Russian Federal Nuclear Center – The All-Russian Research Institute of Experimental Physics
Institute of Applied Physics of the Russian Academy of Sciences
International Science and Technology Center

Prospects of International Cooperation in Ultra-High Intensity Lasers for Civil Applications within the Frame of the ISTC Activities

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Content

Foreword

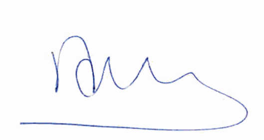
I am very glad that the International Science and Technology Center was able to establish and fund the first stage of the Targeted Initiative on Ultra-High Intensity Light Science and Technologies just at the year of 50th anniversary of the laser discovery. Who could imagine 50 years ago that a relatively simple, tiny but ingenious device of a power of a fraction of Watt constructed by Theodore Maiman would be one of the most important and versatile inventions of the 20th century. Gradually, the laser found its way to a wide variety of civilian uses, from communications and rock-concert visuals to CD players and tattoo removal, aiming even at thermonuclear reactions and power levels of Petawatts.

ISTC has a solid record of supporting projects in laser technologies. Over 300 project proposals from 90 institutes of ISTC member states have been received at the Secretariat and about 50% of them were funded and successfully completed. Over 380 companies, institutes and governmental organizations have been involved in ISTC-funded projects as collaborators or partners. Many of the partners have developed long lasting cooperation at international level. At the same time, ISTC has successfully encouraged and facilitated national cooperation between institutes of Rosatom, Russian Academy of Sciences and Universities.

In the recent decades progress of experimental laser technique, especially with high- and ultrahigh-intensity lasers and ultrashort pulses opened unique opportunities for research in nuclear physics, physics of atomic and radiation processes in plasma, solids chemistry, fast process measuring methods and particle acceleration techniques. Interaction of focused ultrahigh intensity, short pulse laser beams with matter opens a new dimension of ultrarelativistic physics.

This book gives a comprehensive review of the state of the art of Russian ultrahigh power laser research and technology. I am sincerely convinced that ISTC has and can offer a unique framework of international cooperation in this fascinating but also sensitive technology.

I look forward to your reactions to this book,



Adriaan van der Meer
Executive Director
International Science and Technology Center
Moscow

By way of an introduction to this publication I'd like to remind the reader, that in fact, laser direction in the Institute's research emerged immediately after the creation of the first laser in mid 60-ies and was supported by academician Yuli Khariton. Nowadays the major volume of laser related research of VNIIEF is conducted by the Institute of Laser and Physical Research (ILPR), which is, undoubtedly, one of the largest laser institutions in Russia. The efforts of the Institute are focused on the creation of "UFL-900" facility – a setup of a new generation, which will considerably expand the horizons of extreme state physics research.

Recent development and construction of solid-state sub-petawatt and petawatt laser systems with laser pulse duration within 30-500 femtoseconds is marked by a rapid progress. Going beyond the petawatt boundary allowed us to initiate quite a number of larger scale projects, focused on achieving sub-exawatt levels of laser power, which bring us closer to the solution of the problem of nuclear fusion, based on laser-induced thermonuclear reactions.

The aim of the study undertaken within the framework of the Targeted Initiative of the International Science and Technology Center (ISTC) "Ultra-High Intensity Light Science and Technology" was to assess possible collaboration between the Russian laser research centers and large-scale international projects on super-high intensity lasers. The study provides information, related to science and technology potential of the leading Russian institutions and ways of their possible involvement in international projects such as ELI, HiPER.

A special focus is on an extended list of projects, where involvement of the Russian institutes would be encouraged. These projects' commencement date would be defined by the presence of an investor. Implementation of such projects would require consolidation of financial and intellectual efforts of the leading laser laboratories.

In conclusion I would like to wish every success to the ISTC Targeted Initiative and to its participants.

Scientific Director of RFNC-VNIIEF

Academician of RAS Radi I. Ilkaev

Introduction

In recent years a galloping progress has been observed in development and production of solid laser systems with femptosecond pulses. The world leading laser labs have built facilities of subpetawatt and petawatt intensity levels with laser pulse duration of ≈ 30-500 fs. The interest to these lasers has been dictated by their unique abilities to be applied as an investigation tool in fundamental and applied fields of physics, chemistry, biology, medicine, and material sciences. These abilities result from two conditions. First, ultra-short pulse duration allows investigation of various processes with the time resolution earlier unachievable. Second, due to ultra-short pulse duration at a rather moderate energy, the extremely high power ($\geq 10^{15}$ W) and focused radiation intensity ($\geq 10^{20}$ W/cm^2) can be reached in experiment. Such ultra-intense radiation cannot be achieved in laboratory conditions using other methods.

This new tool has promoted a series of investigations in the field of high energy density physics: generation of fast electrons and ions, including generation of proton beams; generation of hard X-rays and attosecond pulses, initiation of nuclear reactions, etc. Various scientific groups perform the theoretical analysis and experimental study to determine possibilities for fast ignition of a thermonuclear target based on simultaneous effect of laser radiation of nanosecond and picoseconds durations.

Successful overcoming of petawatt barrier allowed a number of major projects to be promoted. These projects are oriented to reaching a subexawatt level of lasing power and allow scientists to come close to solving the problem of thermonuclear fusion based on laser initiation of thermonuclear reactions. Implementation of these projects requires coordination and integration of financial and intellectual efforts of the leading laser laboratories. Thus scientific activity in this field proceeds mainly as international collaboration. At the end of 2006 consortia of European countries started implementation of unique scientific megaprojects – ELI and HiPER. This activity can result in revolutionary changes in a number of areas in natural science as well as in development, in a long-term prospective, of controlled thermonuclear fusion as the basis of power of future, acceleration of particles up to ultra-high energies at a laboratory scale and other unique technologies.

The leading laser laboratories of the Russian Federation are renown due to achievements in development and application of powerful laser systems with ultrashort pulse duration. Recently lasers of petawatt level of intensity have been built (Institute of Applied Physics, the Russian Academy of Science – IAP RAS, Nizhny Novgorod, All-Russian Research Institute of Experimental Physics – VNIIEF, Sarov). A number of institutions have facilities of a lower scale. Experiments on interaction of high-intense laser radiation with matter have been carried out. Scientists have been developing methods and equipment for diagnostics of subpicosecond laser light parameters. They have perfected technologies for manufacturing various types of laser targets. The research and production basis for development and fabrication of laser system key components and units is available. Computation models and numerical codes that allow the study of interaction between short-pulse intense laser radiation and matter have been under development.

At the same time it should be noted that the engagement of the leading Russian laser centers into international programs is insufficient and certainly could be more intensive. Only two Russian institutions are full partners of the HiPER project. They are IAP RAS and Lebedev Institute of Physics RAS. Besides, the Russian Federation does not have any agreements neither with foreign governmental agencies nor with the abovementioned European projects, so that these agreements could regulate participation of Russian institutions in scientific investigations and in creation of new laser technologies.

Very important and well-time is the **ISTC Targeted Initiative "Ultra-High Intensity Light Science and Technologies", UHILS&T (TI),** which is the initiative of extended international cooperation in the field of ultra-high intensity lasers.

The International Science and Technology Center (hereinafter – **ISTC, www.istc.ru**) was established on the 27 of November 1992 in accordance with the Presidential Directive #258 issued in 18.03.1992 on "…establishing in Russia an International center to support scientists and specialists" and in accordance with the International Agreement about ISTC establishment (hereinafter – Agreement) that came into effect according to RF president direction issued on December 17, 1993, #767-rp.

ISTC founders have become European Union, Russian Federation, United States of America, and Japan. At present a number of countries joining the Agreement is 39 (including EU countries).

Currently the sponsoring countries are: EU countries, Canada, Norway, Republic of Korea, USA, and Japan. In 2007 Switzerland took a decision to join the Agreement. ISTC board of directors approved this decision. At present Switzerland is making out official papers to join the Agreement.

Beneficiary parties are: Armenia, Belorus, Georgia, Kazakhstan, Kirgizia, Russian Federation, and Tadzhikistan.

ISTC goals were formulated in the Agreement based on the understanding of:

– The necessity to prevent proliferation of mass destruction weapons technologies (nuclear, chemical, biological weapon);

– CIS conversion to market economy;

– The developing processes of disarmament and conversion of industrial potential from military to peaceful activity.

ISTC tasks are formulated in article II of the Agreement and are the following:

– "To provide weapon scientists and specialists…the possibility for reorienting their talents to peaceful activities";

– "To assist …using their projects and activities: in the solution of national and international engineering problems; in conversion to market economy that meets the civilian needs; in supporting the fundamental and applied studies and technical developments, including those in the field of environmental protection, energy production, support of atomic energy safety and encouragement of further involvement of scientists … into international scientific society…".

If at the first stage of ISTC work the highest priority was implementation of the first task, nowadays the ISTC activity focuses in implementation of the more important and promising second task – assisting in solution of national and international technical problems.

In this connection ISTC continuously implements and develops new lines of activity.

TI task is to arrange an international partnership in the field of ultra-high intensity lasers aiming to extend boundaries for fundamental research, to develop new atom and nuclear technologies, material processing technologies and biomedicine by **coordination of activities between scientific centers, governmental agencies and private organizations**. It is assumed that scientists from Russia\CIS will directly participate in the planning of activities and arrangement of international-class laser facilities and will get an access to them after projects accomplishment. The rational use of complementing skills will provide engineering perfection and economic efficiency of joint work. It is assumed that ISTC can provide assistance in arranging the system of interaction between the world-leading institutions and the key institutions in Russia, working either as an agent or coordinator.

The goal of this document is to determine possibilities for collaboration between Russian laser centers and major international projects on ultra-high intensity lasers for advanced fundamental studies and civil applications.

1. Scientific and technical capabilities of Russian research Institutions in projection on Targeted Initiative

Investigations in the field of ultra-high intensity lasers development and application can be divided into several directions:

– Development of ultra-high intensity laser systems with ultra-short radiation pulse duration.
– Development of concepts, designs for perspective developments of ultra-high intensity lasers.
– Development of technology for fabrication and test of ultra-high intensity laser components.
– Experimental study of ultra-high intensity light and material interaction.
– Development of devices for diagnostics of ultra-short light parameters.
– Development of devices for diagnostics of laser plasma parameters.
– Design and theoretical study of interaction between intensive laser light and material. Computation models and numerical codes.

Development of lasers with ultra-short pulse duration, experimental, design and theoretical studies of high-intensity laser-matter interaction have been under way in various departmental institutions. Taking into account areas of developments and investigations that are of interest for large international projects, a number of leading institutions have presented information related to their scientific potential and area of their possible participation under TI. Below is this information tabulated.

1.1. Federal State Unitary Enterprise «The Russian Federal Nuclear Center – All Russian Research Institute of Experimental Physics» (FSUE "RFNC-VNIIEF")

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State Corporation ROSATOM

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Head
Director – Science doctor (engineering) V.Ye. Kostyukov

Operating laser facilities and complexes with ultrashort radiation pulse

1. The "ISKRA-5"12-channel iodine laser ($\lambda = 1315$ nm, $E = 30$ kJ, $\tau_{\text{имп}} = 0.3$–0.5 ns, with the radiation wave-length (able to be converted into the second harmonic).
2. The "LUCH" 4-channel laser on the neodymium phosphate glass ($E \approx 12$ kJ at $\lambda = 1054$ nm at $\tau_{pul} \approx 3$ ns, with the radiation wave-length (able to be converted into the second harmonic). Used in experiments on the various types of target driving and for pumping of an output parametric amplifier of a petawatt channel.
3. "LUCH" petawatt channel ($\lambda = 911$ nm, $E \approx 50$ J, $\tau_{pulse} \approx$ 40–50 fs) – Fig. 1.
4. Subpicosecond laser with the light intensity 3 TW ($\lambda = 1054$ nm, $E \approx 1.5$ J, $\tau_{pul} \approx 500$ fs).
5. Instrument complex for measuring lasing parameters:
   – Energy.
   – Contrast to the depth of 10^8.
   – Duration with the time resolution 1 ps.
   – Divergence.

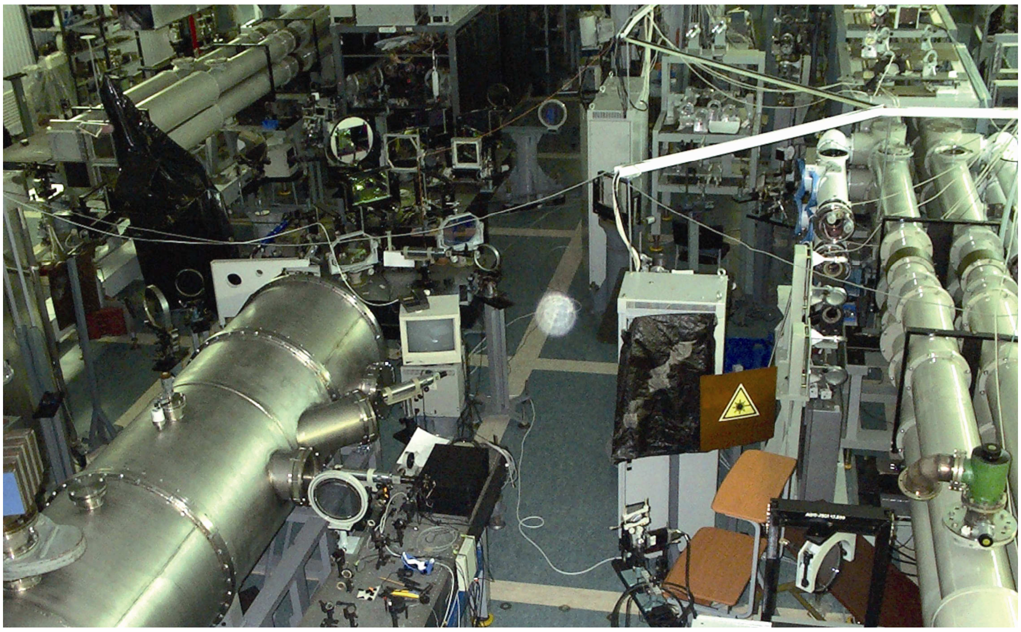

Fig. 1. The interior of "Luch" facility with petawatt channel

6. Instrument complex for measuring laser plasma parameters:
   - Energy balance (absorbed, scattered, X-ray and ion flux energy)
   - Philosophy of measurement of electron & ion plasma radiation parameters within the spectral range from 0.01 to 10 MeV. Types of equipment: electron spectrometers, Faraday cylinders, Thompson spectrometers, ion streak-cameras.
   - Philosophy of measurement of plasma X-radiation parameters:

     Time resolution – up to 20 ps.

     Spatial resolution – up to 20 μm.

     Spectral resolution – from $\lambda/\lambda\Delta$ – to 10^3.

     Spectral range – 0.1÷1000 keV.

     Range of measured plasma electron temperatures – from 0.05 to 100 keV.
   - Complex of measuring techniques for neutron- and gamma-radiation parameters:

     Neutron output measurement.

     Neutron spectrometer with the resolution 100 keV.

     Neutron and γ-pulse recorders with time resolution up to 10 ps.

     Recorder of a target image in neutron radiation with the spatial resolution 50 μm.
7. Neutron generator with the energy 14.1 MeV.
8. Test-beds and measuring equipment for determining neutron parameters of a blanket model with various neutron sources (neutron multiplication factors, spatially-energy neutron distribution, nuclear reaction intensities and cross sections) and for detecting ionizing radiation.
9. Test-beds and equipment for measuring nuclear reaction intensities and cross sections in assemblies of lithium hydride and sodium or zirconium fluorides under the effect of 14.1 MeV neutrons.
10. A computing complex and software and techniques for computation of nuclear reactions, light-substance interaction, nuclear reaction constants testing, and neutron transport in media.

Currently developed laser systems

Under way is development of the next generation laser system: "UFL-900" laser (active medium is neodymium phosphate glass, 160 channels, $\lambda_{3\omega}$ = 351 nm, $E \approx$ 900 kJ, $\tau_p \approx$ 1–5 ns).

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter

1. Development and testing of a number of key systems (technologies): adaptive optics, Pockels cells with plasma electrodes, kinoform optics, targets.
2. Investigations into hydrodynamic (instability, equation of state, etc.) and compression physics in direct and indirect drive targets ("Iskra-5", "Luch").
3. Development of a laboratory X-ray laser pumped by an ultra-short pulse.
4. Development of devices for diagnostics of parameters of high-temperature laser plasma (X-rays, charged particles, neutrons) with high spatial and time resolution ($L \leq 5$ μm, $\tau \leq 10$ ps).

5. Investigations into the processes of parametric amplification of wideband chirped laser pulses in wide-aperture non-linear DKDP crystals under pumping by neodymium laser light converted into the second harmonic.
6. Development and tests of various methods of laser beam smoothing aiming at uniform target exposure.
7. Investigations in the field of high density energy physics when irradiating targets by ultra-short laser pulses ($\tau \approx 50$ fs) with intensities of ~10^{20} W/cm^2.
8. Investigations of material radiation properties when exposed to hard X-rays, high-energy charged particles and neutrons.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)

1. Calculations of optimal geometry for laser target radiation.
2. Numerical study into the heat and compression processes in direct and indirect drive targets.
3. One-D (1D3V) and two-D (2D3V) fully relativistic electro-dynamic PIC-codes KARAT, PLASMA-1 and PLASMA-2, designed for numerical simulation of the interaction between laser fields of ultra-high intensity and the substance. KARAT code includes calculation units taking into account field ionization of atoms and relativistic electron generation of gamma-quanta. Nuclear reaction calculation unit is being developed for KARAT code. A peculiar feature of KARAT PIC-code is a developed graphic interface allowing the preliminary data analysis during a calculation process. Two-D PLASMA-2 PIC code can use various ways of parallelization in numerical simulation plasma behavior in ultra-high laser field.

Intended lines of activity under ISTC Targeted Initiative

1. Experimental, design and theoretical study in the field of high-density energy physics at targets irradiation by ultra-short laser pulses with intensities of up to ~10^{20} W/cm^2.
2. Development and tests of devices for diagnostics of parameters of high-temperature laser plasma with high spatial and time resolution.
3. Development and tests of various methods of laser beam smoothing aiming at uniform target exposure.
4. Experimental and computation investigations aiming to build a hybrid nuclear-thermonuclear reactor based on an ultra-high intensity laser.

List of projects, candidates for participation in the ISTC Targeted Initiative

1. «Experimental and model theoretical investigation of the process of high-energy particle generation by short powerful laser pulses»

Leading institution: RFNC-VNIIEF, Sarov, Russia

Participarting institution: 1) RFNC-VNIITF, Snezhinsk, Russia
2) LPI RAS, Moscow, Russia

Project manager: professor S.A. Bel'kov

Collaborators / Partners:

– Laboratoire pour l'utilisation des lasers intenses, LULI, Ecole Polytechnique, Palaiseau, France
(Prof. Ch. Labaune)
– Institute Lasers and Plasmas-CNRS-CEA-Ecole Polytechnique-University, Bordeaux1, France
(Prof. V. Tikhonchuk)

Estimated cost: $400,000

Project duration: 36 months

Summary Project Information:

Main goal of this study – is to achieve a high-energy source and particle beams of the required quality with an efficiency of laser pulse into the beam energy conversion of 10-20%.

Project objective – is to calculate digitally optimal target parameters and conditions of its irradiation by ultra-short laser pulse to obtain the proton beam necessary characteristics and to prove simulation results experimentally.

To analyze physical processes occurring in particle acceleration there will be applied special software packages, such as 2-dimensional PIC-codes PLASMA-2 and KARAT in RFNC-VNIIEF and the 3-D code MANDOR at Lebedev institute. Scientists at RFNC-VNIITF have developed 2-D hybrid codes PICNIC, molecular dynamic codes MOLOH and HANDRA to simulate a process of a beam passing through material with the consideration made for nuclear reactions.

During project implementation software packages will be further developed. This will solve the issue of parameter optimization for thin metal targets that will be applied in experiments on FEMTO laser machine at RFNC-VNIIEF. It is planned to study aerogel-targets with the interstitial space 10-50 nm. The use of aerogel as target material will smooth non-uniformities of laser light and increase laser pulse absorption.

To check theoretical and simulation results experimentally there will be used the RFNC-VNIIEF FEMTO, a petawatt laser machine based on a principle of parametric amplifying of laser pulses with linear frequency modulation in DKDP crystals. Laser intensity achieves $P_{out} \approx 1$ PW with a pulse energy of about 50 J and pulse duration of about 45 femtoseconds. Laser light intensity on a target can reach 10^{21} W/cm^2.

