LITHUANIAN ENERGY INSTITUTE

2015

ANNUAL REPORT

LEI 60 years
jubilee
in 2016

LITHUANIAN ENERGY INSTITUTE in 2015

MISSION OF THE INSTITUTE

Perform research and develop innovative technologies in the fields of energy engineering, thermal engineering, measurement engineering, material science and economics, in conducting fundamental and applied research, participating in studies' processes, applying the results of applied scientific research results to industry and business, as well as providing consultations to state, public and private institutions/enterprises on the issues related to Lithuanian sustainable energy development. Actively participate with Lithuanian universities and other higher education schools in preparing specialists for Lithuanian science and industry.

THE OBJECTIVES OF THE INSTITUTE:

- perform permanent fundamental and applied scientific research at international level, experimental development activities, which is a must for sustainable development of Lithuania energy and other Lithuanian economy branches and for the integration to the European energy systems and European research area;
- while cooperating with business, governmental and public institutions, transfer scientific knowledge to technically and commercially beneficial processes and facilities, ensuring the development of innovative energy technologies, cost-effectiveness and safety of energy objects and systems, efficient use of energy resources, reduction of environmental pollution and deceleration of global warming;
- provide accessible state-of-the-art scientific information to the society, promote the Lithuanian economy development based on innovations and knowledge;
- actively participate in the EU programmes and international projects, boost co-operation with alike world science research centres.

STRATEGIC OBJECTIVES:

- Long-term top-level scientific research important for national and EU energy development;
- Commercialization of academic research results.

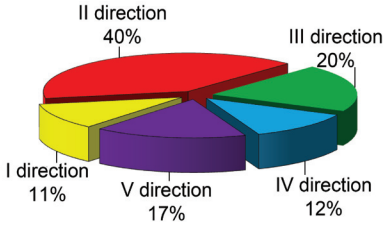
MEMBERSHIP AND COOPERATION WITH NATIONAL AND INTERNATIONAL ORGANIZATIONS

LEI is a member of the following national associations: Association **Baltic valley**, Association **Santaka valley**, Nuclear Energy Association (**BEA**), Smart Technology Association (**SMARRTA**), Lithuanian Biomass Energy Association (**LITBIOMA**), Lithuanian Electricity Association **(LEEA**), Lithuanian Energy Consultants Association (**LEKA**), Engineering Industries Association of Lithuania (**LINPRA**), Lithuanian Research Library Consortium (**LMBA**), Confederation of Lithuanian Industrialists (**LPK**), Lithuanian Thermotechnical Engineers Association (**LIŠTIA**), National Space Association of Lithuania (**NSA**), Association for Energy Economics (**EEA**), Building Product Testing Laboratory Association (**SPBL**).

Institute is active in the following international organisations and networks: European Technical Support Organisations Network (**ETSON**), European Network of Freshwater Research Organisations **(EurAqua**), European Safety, Reliability & Data Associa-

SCIENTIFIC RESEARCH ACTIVITIES OF THE INSTITUTE

I. Thermal physics, gas and liquid dynamics and metrology research;
II. Research of materials, processes and technologies, devoted to use renewable energy sources, to develop hydrogen energy, to efficiently use energy sources and reduce environmental pollution;
III. Safety and reliability research of nuclear and thermal nuclear power engineering and other industrial objects;
IV. Methods of nuclear waste management, also terminating the operation of the Ignalina Nuclear Power Plant;
V. Simulation and management of energy systems, energy economy.



Distribution of researchers according to the research directions

tion **(EsReDA)**, The European Association of National Metrology Institutes **(EURAMET)**, Euro-Asian Cooperation of National Metrological Institutions **(COOMET)**, European Nuclear Safety Training and Tutoring Institute **(ENSTTI)**, International Energy Agency Hydrogen Implementation Agreement **(IEA HIA)**, New European Research Grouping on Fuel Cells and Hydrogen **(N.ERGHY),** Nuclear Generation II and III Association **(NUGENIA),** European Energy Research Alliance **(EERA).**

The Institute also participates in the activities of two international nuclear technological platforms: Sustainable Nuclear Energy Technology Platform (**SNETP**) and Implementing Geological Disposal of Radioactive Waste Technology Platform (**IGD-TP**).

