 4).

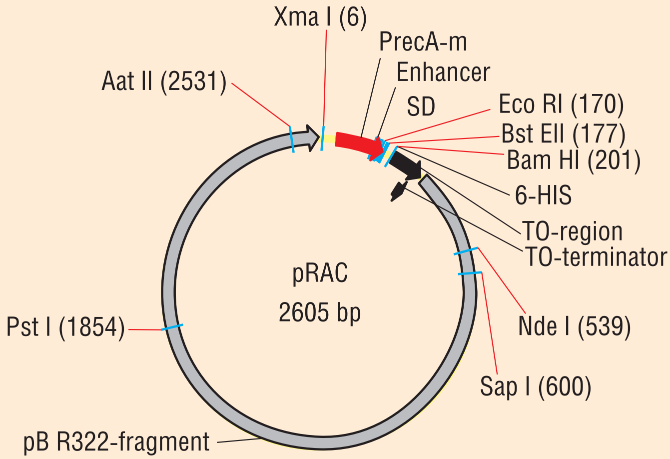


Figure 4: The map of the pRAC expressive vector used for detecting mutagens

• Coding regions of gfp gene were cloned in expressive vector pRAC in E.coli. It was shown that E.coli strain bearing pRAC-GFP hybrid plasmid provides a stable expression of a gfp gene induced by mutagens of chemical and physical nature. The obtained strain can serve as the whole-cellular biosensor for detecting different types of mutagens. The influence of 1,1-DMH and products of its transformation on a genome of E.coli indicator strain was investigated.

• The blocks for measuring the absorbance of whole-cellular biosensor culture and GFP fluorescence have been developed (Figs. 5 and 6). LED with highlight, maximum radiation at 590 nm was chosen as a light emitter. For interfacing the measuring module and PC, the interface consisting of three blocks was developed. The interface allows controlling the fermenter, measuring the fluorescence intensity, and connecting to the managing PC.

• Three new expressing plasmid vectors pRAD-GFP, pRAD2-GFP and PETm-GFP were constructed. On the basis of these vectors, whole-cellular biosensors have been developed for detecting DNA-methylating agents in environmental objects and evaluating toxic properties of 1,1-DMH and its transformation products.

• It was shown that 1,1-dimethylhydrazine, 1-methyl-1H-1,2,4-triazole, tetramethyltetrazene and acetaldehyde dimethylhydrazone exhibit toxic action on E.Coli. indicator strain bearing pETm-GFP plasmid. In addition, 1,1-DMH, NDMA, MT and TMT exhibit pronounced toxic action on peripheral nervous system, though 1,1-DMH cause changes of basic indices of red blood and changes in hemostasis system. 1,1-DMH, AADMH, hydrogen peroxide and formaldehyde exhibit genotoxic action on cells of E.Coli. biosensor strain bearing pRAC-GFP plasmid.

• The final design of a module for automated measurement of absorbance and fluorescence of whole-cellular biosensor has been optimized.

• When introducing different doses of 1-methyl-1H-1,2,4-triazole into soil under wheat Triticim aestivum and Melilotus officinalis, the increase of bacteria with prevailing micromicets of Aspergillus, Penicillium, Bipolaris,

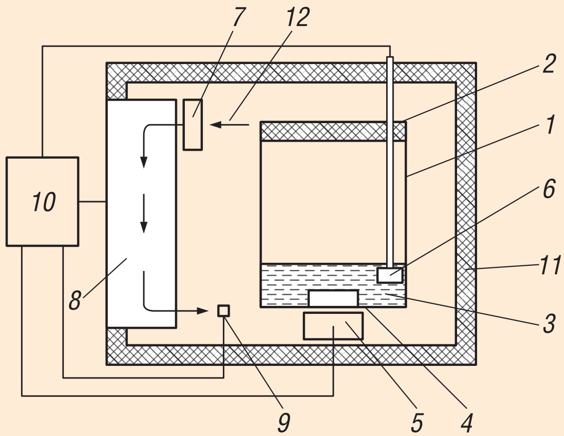


Figure 5: Schematic of a temperature-controlled block for cultivating a whole-cellular biosensor in the fermenter: 1 — fermenter's case; 2 — fermenter's lid; 3 — liquid medium; 4 — magnet; 5 — magnetic stirrer; 6 — sensor of absorption; 7 — fan; 8 — heat exchanger; 9 — temperature sensor; 10 — electronic control unit; and 11 — thermal insulation

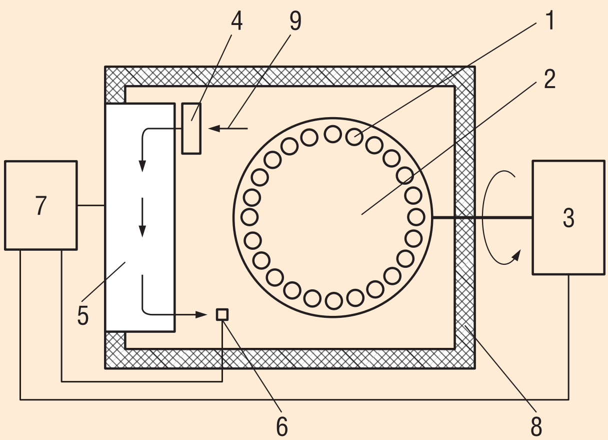


Figure 6: Schematic of the temperature-controlled block for cultivating the whole-cellular biosensor in test tubes: 1 — test tubes with biosensor; 2 — tube holder; 3 — engine for holder rotation; 4 — fan; 5 — heat exchanger; 6 — temperature sensor; 7 — electronic control unit; and 8 — thermal insulation

Trichoderma, and Fusarium was observed. The study of mixed cultures showed the existence of hyperparasitism, mutual aggressive, and territorial antagonism.

• The decrease of quantitative and qualitative indices of germination of Triticim aestivum, Hordeum vulgare, and Medicago sativa was observed in the soil polluted with RFC.

• Melilotus officinalis was stated to be the most sensitive to introduction of 1-methyl-1H-1,2,4-triazole into soil that was seen in the low germination, slow growth of the plant. It was stated that 1,1-DMH and its transformation products show toxic impact on growth and development of wheat which is revealed by delay in germination of seeds, irregularity in approaching of phases of wheat development and formation of underdeveloped reproductive organs of wheat.

• For wheat plants cultivated on polluted soils sampled in fall regions of rocket-carriers, a decrease of their immune status to stem rust has been observed on susceptible (Saratovskaya 29) as well as on steady kind (Omskaya 37).

Institutes – Participants of the ISTC Space Projects

M. V. Frunze Federal State Unitary Enterprise “Arsenal”

Director

SAPEGO Mikhail Kimovich

Address

1-3 Komsomola str., St. Petersburg 195009, Russia

Contact information:

Phones: +7 (812) 542 29 73, 292 48 42
Fax: +7 (812) 542 20 60
E-mail: kbarsenal@peterlink.ru
Website: http://www.kbarsenal.ru

Basic lines of activity:

Investigations aimed at designing perspective space apparatus, space complexes and systems.

Development of space complexes with space apparatus (SA).

Engineering supervision of AS manufacture at the machine-building factory “Arsenal.”

Technical maintenance of running space apparatus, complexes, and systems.

Preparation and realization of scientific experiments on board of SA.

Creation of space platforms of various types and commercial service in designing and manufacturing SA on the basis of platforms, arrangement of their launches and flight control, reception and treatment of the target information.

Designing and manufacturing of automated artillery mounts and rocket launchers for navy.

Designing and manufacturing of civilian products for social and economy purposes (compressors, cryogenic, and refrigerator machinery, driving gears of various types, medical equipment).

Participation in important national and international projects:

– National programs “Cosmos;”

– International programs “Wind-Cone,” “Marine start.”

Brief information about the experimental facilities:

Data base possesses a pilot production plant that implements the following sorts of work:

- mechanoprocessing:
- welding;
- assembling; and
- testing.

The pilot plant participates in manufacturing of all basic designed products.

The production basis of machine-building factory “Arsenal” and experimental basis of cooperating enterprises and institutes that take part in making products are used in creation of space systems.

Institute of Astrophysics of Tajikistan Academy of Sciences

Director

IBADINOV Khursand Ibadinovich

Address

22, Bukhoro, Dushanbe 734042, Tajikistan

Contact information:

Phones: +7 (992) 372 27 46 14, 372 27 46 24

Fax: +7 (992) 372 21 49 11

E-mail: ibadinov@ac.tajik.net, kokhirova2004@mail.ru

Basic lines of activity

The basic lines of scientific research performed at the Institute are: small bodies of the Solar system — asteroids, comets, meteoroids; astrometry and celestial mechanics; Sun and Sun–Earth interaction; physics and evolution of stars and interstellar matter; extragalactic astronomy. Institute is actively involved in schooling of highly qualified researchers.