2. «Development of technique for measuring of fast laser radiation contrast with the time resolution up to 1 ps for the depth for up to 10^5-10^7»

Leading institution: RFNC-VNIIEF, Sarov, Russia.

Project manager: professor D.N. Litvin

Project estimated cost: $600,000

Project duration: 36 months

3. «The use of hybrid reactors in experimental and computational investigation of burning-out efficiency of Pu, Np, Am, Cm isotopes – the most long-living and hazardous components of radioactive wastes»

Leading institution: RFNC-VNIIEF, Sarov, Russia

Project manager:

Collaborators / Partners:

- Los Alamos National Laboratory of USA
- Atomic energy commissariat, Paris, France

Estimated cost: $600,000

Project duration: 36 months

Summary Project Information:

One of the most important problems in nuclear energy are long-living radioactive wastes provided mainly by Pu, Np, Am, Cm isotopes. The unique and choiceless tool of these actinides destruction is a subcritical reactor controlled by an outer neutron source. The outer source can be generated either by a proton accelerator as a result of spall nuclear reactions, or by powerful lasers using thermonuclear D,T-reaction. The second type facilities are called hybrid reactors. Subcritical reactors are saved from the risk of explosive nuclear accidents. Their advantage as burners of plutonium and minor actinides burners is in the fact that operation is possible with typical for plutonium and minor actinides low value of delayed $\beta_{эф}$ neutrons fraction and higher as opposed to standard reactors access of neutrons. Hybrid reactors can successfully operate even only on the extracted from wastes Pu, Np, Am, Cm alone and as a result to burn them out.

It is assumed under the project to perform experimental and design and theoretical study into the processes of actinides accumulation and burning out in a hybrid reactor blanket and the resultant decrease a factor of 100 and more of their long living radioactivity. We will use as a test blanket the system (often discussed and used in projects) on fused fluorine salts ^{7}LiF and $NaF + ZrF_4$ or Pu, Np, Am and Cm fluorides.

Experiments will be performed on compact blanket models composed of spherically symmetric components of LiH available at VNIIEF and on a cylindrical model with NaF, ZrF_4 and so on. Reaction intensities and cross sections the most important for nuclear processes in a blanket will be measured. Comparison between the measured and calculated intensities and cross sections of the stated reactions in models will control reliability of calculated data obtained directly for a blanket.

The output of project activity will be recommendations on the most prospective hybrid reactor designs and blanket composition and conclusions on Pu, Np, Am, Cm burning out speeds, on periodicity of fission products removal from a blanket and on adding the new amount of stated actinides into the blanket to replace the burnt out ones. Also the result will be a construction arrangement for a dummy blanket of a demo hybrid reactor, a burner of long living nuclear power wastes.

Project co-performer:

1. «Development of diagnostic methods for measuring the ion beam parameters and their adaptation to PETAL machine»

Leading institution: RFNC-VNIITF, Snezhinsk, Russia

2. «Creation of experimental base and investigation of the impact of extreme light fields on matter in the visible and infrared spectral ranges»

Leading institution: LPI RAS, Moscow

3. «High-energy particle beam generation by means of super high-power ultrashort laser pulses»

Leading institution: JIHT RAS

4. «Development and investigation of designs and key components of multipetawatt lasers»
Leading institution: NIIKI OEP, Sosnovy Bor

5. «Macroparticle acceleration by ultrashort laser pulse»
Leading institution: NIIKI OEP, Sosnovy Bor

6. «Development, fabrication and study of durability of coatings at the first, second and third harmonic of solid lasers operating at cryogenic temperatures»
Leading institution: SPA «LUCH», Podolsk

7. «Development and fabrication of dimensionally stable cooled large-aperture silicon carbide and silicon mirror for operation with powerful laser radiation in pulsed periodic mode"
Leading institution: SPA «LUCH», Podolsk

8. «Development, fabrication and investigation of an adaptive mirror for "Vulkan" facility»
Leading institution: SPA «LUCH», Podolsk

9. «Development, fabrication and investigation of an experimental sample for an adaptive system mirror of HiPER facility»
Leading institution: SPA «LUCH», Podolsk

10. «Creation of stand and investigation of optical materials damage threshold in a short (3-5 ns) pulse»
Leading institution: "LZOS" JSC, Lytkarino, Moscow region

11. «Investigation of the influence of high density laser radiation on reflecting surface of Astrosital CO-115M mirror»
Leading institution: "LZOS" JSC, Lytkarino, Moscow region

1.2. Russian Federal State Unitary Enterprise «Russian Federal Nuclear Center – E.I. Zababakhin All-Russia Research Institute of Technical Physics» (RFNC-VNIITF)

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Legal address	456770, Snezhinsk, 13 Vasiliev Str., P/B 245 http://www.vniitf.ru
Head	Director – Corresponding Member of RAS G.N. Rykovanov
Operating laser facilities and complexes with ultrashort radiation pulse	1. Nd-glass laser facility SOKOL-P (λ = 1.055 µm): maximum output energy 15 J, pulse duration 0.7÷0.8 ps, beam diameter 130 mm, focusability after compressor – 30% of energy in a circle 3 mm in diameter, focusing optics – off-axis paraboloid with F = 200 mm, peak intensity in focal spot >10^{19} W/cm^2, pulse repetition rate – once in three hours. The laser facility is used in experiments on ion acceleration (maximum energy 10 MeV/nucleon), on X-ray laser generation with neon- and nickel-like ions in a system with nonstationary collision pumping, and on investigation of radiation properties of hot dense plasma. 2. Laser complex ELAS-PF comprised of a Ti:Sa femtosecond laser (λ = 0.8 µm) with maximum energy of 50 mJ and pulse duration 35 fs at 10 Hz and an Nd:glass picosecond laser (λ = 1.055 µm) with 1 TW power. The complex is used primarily for finalizing diagnostic techniques and measuring absorption and reflection coefficients of femtosecond laser radiation with the wavelength of 0.8 µm in a wide intensity range of 10^{12}÷10^{17} W/cm^2.
Currently developed laser systems	1. SOKOL-PM facility. Updating the available phosphate neodymium glass SOKOL-P facility with amplification channel based on rod element will enhance the power up to 100 TW. 2. SOKOL-3 facility with Nd:glass disk amplification elements with maximum power up to 1 PW.
Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter	1. The techological complex of RFNC-VNIITF produces targets for experiments on laser installations: – spherical glass gas-filled targets, including targets filled with a mixture of deuterium and tritium; – metal foam nanostructured low-density targets (density 0.01÷0.1 of the solid body density); – organic films of submicron density; – multilayered plane targets with minimal layer depth down to tens of nanometers. 2. Diagnostic complex of SOKOL-P laser facility. The complex includes equipment for measuring parameters of irradiating laser pulse and energy absorbed by the target, high-rate photoelectron recorders of optical and X-ray range, X-ray spectrometers and spectrographs, as well as instruments for their absolute calibration, charged-particle spectrometer, diagnostic techniques for measuring spectrum and absolute neutron output.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)	A model that combines description of motion of relativistically charged particles and magnetic-gasdynamic description was developed. The model takes into account ionization by the field, the interaction of accelerated particles with medium, the impact of inverse current; the Fokker-Planck equation for nonlocal transfer is solved. The model is based on two-dimensional software PICNIC. For analysis of the formation of clusters consisting of large groups of (10^4÷10^5) atoms and processes of Coulomb explosion PICNIC is used in combination with the software MOLOH used in molecular dynamics. Software HANDRA was developed for calculation of the transmission of proton beams through matter with allowance for nuclear reactions.
Intended lines of activity under ISTC Targeted Initiative	1. Design and theoretical studies of the efficiency of ion beam acceleration by ultrashort laser pulse. 2. Development of diagnostic techniques and joint experiments under PETAL project. 3. Calculation of proton beam transition through tested material. 4. Development and testing of large-aperture optical components for ultrashort pulse installations. 5. Investigation of the properties and justification of the choice of prospective materials for the design of target chamber of the HiPER facility. 6. Development of conceptual design of a tritium vacuum technological system.
List of projects, candidates for participation in the ISTC Targeted Initiative	**1. «Development of diagnostic techniques of measuring ion beam parameters and their adaptation for PETAL facility»** ***Leading institution:*** RFNC-VNIITF, Snezhinsk ***Institutes-participants:*** 1) RFNC-VNIIEF, Sarov, 2) LPI RAS, Moscow ***Project manager:*** professor A.V. Potapov ***Collaborators/partners:*** – CELIA-University, Bordeaux1, France (Dr. Sebastien Hulin) – Institute Lasers and Plasmas-CNRS, Bordeaux1, France (Dr. Henry Hutchinson) ***Estimated budget:*** $600,000 ***Dates of execution:*** 36 months ***Project summary:*** Diagnostics intended for measuring composition, spectrum, angular ion beam distribution (proton streak camera, Thomson mass-spectrometer), as well as polarization interferometer for determining characteristics of plasma forming on laser target under the action of prepulse will be developed. The developed techniques will be finalized in experiments on SOKOL-P laser facility. ***Collaborator of the projects:*** **1. «Experimental and model theoretical investigation of the process of high-energy particle generation by short powerful laser pulses»** ***Leading institution:*** RFNC-VNIIEF, Sarov

1.3. Institution of the Russian Academy of Sciences «Institute of Applied Physics RAS» (IAP RAS)

Departmental affiliation — Russian Academy of Sciences

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Head — Director – academician A.G. Litvak

Operating laser facilities and complexes with ultrashort radiation pulse

1. Petawatt parametric laser complex (PEARL). Peak power 0.5 PW, pulse duration 45 fs, divergence 2 diffraction limits, central wavelength 910 nm – Fig. 2. Being one of five most powerful laser facilities in the world, the laser complex is based on the principle of optical parametric amplification. Its architecture has been recognized worldwide to be most promising for extension into the multipetawatt range. The laser is intended for creation and study of extreme states of matter and for development of novel scientific, medical, and industrial applications.

2. Ti:sapphire laser complex with radiation peak power of 2 TW, pulse duration 70 fs, pulse energy up to 150 mJ, and repetition rate 10 Hz. The laser is used for conducting experiments on acceleration of wake wave electrons, generation of coherent soft X-radiation, and atmospheric discharge initiation by femtosecond radiation in filamentation regime.

Currently developed laser systems

10-petawatt laser complex based on superbroadband amplification in DKDP crystals. The approved concept and available domestic technologies underlie development of this laser.

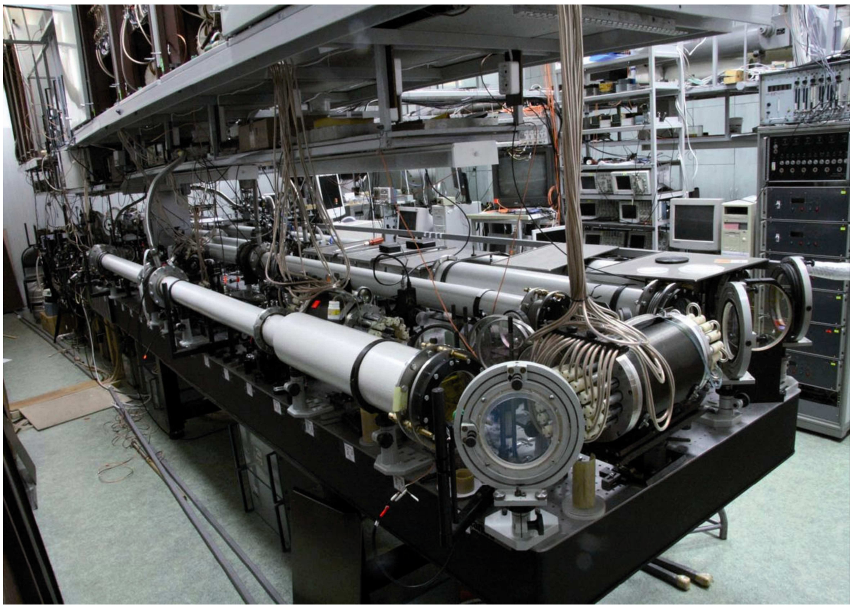


Fig. 2. "PEARL" laser complex with peak power exceeding 0.5 PW

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter

Renovated premises in IAP RAS basement, with total area of 450 m^2, including

- 180 m^2 of clean (cleanliness level 10000) laser room with untied footing, ventilation and air-conditioning system, main vacuum line, equipped with honeycomb optical tables.

– Room for target chambers equipped with radiation protection of personnel.
– Control room.

Several laser laboratories (each having area of about 100 m^2), fully equipped with engineering services: conditioning, electricity, ground connection, plumbing, vacuum installations, etc. are available.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)

Unique PIC codes (including ELMIS – Extreme Laser Matter Interaction Simulator) were developed for calculation of the interaction of laser radiation with gas and solid targets. With the use of these codes a number of original results were obtained and new concepts of laser-plasma charged particles accelerators and sources of X-ray and gamma radiation with record intensity were proposed. All the codes were adapted for calculations on parallel processors; calculations are made on high-performance computers with power up to 30 Teraflops.

Intended lines of activity under ISTC Targeted Initiative

1. Experimental study of physical problems restricting growth of peak power of laser radiation beyond 1 PW. It is expected to develop and test methods and devices allowing advance into the multipetawatt range up to 10 PW. The elaborated systems may become prototypes of facilities used in the 10-petawatt laser complex currently developed by several European countries. Creation of a multipetawatt laser in IAP RAS will permit investigation of the interaction of laser radiation with matter with record intensities up to 10^{23} W/cm^2.

2. Creation of a factory of large-aperture DKDP crystals and fabrication of frequency converters, parametric amplifiers, and Pockels cells for unique laser installations with high energy laser pulse.

List of projects, candidates for participation in the ISTC Targeted Initiative

1. «Large-aperture nonlinear optical elements for superhigh power laser complexes based on high-rate growth KDP crystals»

***Leading research institute**:* Russian Academy of Sciences/ Institute of Applied Physics, Nizhny Novgorod, Russia

Project manager: professor A.A. Babin

Collaborators/Partners:

– Centre Nationale de la Recherche Avancée(CNRS) / Institut de Lumiere Extreme / Ecole Polytechnique, France (Prof. G. Mourou)
– STFC Rutherford Appleton Laboratory, Didcot, UK (Prof. John Collier)
– University of Dusseldorf, Germany (Prof. O. Willi)

Estimated budget: $1,500,000

Dates of execution: 24 months

Project summary:

The technology of high-rate growth of water soluble KDP crystals of preset orientation and fabrication from these crystals of frequency conversion elements and broadband parametric amplification elements for super high-power laser systems. These nonlinear optical elements are needed in super high-power laser complexes intended for solution of global problems (for example, ICF). Such complexes have a status of national (LMJ, NIF) or international (e.g., HiPER, ELI, PHELIX) projects. In Russia, consumers of the elements created by the authors of the project are the Russian Academy of Sciences and the Russian Federal Nuclear Center (Sarov).

The goal of the project is creation at IAP RAS of a complex of clean premises for fabrication, growth and finishing crystals, and depositing of protective and antireflecting coatings, i.e., creation of a factory of large-aperture nonlinear optical elements of KDP crystals. The capacity of this complex is predicted to be 50 elements per year.

The total cost of the project, including fabrication of a pilot batch of elements (5 pieces) ~ 300×300×15 mm in size is assessed to be about 1 mln Euros.

On coming up to full capacity the factory will supply free of charge the European projects with required amount of large-aperture nonlinear optical crystals to the extent equivalent to the European contribution to this project.

2. «Study of basic critical parameters of a prototype of 10-petawatt laser facility»

Leading research institute*:* Russian Academy of Sciences/ Institute of Applied Physics, Nizhny Novgorod, Russia

Project manager: professor E.A. Khazanov

Collaborators/Partners:

– Centre Nationale de la Recherche Avancée(CNRS) / Institut de Lumiere Extreme / Ecole Polytechnique, France (Prof. G. Mourou)
– STFC Rutherford Appleton Laboratory, Didcot, UK (Prof. John Collier)
– University of Dusseldorf, Germany (Prof. O. Willi)

Estimated budget: $1,500,000

Project summary:

The main goal of the project is solution of the basic problems restricting laser facility power enhancement up to 10 petawatt by means of

– creation of efficient lasers for pumping optical parametric and Ti:sapphire amplifiers;
– suppression of parasitic nonlinear effects in glass and crystal lasers;
– exact synchronization of femtosecond lasers and pump lasers;
– increasing time coefficient of output pulse contrasting;
– increasing the repetition rate of output pulses.

The expected results will find application in any petawatt and multipetawatt lasers and will improve their characteristics and simplify design. Results of the project will allow experimental study of the interaction of extreme light fields with matter with intensities up to 10^{23}W/cm^2. Many academic laboratories will obtain a real opportunity to create relatively inexpensive compact laser sources of extreme light fields.

Collaborators of the projects:

1. «High-energy particle beam generation by means of super high-power ultrashort laser pulses»

Leading research institute: JIHT RAS, Moscow

2. «Investigation of the influence of high density laser radiation on reflecting surface of Astrosital CO-115M mirror»

Leading institution: "LZOS" JSC, Lytkarino

1.4. Institution of the Russian Academy of Sciences «P.N. Lebedev Physical Institute RAS» (LPI RAS)

Departmental affiliation

Russian Academy Sciences

Legal address

119991 Moscow, GSP-1 B-333, 53 Leninskiy prospect
http://www.lebedev.ru

Head

Director – academician G.A. Mesyats

Operating laser facilities and complexes with ultrashort radiation pulse

1. Ti:sapphire system generating 50 fs pulses with 10 Hz frequency at the wavelength of 950 nm with the power of 0.2 TW and at the wavelength of 475 nm with 0.1 TW power .

2. Hybrid (solid/gas) femtosecond system consisting of a solid-state Ti:sapphire front-end complex and a photochemical XeF(C-A)-amplifier (Fig. 3) with pulse power 1 TW, pulse duration 50 fs at the wavelength of 475 nm.

Currently developed laser systems

1. Femtosecond laser system with peak power more than 200 TW pumped at the second harmonic generated by spatially low-coherent laser pulse. The use of such radiation for pumping will improve significantly spatial mode of the generated femtosecond pulse due to more uniform pumping of femtosecond amplifier crystals and will ensure higher energy in a femtosecond pulse.

2. Hybrid (solid/gas) femtosecond system consisting of a solid-state Ti:sapphire front-end complex and a photochemical XeF(C-A)-amplifier with pulse power 30 TW, pulse duration 50 fs at the wavelength of 475 nm.

3. Hybrid (solid/gas) femtosecond system consisting of a solid-state Ti:sapphire front-end complex and a photochemical XeF(C-A)-amplifier with pulse power 100 TW, pulse duration 50 fs at the wavelength of 475 nm.

Fig. 3. Photochemical XeF(C-A)-amplifier

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter

The research team has rich experience in conducting experimental investigation of plasma produced by laser pulses of different durations (from tens of nanoseconds to tens of femtoseconds), including problems of laser nuclear fusion, ion and electron acceleration, and generation of X-ray radiation.

A diagnostic complex for studying nonlinear processes in plasma heated by a powerful laser pulse, with high spectral, spatial and temporal resolution was created. The complex includes a unique four-channel polarization microscope, a multichannel fiber-optic system for determining scattered radiation directivity pattern, a calorimetric system for balance measurements of energy distribution in different spectral ranges, and a complex for recording X-ray radiation of laser plasma.

Experimental base for studying the new concept of constructing super high-power femtosecond systems using optically pumped active media in terminal amplification cascades.

All needed means for controlling parameters of short-pulse laser radiation (duration, intensity profile, phase front, contrast on pico- and nanosecond time scales), active medium pump sources, adaptive system, and working area are available.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)

Numerical simulation of the interaction of intense laser radiation with collisionless plasma prepared in advance will be carried out using a multidimensional code «Mandor» that solves a 3D relativistic system of Maxwell-Vlasov equations by the "particle in cell" method (3D3V PIC). The code has been successfully employed for solution of different problems in the physics of laser pulse-plasma interaction.

Software for numerical simulation of nonlinear processes at the interaction of powerful (more than 1 TW/cm^2) large-aperture radiation with optical materials is available.

Intended lines of activity under ISTC Targeted Initiative

- Investigation of a possibility of using nanosecond lasers with low-coherence spatial beams for pumping final cascades of femtosecond laser amplifiers. The ultimate goal is creation of a femtosecond laser system with peak power higher than 200 TW and a center for investigation of the interaction of extreme light fields with matter.
- Development of hybrid femtosecond systems with subpetawatt peak power and the corresponding experimental base.
- Investigation of the interaction of high-intensity laser radiation with matter.