REVIEW OF LEI ACTIVITIES IN 2015

In January, Dr. Egidijus Babilas was awarded a Badge of Honour of the Engineering Industries Association of Lithuania (**LINPRA)** for personal contribution to the development of Lithuanian engineering industry and its international competitiveness. Associate professor Dr. Janusz Podlinski from Szuwalski Institute of Mechanics (Poland) delivered a series of lectures on *Flow visualization, application and mathematical processing of processes* at LEI. Dr. Andrius Tamošiūnas was appointed a Deputy Director. He is in charge of co-ordinating the activities of attracting investments to improve the infrastructure, and is responsible for the development of cooperation of business structures. Project *Development of wind energy and territories important to biodiversity* (**VENBIS**) was launched.

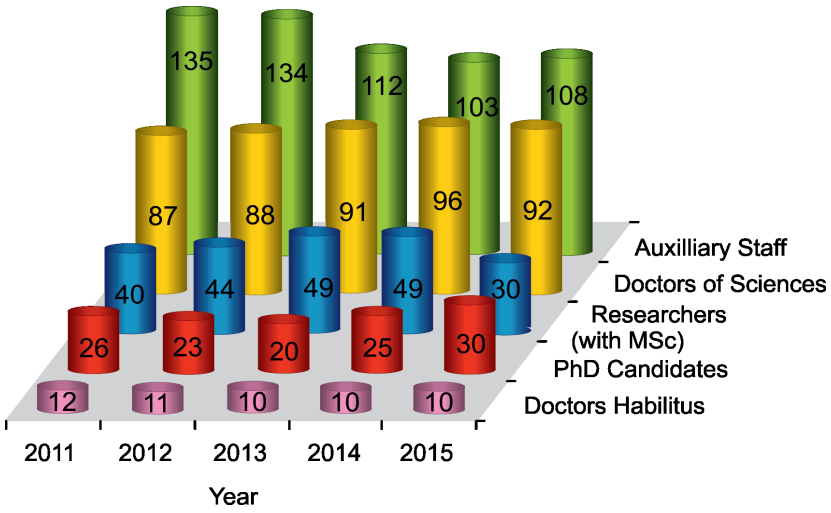
In February Research and Higher Education Monitoring and Analysis Centre (**MOSTA**) expert groups in technological sciences and social sciences visited the Institute. Experts were introduced to the ongoing projects, achievements, experimental base, communicated with researchers and doctorate students. The Institute hosted the meeting of heads and coordinators of Open Access Centres, where Vice Minister of Education and Science of the Republic of Lithuania Dr. Svetlana Kauzonienė participated. During the meeting, the implementation of activity objectives of Open Access Centre, future perspectives that could lead to a successful education-business cooperation were discussed. Conference *Heat Sector Development and Security* was held at the Institute, where politicians, academicians and practitioners gave their speeches. The youth of the Institute participated at *KTU* Career days where they introduced students to LEI activities, opportunities for studies and employment. European Commission presented the evaluation results of 2014–2015 work program proposals for *Horizon2020 EURATOM*. LEI participated by submitting 12 proposals, 5 of which were selected as financeable (success rate – 41.7%). 5 other pro-

MOSTA experts' visit to the Institute

posals passed the evaluation threshold and 2 proposals failed to surpass the evaluation threshold. Success rate of the evaluation threshold accessibility – 83.3 %.

In March representatives from Tokyo University of Technology and *Hitachi* Company visited the Institute, students from Kaunas University of Technology visited Institute and attended the lectures.

In April the Institute was visited by the members of the Lithuanian Academy of Sciences who got acquainted with the laboratories, their activities, achievements and challenges. The Institute hosted EU FP7 Project **ARCADIA** (*Assessment of Regional CApabilities for new reactors Development through an Integrated Approach*) event *Collaboration with European Platforms and Organizations* and the second **ARCADIA** project progress meeting. Head of the Laboratory of Hydrology Dr. Jūratė Kriaučiūnienė was awarded the Letter of Gratitude by Lithuanian Committee of the World Energy Council for application of scientific achievements in the field of hydrology in Lithuania in reducing the impact of climate change. The head of the Laboratory of Combustion Processes Dr. Nerijus Striūgas was granted the Letter of Gratitude from the President of the Lithuanian Electricity Association. In the same month the *Open Doors day* took place at LEI.