Participation in important national and international projects

The Institute accomplished long-term complex (photographic, spectral, television, and radar) investigations within the following programs:

– International geophysical year (IGY));

– The international year of the quiet Sun (IYQS));

– Global system of meteor investigations (GLOBMET);

– The International Halley Watch (IHW); and

– Soviet equatorial meteor mission (Somali, 1968–1970 , led by academician P. B. Babadzhanov).

The Institute actively participated in development and implementation of the international (IHW) and Soviet (SOPROG) programs of investigation of the Halley comet.

The Institute took part in creation of the data base within the international programs “INTERCOSMOS,” “MERIT,” “GREAT CHORD,” in Soviet programs “FON” and “FOKAT,” an astrometric standard in the Swan constellation and catalogue of geostationary satellites were worked out.

The Institute participated in elaboration of USSR State standard “Meteor matter” and of Earth atmosphere models for the needs of space exploration. The results of definition of the orbits of more than 500 bright meteors based on photographic observations and of more than 5000 weak meteors based on radar observations at the equator are included in the international data bank of the International Astronomic Union (Lund, Sweden). The results of observation of Halley comet have been used in realization of the VEGA space mission project in 1985–1986 and are included in the international data archive. The results of investigations of the comet core properties are used in preparation of the international project “ROSETTA” of space mission to comets and asteroids. Position observations of man-made Earth satellites are used to correct the orbits of interplanetary stations and Earth satellites and creation of catalogues of the geostationary satellites.

Short information about the experimental facilities

The experimental basis at the Institute includes three modern astronomic observatories and a bolide network:

(*i*) Gissar astronomic observatory (730 m above the sea level, good astroclimate);

(*ii*) International astronomic observatory "Sanglokh" in the Dangarin district (2300 m above the sea level, the number of clear nights 200 per year); and

High-altitude astronomic observatory Sanglokh

TN180906 bolide belonging to the meteor flow September Dragonides, photo is taken at 9 h 59 min 20 s PM on September 18, 2006 (Sanglokh). The maximum stellar magnitude is 13, mass is 5 kg

(*iii*) Astronomic observatory "Pamir" (branch of the Sanglokh observatory) in the Murgab district of the Gorno-Badakhshan Autonomous Region (the altitude is 4350 m, the number of clear nights is 250 per year). At present, we are modernizing the techniques of astronomic watch, new techniques and technologies are introduced. The use of a CCD matrix improves the quality of observations significantly and makes it possible to obtain information on-line. The bolide network functions since 2009 and comprises 5 watching points covering an about 11 000 m^2 territory located at the southern Tajikistan part.

Gissar astronomic observatory

Forty-centimeter Zeiss Astrograph (D = 400 mm, F = 2000 mm) at Gissar astronomic observatory

TN140707 bolide belonging to Nothern i-Aquarides, the photo is taken with a digital camera on July 14, 2007 at 7 h 39 min 44 s PM at Gissar astronomic observatory

Institution of Russian Academy of Sciences, A. E. Favorskii Irkutsk Institute of Chemistry Siberian Branch RAS

Director

Academician Trofimov Boris Aleksandrovich

Address

1 Favorskii str., Irkutsk 664033, Russia

Contact information:

Phone: +7 (3952) 51 14 31

Fax: +7 (3952) 41 93 46

E-mail: irk_inst_chem@irioch.irk.ru

Website: http://www.inchemistry.irk.ru

The basic lines of activity

• Methodology of synthesis of organic and heteroorganic compounds on the basis of acetylene and its derivatives aimed at production of new biologically active species, polymers, and materials for high technologies, including nanosystems

• Theory of chemical bonds, mechanisms of chemical reactions, reactivity and structure of organosilicon compounds including compounds of hypervalent and three-coordinated silicon

• Chemistry of extractive compounds from wood and natural polymers, including nanocomposites

Participation in important national and international projects

• RFBR grants, including RFBR-Baikal, RFBR-France, RFBR-Germany, RFBR-Mongolia and RFBR-China grants

• ISTC grants

• Grant within the 7th EU Program (**Polysion**)

• ISTC Projects

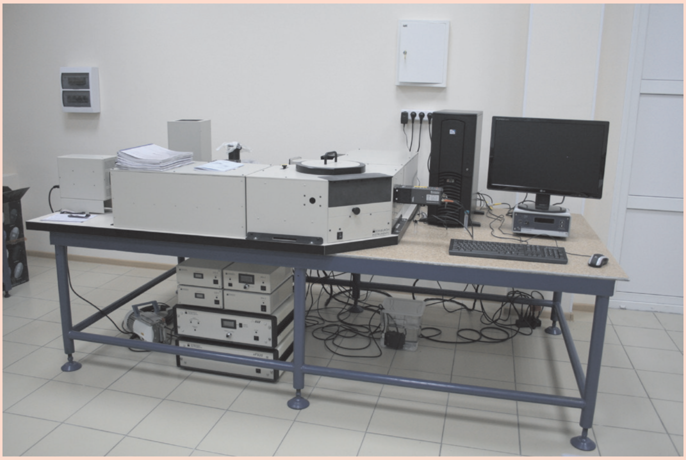
Brief information about the experimental facilities

Analytical instrumentation facilities, intellectual property and highly qualified researchers make up the basis of one of the acting departments that performs analysis of organic compounds — Baikal analytical center of common use (TsKP-Baikal).

The instrumental facilities of the Institute have been renewed virtually completely. The following items of the modern equipment have been purchased: two Vertex 70 IR-Fourier spectrometers with a RAM II Bruker Raman attachment device, ELEXSYS E 500 ISR spectrometer, 5975 Agelent chromato-mass-spectrometer, FLS 920 Edinburg Instruments spectrofluorimeter, Parr high pressure reactor, and SPEKOL 1500 Analytic Jena spectrometer.

Three hundred computers at the Institute are integrated in a common network connected to Internet.

ELEXSYS E 500 ISR spectrometer Bruker, (Germany)



FLS 920 Edinburg Instruments spectrofluorimeter Instruments (Great Britain)

Institution of Russian Academy of Sciences, Institute of Thermal Physics, Ural Branch RAS

Director

BAIDAKOV Vladimir Georgievich

Address

106 Amundsen str., Ekaterinburg 620016, Russia

Contact information:

Phone: +7 (343) 267 88 01
Fax: +7 (343) 267 88 00
E-mail: itp@itp.uran.ru
Website: http://www.itp.uran.ru

Basic lines of activity

- Nonequilibrium processes with phase transitions
- Thermal and physical properties of materials in stable and metastable states
- Heat transfer in high-energy processes and enhancement of reliability in energy engineering

Participation in important national and international projects

In 2006–2009, Institute implemented Project "COSEE" — cooling of seats, electronic box, and cabin equipment within the 6th framework Program of the European Commission.

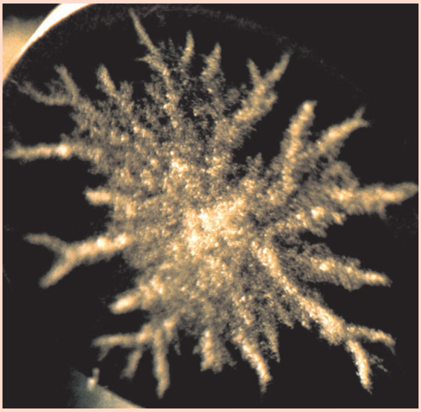
Brief information about the experimental facilities

Five laboratories are functioning at the Institute; the number of researchers working at these laboratories is 37, including one member-correspondent of RAS, 10 doctors of sciences, and 21 candidates of sciences. In 1999, a group of leading researchers was awarded with the RF State Prize in science and engineering for the set of works "Metastable states of liquids: Basic investigations and applications in energy engineering." The basic investigations are focused on exploration of thermal and physical properties of materials, phase transition kinetics, and processes with participation of metastable phases. New techniques are developed at the Institute and new setups are created for studying the kinetics of boiling and crystallization of metastable liquids (cryogenic liquids, solutions, polymers, chemically reacting systems). Shock evaporation regime, barocapillary instability of a superheated liquid, and explosion-like incipience of crystallization centers in a supercooled liquid are discovered. Intense flicker-noise was disclosed in heat exchange processes.

High efficiency heat conducting devices — loop heat pipes — are worked out. A cooling system for the onboard electronic unit of long-distance passenger plains is designed and manufactured on their basis. The shock heating technique is used to design a device for operative indication of volatile admixtures in oils of thermal and energetic equipment. Systematic investigations in the field of electric energy engineering are conducted.