List of projects, candidates for participation in the ISTC Targeted Initiative

«Creation of experimental base and investigation of the impact of extreme light fields on matter in the visible and infrared spectral ranges»

Leading research institution: LPI RAS

Institutes-participants:

1. RFNC-VNIIEF, Sarov
2. International Laser Center of M.V. Lomonosov Moscow State University, Moscow

Project manager: academician O.N. Krokhin

Estimated budget: $1,500,000

Dates of execution: 36 months

Project summary:
Possibilities of significant improvement of spatial quality of the radiation generated by a Ti:sapphire femtosecond laser system due to pumping crystals by pulsed laser radiation with low spatial coherence and energy up to 50 J at the wavelength of 532 nm will be studied under the project. Peak power of the new laser system will amount to 200 TW with pulse duration 20-30 fs.

Theoretical analysis, computer simulation and experimental investigation of dynamics of powerful large-aperture femtosecond radiation propagation in optical media will be carried out. Technologies interesting for hybrid (solid/gas) exawatt power femtosecond systems will be developed.

Theoretical and experimental study of the interaction of extreme light fields with matter in the visible and infrared ranges of femtosecond radiation will be performed.

Collaborators of the projects:
«Development of diagnostic techniques and equipment for research in the physics of high energy densities»
Leading research institute: JIHT RAS, Moscow

«Recording radiation and particle fluxes from plasma formed by femtosecond laser radiation with extreme intensity»
Leading institution*:* ILC MSU, Moscow

1.5. Institution of the Russian Academy of Sciences «Joint Institute for High Temperatures RAS» (JIHT RAS)

Departmental affiliation Russian Academy of Sciences

Legal address Moscow, 125412, 13 Izhorskaya Str., bld.2
http://jiht.ru

Head Director – academician V.E. Fortov

Operating laser facilities and complexes with ultrashort radiation pulse

– Femtosecond terawatt Chromium:forsterite laser system operating in the infrared spectral range (1240 nm, 80 fs, 10 Hz, 2 TW).
– Femtosecond multiterawatt Ti:sapphire laser system (800 nm, 30 fs, 10 Hz, 10 TW) (Fig. 4).

Femtosecond Chromium:forsterite laser systems have no analogs in Russia and abroad and are fabricated using domestic components. (Utility model patent «Laser pulse power amplifier», JIHT, Moscow, No. 47140, priority of 10 March 2005).

Fig. 4. Femtosecond multiterawatt Ti:sapphire laser system in the JIHT RAS
(800 nm, 30 fs, 10 Hz, 10 TW)

Currently developed laser systems

Femtosecond laser system with the following basic parameters:
– radiation wavelength – 820 nm;
– pulse duration – 30 fs;
– pulse energy – 6 J;
– pulse power – up to 200 TW;
– repetition rate – 10 Hz;
– radiated power contrast – 10^{-8} (ns range, 10^{-7} (10 ps range)).

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter

Up-to-date diagnostic equipment, including
– X-ray diagnostic complex,
– digital femtosecond vacuum interferometer,
– nanometric positioning system P-587 with control and monitoring along 6 coordinate axes,

- parametric laser pulse frequency converter for IR and visible spectral regions,
- digital spectrometer with single- and multichannel recording,
- digital gated camera with brightness amplification,
- femtosecond laser "tweezers-knife",
- high-sensitivity spectral complex.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)

Researchers of the institute developed and use a wide variety of physical models for investigation of basic properties of matter at high energy densities both, in strongly nonequilibrium conditions of high-temperature heating of electron subsystem and at thermal equilibrium of electrons and ions. A quantum-mechanical method of density functional is used for analyzing equations of state for strongly non-ideal electromagnetic and quark-gluon plasma. Molecular-dynamic calculations of processes at a microlevel in condensed media under the action of laser radiation are carried out. A two-temperature hydrodynamic model of the interaction of intense ultrashort laser pulses with metals was developed and has been successfully used for interpretation of experiments. The model was implemented as a code describing multicomponent processes taking into account multiphase equations of state in a wide range of temperatures and densities. A hybrid code allowing full-scale modeling of electron acceleration in wake fields generated by relativistically intense ultrashort laser pulses was developed and is used successfully.

Intended lines of activity under ISTC Targeted Initiative

Fundamental investigation of thermodynamic and transport properties of condensed matter and plasma in strongly non-ideal states at high temperatures and pressures.

Study of processes underlying development of high-intensity sources of electromagnetic radiation in a wide range varying from THz to gamma radiation, and generation of beams of high-energy particles by means of ultrashort powerful laser pulses.

Development of diagnostic techniques and equipment for investigation of the physics of high energy densities during the interaction of super high-power laser radiation with matter.

List of projects, candidates for participation in the ISTC Targeted Initiative

1. «Experimental and theoretical study of thermodynamic and transport properties of metals under the action of intense ultrashort laser pulses»

Leading research institute: JIHT RAS, Moscow

Project manager: Dr. Sc. K.V. Khishchenko

Collaborators / Partners:

- Institute Lasers and Plasmas-CNRS-CEA-University, Bordeaux1, France (Dr. L. Hallo);
- GSI-Darmstadt, Germany (Dr. O. Rosmej);
- University of Texas at Austin, USA (Prof. G. McNaughton Dyer);
- Lawrence Livermore National Laboratory, USA

Estimated budget: $ 500,000

Dates of execution: 36 months

Project summary:

The work is concerned with experimental study and construction of physico-mathematical models of behavior of metals under the action of ultrashort laser pulses with high power density. Planning, interpretation and use of results of experiments on laser action on matter demand development of wide-range theoretical models of transport, optical and thermodynamic properties of matter. On the one hand, it is intended to develop such models based on experimental data on the impact of powerful laser radiation on matter. On the other hand, fundamental theoretical approaches, such as plasma kinetics, the theory of solid state, quantum-statistical theory of linear response, quantum-statistical models of thermodynamic properties of matter should underlie such models. The developed techniques are of fundamental importance for analysis and numerical simulation of different physical phenomena at high energy densities.

2. «High-energy particle beam generation by means of super high-power ultrashort laser pulses»

Leading research institute : JIHT RAS

Institutes-participants: 1. RFNC-VNIIEF, Sarov;
2. IAP RAS, Nizhny Novgorod

Project manager: professor N.E. Andreev

Collaborators / Partners:

– Laboratoire de Physique des Gaz et des Plasmas, CNRS – Université Paris–Sud 11 (Prof. G. Maynard, Dr. D. Cros);
– Department of Physics, Lund University, Sweden (Prof. C-G. Wahlstrom);
– Institute Lasers and Plasmas-CNRS-CEA-Ecole Polytechnique-University, Bordeaux1, France (Prof. P. Mora, Prof. V. Tikhonchuk);
– GSI-Darmstadt, Germany (Prof. Th. Stohlker);
– Kansai Photon Science Institute, JAEA, Japan (Prof. Y. Fukuda).

Estimated budget: $400,000

Dates of execution: 36 months

Project summary:

The advance made in recent years in the theoretical and experimental study of laser-plasma acceleration techniques open up wide opportunities for creation of new electron accelerators up to ultrarelativistic energies that would ensure ~1000-fold acceleration rates as compared to traditional radio frequency accelerators, thus reducing their size and cost substantially.

The goal of the project is experimental research, development of theory, and numerical simulation of the processes of nonlinear interaction of ultrashort (subpicosecond) powerful (terawatt-petawatt power) laser pulses with plasma and development of new concepts of particle charge (electrons and ions) acceleration. Diagnostic techniques and equipment for accelerating plasma fields will be developed and laser pulse and target parameters will be optimized to obtain bunches of charged high-energy particles. Basic regularities of acceleration process and conditions for producing ultrarelativistic electron bunches possessing properties needed for practical applications, such as small energy dispersion and small emittance, will be studied. These characteristics together with the requirement of high energy and spatial compactness of accelerated electron bunches are of key importance for their application in sources of coherent X-ray radiation.

3. «A concept of reactor chamber for laser nuclear fusion»

Leading research institute: JIHT RAS

Institutes-participants: 1. ITEP (Rosatom), Moscow;
2. IAM RAS, Moscow

Project manager: Dr. Sci. S.A. Medin

Collaborators / Partners:

– Institute Fusion Nuclear/University Politecnica de Madrid (Prof. M. Perlado);
– Institute of Physics of the ASCR, Prague, Chech Rebublic (Dr. B. Rus);
– Science and Technology Facilities Council, UK (Prof. J. Collier)

Estimated budget: $ 250,000

Dates of execution: 36 months

Project summary:

Different concepts of the first wall of reactor chamber for laser nuclear fusion will be analyzed. A spherical reactor chamber with porous first wall coated by a protective liquid coolant film will be considered. Processes of target compression and burning, microexplosion products scatter in the chamber, energy flux impact on the protective film of the first wall, and response of the elements of blanket design to neutron energy release are analyzed on the basis of hydrodynamic description. Initial data for modeling are chosen to fit parameters of HiPER facility.

4. «Sources of electromagnetic radiation in the THz-to-gamma radiation range using super high-power ultrashort laser pulses»

Leading research institute: JIHT RAS, Moscow

Institutes-participants:GPI RAS, Moscow

Project manager: professor M.B. Agranat

Collaborators / Partners

– Laboratoire de Physique des Gaz et des Plasmas, CNRS - Université Paris–Sud 11 (Prof. G. Maynard);
– Institute Lasers and Plasmas-CNRS-CEA, Bordeaux1, France (Prof. V. Tikhonchuk);
– GSI-Darmstadt, Germany (Prof. Th. Stohlker, Dr. O. Rosmej);
– Kansai Photon Science Institute, JAEA, Japan (Prof. Y. Fukuda)

Estimated budget: $ 250,000

Dates of execution: 36 months

Project summary:

A possibility of using femtosecond laser pulses for generation in plasma of terahertz radiation that is widely employed in biological, medical and chemical studies will be investigated. New methods of generating radiation during the interaction of ultrashort laser pulses with gas, cluster, solid, and nanostructured targets for creation of efficient sources of short-pulse X-ray radiation will be studied. It is intended to analyze a possibility of creating sources of coherent and incoherent gamma-radiation when intense ultrashort laser pulses act on nanoclusters containing long-lived metastable nuclear isomers. Optimal dimensions of isomer nanoclusters and aggregate state of nanostructured medium (gaseous, deposited on a substrate, etc.) fit for producing sources of gamma-radiation on femtosecond laser impact on matter will be found.

5. «Development of diagnostic techniques and equipment for research in the physics of high energy densities»

Leading research institute: JIHT RAS, Moscow

Institutes-participants: LPI RAS, Moscow

Project manager: professor A.Ya. Faenov

Collaborators / Partners

– LULI Ecole Polytechnique, France (Prof. M. Koenig);
– University of Nevada, Reno, USA (V. Kantsyrev);

Estimated budget: $240,000

Dates of execution: 36 months

Project summary:

The project is concerned with development of methods of radiation diagnostics of processes occurring in matter with high energy density in dense and astrophysical plasma. Measurements of parameters of excited matter, such as electron temperature, magnitude of intrinsic nonequilibrium electromagnetic fields, energy of ordered motion of charged particles will be adapted and methods of X-ray spectroscopy of multicharged ions with high spatial resolution will be employed.

Schemes of phase and monochromatic absorption radiography realized by means of special spherically curved dispersive crystal elements will be developed for imaging, determining temporal evolution and measuring density of various structures in plasma (shock waves, plasma jets, turbulence). For imaging internal electromagnetic fields and short-lived objects in plasma proton-ion radiographic techniques will be developed. One of the main trends in the radiographic techniques is development of easy-to-use bright pulsed sources of probing X-ray and corpuscular radiation. Such a source will be created on the basis of the interaction of femtosecond and picosecond laser pulses with special gas-cluster targets.

For recording absorption and phase-contrasted images of small-contrast images in plasma it is intended to propose promising lithium-fluoride detectors of X-ray radiation that will have unique spatial resolution (less than 1 μm), large field of view, and high sensitivity in the soft X-ray radiation range. Research on finding ablation thresholds of optical elements and diagnostic schemes under the action of superintense laser pulses will be carried out.

1.6. Joint Stock Company «Research-and-production Enterprise "Inject"» ("Inject" JSC)

Departmental affiliation 100% stock belongs to the Russian Technologies State Corporation

Legal address 410052, Saratov, 50 years of October prospect, 101
http://www.inject-laser.ru

Head General director – Dr. Sci. G.T. Mikaelyan

Operating laser facilities and complexes with ultrashort radiation pulse. Experimental base "Inject" JSC produces powerful arrays of diode lasers for high-efficiency optical pumping of active elements of solid lasers with spectral absorption bands at the wavelengths of 792, 808, 940 and 980 nm. Consumers of "Inject" JSC products are leading enterprises and research centers of the RF.

Currently developed laser systems It is planned to develop powerful arrays of diode lasers with enhanced power density. Prototypes of such emitters are shown in Fig. 5. The emitters will be used for scaling and creation of perspective super high-power solid-state diode-pumped laser systems.

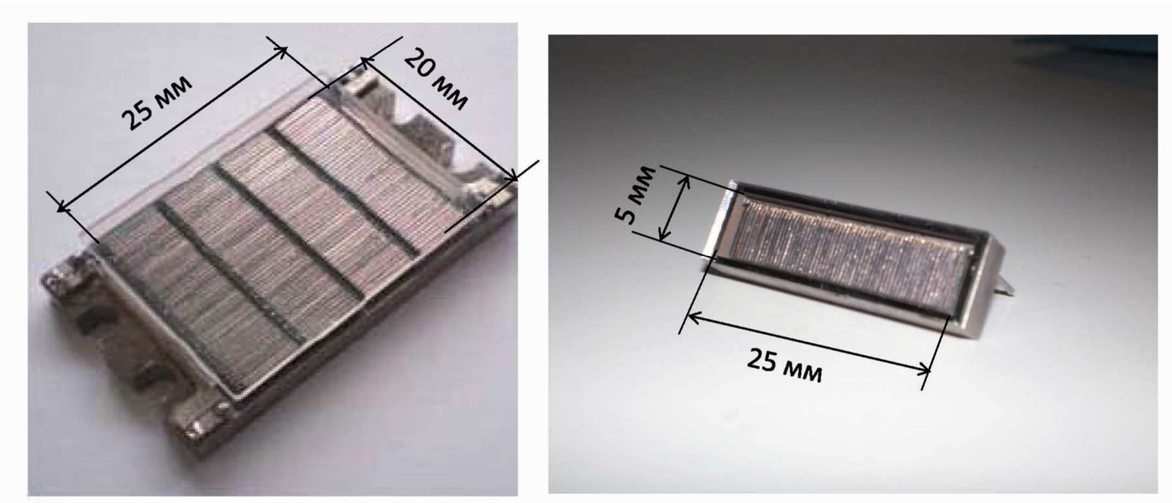


Fig. 5. Scalable diode laser stack arrays. Radiated power density ≥ 4 kW/cm^2.
Pulse repetition rate 10÷100 Hz

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter "Inject" JSC has a full technological cycle for producing diode lasers, research, design and engineering departments where research and development of different types of emitters based on injection lasers, including powerful arrays of diode lasers for selective, high-efficiency pumping of solid and other active media.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs) Mathematical simulation, numerical experiments and product designing are carried out using standard software and software developed in "Inject" JSC.

Intended lines of activity under ISTC Targeted Initiative Development and production of powerful arrays of diode lasers for high-efficiency optical pumping of super high-power solid lasers.

«Creation of powerful scalable arrays of diode lasers with enhanced high power density»

Leading institution: "Inject" JSC, Saratov

Project manager: Dr. Sci. G.T. Mikaelyan

Estimated budget: $1,500,000

Dates of execution: 24 months

Project summary:

Super high-power diode-pumped solid-state laser systems demand large pump surfaces with maximum possible power densities. Cost per unit power is also important. Commercially available power densities of diode laser arrays are about 2 kW/cm^2. A twofold increase of power density, design providing more dense stacking of individual diode lasers into large-scale arrays (scaling), and development of low-cost (as compared to the current market) emitters will allow producing competitive super high-power systems with solid active elements.

1.7. The Federal State Unitary Enterprise «Research Institute for Complex Testing of Optoelectronic Devices and Systems» (NIIKI OEP)

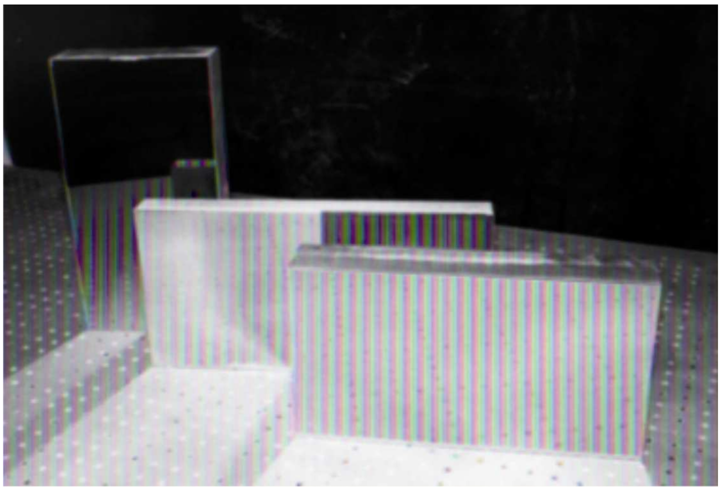
Departmental affiliation — RF Ministry of Industry and Trade

Legal address — 188540, Sosnovy Bor, Leningrad Region
http://www.niiki.ru/index_eng.html

Head — Director General – professor A.D. Starikov

Operating laser facilities and complexes with ultrashort radiation pulse — NIIKI OEP has an Yb:KYW/Nd:glass chirped pulse amplification laser system generating pulses with a duration of 0.8-1.0 ps and power up to 30 TW at the wavelength of 1053 nm with angular beam divergence close to diffraction limit, and intensity $\leq 10^{19}$ W/cm^2. The system comprises a launching laser forming a chirped pulse with energy up to ≈1 J, a four-cascade rod amplifier with the output cascade aperture of 85 mm, 210×420 мм^2 diffraction-lattice beam compressor, and f/1.1 axial parabolic focusing mirror (Fig. 6a).

Currently developed laser systems — Laser facility "PROGRESS-P-100" with radiated power more than 100 TW at pulse duration less than 0.7 ps is now underway. The main channel in this facility is a five-cascade phosphate Nd:glass (KGSS 0180 and GLS 22) rod amplifier with periodic spatial beam filtering and vacuum compressor equipped with holographic arrays with damage threshold ≈1 J/cm^2 (Fig. 6b).



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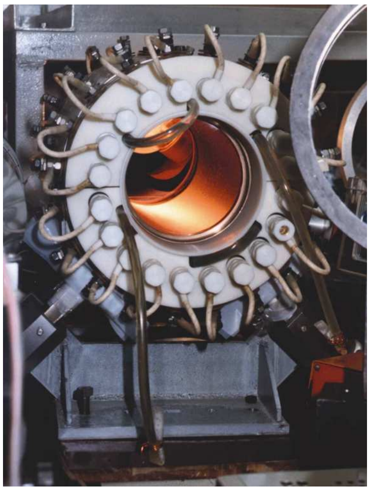


b

Fig. 6. Components for super high-power laser systems:
a – 210x420 mm^2 diffraction arrays with gold coating and protecting film having damage threshold 1.5±0.2 J/cm^2 for nanosecond pulses (joint product with the Russian company HoloGrate);
b – Nd-glass (KGSS 0180) rod laser amplifier having diameter 140 mm

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter

– Development, fabrication and investigation of laser element base and technologies of their testing.
– Development and study of the methods and means of controlling space-time characteristics of powerful lasers.
– Development, study and testing precision techniques of laser alignment and beam guidance to the target.