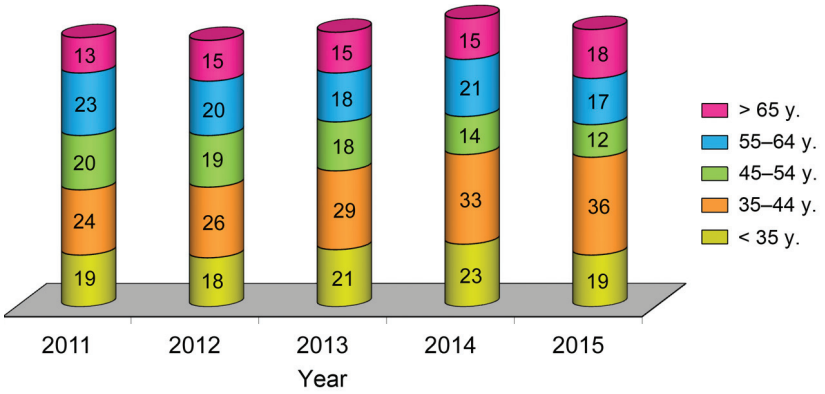


Variation of staff number

In May Institute hosted an International Conference of Young Scientists on Energy Issues (**CYSENI**) for doctorate students and young scientists for the 12th time already. During the conference Minister of Energy of the Republic of Lithuania Mr. Rokas Masiulis gave his speech as well as other guests from the European Commission, Estonia and Latvia. **ENSTTI** training courses **Probabilistic Safety Assessment** were organized at the Institute. Main topics of the lectures were: reliability theory and application, probabilistic safety assessment, probabilistic uncertainty analysis, risk-based decision making. A total of fourteen participants attended the training: from Finland, Egypt, the United Arab Emirates, Indonesia, Malaysia, Vietnam, Ukraine and Lithuania. A meeting with Dr. Mohamed Eid from French Alternative Energies and Atomic Energy Commission was held at Institute. During the meeting, they exchanged information about LEI and CEA conducted research, focused on possible areas of cooperation.

In May, students of Kaunas Antanas Smetona Gymnasium, Alytus Vidzgiris Secondary School, Kaišiadorys Vaclovas Giržadas pro-gymnasium and students of the Faculty of Natural Sciences at Vytautas Magnus University visited the Institute. Secondary school and university students were introduced to the Institute; lectures and demonstrations were organized, students got acquainted with the infrastructure of the National Open Access Scientific Research Centre for Future Energy Technologies. Example of Institute's science-business cooperation is presented on http://url.lei.lt/veidas1. A new video presentation of Institute can be found on http://url.lei.lt/apcvideo.

Representatives from Tokyo University of Technology and HITACHI Company visited the Institute



Dynamics of age of scientists

In June the following projects of programme *Horizon2020* were launched:

- **IVMR** (In-Vessel Melt Retention Severe Accident Management Strategy for Existing and Future NPPs). Molten core retention (stabilization) in the reactor vesel is recognized as a particularly important measure in order to stabilize the situation at the nuclear power plant in the event of severe accident. This measure reduces the quantity of generated hydrogen, prevents interaction of the melt with the concrete, and in this way, very effectively reduces the risk of damaging the protective reactor containment.
- **SITEX-II** (Sustainable network for Independent Technical Expertise of Radioactive Waste Disposal: Interactions and Implementation). The project is aimed at the development of independent technical expertise network in the field of radioactive waste disposal. Independent experts (network) are a mean for creating a dialogue on technical questions between regulating institutions and the organizations conducting the implementation of the repository and the society.

Institute hosted a seminar *Hydrological and hydrodynamic aspects of development of Klaipėda port: Problems and possible ways of dealing with them* organized by Lithuanian Academy of Sciences. Representatives of various research and educational institutions and non-governmental organizations participated in the seminar. Development aspects of Klaipeda Seaport in terms of hydrodynamics were analysed; discussions focused on deepening the Klaipeda port and the concept of installation of the south gate in the Curonian Lagoon; the results on changes of hydrometeorological conditions, their impact on the state of the seacoast and water balance of the Curonian Lagoon were presented.

Members of Lithuanian Academy of Sciences visited Institute

The advisor of Ambassador of Japan Mr. Shinici Yamanaka visited Institute. S. Yamanaka got acquainted with the research carried out at the Institute, paid a visit to the laboratories. During the visit, the possibilities of cooperation of the Institute and Japanese Institutions were discussed.