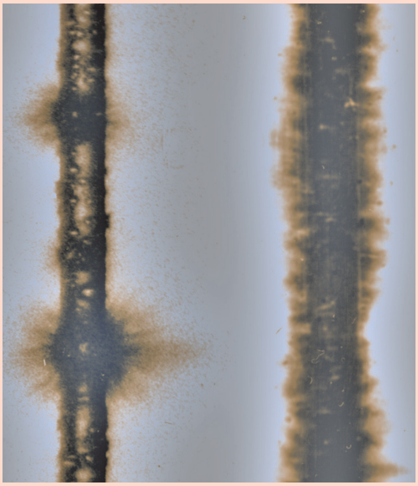
The Institute organizes Russian meetings "Metastable states and fluctuation phenomena" and participates, together with the Institute of Physics of Metals, in organization and conducting of workshops on physics of condensed material state for young scientists.

Instrument for control of volatile admixtures in thermal and energy equipment



Intense water cavitation in an ultrasound field

Explosion-like jet boiling



Explosion-like boiling of electrically conducting jets in the course of their fast Joule heating

Institution of Russian Academy of Sciences S. A. Khristianovich Institute of Theoretical and Applied Mechanics, Siberian Branch of RAS (ITPM SO RAN)

Director

Academician Fomin Vasilii Mikhailovich

Address

4/1 Institutskaya str., Novosibirsk 630090, Russia

Contact information:

Phone: +7 (383) 330 42 68

Fax: +7 (383) 330 72 68

E-mail: admin@itam.nsc.ru

Website: http://www.itam.nsc.ru

Basic lines of activity

- Mathematical modeling in mechanics
- Aerogasodynamics
- Physicochemical mechanics
- Mechanics of solid bodies, deformation and destruction

Participation in important national and international Projects

International relations of the Institute are broad. European Space Agency (ESA–ESTEC), DLR, HTG company, ETW, Aachen Aerodynamic Institute, Stuttgart University (Germany), Aerospacial company, Dassau Aviacion aviation company, INRIA, ONERA (France), PIAM, Beijing University, CARDC (China), Rutgers University, NASA Langley, Wright-Patterson Laboratory Airforce USA, Boeing Aviation Company, Rockwell Scientific Center (USA), Westfield College, London University (GB), University of Antwerpen, von Karman Institute of Fluid Mechanics (Belgium), University of Akita prefecture (Japan), National Scientific Counsel (NSC), and National Space Organization (Taiwan) are partners of the Institute.

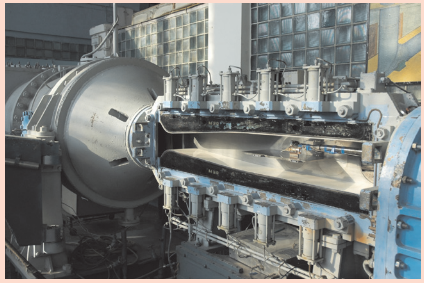
Russian partner organizations are: TsAGI, TsIAM, RSC "Energiya," SPA "Altai," OSA SPA "ISKRA," TsNIIMASH.

The list of ISTC funded projects is: #0128 — 1996, #0612-2 — 1999, #1863p — 2000, #2172p — 2001, #0887 — 2001, #1858 — 2002, #2109 — 2002, #3646 — 2005, #3159 — 2006, #3550 — 2007, #3872 — 2009.

Brief information about the experimental facilities

A unique aerodynamic experimental base is created at the Instute. Gas flows at velocities ranging from low subsonic ones to space velocities (M = 0.1 to 25) and Reynolds numbers of up to their values inherent in hypersonic flights are modeled in wind tunnels at ITPM, this permits the flow parameters to be simulated along the entire flight trajectory of space vehicles (of the "Energiya-Buran" type).

Adiabatic compression hypersonic wind tunnel AT-303



Low-turbulence supersonic wind tunnel T-325

Supersonic wind tunnel T-313

State Scientific Center of Russian Federation, Federal State Unitary Enterprise "M. V. Keldysh Research Center" (SSC FSUE "eldysh Center")

Director

Academician Koroteev Anatolii Sazonovich

Address

8 Onezhskaya str., Moscow 125438, Russia

Contact information:

Phone: +7 (495) 456 46 08

Fax: +7 (495) 456 82 28

E-mail: kerc@elnet.msk.ru; kerc@comcor.ru

Website: http://www.kerc.msk.ru

Basic lines of activity

• Development of methods capable of increasing rocket engine efficiency, including approaches to enhancement of the operation process stability, methods for suppressing high-frequency oscillations, efficient techniques of cooling high-heat areas, methods for increasing strength of TPA units, incorporation of carbon–carbon and carbon–ceramic construction materials in nozzle blocks of solid propellant rocket engines and liquid rocket engines

• Development of application packets of computer codes for mathematical modeling of operation processes in rocket engines

• Creation of electrically driven rocket engines of a wide power range with a high specific thrust impulse

• Search for new schemes and concepts of rocket engines

• Search for new alternative energy sources, problems of hydrogen energetics (original methods of hydrogen synthesis and storing), working out of lithium-ion accumulator batteries for space applications

• Investigations in the field of basic low-temperature plasma properties

• Elaboration of the technology and new composite materials capable of providing long-term operation of hypersonic flying vehicles (HFV) at high temperatures in oxidative media, optimization of the HFV construction units, investigations into stability and efficiency of operation processes, and development of methods of thermal HFV protection.

Participation in important national and international Projects

Activity of the Keldysh Center is arranged based on the necessity of development of breakthrough and innovation technologies. The Project "Transport-energy module based on a nuclear power-propelling setup of a megawatt class" approved by the President of Russian Federation D. A. Medvedev on November 10, 2010 is among such works.

The Keldysh Center has wide scientific relations with space agencies and leading aerospace companies in Europe, Asia, and USA, takes part in international space programs: URAL, Russia-EU dialogue on space problems, and ISS.

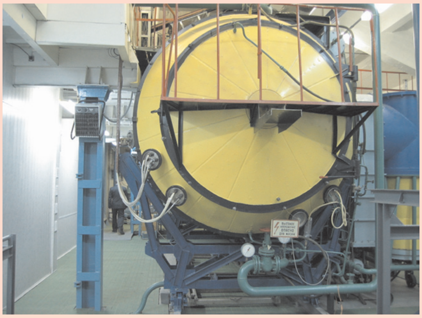
Brief information about experiemntal facilities:

The Keldysh Center possesses an extensive experimental base equipped with modern instruments for measurements and diagnostics, a number of tests benches available at the Center are unique, e.g.:

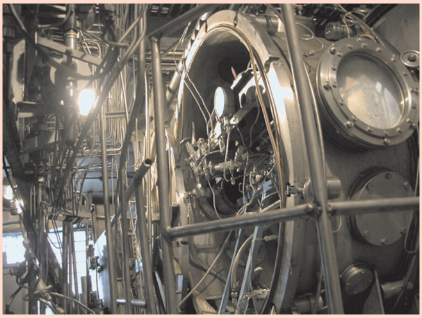
• Cryogenic vacuum test bench for studies of electric rocket engines, the vacuum chamber in it is 90 m^3 in volume and the design productivity of the cryogenic pumps amounts to 200000 liter/s;

• Test bench for studies of basic plasma properties (vacuum chamber 50 m^3 in volume, the deepest vacuum is 10^{-6} Torr);

• A set of test benches at which interaction of oxidative and reducing media with construction materials of rocket engines are studied.



Test bench for electrophysical measurements at which processes and super-high-frequency diagnostics of a low-temperature plasma are studied



Test bench for investigation and testing (including round-the-clock tests) of LRE of low (not higher than 100 kN) thrust

Cryogenic vacuum test bench

Open Stock Association "ac. V.P. Makeyev State Rocket Center" (OSA "GRTs Makeyeva")

Director

DEGTYAR' Vladimir Grigorievich

Address

Russia, Chelyabinsk region, 456300, Miass city, 1 Turgoyarskoe shosse

Contact information:

Telephone:+7 (3513) 28 63 33, fax:+7 (3513) 56 61 91, 24 12 33,

E-mail: src@makeyev.ru

Website: http://www.makeyev.ru

Major lines of activity:

Scientific research in the area of natural and technical science, creation of rocket and rocket-space complexes, space apparatus for various purposes, units and systems of other armament types and weaponry, manufacture of rocket and rocket-space complexes, development of rocket-space complexes of new generation, elaboration of methods for prolongation of operation of rocket complexes and the systems, aggregates, and equipment incorporated in them.

Participation in important national and international projects:

Within the federal space program SRC participates in cooperation with CSDB "Progress" and RSC "Energiya" in creation of rocket-space complex "Vostochnyi" in the Amur region. The SRC works out the first stage of the launcher rocket "Rus'-M" of a medium class to be used in launching manned and cargo transport vehicles of a new generation as well as orbital modules to low near-Earth orbits. In addition, the Vostochnyi complex is intended for putting automated space apparatus to low, medium, and high circular and elliptic orbits, including trajectories of flying-way to planets of the Solar system.