	– Experimental research aimed at creating accelerated ions to be used for radiography of static microstructured objects and fast plasma processes. – Updating the technology of multiframe interferometry for pre-pulse and plasma process diagnostics.
Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)	Special software, e.g. 3D PIC codes used by the collaborators, will be employed for analysis of physical processes in the course of the interaction of high-intensity (sub)picosecond pulses with solid-state targets, including particle charge acceleration
Intended lines of activity under ISTC Targeted Initiative	– Development of powerful laser schemes, creation and investigation of large-aperture optical elements. – Development, investigation and testing precision methods of aligning complex optical systems and beam guiding to small-size objects. – Elaboration of optical methods for measuring the scale of preplasma inhomogeneity produced by prepulse with extremely high spatial resolution. – Development of the method of proton recording of plasma density at given moments of time (the method of preplasma proton radiography). – Macroparticle acceleration by ultrashort laser pulse.
List of projects, candidates for participation in the ISTC Targeted Initiative	**1. «Development and investigation of designs and key components of multipetawatt lasers»** ***Leading institution:*** NIIKI OEP, Sosnovy Bor ***Institutes-participants:*** 1. FSUE RTIOM, St.-Petersburg, 2. RFNC-VNIIEF, Sarov ***Project manager:*** Dr. Sci. A.V. Charukhchev ***Estimated budget:*** $400,000 ***Dates of execution:*** 24 months ***Project summary:*** The goal of the project is solution of the problems concerned with creating powerful laser systems with femto- and picosecond pulse duration, namely: – development of high-efficiency amplification cascades for powerful lasers, including pumping laser systems with parametric amplification; – development of original schemes of powerful lasers with femto- and picosecond pulse duration, including methods of effective suppression of nonlinear effects in active media of amplification paths; – development of methods for increasing time coefficient of output pulse contrasting; – creation of prototypes of active media and their investigation for increasing output pulse repetition rate; – elaboration of the technology of producing prototypes of laser element base and their testing, including high-quality optical elements (mirrors, aspheric lenses up to ∅ 500 mm, laser ceramics, etc.).

2. «Macroparticle acceleration by ultrashort laser pulse»

Leading institution: NIIKI OEP, Sosnovy Bor

Institutes-participants: 1. RFNC-VNIIEF, Sarov,
2. SOI, St.-Petersburg

Project manager: Dr. Sci. A.V. Charukhchev

Estimated budget: $300,000

Dates of execution: 24 months

Project summary:

The goal of the project is optimization of the conditions for accerelating target fragments up to orbital velocities by picosecond laser pulse irradiation. When a solid-state target is irradiated by a picosecond pulse with 10^{13}-10^{15} W/cm^2 intensity, a shock wave (SW) is formed that penetrates deep into the target. On reaching the target backside the SW backreflects, generating a rarefaction wave near the reflection boundary. If the intensity of this wave exceeds ultimate strength of the material, fragments of target material break away. Further, the SW goes back to the front side of the target, and also causes breakaway of material fragments. The number of possible reflections depends on wave energy, as well as on target thickness and state. As a result fragments of target material are accelerated up to ~10^6 cm/s (~10 km/s).

It is intended to study the impact of target parameters (material, shape, thickness) and laser pulse characteristics (intensity, spatial distribution) on the process of target fragments acceleration and to develop a theoretical model of the process of macroparticle acceleration by an ultrashort laser pulse.

3. «Optical and radiographic study of parameters of preplasma and its influence on the process of ion acceleration»

Leading institution: NIIKI OEP, Sosnovy Bor

Project manager: Dr. Sci. A.V. Charukhchev

Estimated budget: $400,000

Dates of execution: 36 months

Project summary:

The goal of the project is development of optical and radiographic methods of detecting preplasma formed by prepulse.

A laser prepulse preceding the main pico- or femtosecond laser pulse forms low-density plasma which interacts with the main pulse. The magnitude of density gradient determining further evolution of plasma formation, including electron and ion acceleration in the target, depends on the prepulse intensity.

The influence of the magnitude of preplasma density gradient on the process of ion acceleration in the target will be investigated theoretically and experimentally. Towards this end, it is intended to update the optical interferometer available in the PROGRESS laser system and to develop a technique of preplasma proton radiography.

Theoretical research will be done in collaboration with scientists from several Russian research institutes.

1.8. Federal State Unitary Enterprise Research Institute Scientific Production Association «LUCH» (SPA «LUCH»)

Departmental affiliation
State Corporation «Rosatom»

Legal address
24 Zheleznodorozhnaya Str., 142100 Modolsk, Moscow region
http://www.luch.podolsk.ru

Head
Director General – professor S.V. Alekseev

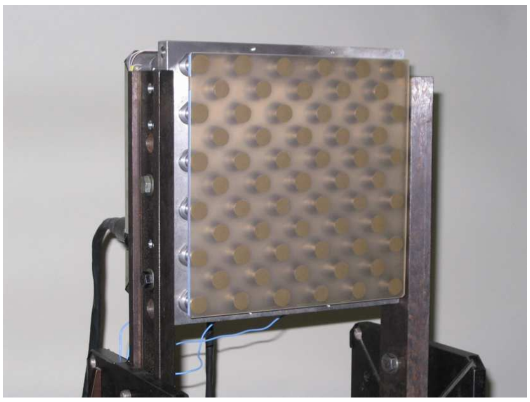
Operating laser facilities and complexes with ultrashort radiation pulse

Currently developed laser systems, subsystems, and elements

Large-aperture adaptive systems for correction of laser radiation wave front are currently developed. Root-mean-square deviation of wave front surface shape of powerful laser radiation using adaptive mirror is 0.1 µm. Cooled adaptive mirrors for powerful laser radiation are elaborated (Fig. 7).

Reflective, antireflective, and other coatings with high damage threshold for the first and second harmonics of solid lasers are developed and fabricated. Coatings for the third harmonic and mirrors for femtosecond lasers are developed.

Research and experimental development aimed at creating silicon carbide, silicon, and other cooled power mirrors is carried out. Experience in fabricating various mirrors, including large-aperture ones for multi-purpose laser systems, is available.



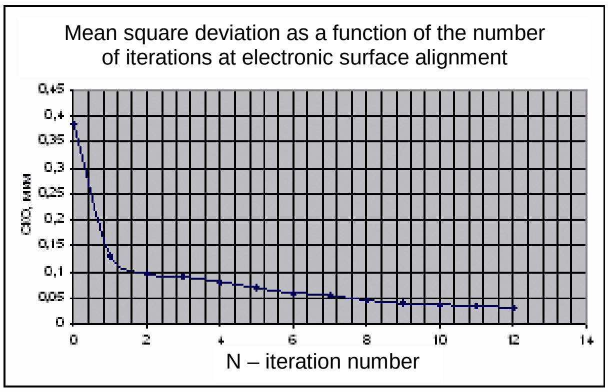


Fig. 7. Adaptive mirror with aperture size 220 mm and 61 actuators; accuracy of surface flattening is 0.03 µm

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter

Tests of damage threshold at the wavelengths of the first, second and third harmonic of neodimium laser may be carried out on small-size optical elements in a 1.5×1.5 mm spot. The tests are conducted on a laser operating in the Q-switch mode that allows research in the regime modeling the operating regime of powerful laser facilities.

Stands for investigation of adaptive systems permitting to control surface shape to an accuracy of 0.02 µm are available.

Premises in the basement of one of the «LUCH» buildings with an area about 100 m^2 have untied footing and engineering infrastructure for installing optical equipment needed for investigation of adaptive mirrors 700 mm in diameter.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)	Software for investigation of behavior of laser mirrors under high radiation load.
Intended lines of activity under ISTC Targeted Initiative	1. Development, fabrication and study of adaptive systems for correcting wave fronts of high-intensity laser radiation. 2. Development, fabrication and study of coatings with high radiation damage threshold. 3. Development and fabrication of cooled large-aperture optical systems for powerful laser facilities with ultrashort radiation pulses. 4. Development of fabrication technique of silicon carbide plates and assemblies for HiPER reactor. 5. Elaboration of a fuel element for the blanket of hybrid reactor of HiPER facility.
List of projects, candidates for participation in the ISTC Targeted Initiative	**1. «Development, fabrication and study of durability of coatings at the first, second and third harmonic of solid lasers operating at cryogenic temperatures»** ***Leading institution:*** SPA «LUCH», Podolsk, Moscow ***Institutes-participants:*** RFNC-VNIIEF, Sarov ***Project manager:*** professor V.G. Zhupanov ***Dates of execution:*** 24 months ***Project summary:*** Damage threshold at repeated irradiation of interference coatings by powerful pulsed lasers is 3-4 times less than at a single irradiation. This may be attributed to temperature rise and increased absorption in the irradiated region. When operating temperature drops down, absorption coefficient of coating materials as well as of substrate material decreases. Therefore, it is interesting to study damage threshold behavior of interference coatings of different types (antireflective, reflective, polarizing) made of different materials at reduced temperatures. It is intended to study damage threshold and working capacity under nominal radiation load of different types of coatings as a function of production conditions at reduced temperatures. Technical procedures of obtaining high damage threshold coatings for operation at reduced temperatures will be developed, and dependence of damage threshold and working capacity of coatings on substrate temperature will be found under the project. **2. «Development and fabrication of dimensionally stable cooled large-aperture silicon carbide and silicon mirror for operation with powerful laser radiation in pulsed periodic mode»** ***Leading institution:*** SPA «LUCH», Podolsk, Moscow ***Institutes participants:*** RFNC-VNIIEF, Sarov ***Project manager:*** professor V.P. Smekalin ***Estimated budget:*** $1,600,000 ***Dates of execution:*** 24 months ***Project summary:*** A prototype of a dimensionally stable, large-aperture mirror with high damage threshold will be elaborated.

3. «Development, fabrication and study of adaptive mirror for Vulcan facility»

Leading institution: SPA «LUCH», Podolsk, Moscow
Institutes participants: RFNC-VNIIEF, Sarov
Project manager: professor O.I. Shanin
Collaborators/Partners:
STFC Rutherford Appleton Laboratory, Didcot, UK
(Prof. John.Collier)
Estimated budget: $550,000
Dates of execution: 24 months
Project summary:
Technologies of manufacturing adaptive mirrors with aperture size up to 300 mm for powerful pulsed lasers were developed in SPA «LUCH».
The goal of the proposed project is development and testing of adaptive mirror with control equipment (optical aperture diameter 100–200 mm, number of actuators 25–100, accuracy of surface flattening 0.04 μm, damage threshold not less than 20 J/cm^2) to provide the currently updated 12-channel Vulcan facility with adaptive optics in 2013–2014.
Adaptive optics will be tested on "Luch" (RFNC-VNIIEF, Sarov, Russia) and "Vulcan" (STFC Rutherford Appleton Laboratory, Didcot, UK) facilities.
Total cost of the project, including fabrication and testing of two sets of adaptive mirrors with control equipment is estimated to be about 440 thousand Euros.

On finishing adaptive optics under the project it is intended to deliver and maintain for two years 15 sets of adaptive optics for the updated "Vulcan" facility.

4. «Development, fabrication and study of a prototype of adaptive system mirror for HiPER facility»

Leading institution: SPA «LUCH», Podolsk, Moscow
Institutes -participants: RFNC-VNIIEF, Sarov
Project manager: professor O.I. Shanin
Collaborators/Partners: STFC Rutherford Appleton Laboratory, Didcot, UK (Prof. John.Collier).
Estimated budget: $3,500,000
Dates of execution: 24 months
Project summary:
Commercial use of ICF facilities implies that they will operate at a rate of 10–15 shorts per second. Adaptive optics to be used in these conditions must be cooled.
The goal of the project is development and testing of a cooled adaptive mirror with control equipment and optical aperture of 400 mm for demonstration of its working capacity as part of the future ICF facilities.
Within the framework of the project it is intended to test adaptive optics on "Luch" facility (RFNC-VNIIEF, Sarov).
Total estimated cost of the project, including updating the experimental base for trying the adaptive mirror prototype is about 2 400 thousand Euros.

On finishing adaptive optics under the project it is intended to fabricate and deliver the experimental adaptive optics for the research prototypes of ICF facilities.

1.9. International Laser Center of M.V. Lomonosov Moscow State University (ILC MSU)

Departmental affiliation	
Legal address	119991 Moscow, Leninskie Gory 1, build. 62 http://ilc.phys.msu.ru
Head	Director – professor V.A. Makarov
Operating laser facilities and complexes with ultrashort radiation pulse	Terawatt Ti:sapphire laser system (up to 100 mJ, 50 fs, 10 Hz, 805 nm, M^2~1.8, contrast better than 10^5 at ps and 10^7 at ns), giving laser radiation efficiency on a target higher than 10^{18} W/cm^2 without adaptive optical devices.
Currently developed laser systems	
Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter	The team has rich experience in solving diverse problems concerned with creation and application of plasma diagnostics in experiments on producing plasma by short-pulse femtosecond pulses of extreme intensity. ILC MSU has a variety of high-vacuum interaction chambers equipped with X-ray (scintillation detectors, pin diodes, spectrometers based on semiconductor detectors or crystals-monochromators), ion (time-of-flight), and optical plasma diagnostics. Radiation is focused on a target by an off-axis parabolic mirror using an original technique of its precision alignment. This technique provides spot diameter on the target corresponding to design minimum with allowance for beam quality (less than 4 μm). Schemes of a three-channel polarization interferometer, including shadow, interference and polarization recording of plasma, needed for investigation of magnetic fields and electron plasma density profile with high temporal and spatial resolution were developed in co-operation with LPI RAS. Another joint work with LPI RAS is creation and application of a wide spectrum of diverse X-ray spectrometers. In collaboration with the FSUE "All-Russia Research Institute of Automatics named after N.L. Dukhov" equipment for recording single fast pulsed processes (optical and ionizing radiation, neutrons) was developed. In particular, the joint team is capable of solving problems, such as – measuring spatial distribution of fast particles (ions, neutrons, electrons with energies from unities of keV to MeV) and quanta (in optical, X-ray and gamma spectral regions) with time resolution up to unities of picoseconds using photochronographs and up to 0.5 ns by means of frame-by-frame recording; – measuring X-ray plasma spectra using focusing X-ray spectrometers with digital data recording both, panoramic and with high spectral resolution; – measuring spatial scale of magnetic field and plasma spread using a three-channel polarization interferometer with time resolution of order unities of picoseconds.
Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)	Theoretical description of processes and experiments planned under the project will be done by skilled theoreticians specializing in the interaction of relativistically strong laser pulses with plasma. Numerical simulation will be carried out using the multidimensional code "Mandor" that solves the three-dimensional relativistic system of Maxwell-Vlasov equations by the "particle in cell" method (3D3V PIC). A distinguishing feature of the code is modular approach that

ensures flexible simulation, in particular, flexibility in specifying target design (preplasma, foils, clusters, multilayered foils, profiled targets, and so on). The "Mandor" code was successfully used for solution of diverse problems in the physics of interaction of short laser pulses with plasma. Numerical simulation will be done on the 8-processor work-station with access to the supercomputer "Chebyshev". In the near future the considered code is expected to be activated on the supercomputer complex "Lomonosov" (the fifth of the most powerful computers in the world.

Intended lines of activity under ISTC Targeted Initiative

– A single-frame position-sensitive recorder based on optoelectronic recorder SFER10, matrix fiber detector and optical CCD matrix will be developed for investigation of space-energetic distribution of relativistic particles in neutron and proton beams from plasma.

– An X-ray spectrometer based on polycrystalline powder monochromator, or bent crystals and semiconductor X-ray pin-code matrix will be developed for panoramic measurements of the spectrum of hard X-ray radiation (10-100 keV).

– A three-channel polarization interferometer that provides shadow, interference and polarization recording of plasma will be developed for investigation of magnetic fields and electron plasma density profiles (including a prepulse formed profile) with time resolution up to 100 fs and spatial resolution of order 5 µm.

– Theoretical basis for the proposed techniques will be provided by means of numerical simulation of laser-plasma processes using the multidimensional code "Mandor" and by updating available numerical and visualization techniques.

The research teams of ILC MSU and LPI RAS collaborate within the framework of the joint Laboratory of Relativistic Laser Plasma. The developed techniques will be tested and finished using the femtosecond laser system available in ILC MSU. Simulation of plasma formation and particle acceleration will be done using the numerical codes of the LPI RAS team and the computational resources of MSU and LPI RAS.

List of projects, candidates for participation in the ISTC Targeted Initiative

«Recording radiation and particle fluxes from plasma formed by femtosecond laser radiation with extreme intensity»

Leading institution: ILC MSU, Moscow

Institutes -participants: 1) FSUE All-Russia Research Institute of Automatics, Moscow,
2) LPI RAS, Moscow

Project manager: professor A.B. Saveliev-Trofimov

Estimated budget: $750,000

Dates of execution: 36 months

Project summary:
Techniques of recording (1) space-energetic spectrum of fast particles (electrons, protons, neutrons), (2) panoramic spectrum of hard X-ray radiation, (3) magnetic fields and profile of plasma\preplasma electron density with high spatial and temporal resolution will be developed. The techniques will be tested using a terawatt femtosecond laser system, a wide variety of diagnostic tools, and multidimensional numerical simulation of plasma processes.

1.10. Joint Stock Company «Lytkarino Optical Glass Factory» ("LZOS" JSC)

Departmental affiliation

RF Ministry of Industry and Trade

Legal address

140080 Lytkarino, Moscow region, 1 Parkovaya Str.
http://lzos.ru/en

Head

Director General – A.P. Patrikeev

Operating laser facilities and complexes with ultrashort radiation pulses

Element base

"LZOS" JSC provides operating laser facilities and complexes of ultrashort pulse duration with optical elements operating in transmitted and reflected light. The "LZOS" JSC activity includes optical materials manufacturing from optical glass melting and annealing to blanks and fiber optic elements.

Currently developed laser systems and components

"LZOS" JSC fabricates optical elements: laser glass plates, optical lenses, mirror elements for prospective laser complexes with a perspective to participate in international projects.

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter

"LZOS" JSC is a manufacturer of glass and glass ceramics of different grades, for laser installations inclusive. The company is ready to collaborate with enterprises using short-pulse laser systems along the following lines:

– joint investigation of radiation and mechanical damage threshold of samples at the transition of laser radiation of different densities through an optical element and at mirror reflection from a coated glass-ceramic material;

– study of changes in sample microstructure, their wear and tear, depending on the initial state, roughness, inclusions and scratches.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)

Theoretical studies of the impact of high-density laser radiation on optical glass and glass-ceramic materials.

Intended lines of activity under ISTC Targeted Initiative

Lines of activity are determined by the potential of the company described above.

List of projects, candidates for participation in the ISTC Targeted Initiative

1. «Creation of stand and investigation of optical materials damage threshold in a short (3–5 ns) pulse»

Leading institution: "LZOS" JSC, Lytkarino, Moscow region

Institutes-participants: RFNC-VNIIEF, Sarov

Project manager: A.N. Ignatov – Production manager in optical media fabrication

Estimated budget: will be coordinated with collaborators

Dates of execution: 36 months

Project summary:

A laser stand with 3–5 ns pulse duration, pulse energy ≈ 5 J at the wavelength of 1.052–1.064 μm will be constructed for measuring bulk and surface damage threshold of glass samples. The impact of high-density laser radiation in a rather large interaction spot (3–5 mm) on laser phosphate glass produced with different parameters of technological process will be investigated aiming at finding optimal methods, accessories and regimes of industrial production. The stand will be further used for testing damage threshold of manufactured active elements, lenses, mirrors, and other optical elements.

2. «Investigation of the influence of high density laser radiation on reflecting surface of Astrosital CO-115M mirror»

Leading institution: "LZOS" JSC, Lytkarino, Moscow region

Institutes-participants: 1) RFNC-VNIIEF, Sarov,
2) IAP RAS, Nizhny Novgorod

Project manager: M.A. Abdylkadyrov – Chief Optician

Estimated budget: will be coordinated with collaborators

Dates of execution: 24–60 months

Project summary:
The influence of high-density laser radiation on reflecting surface of Astrosital CO-115M mirror will be investigated (Fig. 8)

– at different lapping and polishing depths of crystal;
– at different surface roughness;
– at different power (density) of a beam incident on the studied mirror surface;
– at different angles of incidence of laser radiation on reflecting surface;
– for different shapes of scratches and inclusions on the reflecting surface;
– at different degrees of mirror cooling.