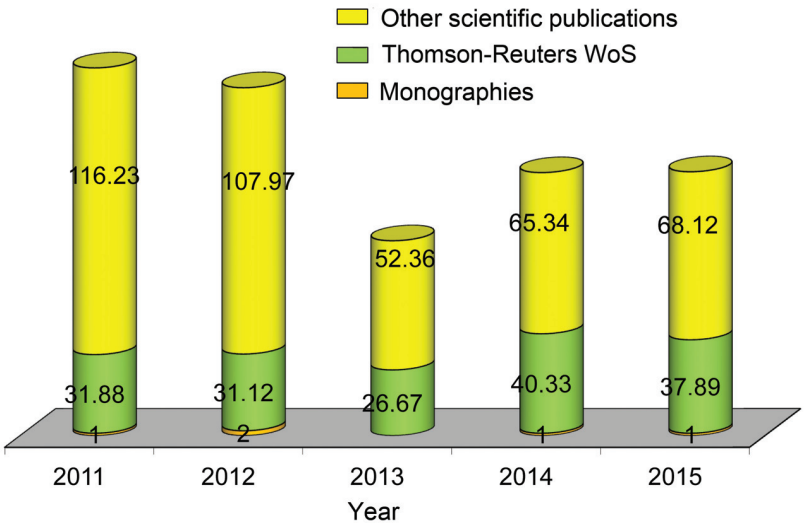
Professor of the Department for Applied Mathematics and Computer Science at Technical University of Denmark Henrik Madsen paid a visit to the Institute. During the meeting, the Institute's activity and achievements were presented, and Prof. H. Madsen group's activity was introduced. Mutual activities in the newly initiated Joined Energy System Integration programme of European Energy Research Alliance were discussed. Senior Research Associate of the Laboratory of Nuclear Installation Safety Dr. Gediminas Stankūnas was awarded the Lithuanian Academy of Sciences young scientist grant 2015–2016.

In July the following *Horizon2020* projects were launched:

- Baltic Region Initiative for Long Lasting InnovAtive Nuclear Technologies **(BRILLIANT)**. The main objective of **BRILLIANT** project is to determine the obstacles preventing nuclear energy development in the states of the Baltic Sea

region, and prepare recommendations for their elimination. The project will promote cooperation between research centres and universities of the Baltic countries.

- **INCEFA-Plus** (INcreasing Safety in NPPs by Covering gaps in Environmental Fatigue Assessment). The main objective of the project is preparation of new requirements, assessing predisposition of nuclear power plant components to fatigue degradation, taking place as a result of the impact of the environment conditions.



Variation of publication number (authors' contribution evaluated)

In August on the occasion of the 60th anniversary of a Member of the Lithuanian Academy of Sciences, Chairman of the Scientific Council of the Lithuanian Energy Institute, Head of the Laboratory of Nuclear Installation Safety, Prof. Dr. Habil. Eugenijus Uškuras, a large number of guests, friends, colleagues and associates gathered to listen to academic readings and to celebrate this delightful anniversary together. On the same occasion Letter of Gratitude was granted by the Ministry of Education and Science of the Republic of Lithuania to Prof. Dr. Habil. Eugenijus Ušpuras for long-term management of the Lithuanian Energy Institute and a substantial contribution to research in the field of energy.

Gratitude of Director of the Agency for Science, Innovation and Technology, Arūnas Karlonas was expressed to the head of the National Open Access Scientific Research Centre for Future Energy Technologies of the Lithuanian Energy Institute, Rimantas Levinskas, "for the personal contribution to the development of the Open Access Centre and promotion of the transfer of research results to businesses".

Impact assessment of climate change and other abiotic environmental factors on aquatic ecosystems (KLIMEKO) of the National Research Programme *Sustainability of agro-, forest and aquatic ecosystems* was launched.

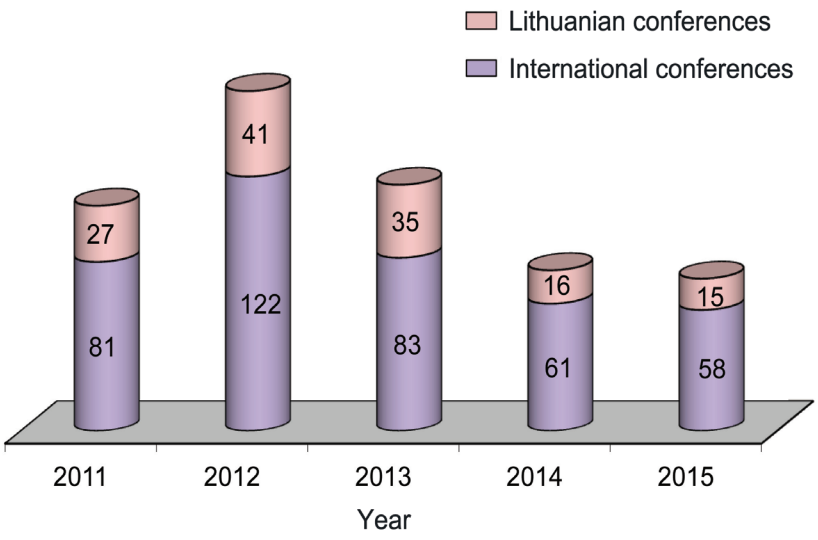
Representatives of Norwegian company *Nofir* visited the Institute. During the visit cooperation possibilities in solving waste disposal issues of the company were discussed. Chief Research Associate of the Laboratory of Hydrology at the Lithuanian Energy Institute, Dr. Habil. Brunonas Gailiušis, was granted Honorary badge of the employee of the Republic of Lithuania sea transport, by order No. 3P-139 of the Minister of Transport and Communications of the Republic of Lithuania.