In compliance with the order of the "Air start" (Vozdushnyi start) company, the Center elaborates a prospective aviation rocket complex of space designation. The "Air start" Project according to which a one hundred ton rocket designed with the use of technologies of manufacturing ballistic rockets for submarines (BRSM) is to be launched from the board of transport plane "Ruslan" (AN-124-100), would allow satellites to be launched to orbits of altitudes and inclinations varying in a wide range without building of expensive start constructions. Moreover, due to start in rarified atmosphere layers and additional plane velocity the rocket can put into a space orbit 30 or 40% heavier payloads than does a rocket launched from the Earth surface, which in the final run would significantly lower the cost of specific expenditures per 1 kg of the satellite weight.

The specialists at the Association worked out a small-size space platform that permits one to promptly create various types of space apparatus, in particular, exploration satellites of the "Compass" series, the last of which was put into orbit in 2006. The data furnished by the satellite are used by scientists to record abnormal physical phenomena and representative indicators in the ionosphere caused by volcanic, seismic, and cyclonic activity and to measure radiation from the radiation belts of Earth and space rays.

The Makeyev Center actively participates in international space programs, including technological assistance to Brazilian specialists in enhancing reliability and safety of the "VLS-1" rocket.

A dialog is going on in which extension of the cooperation in the field of creation of promising launchers for the “Alcantara” space launching site is discussed.

Scientists from Italy, France, Germany, and other countries are interested in developments of the Center including supersmall launchers based on modified BRSM. The high adaptivity of the rockets created permits various experiments to be conducted in space to elaborate new technologies for the sake of space instrument engineering, promising transport vehicles for interplanet flights, missions associated with landing on other planets and return to the Earth, and for solving many other complicated problems. Payloads (PL) have been launched with the aid of remodeled ballistic rockets of submarines since 1991.

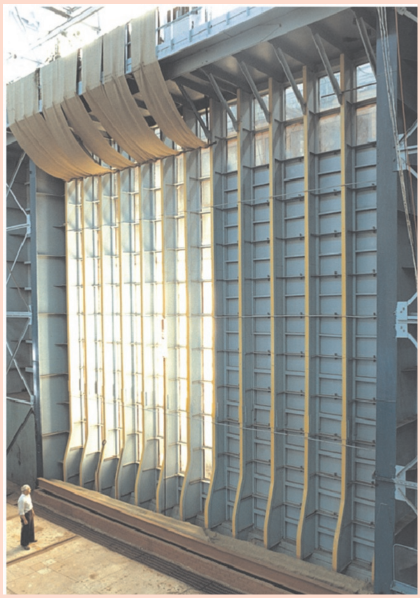
At present, the Center is involved in implementing the tasks of the EXPERT Project, which is a research program of aero-thermodynamic tests of multiple-launch space system constructions (EKA, TAS-I company), “Volan–EADS” aimed at the use of superconducting magnetic systems in space systems (EKA, Astrium-ST company) and others.

Design of promising wind-driven power plants is another prospective line in research works. The partners in this work are the Laurence National Laboratory at Berkeley, Empire Magnetics Inc. (USA) and Russian companies.

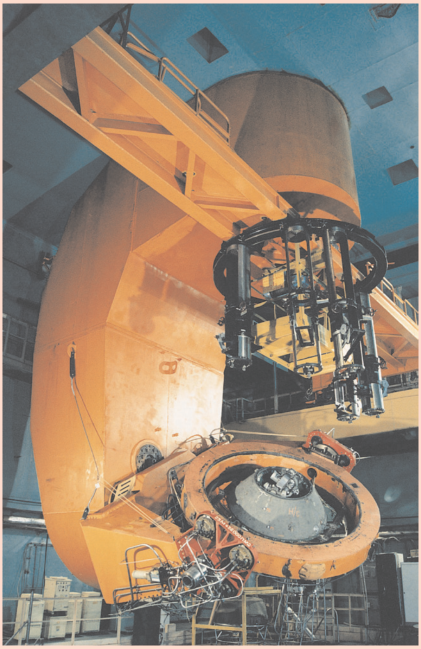
Brief information about experimental facilities:

The modern experimental facilities available at the Center permit conduction of full-scale tests of rocket-space engineering specimens subjected to all types of operation loads. The test center at the SRC can also certify products of the transport, power, and chemical machine-building, medical engineering items, and production of the building industry and household appliances.

Vacuum dynamic test bench



Hydropond



Complex modeling test bench

Strength tests of a tubing

OSA “V. L. Glushko SPE Energomash

Director

PAKHOMOV Dmitrii Vyacheslavovich

Address

1 Burdenko str., Khimki, Moscow region 141400, Russia

Contact information:

Phones: +7 (495) 777 02 71, 572 76 49

Fax: +7 (495) 777 21 36

E-mail: energo@online.ru

Website: http://www.npoem.ru

Major lines of activity

• Development of powerful liquid propellant rocket engines for the first and second launcher stages fueled with low- and high-boiling liquid components

• Theoretical investigations aimed at designing liquid fuel rocket engines

• Experimental finishing of liquid rocket engine constructions, their units and aggregates

• Expert evaluation of the results of testing liquid rocket engines as a whole and of their individual aggregates

• Elaboration of the newest technologies of liquid rocket engine building

• Supervision of in-flight tests of launchers

Participation in important national and international projects

• RE-180 Program aimed at production of an RE-180 engine for the USA launcher “Atlas 5” and develpment of materials for a draft design of launcher rocket “Rus’-M” to be launched from the “Vostochnyi” launching site.

• RE-191 Program which is finalizing of the RE-191 engine elaboration for the new family of Russian launchers “Angara”

• Program of modernization of engines for launcher “Soyuz:” author’s supervision of production 14D21 and 14D22 engines used in launchers of the “Soyuz” family

• Program of modernization of the engines for launcher “Proton:” author’s supervision of serial production of 14D14M engines for launchers “Proton”

• Program of modernization of engines RD-171 for launcher “Zenith” within the Federal “Earth start” (Zemnoi start) program and in the interests of Defense Ministry of RF.

Brief information about experimental facilities

SPA ENERGOMASH possesses a well developed infrastructure that includes all necessary components of the technological cycle of LRE design and production:

• Design bureau with a powerful intellectual and personnel potential. Author’s supervision of manufacturing the engines and engineering maintenence of serial production of the engines and in-flight tests of launcher rockets is one of the functions of the Design bureau. For this purpose, the Design bureau has a number of its branches (at Samara, Perm, and St. Petersburg);

• Factory equipped with modern versatile and specialized facilities. The pilot plant has at its disposal qualified production workers and specialists that elaborate the technology, process, manufacture, and assemble rocket engines;

• Scientific-test center that has unique test-bench facilities (more than 80 test benches) for all kinds testing of LRE as a whole and of its individual aggregates. There are two unique test bench complexes for firing tests of engines with a thrust value of up to 1000 ts.

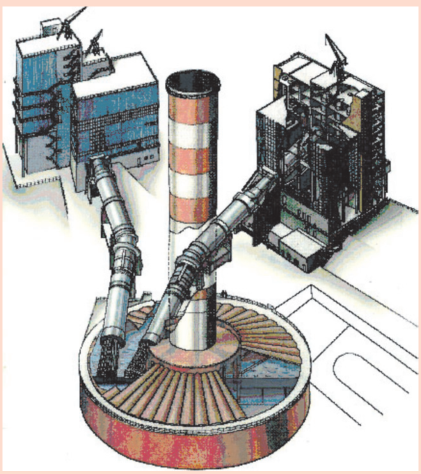
The test bench facilities comprise:

• complex of test benches for firing tests of engine systems, beginning with injector devices through to engines with a thrust of up to 1000 ts;

• a number of test benches for conducting static and dynamic tests of individual engine units and aggregates with the use of model and conventional liquids and gases within a wide range of parameters, flow rates of the components, and climatic factors;

• test bench for gasdynamic studies relevant to solution of the problems of construction material and coating ignition in aggressive high-temperature media;

• a set of facilities and instruments for chemical analysis.