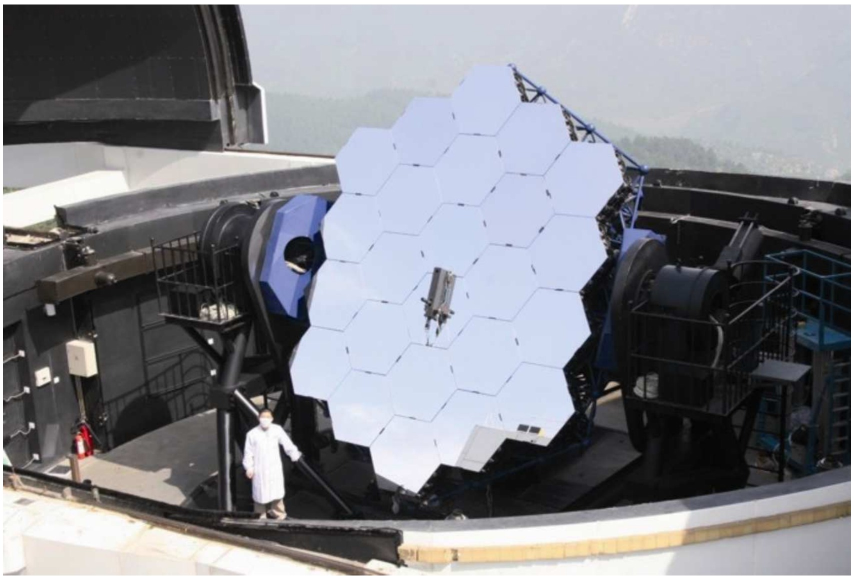


Fig. 8. Example of a segmented Astrosital mirror 5.7 m x 4.4 m in size for the project LAMOST (China). The developed technology may be used for fabricating large mirrors for laser facilities. The influence of high-density laser radiation on the reflecting surface of Astrosital mirror

1.11. Institution of the Russian Academy of Sciences «Institute of Laser Physics of the Siberian Branch of RAS» (ILP SB RAS)

Departmental affiliation	Russian Academy of Sciences
Legal address	630090 Novosibirsk, 13/3 Ac. Lavrentyev prosp. http://www.laser.nsc.ru
Head	Director – academician S.N. Bagaev
Operating laser facilities and complexes with ultrashort radiation pulse.	Femtosecond laser system with radiation peak power up to 3 TW, pulse duration 45-50 fs, central wavelength 800 nm, pulse energy up to 150 mJ, and repetition rate 10 Hz (Fig. 9). The laser system is used in experimental research on radiation propagation and filamentation in gas media and in an atmosphere and on formation of ultrashort optical pulses.
Currently developed laser systems	Petawatt laser complex based on the principle of multichannel formation of high-intensity femtosecond radiation through coherent combining of the fields of the channel whose phase and frequency parameters of radiation are locked to one optical frequency standard (optical clock). The laser complex is intended for advancing basic research trends concerned with investigation of the properties of matter and phenomena in extreme light fields, generation of coherent X-ray radiation, study of new methods of charged particle acceleration (in collaboration with the Institute for Nuclear Research SB RAS), and development of new technological applications. The developed principle opens up an opportunity for creating exawatt and more powerful systems.

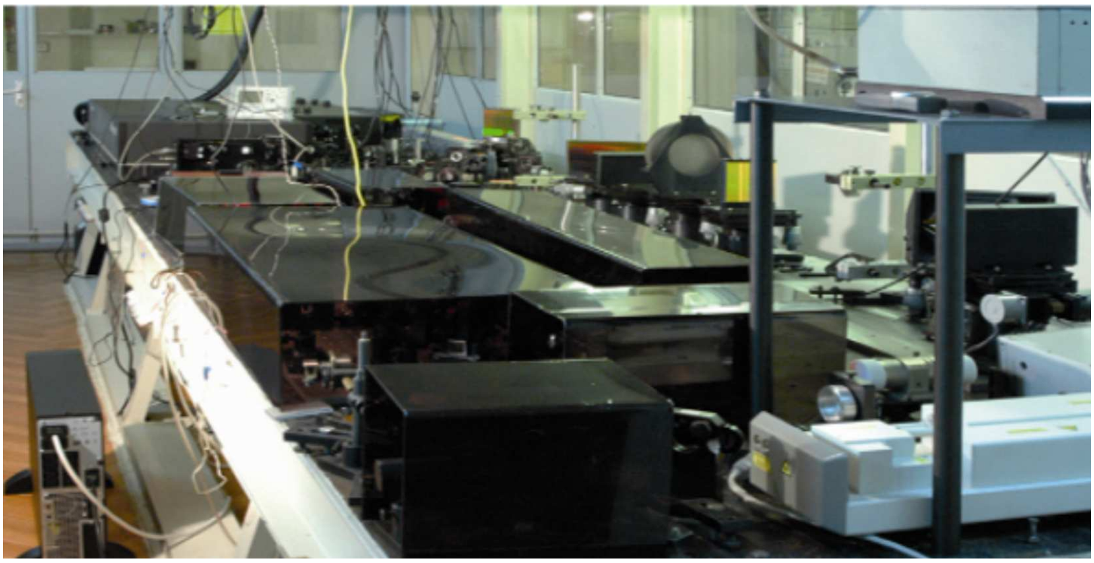


Fig. 9. Table-top terawatt laser complex in ILP SB RAS

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter	Premises in ILF SB RAS with the total area of ~250 m^2, including – laser room (cleanliness 7), area 75 m^2, ventilated and conditioned, equipped with honeycomb optical tables; – laser box (cleanliness 8), area 30 m^2, ventilated and conditioned, equipped with a 6 m optical table (Fig. 9); – adjacent laboratory rooms with the total area of more than 100 m^2, provided with needed research and engineering equipment.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)	A number of PIC codes were developed for computation and analysis of the interaction of high-intensity femtosecond laser radiation with nanofilm targets. Important results on electron acceleration and formation of relativistic electron mirrors by laser radiation were obtained. A model of femtosecond laser radiation filamentation in gas media was developed; results of calculation were used for analysis of experimental studies. A model for calculating parametric cascades of CPA-amplification for petawatt laser systems on large-size nonlinear optical crystals was developed.
Intended lines of activity under ISTC Targeted Initiative	1. Experimental and theoretical development of the basis for formation of high-intensity multipetawatt radiation by the method of coherent combining of the fields of a multichannel femtosecond laser system. Methods and tools enabling phase and frequency locking of channel radiation to optical frequency standard and coherent combining of the channels up to the multipetawatt level will be developed. Creation at ILP SB RAS of a laser complex based on such principle will open up a way for formation of radiation with intensity exceeding the relativistic one, for investigation of the features of interaction of this radiation with material media in the X-ray range, as well as for experimental and theoretical development of new principles of charged particle acceleration (in collaboration with the Institute for Nuclear Physics SB RAS, INP SB RAS). 2. Development of technologies of producing high-efficiency large-aperture, nonlinear optical elements for laser systems with high peak power on large-size borate (LBO and BBO) crystals (in collaboration with the Institute of Geology and Mineralogy SB RAS, IGM SB RAS).
List of projects, candidates for participation in the ISTC Targeted Initiative	**1. «Experimental and theoretical investigation of the method of formation of multipetawatt radiation by coherent combining of the fields of a multichannel femtosecond laser system»** ***Leading institution:*** ILP SB RAS, Novosibirsk ***Project manager:*** professor V.I. Trunov ***Collaborators/Partners:*** – Centre Nationale de la Recherche Avancée(CNRS) / Institut de Lumiere Extreme / Ecole Polytechnique, France (Prof. G. Mourou) – Max Born Institute, Germany (Prof. Ul.Eichmann) ***Estimated budget:*** $1,500,000 ***Project summary:*** The goal of the project is development of methods and tools enabling coherent combining of fields in a multichannel femtosecond laser system with sub10 fs pulse duration to form multipetawatt peak power radiation. Primary attention will be focused on – development of precision methods that would permit to achieve, using optical clock, phase synchronization of sub10 fs radiation pulses in laser system channels to an accuracy meeting the requirements of coherent combining of optical fields; – creation of efficient broadband CPA-parametric amplifiers on large-aperture borate crystals with picosecond laser pumping;

– investigation of femtosecond pulse time jitter at each amplification stage;

– finding basic sources of instability, and elaboration of methods of their elimination;

– development of techniques of generating high-contrast amplified pulses.

The obtained results will be used as a basis for development and creation of exawatt laser systems, thus opening a way to forming Schwinger intensities (10^{30} W/cm^2) and development of new fundamental and applied trends.

2. «Fabrication and characterization of high-efficiency large-aperture nonlinear optical elements from large-size LBO and BBO crystals for high peak power laser systems»

Leading institution: ILP SB RAS, Novosibirsk

Project manager: professor E.V. Pestryakov

Collaborators/Partners:

– Centre Nationale de la Recherche Avancée(CNRS) / Institut de Lumiere Extreme / Ecole Polytechnique, France (Prof. G. Mourou)

– Max Born Institute, Germany (Prof. U. Eichmann)

Estimated budget: $1,500,000

Project summary:

The researchers at ILP SB RAS developed a technology of fabrication and characterization of large-aperture nonlinear optical elements (frequency converters at second harmonic generation, parametric amplifier elements, and so on) from large BBO and LBO crystals the growth technique of which was developed at the Institute of Geology and Mineralogy SB RAS. Currently available LBO nonlinear optical crystals have a diameter up to 50–60 mm. Thanks to the updated growth technique, they have optics comparable to that of water soluble KDP crystals and surpass the latters in efficiency. In the near future it is expected to start growing crystals for elements with diameter amounting to 80–100 mm.

Large-aperture nonlinear optical elements from LBO crystals are prospective for creation of femtosecond laser systems with multipetawatt peak power.

1.12. Institution of the Russian Academy of Sciences «A.M. Prokhorov General Physics Institute RAS» (GPI RAS)

Departmental affiliation
Russian Academy of Sciences

Legal address
119991 Moscow, 38 Vavilov Str.

Head
Director – Corresponding member of RAS I.A. Shcherbakov
http://www.gpi.ru

Operating laser facilities and complexes with ultrashort radiation pulse
1. Terawatt parametric laser complex with a module for generation of megavolt terahertz electromagnetic pulses (TERAFEM) with laser peak power 1 TW, pulse duration 45 fs, wavelength 910 nm; the electric field amplitude of terahertz radiation is $5x10^6$ W/cm (Fig. 10). The terahertz laser complex operating on the principle of optical rectification of femtosecond laser pulses with oblique intensity front in nonlinear crystals is the source of terahertz radiation with the highest intensity in Russia. It is intended for investigation of extreme states of matter in the terahertz region of the spectrum and for solution of some applied problems. The laser part of the complex may be used independently for conducting experiments on generation of charged particles, generation of X-ray radiation, and for studying processes of plasma formation and filamentation of laser radiation.

Currently developed laser systems
Laser system generating multimegavolt (with electric field intensity higher than 10^8 V/cm), ultrashort terahertz electromagnetic pulses. The laser system is developed on the basis of the operating source of megavolt (10^6 V/cm) terahertz electromagnetic pulses created at GPI RAS.

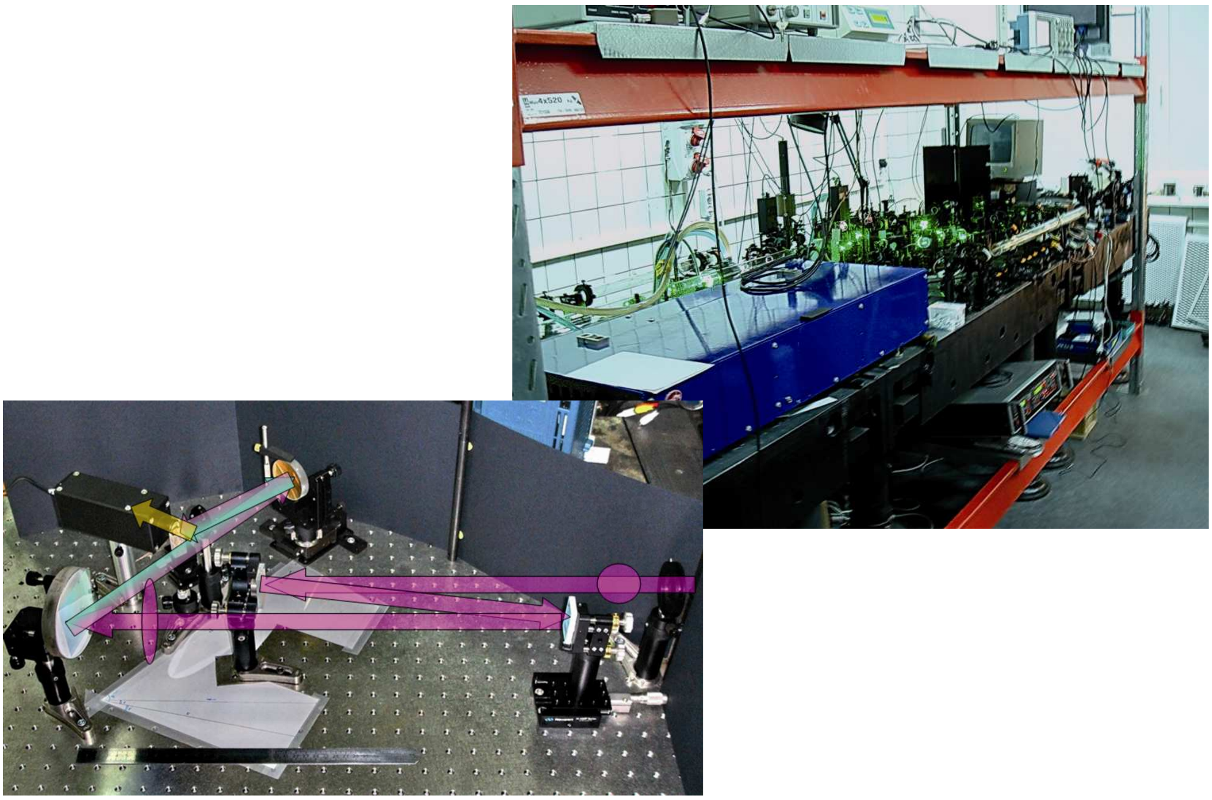


Fig. 10. Terawatt parametric laser complex with a module generating megavolt terahertz electromagnetic pulses (TERAFEM)

Experimental resources for research in the field of short-pulse laser development and interaction of high intensity laser radiation with matter

Several modern laser laboratories (total area about 600 m^2) with full infrastructure and needed engineering and research equipment.

Design-theoretical potential of research in the field of the physics of high energy densities using lasers (available and physical models and models under way, numerical code, and programs)

1. A unique software FRESNEL was developed for calculation of the propagation, amplification, and conversion of radiation in laser systems. The software includes several absolutely new algorithms which speed up calculation of some important problems by several orders of magnitude as compared to analogous software, such as PROP92 (USA), Miro (France). A number of original results on self-focusing effects and formation of nonlinear holographic images were obtained using FRESNEL. The software is adapted for computations on uni- and multinuclear processors. The software is used in the research concerned with development of solid-state laser systems carried out in the RFNC-VNIIEF (Sarov).

2. A unique, fully three-dimensional (3D-3D) computer PIC code «KARAT» was developed for modeling electrodynamics and plasmodynamic processes of the interaction of electromagnetic radiation of arbitrary wavelength, duration and intensity with plasma, gas, liquid and solid media. The code was successfully used for development of powerful strong-current microwave radiation sources in the Russian research institutes (IAP RAS, Nizhny Novgorod, Institute of High Current Electronics SB RAS (IHCE SB RAS), Tomsk, Institute of Electrophysics, Ural Branch of RAS (IEP UB RAS), Ekaterinburg, LPI RAS, Moscow, JIHT RAS, Moscow) and some foreign countries (France, USA, China). Recently the code was supplemented with new functions that allow studying processes of laser acceleration of charged particles, gas and liquid ionization, generation of γ- and X-ray radiation, and launching of nuclear reactions during the interaction of high intensity (>10^{21} W/cm^2) laser radiation with matter. The unique feature of the code is that it is adapted for work on personal computers. Currently the code was parallelized and may work if necessary on multiprocessor supercomputers.

Intended lines of activity under ISTC Targeted Initiative

1. Creation of laser multimegavolt sources of terahertz (10^{-12} Hz) electromagnetic radiation with ultrahigh field intensity comparable with intensity of intraatomic field (~10^9 V/cm).

2. Theoretical and experimental study of processes of the interaction of ultrahigh-intensity laser and terahertz radiation with plasma, gas, liquid, and solid media.

List of projects, candidates for participation in the ISTC Targeted Initiative

1. «Laser techniques of generating ultrahigh-intensity ultrashort terahertz pulses»

Leading research institution: GPI RAS, Moscow

Institutes-participants:
1. Institute of Laser Physics RFNC-VNIIEF, Sarov
2. LZOS JSC, Lytkarino

Project manager: Dr. Sci. S.V. Garnov

Estimated budget: $800,000

Dates of execution: 24 months

Project summary:
Generation of terahertz electromagnetic radiation with ultrahigh multimegavolt field intensity comparable with intraatomic field intensity (~10^9 V/cm) is a problem of fundamental importance for

solution of numerous basic and applied problems in the physics of the interaction of radiation with matter. The current highest electric field intensities in the THz range amount to 10^6 V/cm. Such fields were obtained as a result of focusing single-period THz pulses with 100 μJ energy generated using large accelerators of relativistic subpicosecond electron beams and free electron lasers.

The method of optical rectification of femtosecond laser pulses with inclined intensity front in nonlinear crystals permits generating single-period picosecond THz pulses with energy higher than 100 μJ and field intensity amplitude up to 10^9 V/cm. Such pulses may be produced on the femtosecond laser facility "Luch" in the Institute of Laser Physics of RFNC-VNIIEF in Sarov and on other multiterawatt laser facilities.

A unique source of multimegavolt terahertz radiation with terawatt intensity that has no analogs worldwide will be created under the project.

2.«The interaction of superhigh intensity ultrashort terahertz pulses with condensed and plasma media»

Leading research institution: GPI RAS, Moscow

Institutes-participants: Institute of Laser Physics RFNC-VNIIEF, Sarov

Project manager: Dr. Sci. S.V. Garnov

Estimated budget: $350,000

Dates of execution: 24 months

Project summary:

The goal of the proposed project is experimental and theoretical study of the processes of interaction of high-intensity ultrashort electromagnetic pulses of the terahertz spectral range with condensed media and laser plasma. The basic feature of the project is an opportunity of conducting the proposed research in the terahertz field of superhigh amplitude up to 10^8V/cm and higher. Such fields are generated by available and created by our team compact sources of pulsed terahertz radiation based on optical rectification of powerful femtosecond laser pulses with inclined intensity front in $LiNbO_3$ crystals. The attained megavolt intensities of terahertz field open up wide prospects for the new scientific trend – nonlinear physics of terahertz waves active development of which was stimulated by the appearance of the mentioned new sources of terahertz pulses. Until recently such high terahertz fields were almost inaccessible to the broad research community (sources of such fields were free electron lasers and accelerators of pulsed relativistic electron beams in Brookhaven National Laboratory, USA); therefore behavior of matter in such fields, including nonlinear processes in the terahertz spectral range, has been poorly studied so far.

3. «Charged particle electodynamics in relativistic electron fields for diagnostics and other applications»

Leading research institution: GPI RAS, Moscow

Institutes-participants: 1. ILC MSU, Moscow;
2. Institute for Nuclear research RAS, Mosow

Project manager: Dr. Sci. V.V. Korobkin

Collaborators/Partners:

– Max-Born-Institut fuer Quantenoptik und Kurzzeitspektroskopie, Deutschland (Dr. M. Kalashnikov, Prof. W. Sandner);
– Humboldt Universitaet zu Berlin, Institut fuer Physik (Prof. W. Ebeling, Prof. I. Sokolov)

Estimated budget: $350,000

Dates of execution: 36 months

Project summary:

Investigation of the interaction of ultrashort laser pulses having duration down to one period of optical oscillations with matter is currently one of the principal trends in laser physics. Consequently, diagnostics of such laser pulses with intensity 10^{21} W/cm^2 and higher, as well as other related applied problems become of great importance. It is intended to investigate two problems: new methods of diagnostics of such radiation by spectra of electrons escaping from the laser pulse region, and producing ion beam energies obtained at irradiation of specially structured solid-state targets by super-high power femtosecond laser pulses of minimal energy needed for practical applications (for instance ~ 200 MeV for medical applications).

The motion of a charged particle will be analyzed using an exact expression for the Lorentz force, as the frequently employed concept of ponderomotive force is meaningless in the case of short pulses. Energy spectra of escaping electrons will be found, applicability range of the single-particle problem will be determined, and plasma effects (Coulomb and magnetic) will be taken into account. Spectra will be found in experiment using the system for measuring beta-radiation. Software and interface for measuring laser radiation intensity in a vacuum chamber will be developed.

Another direction of work will be study of structured solid targets. The interaction of laser pulses with such targets will be simulated by means of Mandor2 3D PIC-code. Optimal layer structure of different substances in a foil target, as well as the size and rate of holes will de determined.