On the occasion of the 60th anniversary Chairman of the Scientific Council of the LEI E. Ušpuras congratulated by rectors of Vytautas Magnus University Prof. V. Kaminskas (1996–2006) and Prof. J. Augutis (elected on 2015)

In September the Institute hosted a meeting with Prof. Krzysztof Kołowrocki (Full Professor at Gdynia Maritime University – GMU). During the meeting, the parties exchanged information about scientific research carried out at LEI and GMU.

American Nuclear Society held 16th International Topical Meeting on Nuclear Reactor Thermalhydraulics (NURETH-16), where T. Kaliatka, E. Ušpuras and A. Kaliatka's paper *Integrated Assessment of Thermal Hydraulic Processes in W7-X Fusion Experimental Facility* was selected as one of the 7 best conference papers.

In October delegation of repre-



Number of papers in scientific conferences

sentatives from Azerbaijan Ministry of Economy and Industry, Baku Business Training Center, HITACHI representatives, representatives of the Danish company MM Composite paid a visit to the Institute. Working meeting for Baltic Region Initiative for Long Lasting InnovAtive Nuclear Technologies (**BRILLIANT**) project was held.

Project **FASTNET** (FAST Nuclear Emergency Tools) of the EU Framework Programme for Research and Innovation *Horizon2020* was launched. The objective of the project is to develop a methodology that would cover issues of the assessment of emergency discharge of radioactive material and emergency preparedness planning.

A jubilee lecture was delivered by Dr. Habil. Antanas Pedišius. In the abundant circle of long-standing colleagues, friends and relatives that have gathered on the occasion of the seventy-fifth anniversary, Mr. A. Pedišius' scientific activities, and the most significant moments of his work at the Institute were presented.

Institute welcomed a number of young visitors: students from Vilnius Jesuit Gymnasium and teachers of the exchange program visited the Institute as well as students from Vilnius College of Technologies and Design.

In November Institute organized Project **BRILLIANT** meeting at the Ministry of Energy of the Republic of Lithuania, where the project was presented to politicians and decision makers in the countries of the Baltic sea region. A general assembly and board meeting of the Association *Santaka Valley* took place at the Lithuanian Energy Institute. Representatives of the Nuclear Chemistry and Technology Institute in Poland as well as representatives of Hazardous Waste Management Association visited the Institute.

In December the Institute was visited by Kaunas city Vice-mayor Povilas Mačiulis who presented a vision of establishing a National Science and Innovation centre (the Science Island) on the Nemunas island in Kaunas. The Vice-mayor invited the Institute to become one of the members of initiative group. The Institute expressed its deep wish to support the establishment of such centre in Kaunas city by presenting science achievements in the field of energetics.

Seminar *Present and perspectives of Lithuanian electricity energy* was held at Institute. The following issues were discussed: the impact of implementation of strategic projects on national energy sector, issues of energy security, challenges and future perspectives.

Joint activity agreement was signed between Lithuanian Energy Institute and JSC ALTECHA.

Lithuanian Energy Institute was awarded a gold medal at the contest **Lithuanian Product of the Year 2015** for a device *Standard bell type prover for calibration and testing of air/gas flow meters* was granted a gold medal in the section of "Machinery and equipment industry". Lithuanian Energy Institute developed an original construction of bell type prover, which meets the best world examples. The facility is designed for calibration and testing of gas and flow meters. Up to 6 gas or flow meters may be tested/calibrated at the same time.