Schematic of the firing test benches available at the "ac. V.P. Glushko OSA Energomash"

Test bench at which liquid pumping powerful LRE pumps are tested

OSA “Specialized Research Institute of Instrument-Building” (OAO SNIIP)

Director

PELEVIN Aleksandr Fedorovich

Address

5 Raspletina str., Moscow, Russia

Contact information:

Phone: +7 (499) 198 97 64

Fax: +7 (499) 943 00 63

E-mail: info@sniip.ru

Website: http://www.sniip.ru

Major lines of activity

- Apparatus for control and management at APP (atomic power plants)
- Instruments for RF Defense Ministry objects
- Environment controlling instruments (standardizing and metrology)
- Computer modeling technology (modeling complexes)
- Plasma complexes for waist treatment
- Nano- and microelectronics: realization of nanotechnologies (creation of a special element resource)
- Elaboration of special optical fibers

Participation in important national and international projects

Projects: “Zond,” “Cosmos,” “Venera,” “Luna,” “Mars,” “Oreol,” “Salute,” “Prognoz,” “Vega,” and “Fobos:”

- measurements of fluxes and energies of gamma-quanta and electrons, protons and neutral molecules on near-Earth orbits and in interplanetary space;
- measurements of gamma-quanta energies on near-Moon orbits;
- measurements of parameters of space apparatus impingement on surface;
- measurements of UV-quanta fluxes in inter-planetary space;
- investigation of the plasma parameters on near-Earth orbits with electric probes;
- measurements of fluxes and energies of protons and electrons at near-pole areas of near-Earth orbits;
- search for X-ray sources (X-ray astronomy);
- measurement of mass-spectra of dust particles and plasma parameters at the “head” of the Halley comet;

• measurement of the spectrum of gamma-radiation from the Venus surface with the aid of a descending space apparatus;

• investigation of radiation fluxes in magnetosphere from space.

•

Brief information about experimental facilities:

OSA SNIIP has an attested and accredited State Center for testing of measurement techniques, which allows us to certify dose-monitoring and radiometric apparatus produced not only at OSA SNIIP but at other organizations. The institute performs metrological expertise of technical documentation and develops measurement techniques. OSA SNIIP has a Test department (heat and cold chambers, chambers for pressurizing tests, test benches for shock loading and shaking, and other equipment).

Heat and cold chamber

Setup for attestation of radiometric and dosimetric instruments

Yerevan Physics Institute after A. I. Alikhanian

Director

Prof. Ashot Chilingarian

Address

2 Alikhanyan Brothers str., Yerevan 0036, Armenia

Contact information:

Phone: +7 (374) 10 34 15 00

Fax: +7 (374) 10 35 20 41

E-mail: chili@aragats.am

Website: http://www.yerphi.am

Main activities

The Yerevan Physics Institute was founded in 1943 as a branch of the Yerevan State University by brothers, Academicians Abraham Alikhanov and Artem Alikhanian. A year later it was turned over to the Armenian Academy of Sciences. Now Yerevan Physics Institute is governmental noncommercial institution belonging to the ministry of Economy of RA.

Among the key results of Yerevan Physics Institute (YerPhI) were the discovery of protons and neutrons in cosmic rays, and the establishment of the first evidence on existence of the particles with masses between that of muons and protons. The foundation of the cosmic ray station on Mt. Aragats at 3250 m above sea level was one of the steps establishing the development of particle physics in Armenia. These stations have remained the main research base of the Cosmic Ray Division of YerPhI until now. Recent achievements are the discovery of sharp knee in light components of primary nuclei, research of the fine structures in energy spectra, detection of the highest energy protons accelerated on the Sun, and the creation of the Aragats Space environmental Center in 2000.

Participation in significant domestic and international projects

During the last years, groups of scientists from Yerevan Physics Institute have actively participated in medium and high energy physics experiments abroad (JLAB, DESY, CERN), exploring the meson and nucleon structures, electromagnetic interactions of the nucleon, quark-hadron duality, short range nucleon–nucleon correlations, quark hadronization in nuclear medium, quark-gluon plasma, and many other topics, as well as in construction of experimental hardware and development of the software for data acquisition and analysis.

The theoretical department continues working in various fields, including QCD and Related Phenomenology, Standard Model Phenomenology, Neutrino physics, Cosmology, Quantum Field Theory, String/M-theory, Integrable Models, Statistical physics, Condensed Matter and Quantum Information. YerPhI theorist made also key contribution to several experimental projects in JLAB and CERN.

Summary of the experimental base

- One of the world largest 6 GeV electron ring accelerators
- A number of modern automated physical installations for investigations using the electron and photon beams of Yerevan synchrotron
- High-altitude Nor Amberd and Aragats stations (2,000 and 3,200 m above sea level) for the study of cosmic rays at superhigh energies
- Special modern instruments and equipments for scientific and technical works in applied fields
- A powerful computer center
- A developed pilot production

Aragats research station

Nor Amberd research station

General view of the SES (space environment simulating)

Open Stock Association "Lytkarino factory of optical glass" (OSA "LZOS")

Director

PATRIKEEV Aleksei Pavlovich

Address

1 Parkovaya str., Lytkarino, Moscow region 140080, Russia

Contact information:

Phone: +7 (495) 552 32 95

Fax: +7 (495) 552 17 90

E-mail: office@lzos.ru

Website: http://www.lzos.ru

Basic lines of activity

There are five specialized lines of OSA "LZOS" activity:

(*i*) melting of optical glass and fiber optics;

(*ii*) processing of optical materials;

(*iii*) astronomy and space optics;

(*iv*) optical instrument production; and

(*v*) science and technology center.

OSA "LZOS" produces 98% of optical glass made in Russia. Longtime experience of production and efficient cooperation with "S. I. Vavilov State Optical Institute" permitted OSA "LZOS" to issue more than 240 brands of colorless optical glass and more than 60 sorts of colored glass. The factory supplies its production both to enterprises in Russia and UIS and to various countries in Europe, America, Africa, and Asia. The high quality of the glass made at the factory is warranted by application of advanced technologies, extrapure raw materials, and tolerance control of the main optical glass parameters.

Participation in important national and international projects

The scientific and engineering experience accumulated by the factory made it possible to come in middle of 1970s to the international market of large-size astronomy optics. Since 1994, OSA "LZOS" made optical products of diameter ranging between 500 and 4100 mm within more than 50 international projects. Among them, the basic projects are:

– seven sets of chief mirrors 2 m in diameter and secondary mirrors 648 mm in diameter have been made for telescopes of TTL company (Telescope Technologies Ltd, Great Britain) and LCOGT (Las Cumbres Observatory Global Telescope Network, USA and Great Britain);

– set of astronomy mirrors of up to 2 m in diameter have been made for the Chinese Academy of Space Engineering;

– the chief mirror of telescope 1.23 m in diameter was made for the Heidelberg Max Planc Institute (Germany);

– two chief telescope mirrors 2650 mm in diameter and the secondary mirror 938 in diameter were produced for the VST project (VLT Survey telescope, Osservatorio Astronomico di Capodimonte Napoli Italy). Asphericity of the mirrors is about 100 μm;

– the chief telescope mirror 2.3 m in diameter for the National observatory in Athens (Greece);

– 96 half-finished segments of the chief mirror 11 m in diameter for the SALT telescope (South African Large Telescope);

– 20 of half-finished items for the MB mirror about 4.5 m in diameter for the Chinese LAMOST telescope; and

– set of mirrors for the telescope of Southern Europe observatory VISTA (Visible and Infrared Survey Telescope for Astronomy).

Brief information about experimental facilities

The Production-Engineering Complex OSA “LZOS” comprises:

• facilities for glass melting;

• facilities for milling of optical units up to 6 m in diameter with precision of up to 10 μm;

• constant-temperature compartments for optics processing;

• automated computer-controlled machines of the AD series for shaping optical units of size varying from 100 to 6000 mm;

• a set of interferometers used to control the surface shape at all technology stages;

• wave front correctors controlling the surface shape of aspherical units. They are designed and manufactured at our factory;

• a set of routines for calculations of lightweight astronomy mirror constructions (weight reduction of up to 80%) and of their deformations at unloading of the system; and

• a set of technological routines applied to treat on line wave front interferograms of the item controlled, to calculate technological parameters of automated shaping, to automatically correct the technological process based on the results of the automated processing seance, and to predict the resulting surface shape.

Federal State Institution Russian Scientific Center “Kurchatov Institute”

President

Academician VELIKHOV Evgenii Pavlovich

Director

Professor KOVALCHUK Mikhail Valentinovich

Address

1 Academician Kurchatov sq., Moscow 123182, Russia

Contact information:

Phone: +7 (499) 196 91 25

Fax: +7 (499) 196 18 70

E-mail: koval@kiae.ru

Website: http://www.kiae.ru

Basic lines of activity

- Nanobiotechnologies, nanomaterials, and nanosystems
- Atomic energetics and promising energy technologies
- Thermonuclear synthesis and ion-plasma technologies
- Interdisciplinary fundamental studies
- Information technologies and systems
- Dual application technologies and products
- Nonproliferation, rehabilitation, and physical protection
- Biomedical technologies and nuclear medicine
- Technology of isotope separation
- Convergence of nano-, bio-, and infocognitive sciences and technologies and creation of a basically new research infrastructure oriented to interdisciplinary investigations and developments are one of the most important scientific tasks of Kurchatov Institute development at present.