4. «Generation of hard, including coherent, gamma-radiation by charged particles moving in the field of superintense laser pulses from several oscillations »

Leading research institution: GPI RAS, Moscow

Project manager: Dr. Sci. M.Yu. Romanovsky

Collaborators/Partners:

– Research Institute for Solid State Physics and Optics, Hungary (Dr. A. Czitrovsky)
– Max-Born-Institut fuer Quantenoptik und Kurzzeitspektroskopie, Deutschland (Dr. A. Andreev, Dr. M. Kalashnikov)

Estimated budget: $200,000

Dates of execution: 36 months

Project summary:

Detailed investigation of electromagnetic radiation generated by an electron in the course of interaction with intense laser field is a problem of great interest. Specific analysis of particle motion in the field of a high-frequency relativistic-intensity laser pulse is not available in the literature. The principal goal of the present work is description of temporal and spectral characteristics of electromagnetic radiation of an electron in the field of a relativistic laser pulse. We expect to obtain electromagnetic pulses with duration up to unities of yoctoseconds. In case of phase synchronized emission of such pulses from individual electrons, which can be attained under special experimental conditions, powerful electromagnetic pulses with duration up to tens of zeptoseconds may be generated.

Out-of-phase pulses from a single electron give a wide spectrum which will be investigated. It is expected that, when electrons at rest interact with superintense laser pulses, significant spectral brightness up to 100 MeV may be obtained, and it may amount to 10 GeV for the electrons moving in a relativistic beam. For phased pulses hard gamma-radiation is expected to be coherent. The action of radiation friction under such electron motion will be analyzed.

To conclude this section, we present a list of projects that may be presented by the Russian research institutes under the ISTC Targeted Initiative (Table 1.1) and summary data on the directions of research (Table 1.2).

Table 1.1. **List of projects that may be proposed for execution under the ISTC Targeted Initiative**

	Project title	Institutes-participants	Cost, $US
1	Experimental and model-theoretical study into processes of high-energy particle generation by short intensive laser pulses	RFNC-VNIIEF, Sarov RFNC-VNIITF, Snezhinsk LPI RAS, Moscow	400,000
2	Development of technique for measuring of fast laser radiation contrast with the time resolution up to 1 ps for the depth for up to 10^5-10^7"	RFNC-VNIIEF, Sarov	600,000
3	The use of hybrid reactors in experimental and computational investigation of burning-out efficiency of Pu, Np, Am, Cm isotopes – the most long-living and hazardous components of radioactive wastes	RFNC-VNIIEF, Sarov	600,000
4	Development of diagnostic techniques of measuring ion beam parameters and their adaptation for PETAL facility	RFNC-VNIITF, Snezhinsk RFNC-VNIIEF, Sarov LPI RAS, Moscow	600,000
5	Large-aperture nonlinear optical elements for superhigh power laser complexes based on high-rate growth KDP crystals	IAP RAS, Nizhny Novgorod	1,500,000
6	Study of basic critical parameters of a prototype of 10-petawatt laser facility	IAP RAS, Nizhny Novgorod	1,500,000
7	Creation of experimental base and investigation of the impact of extreme light fields on matter in the visible and infrared spectral ranges	LPI RAS, Moscow RFNC-VNIIEF, Sarov ILC MSU, Moscow	1,500,000
8	Experimental and theoretical study of thermodynamic and transport properties of metals under the action of intense ultrashort laser pulses	JIHT RAS, Moscow	500,000
9	High-energy particle beam generation by means of super high-power ultrashort laser pulses	JIHT RAS, Moscow RFNC-VNIIEF, Sarov IAP RAS, Nizhny Novgorod	400,000
10	A concept of reactor chamber for laser nuclear fusion	JIHT RAS, Moscow ITEP, Rosatom, Moscow IAM RAS, Moscow	250,000
11	Sources of electromagnetic radiation in the THz-to-gamma radiation range using super high-power ultrashort laser pulses	JIHT RAS, Moscow GPI RAS, Moscow	250,000

12	Development of diagnostic techniques and equipment for research in the physics of high energy densities	JIHT RAS, Moscow LPI RAS, Moscow	240,000
13	Creation of powerful scalable arrays of diode lasers with enhanced high power density	"Inject" JSC, Saratov	1,500,000
14	Development and investigation of designs and key components of multipetawatt lasers	NIIKI OEP, Sosnovy Bor FSUE RTIOM SOI,, St.-Petersburg, RFNC-VNIIEF, Sarov	400,000
15	Macroparticle acceleration by ultrashort laser pulse	NIIKI OEP, Sosnovy Bor RFNC-VNIIEF, Sarov SOI, St.-Peterburg	300,000
16	Optical and radiographic study of parameters of preplasma and its influence on the process of ion acceleration	NIIKI OEP, Sosnovy Bor	400,000
17	Development, fabrication and study of durability of coatings at the first, second and third harmonic of solid lasers operating at cryogenic temperatures	SPA "LUCH", Podolsk RFNC-VNIIEF, Sarov	600,000
18	Development and fabrication of dimensionally stable cooled large-aperture silicon carbide and silicon mirror for operation with powerful laser radiation in pulsed periodic mode	SPA "LUCH", Podolsk RFNC-VNIIEF, Sarov	1,600,000
19	Development, fabrication and study of adaptive mirror for Vulcan facility	SPA "LUCH", Podolsk RFNC-VNIIEF, Sarov	200,000
20	Development, fabrication and study of a prototype of adaptive system mirror for HiPER facility	SPA "LUCH", Podolsk RFNC-VNIIEF, Sarov	3,000,000
21	Recording radiation and particle fluxes from plasma formed by femtosecond laser radiation with extreme intensity	ILC MSU, Moscow FSUE "All-Russia Research Institute of Automatics named after N.L. Dukhov", Moscow LPI RAS, Moscow	750,000
22	Creation of stand and investigation of optical materials damage threshold in a short (3-5 ns) pulse	"LZOS" JSC, Lytarino, Moscow region RFNC-VNIIEF, Sarov	to be estimated
23	Investigation of the influence of high density laser radiation on reflecting surface of Astrosital CO-115M mirror	"LZOS" JSC, Lytarino, Moscow region RFNC-VNIIEF, Sarov IAP RAS, Nizhny Novgorod	to be estimated
24	Experimental and theoretical investigation of the method of formation of multipetawatt radiation by coherent combining of the fields of a multichannel femtosecond laser system	ILP SB RAS, Novosibirsk INP SB RAS	1,500,000

25	Fabrication and characterization of high-efficiency large-aperture nonlinear optical elements from large-size LBO and BBO crystals for high peak power laser systems	ILP RAS, Novosibirsk IGM SB RAS	1,500,000
26	Laser techniques of generating ultrahigh-intensity ultrashort terahertz pulses	GPI RAS, Moscow RFNC-VNIIEF, Sarov "LZOS" JSC, Lytkarino	800,000
27	The interaction of superhigh-intensity ultrashort terahertz pulses with condensed and plasma media	GPI RAS, Moscow RFNC-VNIIEF, Sarov	350,000
28	Charged particle electodynamics in relativistic electron fields for diagnostics and other applications	GPI RAS, Moscow ILC MSU, Moscow INR RAS, Mosow	350,000
29	Generation of hard, including coherent, gamma-radiation by charged particles moving in the field of superintense laser pulses from several oscillations	GPI RAS, Moscow	200,000
		TOTAL:	21,790,000

Table 1.2. **Summary data on the directions of research**

Direction of research	Number of projects	Leading Institutes
Experimental and design-theoretical studies in the field of interaction of high-intensity laser radiation with targets	**10** (Nos. 1,7,8,9,11,15,16,27,28,29 from Table 1.1)	RFNC-VNIIEF, Sarov RFNC-VNIITF, Snezhinsk LPI RAS, Moscow ILC MSU, Moscow JIHT RAS, Moscow IAP RAS, Nizhny Novgorod GPI RAS, Moscow NIIKI OEP, Sosnovy Bor
Techniques and devices for measuring parameters of laser radiation and laser plasma	**4** (Nos. 2,4,12,21 from Table 1.1)	RFNC-VNIIEF, Sarov JIHT RAS, Moscow LPI RAS, Moscow ILC MSU, Moscow
Element base of laser systems with ultrashort pulse duration	**9** (Nos. 5,13,17,18,19,20, 22,23,25 from Table 1.1)	IAP RAS, Nizhny Novgorod "Inject" JSC, Saratov SPA "LUCH", Podolsk RFNC-VNIIEF, Sarov "LZOS" JSC, Lytkarino ILP SB RAS, Novosibirsk
Prospective developments	**6** (Nos. 3,6,10,14,24,26 from Table 1.1)	RFNC-VNIIEF, Sarov IAP RAS, Nizhny Novgorod GPI RAS, Moscow JIHT RAS, Moscow ILP SB RAS, Novosibirsk NIIKI OEP, Sosnovy Bor

It is clear from the tables that the projects include nearly all directions of research and application of powerful laser systems with ultrashort pulse duration. The proposed projects imply wide cooperation of the leading Russian laser centers. Project proposals in the format adopted by the ISTC may be presented within six months.

2. Targeted Initiative as an instrument for expanding international science and technology cooperation in the field of ultrahigh intensity lasers

2.1. Brief overview of large-scale international and national projects in the field of development and application of ultrahigh intensity lasers

About 20 facilities with radiation peak power > 100 TW and pulse duration < 1 ps are currently available in laser centers worldwide (Table 2.1). Not less than 10 installations of the same level are now under construction or being upgraded. Large laser nuclear fusion complexes, such as NIF (USA), LMJ/PETAL (France) and HiPER project (UK) may also be referred to the scope of interests of the Targeted Initiative. These complexes use (or intend to use) laser pulses from tens of nanosecond radiation channels the total power of which is close to that mentioned above; besides, to provide fast ignition it is intended to construct picosecond multipetawatt laser channels. The largest national laser projects and parameters of operating facilities are listed in Table 2.1.

Of particular interest for the Targeted Initiative are prospective projects that are now at the preparatory stage or at the very beginning of implementation, where participation of Russian research centers may be especially fruitful. Such projects are two infrastructure megaprojects ELI and HiPER, Vulcan-10PW in the Rutherford Laboratory (UK), and ILE-Apollon at the Institute for Extreme Light (Institut de la Lumière Extrême (ILE), France).

Table 2.1. **Operating facilities with radiation peak power ≥ 100 TW and pulse duration ≤ 1 ps**

Country Laser (laboratory)	Laser type	Peak power	Pulse energy	Min. duration	Max. intensity	Repetition rate	Basic directions of research
USA							
NIF (LLNL)	Nd:Glass	500 TW	1.8 MJ	3 ns		Few/day	Laser nuclear fusion
OMEGA EP(LLE)	Nd:Glass	1 PW	2 kJ		10^{20} W/cm^2		New ignition schemes in LNF, experiments of high energy density
HERCULES (CUOS)	Ti:Sa	300 TW	17 J	50 fs	2x10^{22} W/cm^2	0.1 Hz	Relativistic laser plasma, particle acceleration, generation of X-Ray radiation
Texas Petawatt (UTexas)	Nd:Glass	1.1 PW	186 J	165 fs		Few/hour	Particle acceleration, biomedical applications
France							
(LULI)	Nd:Glass	100TW	30 J	300 fs	1.5 10^{20} W/cm^2	1 shot in 20 min	Interaction of laser radiation with matter
(LOA)	Ti:Sa	100TW	2.5J	25fs		10Hz	Laser acceleration of particles
UK							
Vulcan (RAL)	Nd:Glass	1 PW	500 J	500 fs	10^{21} W/cm^2	Few/hour	LNF physics, extreme states of matter, laser acceleration of particles, laboratory astrophysics
Astra-Gemini (RAL)	Ti:Sa	0.5 PW × 2	20 J x 2	40 fs	10^{22} W/cm^2	1/20 Hz	Laser acceleration of particles, coherent X-ray sources, laboratory astrophysics

Germany							
ATLAS(MPQ)	Ti:Sa	100 TW	2 J	25 fs		5Hz	Particle acceleration
PHELIX (GSI)	Nd:Glass	1PW	500J	500fs			Interaction of laser radiation with heavy ion beams
(UDusseldorf)	Ti:Sa	100 TW	2.5 J	25 fs			Relativistic laser physics
Japan							
(ILE, Osaka)	Nd:Glass	1PW	500J	500 fs	10^{20} W/cm^2	3-4 per day	Laser nuclear fusion, physics of high energy densities
(Advanced Photon Research Center, JAEA)	Ti:Sa	850 TW	28.4j	33 fs		10 Hz	Relativistic optics
Canada							
ALLS (INRS)	Ti:Sa	200TW	5J	25fs	10^{20} W/cm^2	10Hz	Interaction of laser radiation with matter in the X-ray to IR range
Korea							
(GIST)	Ti:Sa	100 TW 1 PW	3 J 33J	30f 30fss		10 Hz 0.1Hz	Relativistic Thomson scattering, generation of high-energy X-ray radiation, electron acceleration
China							
(SIOM)	Ti:Sa	890 TW		29 fs			Relativistic laser plasma, particle acceleration, generation of X-ray radiation

ELI will be a unique research infrastructure open to scientists studying problems of laser-matter interaction with maximum possible power and the corresponding applications. Four basic directions of applications have been outlined: vacuum physics in the presence of extreme light fields, attosecond physics, creation of secondary sources of accelerated charged particles and hard photons, and nuclear processes in ultraintense laser fields.

A laser generating peak power pulses of 0.2 exawatt ($0.2 \cdot 10^{18}$ W) will be the most promising part of ELI. ELI will reach such unprecedented power due to a concentration of relatively small energy (about 3–4 kJ) in supershort time intervals (about 15 fs). In spite of small energy compared to megajoule complexes for LNF, thanks to its ultrashort pulse duration ELI will provide peak power hundreds of times higher than the most powerful lasers. Along with the exawatt laser, three other unique laser complexes with multipetawatt peak power from 10 to 20 PW will be constructed under the ELI project.

It is expected that the ELI laser complexes will greatly advance the frontiers of science and technology in the mentioned directions. The electric and magnetic fields attainable in ELI will act on charged particles with giant acceleration, which will allow verifying basic physical laws in different fields, such as plasma physics, astrophysics, nuclear physics or high-energy physics under unprecedented conditions, and to create unique sources of beams of hard photons and charged high power energy. The unique properties of such beams are record brightness and space-time concentration of electromagnetic energy on nanometer spatial and attosecond temporal scales. Superbright beams of protons and X-ray beam in ELI may make a revolution in diagnostics and treatment of cancer, as well as in structural biology through their application in proton-ion therapy, phase-contrast X-ray and diffraction X-ray of individual biological molecules and nanoobjects. On the other hand, high-brightness attosecond X-ray beams will enable producing 4-dimensional images with subatomic resolution, i.e., recording dynamic changes in the microscopic structure of matter with picosecond resolution in space and attosecond resolution in time.

Laser complexes for the ELI project will be based on technologies currently developed in three leading research centers: Institute for Extreme Light (ILE, France), Max-Planck Institute of Quantum Optics (MPQ, Germany), and Rutherford Laboratory (RAL, UK). It is intended to create under the ILE project (France) a 10 PW laser ILE-Apollon using the CPA-technique (Chirped Pulse Amplification) with terminal amplification cascade on a Ti:Sa crystal 20 cm in diameter. A basic technology of amplification of ultrashort pulses with duration up to 5 fs using the OPCPA-technique (Optical Parametric Chirped Pulse Amplification) on nonlinear optical BBO crystals was developed in MPQ; the same technology is employed for construction of Vulcan-10 PW laser with terminal large-aperture DKDP crystals (note that the Russian facilities PEARL and FEMTO are still record-holders in generating peak power of about 1 PW using the OPCPA technique).

The preparatory phase of the project (2008–2010) is supported under the 7-th Framework EC program (section – infrastructured megaprojects, ESFRI subprogram – European Strategy Forum on Research Infrastructures). Full project financing from the EC infrastructure funds is expected to be about 740 mln euros for the period of 5-6 years; the total number of researchers involved in the project exceeds 600 persons. Project location has been chosen: the Czech Republic (basic physical processes in superintense electromagnetic fields), the Republic of Hungary (study of atto- and zeptosecond beams), and Romania (photonuclear processes).

The goal of **HiPER** is construction of the first demonstration inertial-nuclear fusion reactor that will play the role analogous to ITER on mastering controlled magnetic nuclear fusion. The project is at its preparatory phase that will be completed in 2011 and its further development and the transition to the demonstration phase will greatly depend on the nearest results of operation of the US facility NIF. After launching all laser channels in 2009, experiments on nuclear target compression are full under way on NIF. It is expected to demonstrate ignition of nuclear reaction in the regime of indirect irradiation with energy output factor of 10-30 in the near 1-2 years. Experimental confirmation of the "Proof of Principle" half a century after formulation of the idea will finally make the use of the LNF reaction for producing energy a practicable task. This will make HiPER a pioneer international project of an engineered laser nuclear fusion reactor.

Given successful course of events on NIF, HiPER will enter the demonstration stage in 2011-2012 and during the next decade the following tasks will be accomplished: laser complex for launching thermonuclear reaction with 5-10 Hz repetition rate, laser target factory, chamber for radiation-target interaction, and outer shell for continuous energy conversion of products of thermonuclear reaction into heat will be constructed. The laser complex will have ≥ 50 channels for quasi-uniform target compression with average laser radiation power in the channel of about 100 kW, pulse energy in each channel of 10 kJ, pulse duration of several nanoseconds, and pulse repetition rate 5 Hz. For launching the reaction in the regime of fast ignition or shock wave separate channels of picosecond duration should be provided.

The operation stage of the project is scheduled for the 2020s. At this stage HiPER must become an integrated system with fully approved maintenance technologies meeting the future standards of producing energy and required safety. HiPER must become a generic system for further replication of thermonuclear power plants worldwide.

We have to admit that currently there is no complex of laser, plasma, nuclear, heat-and-power engineering and other technologies for detailed design of the facility. In this respect, the demonstration stage of the project in the near future will open up wide opportunities for international collaboration and important contribution of Russian research centers to HiPER development. The experience of Russian scientists may be useful for all the considered technologies, first of all in laser construction and the physics of the interaction of intense laser pulses with matter, which is the goal of the ISTC Targeted Initiative.

Vulcan-10 PW (Rutherford Laboratory, UK) is aimed at creating a source of laser pulses with the energy of 300 J, duration of 30 fs, intensity up to 10^{23} W/cm^2, and repetition rate 2 pulses per hour using the parametric chirped pulse amplification technique. Vulcan-10 PW laser will use as a pump system for parametric amplification kilojoule pulses produced by the Vulcan laser amplification cascades. It is intended to build two final OPCPA cascades on large-aperture (40×40 cm^2) DKDP crystals. It is scheduled to start construction of the 10 PW laser in the second half of 2010, when Vulcan facility will be closed for experiments; the construction is to be completed in 2013. The project leader is Prof. John Collier.

Vulcan-10 PW has a status of a national project with financing from the STFC funds (Science and Technology Facility Council). However, it may be of considerable interest for the ISTC Targeted Initiative. The point is that an analogous project – PEARL-10 – is realized at IAP RAS in Russia. The Russian project is based on the domestic technology of parametric pulse amplification in large-aperture DKDP crystals that was used in the petawatt lasers PEARL and FEMTO. The results achieved with this technology in the Rutherford Laboratory are significantly inferior (terawatt power level) to the Russian ones, which is recognized by the British scientists. Moreover, approval of the Vulcan-10PW project was largely stimulated by record achievements of the Russian scientists. This means that the British party is interested in co-operation both, in terms of mastering the OPCPA technique at the petawatt level, and in purchasing basic laser complex components, for example, nonlinear optical crystals produced in Russia.

The goal of ILE-Apollon (Institute of Extreme Light, France) is creation of a laser with peak power of 10 PW, maximum intensity 10^{24} W/cm^2, pulse energy 150 J, duration 15 fs, and repetition rate one pulse in a minute. It is intended to make terminal amplification cascades from active Ti:Sa crystals 20 cm in diameter. Crystals of such size with required optical qualities are not available at the present, but the US company CRYSTAL SYSTEMS and the French company RSA Le Rubis are working on this problem under contract with ILE. Another important technology to be developed is creation of pump lasers with kilojoule energy operating with the repetition rate of one short per minute. Absence of adaptive mirrors – wave front correctors – for focusing large energy pulses into a spot with a diameter of about 1 μm, which is needed for attaining high intensities, may also be a significant problem. Upon the whole, project implementation demands solution of some complex technological tasks, where the role of international collaboration cannot be overestimated.