STATE FUNDED PROJECTS

In 2015 researchers of the Institute continued work at ***Long-term scientific research and experimental development programmes (2012–2016)***, approved on 23 02 2012 by the Order No. V-323 of the Minister of Education and Science of the Republic of Lithuania:

1. **Investigation of nuclear power plants' operation disruption and nuclear waste and spent fuel management processes and radiation impact analysis**. Programme's leader Prof. Dr. Habil. P. Poškas.
2. **Research on environmental impact and efficient use of renewable energy sources for energy production**. Programme's leader Prof. Dr. Habil. V. Katinas.
3. **Scientific research of safety important processes in nuclear and thermal-nuclear equipment**. Programme's leader Prof. Dr. Habil. E. Ušpuras.
4. **Experimental and numerical research of combustion and plasma processes for improvement of**

energy generation technologies from renewable biofuel and reduction of environmental pollution. Programme's leaders Dr. N. Striūgas, Dr. V. Valinčius.

5. **Economy and sustainability analysis of energy sector**. Programme's leader Prof. Dr. Habil. V. Miškinis.
6. **Investigation of single-phase and two-phase flow dynamics, heat and mass transfer processes**. Programme's leader Dr. R. Poškas.

In 2015, **13** state funded projects were implemented and 4 of them had been completed and defended, namely:

1. ***Integrated research on generation of radioactive contamination, its impact and migration upon termination of RBMK-1500 reactor operation and storage and disposal of radioactive waste*** (project leader Dr. Habil. P. Poškas).
2. ***Research of Extreme Hydrological Phenomena of Lithuanian Rivers*** (project leader Dr. J. Kriaučiūnienė).
3. ***Application of best-estimate method in the analysis of thermal-hydraulic processes in nuclear and thermonuclear devices*** (project leader Dr. Habil. A. Kaliatka).
4. ***Research of gas flow mixing and its interaction with structured surfaces aiming at efficient use of biofuel in heat equipment with minimal pollution of the environment*** (project leader Dr. Habil. A. Pedišius).

INTERNATIONAL PROJECTS

In 2015, **26** international programme projects were conducted, out of which:

Seven EU Research and Innovation Programme *Horizon2020* projects:

1. ***Implementation of activities described in the Roadmap to Fusion during* Horizon2020 *through a joint programme of the member of the EUROfusion consortium*** (***EUROfusion***). LEI representative Prof. Dr. Habil. E. Ušpuras.
2. ***Facilitating Multi-level governance for energy efficiency (multiEE).*** LEI representative Dr. R. Škėma.
3. ***Sustainable network of Independent Technical Expertise for radioactive waste Disposal II (SITEX II).*** LEI representative Dr. A. Narkūnienė.
4. ***In Vessel Melt Retention Severe Accident Strategy for existing and future NPPs (IVMR).*** LEI representative Prof. Dr. Habil. E. Ušpuras.
5. ***Baltic Region Initiative for Long Lasting InnovAtive Nuclear Technologies (BRILLIANT)***. Project Coordinator Dr. S. Rimkevičius.
6. ***FAST Nuclear Emergency Tools (FASTNET)***. LEI representative Dr. E. Urbonavičius.
7. ***INcreasing Safety in NPPs by Covering gaps in Environmental Fatigue Assessment (INCEFA PLUS)***. LEI representative G. Dundulis.

LEI together with partners in 2014-2015 submitted 38 *Horizon2020* Project proposals. 9 projects received financial support (23.7 % success rate).

Eight projects of 7th Framework Programme (FP7):

1. ***Code for European Severe Accident Management (CESAM).*** LEI representative Dr. V. Vileiniškis.
2. ***CArbon-14 Source Term (CAST).*** LEI representative Prof. Dr. Habil. P. Poškas.
3. ***Advanced Safety Assessment: Extended PAS (ASAMPSA_E).*** LEI representative Dr. R. Alzbutas.
4. ***Building a platform for enhanced societal research related to nuclear energy in Central and Eastern Europe, (PLATENSO).*** LEI representative Prof. Dr. Habil. P. Poškas.
5. ***Nuclear Cogeneration Industrial Initiative – Research and Development Coordination (NC2I-R).*** LEI representative Dr. S. Rimkevičius.
6. ***Resource Efficient cities implementing ADvanced smart citY solutions (READY).*** LEI representative Dr. R. Gatautis.
7. ***Assessment of Regional CApabilities for new reactors Development through an Integrated Approach (ARCADIA).*** LEI representative Dr. E. Urbonavičius.
8. ***Preparing NUGENIA for Horizon2020 (NUGENIA-PLUS).*** LEI representatives Dr. R. Alzbutas and Dr. V. Vileiniškis.