Participation in important national and international projects

- Scientific coordinator of activity in the field of nanobiotechnologies, nanosytems and nanomaterials in Russia
- Scientific supervisor of works aimed at creation APS-2006 and VVER-TOI
- Active participant of global scientific projects: thermo-nuclear reactor ITER, CERN, XFEL, FAIR, Russian–German laboratory studying synchrotron radiation, etc.

Brief information about experimental facilities

- Six nuclear research reactors
- Fourteen critical reactor assemblies
- Specialized source of synchrotron radiation
- Thermonuclear facilities TOKOMAK
- Material research complex of hot chambers for studies of irradiated materials
- Cluster technological line for producing integral circuits
- Facilities for isotope separation
- Complex of physical, chemical, and radiochemical laboratories

Web-sites of other Institutes participants of space ISTC projects

Name of the Institute	Web-site (Russian version)	Web-site (English version)
FSUE "Krasnaya Zvezda" (Red Star) State Corporation "Rosatom"	http://www.redstaratom.ru	
Al-Farabi Kazakh National University	http://www.kaznu.kz/ru	http://www.kaznu.kz/en
FSUE "State Scientific Center of Russian Federation — A. I. Leipunskii Physico-Energetic Instutute"	http://ippe.ru	
FSUE "NII NPO "LUCH" (Research Institute Scientific-Production Association LUCH)	http://www.luch.podolsk.ru	
P. L. Kapitsa Institute of Physical Problems RAS	http://www.kapitza.ras.ru/index.php?cont=index&lang=ru	http://www.kapitza.ras.ru
V. A. Kotelnikov Institute of Radio Engineering and Electronics RAS	http://cplire.ru/rus/index.html	http://cplire.ru/html/index.html
Alma-Ata Institute of Energetics and Communications	http://www.aipet.kz	
Tbilisi State Medical University		http://www.tsmu.edu/eng/ index.php
N. A. Dollezhal Research and Design Institute of Energy Engineering	http://www.nikiet.ru/rus/index. html	http://www.nikiet.ru/eng/index. html
FSUE State Scientific Center of Virology and biotechnology "Vector"	http://www.vector.nsc.ru	http://www.vector.nsc.ru/DesktopDefault.aspx?lcid=9
FSUE "State Research Institute of Aviation systems" (GosNIIAS)	http://www.gosniias.ru	http://www.gosniias.ru/index-e.htm
Institute of Space Investigations RAS	http://iki.rssi.ru	
FSUE M. F. Stel'makh Research Institute "Polyus"	http://polyus.msk.ru/RU/mainieru.html	http://polyus.msk.ru/ENG/ mainie.html
Moscow Phisico-Technical Instiitute State University	http://mipt.ru	http://phystech.edu
N. V. Pushkov Institute of Earth Magnetism, Ionosphere, and Radiowave Propagation RAS (IZMIRAN)	http://izmiran.ru	http://izmiran.ru

Name of the Institute	Web-site (Russian version)	Web-site (English version)
V. I. Smirnov Research Institute of Mathematics and Mechanics at the Faculty of Mathematics and Mechanics St. Petersburg State University	http://www.math.spbu.ru/ru/ index.html	http://www.math.spbu. ru/en/ index.html
FSUE "N. L. Dukhov All-Russia Research Institute of Automatics," State Corporation "Rosatom"	http://vniia.ru	http://vniia.ru/eng/index. html
S. P. Korolev Rocket-space Corporation "Energiya"	http://www.rsce.ru	
Institute of Laser Physics RPC "S. I. Vavilov State Optical Institute"	http://npkgoi.ru	http://npkgoi.ru
FSUE SPA "V. G. Khlopin Radium Institute," "State Corporation "Rosatom"	http://www.khlopin.ru/	http://www.khlopin.ru/ english/ index.php
P. N. Lebedev Physical Institute RAS	http://lebedev.ru/ru	http://lebedev.ru/en
Institute of Mechanics MSU (Moscow State University)	http://www.imec.msu.ru	
FSUE "S. A. Lavochkin Scientific-Production Association"	http://www.laspace.ru/rus/ index.php	
FSUE "Central Research Institute of Machine-building" (TsNIIMASH)	http://new.tsniimash.ru	
OSA "Design Bureau of Chem-automatics"	http://www.kbkha.ru	http://www.kbkha. ru/?lang=en
FSUE "All-Russian Federal Nuclear Center E. I. Zababkhin Research Institute of Technical Physics," State Corporation "Rosatom"	http://www.vniitf.ru	
OSA "All-Russian Research Institute of Transport Machine-Building"	http://vniitransmash.ru	
State Scientific Center RF FSUE "State Labor Red Banner Order Research Institute of Chemistry and Technology of Hetero-organic Compounds" (GNTs RF GNIKhTEOS)	http://www.eos.su/index. php/ru.html	http://eos.su/index.php/ en.html

Name of the Institute	Web-site (Russian version)	Web-site (English version)
National Research Nuclear University “MEPhI” (Moscow Institute of Physical Engineering)	http://mephi.ru	
Physical Faculty MSU (Moscow State University)	http://phys.msu.su	
State Scientific Center of RF “Institute of Medical and Biological Problems” RAS	http://www.imbp.ru/	
A. Yu. Ishlinskii Institute for Problems in Mechanics RAS	http://ipmnet.ru/	http://ipmnet.ru/in-dex_en.htm
FSUE Russian Scientific Center “Applied Chemistry”	http://rscac.spb.ru	
Institute of Applied Mechanics RAS	http://iam.ras.ru	

List of the Project Proposals (open for funding)

Russia

#0308 "Prediction of an Indicatrix of an Earth Natural Radiation Proton and Electron Flow on Surface of Orbital Space Vehicles"

(Proton and Electron Flow on Space Vehicles)

Central Research Institute of Machine Building (TsNIIMash)

Project Manager: V. A. Arkhipov

Phone: +7 (495) 513 59 51

E-mail: corp@tsniimash.ru

Website: http://www.tsniimash.ru/

#0390 "Development of the Simulation Methods for the Space Nuclear Power Systems in Support of International Projects (Pioner)"

(Space Nuclear System Simulation)

State Enterprise Krasnaya Zvezda

Project Manager: A. B. Senyavin

Phones: +7 (495) 112 95 48, 112 95 81, 112 23 23

Fax: +7 (495) 113 34 88

#0391 "Design of a Large Astronomical Adaptive Telescope of New Generation with Segmented Primary Mirror with 10 Meters in Diameter"

(10-Meter Telescope)

NPO Astrophysica

Project Manager: V. V. Sychev

Phone: +7 (495) 491 85 26

Fax: +7 (495) 491 13 92

#0418 "Development of Engineering Proposal to Create Rocket and Space Complexes on the Base of Decommissioned Ballistic Missiles for Carrying Out Tropical Cyclones Research"

(Tropical Disturbances Investigations)

Central Research Institute of Machine Building (TsNIIMash)

Project Manager: G. A. Tsuboulsky

Phone: +7 (495) 513 59 51

E-mail: corp@tsniimash.ru

Website: http://www.tsniimash.ru/

#0432 “Autodriver (Control Systems for Mobile Autonomous Robots”

(Autonomous Robots)

State Institute of Physics and Technology

Project Manager: G. A. Buyvolov

Phones: +7 (495) 201 23 25, 201 70 40

Fax: +7 (495) 201 24 94

#0719 “Research the Development of Optimal Technology for Preparation and Launch of Commercial Flight Vehicles by Converted Submarine-Launched Ballistic Missiles Using Russian Ranges”

(Missiles Conversion Technology)

Makeyev Design Bureau of State Rocket Center

Project Manager: V. N. Rudin

Phones: +7 (351-35) 2 61 05, 2 63 70

Fax: +7 (351-35) 5 22 91

#0754 “Launch of Recoverable Vehicle Carrying Foreign User’s Scientific Equipment for Microgravity Experiments by the “VOLNA” Launch Vehicle”

(Microgravity Experiments in Rocket)

Makeyev Design Bureau of State Rocket Center

Project Manager: V. N. Rudin

Phones: +7 (351-35) 2 61 05, 2 63 70

Fax: +7 (351-35) 5 22 91

#0785 “Advanced Thermostabilization System of Devices for High Power Spacecraft”

(Thermostabilization Devices for Spacecrafts)

Scientific and Technical Center ELECTROCOSMOS

Project Manager: I. P. Bogush

Phone: +7 (495) 112 83 08

Fax: +7 (495) 113 34 88

#0864 “New Generation Global Low-Earth-Orbit Satellite Communications: Concept Definition and Development of Scientific-Technical and Technological Fundamentals”