It should be noted that the ILE-Apollon project has a special role in the development of ELI. Firstly, it is intended to construct the Czech and the Romanian ELI complexes on the basis of Apollon laser schemes. Secondly, it is highly probable that the fourth ELI complex for investigation of the properties of vacuum in superintense fields that will be constructed in France after 2012 under leadership of the Institute for Extreme Light will use Apollon as the prototype of an exawatt laser channel.

The leader of the project is Prof. J.-P. Chambaret, Technical Director of the Institute for Extreme Light. Project financing is about 25 mln euros.

2.2. Determining available and prospective contacts and cooperation of foreign and international organizations to be involved in project implementation

Large-scale short-pulse laser facilities are costly projects that are implemented at the top level of modern science and technology. That is why active international collaboration furnishing the best world experience for the most efficient and practical solution of problems is of major importance. In this section the principal international structures and co-operations functioning in the field under consideration are presented.

International Committee on Ultrahigh Intensity Lasers (ICUIL, www.icuil.org) – provides general coordination of the international collaboration on ultrahigh intensity lasers in science, technology, and education. The Committee was established in 2003 as an IUPAP working team (International Union of Pure and Applied Physics). At present, it consists of 17 members from 11 countries. The Committee is headed by Prof. T. Tajima (Ludwig-Maximilians-University of Munich, Germany), Russia is represented by Prof. A. Sergeev (IAP RAS). An important line of activity of the Committee is organization on international conferences on ultrahigh intensity lasers, the next of which will be held in the USA in September 2010.

Laserlab-Europe (www.laserlab-europe.net) – a consortium of 26 European laser laboratories for collective access and use of laser complexes for scientists from 16 countries of the European Community. The consortium was founded in 2004 and is currently financed under the 7-th EC Framework Programme. At present the consortium provides an opportunity for joint experiments on 20 laser facilities for 1100 hours per year. The coordinator of Laserlab-Europe is Prof. W. Sandner (Max Born Institute, Germany). Russia has no official representative in the consortium, although Russian institutes are invited for participation in joint research on the installations for collective use of consortium members.

ELI (Extreme Light Infrastructure, www.extreme-light-infrastructure.eu) – consortium including governmental organizations, scientific agencies, and large research centers from 13 European countries that combined efforts for realizing a megaproject aimed at creation and use of laser sources with peak intensities exceeding the available ones (1 PW) by tens and hundreds times. Professor Gerard Mourou (Institute for Extreme Light, France), Foreign Member of the Russian Academy of Sciences is coordinator of the project. The organizations-participants are now working on the legal point of establishing the consortium –

the legal entity of the ELI project. Towards this end, a new European entity was chosen – ERIC (European Research Infrastructure Consortium). Location of the managing company is now discussed (Vienna, Austria or Brussels, Belgium). Legal implementation of the consortium is expected to be completed in 2010, financing will be started by the end of 2010. The Russian Federation was affiliated with the ELI project as an associate member in 2008.

HiPER (High Power laser Energy Research project, www.hiper.org) – international consortium that includes 26 participants (9 national agencies and 17 research centers) from 10 European countries aimed at implementing a megaproject of using laser fusion for power generation and investigation of the related problems in science and technology. The project is now at its preparatory phase (2008-2011), at which it is funded under the 7-th EC Framework Program (the section of infrastructure megaprojects, subprogram ESFRI), as well as by the national agencies STFC (UK) and MSMT (The Czech Republic). The demonstration phase of the project is scheduled for 2011-2018; the main goal is creation in UK (Rutherford Laboratory) of a laser facility with about 50 channels and average power in each channel up to 100 KW and attaining laser fusion reaction with frequency 5-10 Hz. Professor K. Edwards (Central Laser Facility, UK) is coordinator of this project. At the preparatory phase of the project the Russian Federation is represented by Lebedev Physical Institute RAS and Institute of Applied Physics RAS.

Bilateral collaboration of foreign laboratories. It is a traditional and well-developed form of cooperation in the considered field or research. Such a collaboration is usually established when it is necessary to attract novel science and technology achievements for development of laser installations, conducting laser-plasma experiments and diagnostic measurements. Bright examples are the collaboration between Rutherford Laboratory and Livermore National Laboratory, and Institute of Laser Engineering and Osaka University. In the first case, the Livermore powerful Nd:glass amplifier with large-aperture diffraction arrays enabled construction in Rutherford Laboratory of the petawatt laser Vulcan in 2003. In the second case, conic targets for LNF, that is one of important technologies for HiPER, are currently jointly developed.

2.3. Cooperation of Russian institutes in development and application of powerful short-pulse lasers

Examples of the largest Russian projects on creating powerful short-pulse lasers in the recent 10 years are laser facility «Luch» in RFNC-VNIIEF and petawatt complexes «PEARL» in IAP RAS and «FEMTO» in RFNC-VNIIEF. These facilities are a joint effort of several research centers of the country. A large interdepartmental consortium comprising more than 10 institutions (RTIOM, NIIEFA, NIIKI, TRINITI, IAP RAS, LPI RAS, and others) was organized under the aegis of RFNC-VNIIEF for construction of "Luch". The petawatt laser complexes were built as a result of cooperation between IAP RAS and RFNC-VNIIEF.

Examples of cooperation aiming at creating powerful laser complexes are also available in RAS. For example, a multi-hundred-terawatt excimer laser complex is now constructed jointly by LPI RAS and IHCE SB RAS.

Well developed collaboration between Russian research institutes has been established in investigations of the interaction of powerful femtosecond laser pulses with matter. The cooperation is supported under the Program of Basic Research of RAS Presidium "Extreme Light Fields and Their Applications", by RFBR grants, as well as within the framework of bilateral agreements and contracts. Joint projects between GPI RAS and IAP RAS on diagnostics of femtosecond laser plasma using electromagnetic radiation in different frequency ranges are executed under the program of RAS Presidium. Moscow Engineering Physics Institute and LPI RAS carry out a joint theoretical project on the interaction of ultrarelativistic electromagnetic pulses with vacuum and plasma under support of RFBR. Some agreements were concluded between LPI RAS and RFNC-VNIITF on laser-plasma processes and technologies using high-intensity ultrashort laser pulses, and between LPI RAS and MSU on creation of a laboratory of relativistic laser plasma.

The available and prospective cooperation between the Russian institutes is reflected in the list of projects in Section 1.

An important component of the development of collaboration is organization of international scientific conferences and meetings in the field of the Targeted Initiative in Russia and abroad under ISTC support. Creation of powerful laser systems and investigation of the interaction of superintense optical fields with matter are traditional topics of large international conferences held in Russia. Only in 2010, 6 such meetings were held: XIX International Conference on Coherent and Nonlinear Optics (ICONO) in Kazan, 14-th International Conference in Laser Optics (Laser Optics) in St.-Petersburg, 37-th International Conference on Plasma Physics and CLF in Zvenigorod, XIII Khariton Topical Scientific Readings in Sarov, X Zababakhin Readings in Snezhinsk, IV International Conference "Frontiers of Nonlinear Science" in Nizhny Novgorod. More than 500 foreign scientists took part in these meetings.

Starting with 2008, ISTC organizes topical international meetings under the Targeted Initiative. 4 meetings concerned with participation of Russian institutes in large western research projects have been held: Russian ELI/HiPER/PETAL Workshop (Moscow, 2008), Franco-Russian ISTC Workshop on the physics with PETAL and the diagnostic development (Bordeaux, 2009), 1st HiPER/Russia Workshop (Nizhny Novgorod, 2009), 2nd HiPER/Russia Workshop (Abingdon, 2010). As a result of the meetings specific proposals on collaboration that will be presented in the next section were formulated.

2.4. Outlining potential fields of collaboration

Collaboration of Russian and foreign research centers in international projects ELI and HiPER are frequently discussed at scientific conferences, topical meetings, including meetings with participation of ISTC, as well as at scientific councils and workshops with participation of Russian scientists. Below some proposals formulated at these meetings and coordinated with the project leaders are presented.

Joint research under ELI project:

1. Development of sources of extreme multipetawatt and exawatt light fields

Peak laser pulse power of 1 PW using the CPA (chirped pulse amplification) and OPCPA (optical parametric chirped pulse amplification) techniques were developed in several countries worldwide. Theoretically these two techniques may provide the energy of 10 PW and higher. However, hybrid architecture: OPCPA in the input system (1 PW) and CPA as the output amplifier may prove to be more interesting. Such an architecture combines the merits of the two techniques: very high amplification rate of parametric amplifiers and high energy conversion coefficient of Ti:Sa amplifiers. One of the most challenging tasks in collaboration with ELI is experimental testing of a 10 PW laser that may become a prototype of a channel for an exawatt complex comprising several tens of such synchronized identical channels. Possible joint work may include:

- Development of hybrid OPCPA/CPA technique using large-aperture (20 cm in diameter) Ti:Sa optical crystals at the terminal amplification stage for achieving 10 PW peak power in laser pulses with 200 J energy, 20 fs pulse duration, and the repetition rate of one shot in a minute (IAP RAS, SOI, NIIKI).
- Development of OPCPA laser amplification scheme using large-aperture (up to 40 cm in diameter) KD*P crystals for producing peak power of 10 PW in one channel (IAP RAS, VNIIEF).
- Development of methods of synchronizing multipetawatt laser beams to provide coherent combining of several laser beams on a target (VNIIEF, VNIITF, LPI RAS, IAP RAS, GPI RAS).
- Analysis of alternative techniques of generating multipetawatt laser beams, such as amplification in gas media (excimer and CO_2 lasers) and pulse compression at forced scattering in plasma (LPI RAS, SOI, MSU, ILIT RAS).

2. Study of the interaction of ultrahigh intensity laser fields with matter and development of the corresponding applications

Creation of multipetawatt and exawatt laser facilities will open up opportunities for investigation of light-matter interaction in parameter ranges unattainable before. Study of new physical phenomena in extreme laser fields will advance the frontiers of science towards creation of compact laser accelerators of charged particles and superbright radiation sources in X-ray and gamma-ranges, development of attosecond and zeptosecond sources of radiation, laboratory astrophysics for modeling processes in stars and in the interior of planets, coherent nuclear optics, and nonlinear physics of vacuum. The insight into the new phenomena will show prospects for future applications in biology, medicine, nuclear energetics, the most promising among which are hadron therapy, phase-contrasted X-ray tomography of biotissues, and X-ray diffraction imaging of individual biological elements and nanostructures. But before it becomes possible to observe these phenomena in ELI experiments and before proposing them for practical applications, comprehensive theoretical modeling and computer calculation of the processes of interaction of extreme light fields with matter are required. Potential problems for collaborative research include:

- Investigation of electron and ion acceleration up to 10-10^3 GeV energies using laser pulses with intensities > 10^{23} W/cm^2; development of laser targets for more efficient generation of high energy particles; analysis of possible applications of accelerated ions for producing isotopes for positron-emission tomography and hadron therapy (IAP RAS, LPI RAS, VNIITF, VNIIEF, JIHT RAS).
- Investigation of generation of coherent attosecond and zeptosecond X-ray pulses at laser-plasma interaction in ultrarelativistic regimes (IAP RAS, GPI RAS).
- Laboratory modeling of astrophysical processes at laser-matter interaction at high pressures, temperatures, and energy densities (JIHT RAS, VNIIEF, IAP RAS).
- Theoretical study of nonlinear effects in vacuum in the presence of ultrahigh intensity laser fields: producing e+e pairs at sub-Schwinger intensities, light scattering by light, generation of showers caused by the interaction of laser pulses with high-energy electrons or photons (MEPhI, LPI RAS, IAP RAS).
- Development of the theory of quantum electrodynamics with self-consistent description of ultraintense laser pulses producing vacuum breakdown (MEPhI).
- Development and use of parallel codes for three-dimensional fully relativistic modeling by the method of large particles (PIC) of laser-matter interaction in multiprocessor parallel computer systems (VNIIEF, VNIITF, IAP RAS, LPI RAS
- Design and theoretical modeling of basic experiments under the ELI program "Grand Challenges" (LPI RAS, GPI RAS, MIPhI, MSU, IAP RAS, JIHT RAS, ILP SB RAS).

3. Creation of new materials, devices and diagnostics for applications in ultrahigh intensity laser fields

The advance of laser pulses to multipetawatt and exawatt energies is impossible without development of laser materials and components with improved characteristics. Besides, complex experiments at the interface between the physics of high intensity fields and high-energy physics demand new diagnostic approaches and techniques. Several trends in this field are attractive for international collaboration, including

- Investigation and development of diffraction arrays with high damage threshold (up to several Joules per cm^2) and large aperture (up to 40×40 cm^2) (SOI, NIIKI).
- Development of DKDP, BBO and LBO nonlinear crystals for parametric amplification, nanosecond pulse generation at the second harmonic, and shortening and contrasting of femtosecond pulses (IAP RAS, Institute of Mineralogy SB RAS).
- Development of large-aperture adaptive optics for wave front correction of powerful short-pulse lasers and powerful nanosecond lasers (Nd:glass laser in OPCPA and CPA pump channels and in a CPA laser channel) (ILIT, "LUCH").
- Investigation of the phenomenon of nonlinear propagation of ultrashort pulses in photon-crystal fibers for improved optical synchronization of intense ultrashort pulses and pump lasers (MSU).
- Development of new compact solid lasers with frequency doubling for pumping femtosecond lasers; creation of a family of compact pulsed and CW laser sources operating in the 480-600 nm spectral range using fibers of monocrystals alloyed with rare-earth elements and monocrystal nonlinear fibers (GPI RAS, ILP SB RAS).
- Development of diode pumped solid lasers with pulse repetition rate of 1 kHz for pumping OPCPA/CPA lasers (IAP RAS).

Cooperation under the HiPER program is possible in the following areas:

1. Development of the technology of constructing solid-state laser complexes with diode pumping that would provide parameters needed for a HiPER laser channel

The laser complex HiPER will comprise about 50 channels for laser target compression, each of which will provide average power of laser radiation up to 100 kW, 10 kJ pulse energy at the fundamental, pulse duration of several nanoseconds, and pulse repetition rate 5-10 Hz. Not a single laser complex in the world can provide such a set of parameters today. The most close to meet such requirements is the development of the US company Northrop Grumman that demonstrated in 2009 Nd:YAG laser complex with coherent combining of 8 channels of CW radiation with total power of about 100 kW. The task to be solved by HiPER is more complicated, as high average power in a channel must combine with short pulse duration, i.e., rigid heat regime requirements must be met simultaneously with the requirement of the absence of nonlinear effects in amplification media. It is supposed that this may be achieved in a scheme of cooled solid laser amplifiers with diode pumping. Joint investigation of such schemes may include the following:

- Development of the architecture of short pulse laser systems with average power of 10-100 kW using different solid amplification media, including laser crystals, ceramics and glass under conditions of effective heat sink (IRE RAS, GPI RAS, IAP RAS, VNIITF, VNIIEF, SOI).
- Investigation of a possibility of realizing diode pumping for solid lasers with high average and peak power ("Inject", VNIITF).
- Study of functioning of optical elements for the HiPER complex at high heat and radiation loads (VNIITF, IAP RAS, SOI).
- Laboratory modeling of a single laser channel for HiPER (GPI RAS, IAP RAS).

2. Development of technologies for solid-state multipetawatt amplification complexes for fast ignition HiPER channels

The project implies construction of several laser channels with picosecond pulses for launching thermonuclear reaction. It is not clear yet whether the reaction will be launched by a 10 ps pulse in the regime of fast ignition or it will be more efficient to use the regime of shock wave ignition at the stage of a compressed target when pulse duration of several hundreds of picoseconds is sufficient. It is clear, however, that in any case, requirements to a launching pulse differ from those on nanosecond radiation for target compression in the primary channels of the complex. Of key importance here will be use of the CPA technique up to the 10-100 kJ energy with subsequent compression in optical compressor with large-aperture diffraction arrays having high damage threshold. Collaboration is expected in the following areas:

- Development of large-aperture diffraction arrays with damage threshold > 1 J/cm^2 using hybrid metal-dielectric coatings for optical compression of multikilojoule optical pulses (SOI, NIIKI).
- Development of optical systems for coherent combining of radiation from several laser channels with petawatt peak power (VNIIEF, VNIITF, IAP RAS).
- Development of OPCPA technique for producing pulses with peak power > 10 PW (IAP RAS).

3. Development and fabrication of new optical components and devices for HiPER

Long work under conditions of high radiation and heat loads imposes special requirements to characteristics of optical components and devices in the laser complex HiPER. These requirements are aggravated by the wide aperture of light beams as a result of which quite a number of optical elements must have sizes that are record ones today. Some Russian optical institutes have unique technologies of fabricating large-aperture components and devices for power optics, which may be attractive for international collaboration. These include:

- Fabrication of large-aperture (up to 50 cm in diameter) mirrors, lenses, etc. With high damage threshold ("LZOS", "LUCH").
- Fabrication of optical coatings with high damage threshold, including those operating under the condition of cooling ("LUCH").
- Fabrication of nonlinear optical KDP and DKDP crystals (with aperture up to 40x40 cm^2) and LBO crystals (with aperture up to 10x10 cm^2) for radiation frequency up-conversion; development of the technology of DKDP crystal growth with 100% deuteration (IAP RAS, IMP SB RAS).
- Fabrication of adaptive optical mirrors with diameter up to 20 cm operating at high average power radiation ("LUCH", ILIT RAS).

4. Reactor design and modeling

- Development of design and technology of fabricating laser targets for LNF with fast ignition and ignition by a shock wave (LPI RAS).
- Modeling and designing a reactor chamber with allowance for heat and radiation operating regimes and safety requirements (VNIITF, JIHT RAS).

5. Experimental and theoretical modeling of processes of laser-plasma interaction at inertial nuclear fusion

This section includes a wide scope of processes developing when laser beams act on a plasma target, such as conversion of the energy of laser radiation into plasma, plasma compression and heating, ignition and progressing of thermonuclear reaction, etc. Theoretical modeling of these processes usually requires powerful computer resources and original software available in several Russian laser centers (VNIIEF, VNIITF, GPI RAS, LPI RAS, IAP RAS, SOI). Experimental modeling may be carried out on the terawatt and petawatt laser facilities functioning in Russia (IAP RAS, VNIIEF, VNIITF, JIHT RAS, NIIKI), as well as on the kilojoule multicascade facility "Luch" in VNIIEF.

3. Potential sources of project financing and co-financing under Targeted Initiative

The Russian Foundation for Basic Research and the Russian Academy of Sciences may allocate funds under some programs to support Russian projects within the framework of the ISTC Targeted Initiative. At present there are 3 such programs under which the research of the Russian institutes working on problems within the scope of the Targeted Initiative is supported.

- **The RFBR program of oriented basic research (OBR) "Fundamental problems of the interaction of high intensity electromagnetic fields with matter" for 2009-2010.** Under this program 12 projects were selected on a competitive basis with total funding of 60 mln rbls. The list of these projects presented below gives an insight into program priorities and distribution of scientific potential in this field among different institutes.

1). Effective generation of quasimonochromatic X-ray radiation using ultrahigh intensity femtosecond laser pulses and nanosize targets (SOI).

2). Controlling powerful laser beams to provide the specified space, time and spectral structure of pulsed radiation for precision physical experiments on investigation of shock compressibility of matter and development of hydrodynamic instabilities (RFNC-VNIIEF).

3). The interaction of ultrashort multipetawatt UV laser pulses with gas and condensed media (LPI RAS).

4). Investigation of mechanical and thermodynamical properties of matter at ultrafast deformation produced by the petawatt laser facility "Kamerton-T" (GPI RAS).

5). New potential of generating ultraintense laser pulses using their phase self-modulation and compression by diffraction arrays (SOI).

6). Front-end complex of exawatt laser system – multiterawatt small-period femtosecond laser system with active stabilization of phase and frequency parameters of radiation by the optical standard (ILP SB RAS).

7). New principles of generation of ultrashort optical pulses and of attosecond diagnostics using the phenomena and methods of nonlinear wave optics (MSU).

8). Development of the basis of constructing a multipetawatt ten-micron pico- and subpicosecond laser system (MSU).

9). Multipetawatt laser complex based on optical parametric amplification (IAP RAS).

10). Theoretical and experimental study of the mechanisms of laser acceleration of particles and accompanying electromagnetic and nuclear processes (LPI RAS).

11). Generation of GeV beams of charged particles during the interaction of petawatt laser pulses with plasma targets (IAP RAS).

12). The interaction of ultrarelativistic electromagnetic pulses with vacuum and plasma: New effects (MEPhI).