LEI together with partners submitted 64 FP7 project proposals. 38 of them passed the evaluation threshold (~59.4 %). 24 projects received financial support (37.5 % success rate).

Three Intelligent Energy - Europe projects:

1. ***New Business Opportunities for Solar District Heating and Cooling (SDHplus)***. LEI representative Dr. A. Lisauskas.
2. ***Policy dialogue on the assessment and convergence of RES policy in EU Member States (DIA-CORE).*** LEI representative Dr. I. Konstantinavičiūtė.
3. ***Monitoring of energy efficiency in Europe (ODYSSEE-MURE).*** LEI representative Dr. I. Konstantinavičiūtė.

In adition six COST and two IAEA projects were conducted.

DOCTORAL STUDIES

Lithuanian Energy Institute together with the universities prepare scientists in the following fields of PhD studies:

– Power and Thermal Engineering (Technological Sciences, 06T) – together with Kaunas University of Technology;
– Environmental Engineering and Land Management (Technological Sciences, 04T) – together with Kaunas University of Technology and Aleksandras Stulginskis University;
– Economics (Social Sciences, 04S) – together with Kaunas University of Technology and Klaipėda University.

In the period 1992–2015 PhD studies were completed by 101 PhD students (out of 114), the dissertations were defended by 68. In 2015 8 PhD students were accepted to PhD studies. In total 30 PhD students studied.

In 2015 the following PhD theses were defended:

- on 23 April – ***Investigation of Pulsating Flow Effect on Meters with Rotating Parts*** (06T), **Andrius Tonkonogovas** (Laboratory of Heat- Equipment Research and Testing). Scientific supervisor Dr. Habil. Antanas Pedišius.
- on 7 May – ***The Criticality Assessment of Energy Systems Critical Infrastructure*** (06T), **Benas Jokšas** (Laboratory of Nuclear Installation Safety). Scientific supervisor – Dr. Habil. Juozas Augutis.
- on 12 June – ***Investigation on Thermal Decomposition of Biomass and Tar Destruction Efficiency*** (06T), **Kęstutis Zakarauskas** (Laboratory of Combustion Processes). Scientific supervisor – Dr. Algis Džiugys.
- on 4 December – ***Energy Economic Model for Green Settlements*** (04S), **Kęstutis Biekša** (Laboratory for Renewable Energy and Energy Efficiency). Scientific supervisor – Dr. Habil. Valentinas Klevas.
- on 18 December – ***Warm Season Thermal Regime of Lithuanian River Water and its Forecast in the Context of Climate Change*** (04T), **Aldona Jurgelėnaitė** (Laboratory of Hydrology). Scientific supervisor – Dr. Habil. Brunonas Gailiušis.

Dr. A. Tonkonogovas

Dr. B. Jokšas

Dr. K. Zakarauskas

Dr. K. Biekša

Dr. A. Jurgelėnaitė

In 2015, at the initiative of LEI Young Scientists Association, the **Contest of the most active young scientists and PhD students** was organized.

The most active PhD students were:

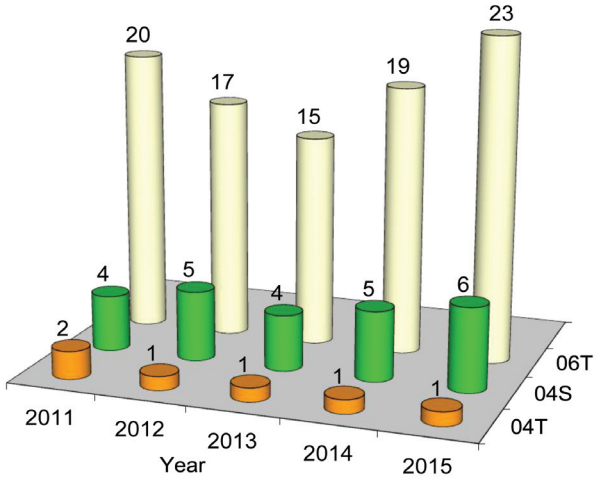
- second year – Andrius Tidikas (Scientific supervisor Dr. Gediminas Stankūnas**)**;
- third year – Giedrius Gecevičius (Scientific supervisor Dr. Mantas Marčiukaitis);
- fourth year – Rolandas Paulauskas (Scientific supervisor Dr. Algis Džiugys).

The title of the most active young scientist (until the age of 35) was given to Tadas Kaliatka (Laboratory of Nuclear Installation Safety).