(Low-Orbit Satellite Communications)

Central Research Institute of Machine Building (TsNIIMash)

Project Manager: G. I. Touzov

Phones: +7 (495) 513 59 51, 513 44 42, 513 46 43; 513 41 89

E-mail: corp@tsniimash.ru

Website: http://www.tsniimash.ru/

#0931 “Technological Enhancement of Control Valve Hydraulic Systems for Liquid Propellant Rocket Engines”

(Hydraulic Systems for Rocket Engines)

NPO EnergoMash

Project Manager: B. M. Gromyko

Phones: +7 (495) 572 29 90, 573 00 47

Fax: +7 (495) 251 75 04

#0978-2 “Researches on Providing Interference Protection and Development of the Automatic Optical System to Check Rendezvous Parameters of Co-operating Space Vehicles”

(Cooperating Space Vehicles)

NPO Geophysica / Special Design Bureau “GeoKos”

Project Manager: V. S. Kouzmin

Phone: +7 (495) 462 03 43

Fax: +7 (495) 462 15 06

#0980 “Fundamental and Applied Studies to Support the Development of a New Generation of Medium-Power Stationary Plasma Thrusters and Ablative Plasma Thrusters”

(Ablative Plasma Thrusters)

MAI (Moscow Aircraft Institute) / Research Institute of Applied Mechanics and Electrodynamics

Project Manager: G. A. Popov

Phone: +7 (495) 158 00 20

E-mail: riame@mai2.rcnet.ru

#1053 “Analysis of Prospects for Creating Geostationary Communication Satellites with Propulsion and Power Modules on the Base of Nuclear and Solar Power Plants and Electric Rocket Thrusters”

(Analysis of Prospects for Geostationary Communication Satellites)

Lavochkin Association

Project Manager: I. P. Zaitsev

Phone: + 7 (495) 573 57 38

E-mail: npol@laspace.ru

#1074 “Study of Space Object Interaction with the Earth’s Atmosphere”

(Space Objects Interaction)

VNIITF

Project Manager: T. A. Mukhamadieva

Phone: +7 (35146) 2 43 15

E-mail: vniitf@ch70.chel.su

#1173 "Development of Universal Self-Guided Platform for the Automation of the Assembly Work on the Earth and in Space"

(Self-Guided Platform)

Russian Academy of Sciences / Space Research Institute

Project Manager: V. M. Balebanov

Phone: +7 (495) 333 32 77

E-mail: zakharov@mx.iki.rssi.ru

#1265 "Rover with Automatic Navigation System"

(Rover with Video-Navigation System)

Lavochkin Association

Project Manager: S. A. Sokolov

Phone: +7 (495) 573 57 38

Fax: +7 (495) 573 35 95

E-mail: npol@laspace.ru

#1359 "Experimental Complex for Development Testing of Systems of Recoverable Spacecrafts and Investigation of Processes Accompanying Their Flight within the Atmosphere by Launching a Volna Rocket Along Ballistic Trajectories"

(Spacecraft Behaviour in Atmosphere)

Makeyev Design Bureau of State Rocket Center

Project Manager: V. N. Rudin

Phones: +7 (351-35) 2 61 05, 2 63 70

Fax: +7 (351-35) 5 22 91

#1374 "Search for Homochirality as a Signature of Extraterrestial Life"

(Homochirality as Extraterrestial Life Indicator)

FIAN Lebedev

Project Manager: V. A. Tsarev

Phone: +7 (495) 135 42 95

Fax: +7 (495) 135 78 80

#1375 "Ionization-Neutron Calorimeter in orbit (INCAO); First Phase: Experimental Balloon Module"

(Orbital Ionization-Neutron Calorimeter)

FIAN Lebedev

Project Manager: V. A. Tsarev

Phone: +7 (495) 135 42 95

Fax: +7 (495) 135 78 80

#1385 “Design of a Space System LV/SC based on Converted Ballistic Missiles and a Small Universal Space Platform for Solar System Exploration”

(Space System based on Conversion Missiles)

Khrunichev State Space Science and Production Center

Project Manager: V. K. Karrask

Phone: +7 (495) 145 93 35

Fax: +7 (495) 956 24 41

#1451 “Mathematical Modeling of Space Experiments Using of High-Velocity Impacts of Artificial Objects with Surface of Small Bodies of the Solar System”

(Space Impact Experiments)

Russian Academy of Sciences / Space Research Institute

Project Manager: O. F. Prilutsky

Phone: +7 (495) 333 32 77

Fax: +7 (495) 310 70 23

#1533 “Research and Development Tank-Car from Polymeric Composite Materials”

(Polimer Composite Tank-car)

Institute of Specialized Machine Building

Project Manager: I. P. Dmitrienko

Phones: +7 (254) 3 24 03, 584 55 11

Fax: +7 (496) 543 90 56

#1578 ”Space Remote Energy Transmission (Development, Simulation and Pre-Starting Procedures for Remote Energy Transmission Experiment in Outer Space)”

(Space Remote Energy Transmission)

VNIIEF

Project Manager: Y. N. Bulkin

Phone: +7 (83130) 4 56 46

E-mail: bulkin@otd13.vniief.ru

#1812 “Conception of Creation of Research Spacecraft with Kinetic Penetrators for Aimed Attack on Asteroids to Study Their Properties”

(Research Spacecraft for Asteroids Studies)

Makeyev Design Bureau of State Rocket Center

Project Manager: V. N. Rudin

Phones: +7 (351 35) 2 61 05, 2 63 70

Fax: +7 (35135) 5 22 91

#2023 “The Research of Extragalactic and Galactic Sources of Gamma-Quanta with Energy 1–100 TeV by Mirror Telescopes System Shalon”

(Extragalactic Gamma-Quanta)

FIAN Lebedev

Project Manager: V. G. Synitsina

Phones: +7 (495) 135 42 75, 135 50 11

E-mail: sinits@shi.lpi.msk.su

#2222 “Experimental Research of Chemical Evolution of Substance of the Moon and Other Bodies of Solar System by Methods of High-Speed Shock Modeling”

(Chemical Evolution of Planet Substance at Impact)

VNIIEF

Project Manager: G. V. Belov

Phones: +7 (83130) 4 50 09, 5 69 74, 4 53 73, 4 58 93, 4 52 60

Fax: +7 (83130) 4 59 58, 5 45 65, 5 38 08

E-mail: root@gdd.vniief.ru, rvg@vniief.ru

#2471 “Elaboration of the Space Environment Activity Index Taking into Account the Actual State of the Ionosphere and Magnetosphere”

(Space Environmental Index)

Arctic and Antarctic Research Institute

Project Manager: O. A. Trosichev

Phones: +7 (812) 352 65 30, 352 27 91

Fax: +7 (812) 352 26 88

E-mail: olegtro@aari.nw.ru, aaricoop@aari.nw.ru

#2495 “The Weak Microlensing Effect and Its Influence on Very Long Baseline Radiointerferometry Observation”

(Microlensing Effect in Radioastronomy)

Moscow State University / Sternberg State Institute of Astronomy

Project Manager: M. V. Sazhin

Phones: +7 (495) 939 50 06, 939 28 58, 939 20 40

Fax: +7 (495) 932 88 41, 939 16 61

E-mail: sazhin@sai.msu.ru

#2634 “Experimental and Theoretical Study of Piercing Protective Shells by Space Dust Particles in Regime of Ultra-Deep Penetration”

(Shells Piercing by Space Dust Particles)

MISIS (Steel and Alloys)

Project Manager: V. P Balakin

Phone: +7 (495) 236 73 09

E-mail: d.livanov@misis.ru

#2726 “Guided Inflatable Aeroshell System (GIAS)”

(Guided Inflatable Aeroshell System)

Lavochkin Association

Project Manager: S. N. Alexashkin

Phones: +7 (495) 575 52 12, 573 25 84

Fax: +7 (495) 573 25 84

E-mail: npol@laspace.ru, alexashkin@berc.rssi.ru , tatall@berc.rci.ru

#3001 “Investigation and Prediction of Explosive Phenomena in the Solar Corona and of Coronal Mass Ejections to Improve Safety of Aerospace Flights”

(Explosive Phenomena in the Solar Corona)

Institute of Physical Chemistry and Electrochemistry

Project Manager: A. I. Malkin

Phone: +7 (495) 955 44 73

E-mail: mlkn@list.ru

#3332 “Development of a Computer-Aided System for Forecasting Powerful Explosive Solar Phenomena and Estimating Disturbances Caused by them in the Earth Space Environment”

(Forecasting Powerful Explosive Solar Phenomena)

NIIIT (Pulse Techniques)