- **The program of basic research of the Presidium of RAS "Extreme light fields and their applications" for 2009-2011**, in which 18 institutes of the Russian Academy of Sciences take part. 50 mln rbls were allocated to finance this program in 2010. 29 projects under 5 large sections are supported within the framework of the program.

1). *Multipetawatt and petawatt laser pulse sources*

1.1. 10-PW laser complex based on superwideband amplification in DKDP crystals (IAP RAS).

1.2. Development of a diode pumped powerful femtosecond laser system on materials doped with ytterbium ions (ILP SB RAS).

1.3. Development of a multipetawatt small-period femtosecond laser system with relativistic intensity (ILP SB RAS).

1.4. Creation of a hybrid femtosecond system using photochemical amplifiers (LPI RAS).

1.5. Multipetawatt Ti:Sa-KrF laser system and investigation of the interaction of femtosecond UV pulses with matter (LPI RAS).

2). *Development of the basis for practical applications of extreme light fields, including coherent sources of X-ray and gamma-radiation, attosecond pulse sources, and sources of ultrarelativistic particles*

2.1. Intense femtosecond laser pulses in dielectric capillaries: generation of coherent radiation and creation of relativistic ion sources (IAP RAS).

2.2. Development of sources of coherent VUV radiation pulses of 100-attosecond duration (IAP RAS).

2.3. Laser-plasma acceleration of ultrarelativistic particles and superbright radiation sources (JIHT RAS).

2.4. Generation of high-energy beams of charged particles during the interaction of petawatt laser pulses with solid and gas targets (IAP RAS).

2.5. Biological and medical applications of superintense fields (IChP RAS, JIHT RAS, IACP FEB RAS, ILP SB RAS).

2.6. Modification of matter by femtosecond laser pulses (GPI RAS, IAP RAS, IS RAS, IAE SB RAS).

3) *Ultrastable sources of optical radiation and high-precision femto- and attosecond metrology*

3.1. Development of sources of ultrastable femtosecond pulses and high-precision spectroscopy using femtosecond comb (LPI RAS).

3.2. Investigation and development of atomic frequency standard on the basis of ultracool atoms localized by femtosecond pulses (IS RAS).

3.3. Development of optical clock and frequency standards (ILP SB RAS).

3.4. Subfemtosecond photoelectron metrology (GPI RAS).

3.5. Femtosecond laser plasma (GPI RAS, IAP RAS).

4)*. The physics of the interaction of strong optical fields with matter.*

4.1. Dynamics of ultrafast processes in semiconductors, condensed and gas media (IS RAS, IPM RAS, LPI RAS, ISSP RAS).

4.2. Femtosecond laser pulses in an atmosphere (IAP RAS, IAO SB RAS).

4.3. Investigation of nonlinear processes caused by the interaction of strong laser fields with matter (GPI RAS).

4.4. Powerful coherent source of terahertz radiation and its applications (IAP RAS).

5). *New optical materials and element base for sources of extreme light fields.*

5.1. Fabrication and diagnostics of active ceramic elements for powerful lasers (IRE RAS).

5.2. Creation of new optical materials and investigation of their properties using nanotechnologies (IEP UB RAS, ILP SB RAS).

5.3. Development and updating the technology of fabricating laser ceramics and nonlinear crystals (ILP SB RAS, IGM SB RAS).

5.4. Search and complex characterization of new crystal-ceramic materials for producing ultrahigh intensity laser fields, development of new principles and functional diagrams of femto- and subfemtosecond lasers of new generation (IC RAS).

5.5. Kilohertz terawatt cryogenic laser on Yb:YAG-ceramic disks (IAP RAS).

5.6. Development of physico-chemical basis for producing nanosize aluminium oxide powders and rare-earth elements and laser ceramics sintering (IHPS RAS, IAP RAS).

5.7. Large-aperture nonlinear optical elements for parametric amplifiers of femtosecond pulses in petawatt laser complexes (IAP RAS).

5.8. Creation of diagnostic equipment using multilayer dispersion elements and conducting experiments on X-ray diagnostics of femtosecond laser plasma (IPM RAS).

5.9. Fiber generator of ultrashort laser pulses (FORC RAS, IAP RAS).

- **The program of basic research of the RAS Department of Physical Sciences «Nonlinear optical methods and materials for creating laser systems of new generation» for 2009-2011**, in which 5 institutes of the Russian Academy of Sciences participate. Financing of the program in 2010 will be 3.5 mln rbls. The program includes the following sections:

1) New materials and devices for nonlinear optical conversion of laser radiation frequency (IAP RAS, GPI RAS).
2) Second harmonic generation of powerful broad-band laser radiation (IAP RAS, LPI RAS).
3) Nonlinear optical methods of generating radiation at mid-IR and THz wavelengths (IAP RAS).
4) Nonlinear optical methods of controlling parameters of powerful laser radiation and adaptive optics (FORC RAS, LPI RAS, IAP RAS, IAO SB RAS, IACP FEB RAS).
5) Nonlinear optical methods of generation of superintense fields (IAP RAS).

The leaders of the above programs are interested in collaboration with ISTC under the Targeted Initiative. For determining the form and status of the projects realized under conditions of co-funding it is expedient to organize a special meeting with participation of representatives of ISTC, RAS, and RFBR.

Another source of co-financing may be the Federal Target Program «Scientific and scientific-educational brainpower of innovative Russia». Several scientific-educational centers already function under this program in MSU, IAP RAS and other institutions – winners of the competition "Research conducted by collectives of scientific-educational centers in the field of optics, laser physics and laser technologies». Financing – up to 5 mln rbls a year for one center.

Of great interest for the Targeted Initiative is a new program of the Government of the Russian Federation designed to support scientific research projects implemented under the supervision of leading scientists at Russian institutions of higher education. According to the terms of the competition renowned foreign scientists may be invited to Russian universities for organization of new laboratories that will work under their supervision. The grants issued to support scientific research projects in 2010-2012 will be in amount of up to 150 million roubles each. Several applications concerned with femtosecond optics were submitted for the 2010 competition. Results of the competition will be announced by November 2010.

A special program on full-scale participation of Russia in the ELI project is also a prospective source of financing research of the Russian institutes under the ISTC initiative. Professor Gerard Mourou, ELI project coordinator, wrote a letter to academician Yu.S. Osipov, President of the Russian Academy of Sciences, with an invitation for Russian scientists to take part in construction of the ELI complex. The RAS President, in turn, appealed to the RF President with the proposal of the French party and with justification of the importance of RF participation in the project. The proposal had a positive response; technical and economic assessment of RF participation in the project with funding of about 80 mln euros is currently formulated. The most likely form of participation is creation in the RF of a large-scale laser facility with laser radiation power of about 100 PW and its exploitation as a multiple-access facility for scientists from countries-ELI participants. This format would allow, along with substantial monetary RF contribution to the development of the considered scientific trend, attracting additional resources from the European countries interested in using the Russian facility.

The European agencies financing research and interested in collaboration with Russian institutes under the Targeted Initiative may also allocate support. These may include CNRS (France), STFC (UK), Helmholtz Association (Germany). CNRS clearly formulated its interest in the protocol of intentions on development of collaboration in the field of extreme light fields between CNRS and RFBR that was signed in November 2008. Joint efforts resulted in establishing a scientific community ELISA (Extreme Light Infrastructure Support Activities) with participation of 11 Russian and 12 French institutes. Grant projects and scientific exchange under ELISA are financed by RFBR, RAS and CNRS. It is intended to organize an international laboratory and announce project competition on extreme light fields.

An analogous scheme of collaboration could be adopted between Russia and Helmholtz Association and STFC. For example, RFBR has a framework agreement on collaboration with Helmholtz Association under which a special grant competition may be organized on extreme light fields. There is no formal agreement with STFC so far, but the British party is interested in concluding such an agreement, first of all, in connection with the participation of Russian scientists in HiPER.

4. Review of issues, related to intellectual property, export control, risk of dual use technologies, attractiveness of this activity to industrial sector and other important factors

4.1. Analysis of issues related to intellectual property

While implementing TI projects it is expected to get valuable results in scientific and technical activity. The issues of protection of intellectual property will be solved by participating institutions with the absolute observance of the RF laws and ISTC basic documents. Interaction between participating institutions and ISTC in these issues will be determined on the basis of signed Agreements.

For legal safety of results in each particular case it is suggested that one should choose the most optimal form of intellectual property protection: patenting, commercial secret or copyright. These forms of the intellectual property use and protection will be thoroughly considered in order to make a sound choice based on the technical analysis of products patentability and suitability for commercial use. Intellectual property obtained as a result of project activity can be protected by open publications and in case of patentable results – by patenting in Russia and abroad, including joint patenting with the project collaborators. It is planned to make the patent study in order to determine possibilities and perspectives of patenting in Russia or in particular countries as well as expert evaluations in order not to loose advantages of invention novelties. There will be developed a strategy of working with intellectual property objects, including procedures of their commercial value estimation and procedures of their introduction into economy. Special attention will be made to the search of organizations interested in licensing of the patents obtained.

When distributing intellectual property rights all participating institutions will be governed by article XIII of the ISTC Charter. In accordance with this article the rights on industrial property units will be transferred to other project participants including a possible partner. The former IP will be used in developments provided it is protected by patents (or is under know-how protection) and the owner of this IP is a designer (participating institution) that avoids the risk of violating the rights of the third parties. It is assumed that in case the project has several participating institutions the intellectual property will be governed by the leading institution.

Many participating institutions have a large experience in the field of IP protection, they perform patent and license activity and have a staff of qualified patent engineers. For example, RFNC-VNIIEF claims for 100 industrial property units every year, it has a noticeable economic effect as a result of implementation of new engineering approaches protected by RF patents. RFNC-VNIIEF has over 50 inventions in the field of lasers.

4.2. Dual use technology. Export control

The analysis of TI activity lines and their identification with control Presidential Lists has shown that the resultant products can have dual use technologies, and their export will be controlled by executive authorities. The List of dual use technologies approved by the RF President controls not only techniques of development and production of high-energy laser complexes and their components, but the use of these complexes for production of high-energy particle beams and interaction of these beams with substance and targets.

If scientific and technical products come within the Presidential Control List of dual use technologies, a designer is obliged to get permits from executive authorities, in this case a license from Federal Agency on Technical and Export Control, if these products are going to be transferred to foreign users.

Collaborators in some of the projects are Los Alamos National Laboratory, Lawrence Livermore National Laboratory, US Department of Energy, Commissariat on Atomic Energy of France that are engaged in developments in the field of nuclear and other weapons. In this connection transfer of any scientific or technical product obtained as a result of TI project activity to these institutions is possible only with the permit of the RF Export Control Commission.

The final decision on this or that project coming with the List of dual use technologies will be made based on the analysis of a detailed Project Proposal.

4.3. Consideration of aspects related to attractiveness of projects for industrial sector.

As follows from the analysis performed in Sections 1-3 of this Study the major portion of subjects of the possible TI activity is connected with R&D. At the same time there are some developments that require some advanced technologies attractive for industry for their implementation. These developments can be the following:

- **"Development of technique for measuring of fast laser radiation contrast with time resolution of up to 1 ps for the depth of up to 10^5-10^7" ("RFNC-VNIIEF", Sarov).** Development of this technique and its testing will provide the possibility to begin half-industrial production of devices necessary practically at each laboratory using ultra-high intensity lasers in its research activity.
- **Establishing of a complex of clean rooms in IAP RAS for production, growing, finishing and application of protective and antireflection coatings – a factory of wide-aperture nonlinear-optic KDP-group crystal elements.** According to projection the efficiency of this complex will be 50 elements per year. After the facility starts working for total output, it will provide European laser projects with wide-aperture nonlinear optic crystals for free in the amount equivalent to the Europe contribution to this project.

- **Generation of high-power scalable sets of diode lasers with the increased power density ("INJEKT"JSC, Saratov).** This development is aimed at making a technology for production of high-power sets of diode lasers for high-effective optical pumping of solid lasers. It is assumed to double the radiation power density, to implement a closer pack of some diode laser arrays into large-scaled sets and produce radiators at lower costs (as opposed to current market costs). It should be noted that solid lasers with semiconductor pumping gradually replace traditional lasers. In addition when commercially available semiconductor pumping lasers enter the market, it is not only changes dramatically the solid laser architecture, but stimulates the development of new laser media. By this reason competitive laser diode matrices with improved properties will be certainly in demand with industrial enterprises that produce lasers of various designs.
- **Development and investigation of circuit designs and key elements of multipetawatt-power laser systems (NIIKI OEP, Sosnovy Bor).** It is assumed to develop a technique for production of laser component pilot samples, including high-quality optical components (mirrors, aspheric lens up to ∅ 500 mm, laser ceramics prototypes, etc.) These components will find wide application in designed large-scale laser systems, such as HiPER.
- **Development and fabrication of coatings and analysis of their lifetime for the first, second and third harmonics of solid lasers for operation at cryogenic temperatures (SPA "LUCH", Podolsk)** Solid laser media operating at cryogenic temperatures are considered as prospective in building large-scale ultra-high power laser systems. High-strength optical coating technology can be needed by industrial enterprises producing components.
- **Development, fabrication and analysis of experimental samples of "Vulkan" and "HiPER" adaptive system mirrors (SPA "LUCH", Podolsk).** Adaptive mirrors are integral parts of various laser machines with a high-quality laser beam, including those with ultra-short duration of a light pulse.
- **A number of proposed techniques and devices for laser plasma parameter measurements also can be needed by research laser centers, thus be of interest for scientific instrument engineering.**

Conclusion

This study is performed following the instructions of the International Science and Technology Center, it includes assessment of prospects for scientific collaboration under ISTC in the field of ultra-high intensity ultra-short laser light for peaceful purposes. The bellow is the summary of the analysis:

1. The analysis of scientific and technical abilities of the leading Russian laser centers in the field of the use of ultra-high intensity ultra-short light for peaceful purposes has shown the following:
   - The Russian Federation has about a dozen of various departmental institutions that perform world-level experimental and design studies in this field.
   - These institutions can provide at the nearest future around 30 proposals including practically all lines in development and application of high-intensity laser systems with ultra-short radiation pulse. These proposals assume wide cooperation of the leading laser centers.
2. RF research institutions have wide interactions in the field of ultra-high intensity laser system developments and the interaction between high-intensity femtosecond laser pulses and the substance. A number of large-scale projects were performed in cooperation of RosAtom and RAS enterprises. This cooperation is supported by the Program of Fundamental Investigations under RAS Presidium, RFBR grants and bilateral Agreements.
3. The analysis of interactions between laser projects and related activities all over the world outlined possible specific fields for cooperation:
   - Development of extreme light field sources of multipetawatt and exawatt power.
   - The study into interaction of ultra-high intensity laser fields with matter and development of relevant applications.
   - Developing of new materials, devices and diagnostics for application in the field of ultra-high laser fields.
   - Development of techniques for building diode pumping laser complexes that provide the required parameters for HiPER laser channel.
   - Development of techniques for building multipetawatt intensity amplifying complexes for ELI and for fast ignition channels in HiPER facility.
   - Development and fabrication of new optical components and devices for the use in ELI and HiPER laser facilities.
   - Reactor design and simulation.

- Experimental and theoretical simulation of laser-plasma interaction processes in inertial thermonuclear fusion.

4. Review of funding (co-funding) scenarios of the assumed subjects has shown:
   - It is reasonable to fund long-term activities under TI using ISTC infrastructure, basically partner projects.
   - Some programs under the Russian Foundation for Basic Research and of the Russian Academy of Sciences can be co-sponsors from the Russian side under ISTC Targeted Initiative: *Program of oriented fundamental investigations (OBR) RFBR* ***"Fundamental problems of the interaction of high intensity electromagnetic fields with matter"*** *for 2009-2010*, *Program of basic research of RAS Presidium "Extreme light fields and their applications" for 2009-2011, and Program of basic research of the RAS Department of Physical Sciences «Nonlinear optical methods and materials for creating laser systems of new generation" for 2009-2011.*
   - Managers of abovementioned programs express their interest to cooperative work with ISTC under the Targeted Initiative. In order to determine the project form and status performed on conditions of co-funding a reasonable thing is arrangement of a special working group with participation of representatives from ISTC, RAS, departmental institutions and RFBR.

5. Review of aspects related to intellectual property, export control or risk of dual use technology existence has shown the following:
   - The issues of protection of intellectual property will be solved by participating institutions with the absolute observance of the RF laws and ISTC basic documents. Interaction of participating institutions with ISTC in these issues will be determined on the basis of signed agreements.
   - The analysis of TI activity lines and their identification with control Presidential Lists has shown that the resultant products can have dual use technologies, and their export will be controlled by executive authorities.
   - If scientific and technical products come within the Presidential Control List of dual use technologies, a designer is obliged to get permits from executive authorities, in this case a license from Federal Agency on Technical and Export Control, if these products are going to be transferred to foreign users.
   - The final decision on this or that project coming with the List of dual use technologies will be made based on the analysis of detailed Project Proposals.
   - In the proposed lines of TI activities there are some new technologies attractive for industrial sector. These are components for up-to-date promising big laser systems, and methods and device for measuring laser light and plasma parameters.

Abbreviation of Institution's names

FORC RAS	Fiber Optics Research Center RAS, Moscow
FSUE RTIOM	Research and Technical Institute of Optical Materials, St.-Petersburg
GPI RAS	A.M. Prokhorov General Physics Institute RAS, Moscow
IACP FEB RAS	The Institute of Automation and Control Processes, Far Eastern Branch of RAS, Vladivostok
IAE SB RAS	Institute of Automation and Electrometry, Siberian Branch of RAS, Novosibirsk
IAM RAS	Institute of Applied Mathematics RAS, Moscow
IAO SB RAS	Institute of Atmospheric Optics of Siberian Branch of RAS, Tomsk
IAP RAS	Institute of Applied Physics RAS, Nizhny Novgorod
IC RAS	Shubnikov Institute of Crystallography RAS, Moscow
IChP RAS	N.N. Semenov Institute of Chemical Physic**,** RAS, Moscow
IEP UB RAS	Institute of Electrophysics, Ural Branch of RAS, Ekaterinburg
IGM SB RAS	V.S. Sobolev Institute of Geology and Mineralogy, Siberian Branch of RAS, Novosibirsk
IHCE SB RAS	Institute of High Current Electronics, Siberian Branch of RAS, Tomsk
IHPS RAS	Institute of Chemistry of High-Purity Substances RAS, Nizhny Novgorod
ILC MSU	International Laser Center of M.V. Lomonosov Moscow State University, Moscow
ILIT RAS	Institute on Laser and Information Technologies RAS, Shatura
ILP SB RAS	Institute of Laser Physics,Siberian Branch of RAS, Novosibirsk
"Inject" JSC	Joint Stock Company «Research-and-production Enterprise "Inject"», Saratov
INP SB RAS	Budker Institute for Nuclear Physics,Siberian Branch of RAS, Novosibirsk
INR RAS	Institute for Nuclear Research RAS, Moscow
IPM RAS	Institute for Physics of Microstructures RAS, Nizhny Novgorod
IRE RAS	Institute of Radiotechnics and Electronics RAS, Moscow
IS RAS	Institute for Spectroscopy RAS, Troitsk
ISSP RAS	Institute of Solid State Physics RAS, Chernogolovka
ITEP	Institute for Theoretical and Experimental Physics, Rosatom, Moscow
JIHT RAS	Joint Institute for High Temperatures RAS, Moscow
LPI RAS	P.N. Lebedev Physical Institute RAS, Moscow
"LZOS" JSC	Joint Stock Company «Lytkarino Optical Glass Factory», Lytkarino
MEPhI	National Research Nuclear University "MEPhI", Moscow
MSU	M.V. Lomonosov Moscow State University, Moscow
NIIEFA	D.V. Efremov Scientific Research Institute of Electrophysical Apparatus, St.-Petersburg
NIIKI OEP	Research Institute for Complex Testing of Optoelectronic Devices and Systems, Sosnovy Bor
RFNC-VNIIEF	Russian Federal Nuclear Center – All Russian Research Institute of Experimental Physics, Sarov
RFNC-VNIITF	Russian Federal Nuclear Center – E.I. Zababakhin All-Russia Research Institute of Technical Physics, Snezhinsk
RTIOM	Research and Technical Institute of Optical Materials, St.-Petersburg
SOI	Vavilov State Optical Institute, St.-Petersburg
SPA "LUCH"	Federal State Unitary Enterprise Research Institute Scientific Production Association «LUCH», Podolsk
TRINITI	Troitsk Institute for Innovation & Fusion Research, Troitsk

International Science and Technology Center.
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