Project Manager: A. K. Baryshnikov

Phone: +7 (495) 324 52 90

Fax: +7 (495) 321 48 55

E-mail: baryshnikov@niiit.ru

#3370 “Special-Purpose Equipment Set for Correlated Investigations of the Dynamics of Relativistic Electron Fluxes in the Earth’s Outer Radiation Belt”

(Relativistic Electrons in the Earth’s Outer Radiation Belt)

Scientific Engineering Center SNIIP

Project Manager: A. B. Komissarov

Phone: +7 (495) 727 18 47

Fax: +7 (495) 727 18 47

E-mail: komissar@sniip.ru

#3447 "Study of Sorption Properties of Carbon Nanostructures for Selecting the Optimum Ones for Hydrogen Storage"

(Hydrogen Storage in Carbon Nanostructures)

VNIIEF

Project manager: V. S. Kravchenko

Phone: +7 (83130) 4 25 45

Fax: +7 (83130) 4 57 98

E-mail: vsk@astra.vniief

#3606 "Development of Spacecraft Active Protective Shielding against Meteoroids and Orbital Debris and New Methods of Shielding Testing at Hypervelocity Impact"

(Spacecraft Active Protective Shielding)

Institute of Physical Chemistry and Electrochemistry

Project Manager: A. I. Malkin

Phone: +7 (495) 955 44 73

E-mail: mlkn@list.ru

#3647 "Development of Advanced Cycle Driving Gear for Special Racing Bicycles and General Bicycles"

(Cycle Driving Gear)

VNIIEF

Project Manager: V. S. Chebotar

Phone: +7 (83130) 4 29 00

Fax: +7 (83130) 4 09 96

E-mail: chebotar@iskra5.vniief.ru

#3657 "Creation of the Autonomous System for Own Air Atmosphere Pressure Control of Space Vehicles for Extra Vehicle Ativity Monitoring and Leakproofness Control of Orbital Complexes in Pilot or Automatic Regimes of Flight"

(Own Air Atmosphere Pressure of Space Vehicles)

Institute of Robotics and Technical Cybernetics

Project Manager: A. S. Kondratiev

Phone: +7 (812) 552 11 50

E-mail: kondr@rbc.ru, kondr@stu.neva.ru, info@neva.ru

#3704 "Study of Fast Flashes of Electromagnetic Radiation in Earth Atmosphere Aboard of Artificial Satellites of the Earth. Experiment, Theory, Numerical Simulations"

(Electromagnetic Radiation Flashes in the Atmosphere)

Moscow State University / Institute of Nuclear Physics
Project Manager: I. V. Yashin
Phone: +7 (495) 939 18 10
Fax: +7 (495) 939 11 58
E-mail: ivn@eas.sinp.msu.ru

#3742 "Analysis of the Advanced Moon Explorations"

(Moon Explorations)

Lavochkin Association
Project Manager: S. B. Konstantinov
Phone: +7 (495) 573 91 38
Fax: +7 (495) 573 91 38
E-mail: konstantinov@laspace.ru

#3841 "A System for Reducing Car Exhaust Toxicity Based on a Hydrogen Additive to the Air–Fuel Mixture"

(Reducing Car Exhaust Toxicity)

MISIS (Steel and Alloys)
Project Manager: M. I. Belov
Phone: +7 (495) 237 99 88
Fax: +7 (495) 237 87 56
E-mail: Belov46@inbox.ru

#3842 "Hardening of the Working Surface of the Aluminum Cylinder Block for Internal-Combustion Engines by the Microarc Oxidation Method"

(Treatment of Cylinder Blocks of Combustion Engines)

MISIS (Steel and Alloys)
Project Manager: A. S. Posviryakov
Phone: +7 (495) 955 01 34
Fax: +7 (495) 237 87 56
E-mail: Popov58@inbox.ru

#3844 "A Method of Gas-Thermal Deposition of Coatings on the Inner Surfaces of Holes and Its Implementation for Cylinder Blocks of Internal-Combustion Engines"

(Gas-Thermal Deposition of Coatings)

MISIS (Steel and Alloys)

Project Manager: I. V. Gontar

Phone: +7 (495) 230 44 45

Fax: +7 (495) 237 87 56

E-mail: d.livanov@misis.ru, Popov58@inbox.ru

#3954 "Development of the Advanced Systems of Concentration of Radiation of Hard X-Ray Range for Astrophysical Studies"

(Hard X-Ray Concentrator for Astrophysics)

VNIIEF

Project Manager: V. A. Starodubtsev

Phones: +7 (83130) 2 22 79, 4 21 66

Fax: +7 (83130) 4 56 46

E-mail: starodub@old13.vniief.ru, rvg@dc.vniief.ru

Armenia

#A-1865 "Study of the Effect of Space Factors on the "Silicon-on-Insulator" Structure and Microelectronic Elements on Its Basis Using the Yerphi Facility Modeling the Space Exposure"

(Space and "Silicon-on-Insulator" Structure)

A. I. Alikhanyan National Science Laboratory

Project Manager: H. N. Yeritsyan

Phone: +7 (3741) 341 065

Fax: +7 (3741) 341 065

E-mail: grant@yerphi.am, Grant@uniphi.yerphi.am

Belarus

#B-248 "Development and Making a New Generation of Broadband Equipment of Analysis of Cosmic Radioradiating"

(Cosmic Radio Wave Detection)

National Academy of Sciences of the Republic of Belarus / Institute of Electronics

Project Manager: V. P. Melnikov

Phone: +7 (017) 265 61 19

E-mail: inel@inel.bas-net.by

#B-1015 "Creation of a Pilot Sample of the Transport Tractive Machine Based on a Biomechanical Reciprocating Principle of Motion of Wheels"

(New Type Transport Device)

National Academy of Sciences of the Republic of Belarus / Institute of Informatics Problems

Project Manager: A. I. Dobrolyubov

Phones: +7 (375-17)284 21 46, 284 21 75, 284 21 71, 284 20 70

E-mail: dobr@newman.bas-net.by, itekan@newman.bas-net.by

Georgia

#G-458 "Development of the Information and Expert System of Support, Self-Control and Interpretation of Functional and Psycho-Somatic States of a Spaceman in Conditions of the Autonomous Flight on the International Manned Space Stations"

(Expert Systems for Astronauts)

Georgian Technical University

Project Manager: Z. I. Tsikhelashvili

Phone: (995 32) 366 544

Fax: (995 32) 942 033

E-mail: info@gtu.kheta.georgia.su

#G-494 "Extrapolation, Smoothing and Filtering of Stochastic Dynamical Systems Dependent on Unknown Parameters"

(Dynamics of Systems with Stochastic Parameters)

Institute of Computational Mathematics (Mukhelishvili)

Project Manager: A. Shangua

Phone: 995 32 332 438

Fax: 995 32 332 438

#G-603 "Developing New Means of Stabilization of Hydrodynamic Processes in Pipelines During Multiphase Hydroaeromixture Transportation"

(Hydrodynamic Processes in Pipelines)

Institute of Mining Mechanics

Project Manager: L. I. Makharadze

Phones: (995 32) 660 722, 988 506, 711 226

Fax: (995 32) 988 513, 988 497

E-mail: K_Khatiashvili@yahoo.com

#G-679 "Technical and Economical Basing of Space Development Using Celestial Bodies"

(Interplanetary Station on Celestial Bodies)

Georgian Technical University

Project Manager: G. V. Bokuchava

Phones: (995 32) 226 347, 32 335 590

Fax: (995 32) 335 590

E-mail: giab@giniko.ge, gtu@nilk.org.ge

Kazakhstan

#K-793 "Remote Sensing of the Ecologicaled Destabiliz Regions Owing to Pesticide Pressure"

(Remote Sensing of the Ecologically Destabilized Regions)

Kazakh Research Institute of Plant Protection

Project Manager: J. D. Julmuhamedova

Phones: +7 (3272) 306 817, 295 609

E-mail: ingeo@mail.kz

Tajikistan

#T-1847 "Meteorite-Dropping Meteoroids, Its Associations with Asteroids and Comets and Influence of Meteor Matter on the Upper Atmosphere

(Meteorite-Dropping Meteoroids, its Orbits and Sources)

Institute of Astrophysics

Project Manager: N. A. Konovalova

Phone: +7 (992-37) 223 03 67

E-mail: nakonovalova@mail.ru

#T-1889 "Interaction of the Meteorite-Producing Meteoroids with the Earth's Atmosphere and Influence of Meteoric Matter on the Ionospheric E-Region"

(Meteoric Matter in the Earth's Atmosphere)

Institute of Astrophysics

Project Manager: N. A. Konovalova

Phone: +7 (992-37) 223 03 67

E-mail: nakonovalova@mail.ru