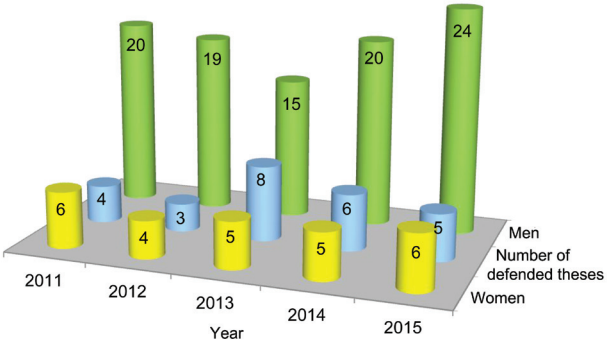
Acceptance to LEI PhD studies takes place in July, when there are spare places, the acceptance is continued in September.

Institute's director Dr. S. Rimkevičius congratulates PhD student G. Gecevičius at the New Year Carnival

During PhD studies there is a possibility to participate in international projects, to take traineeships in foreign scientific centers, to participate in international conferences.



Arrangement of PhD students according to science directions



Number of PhD students and defended theses

More information on PhD studies may be accessed at institute's webpage **http://www.lei.lt,** section – Information – PhD studies.

Contact person: ***Jolanta Kazakevičienė***
Studies Administrator
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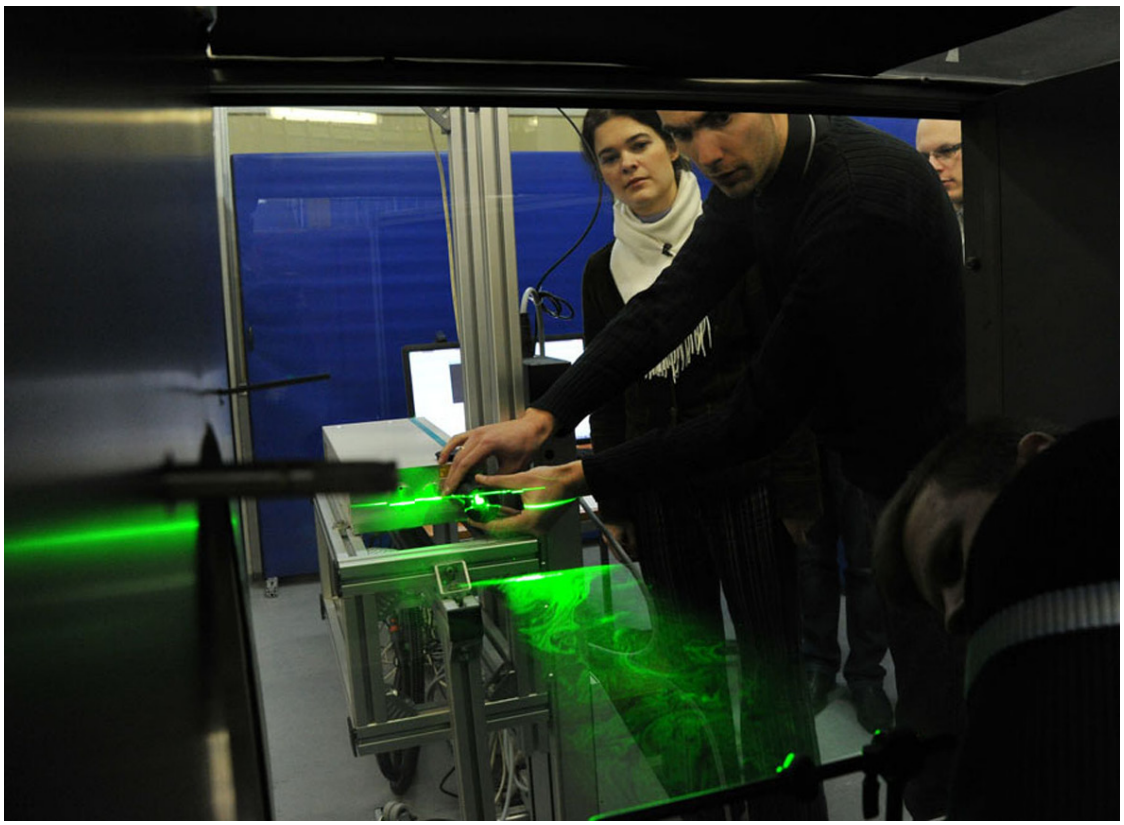

LABORATORY of HEAT-EQUIPMENT RESEARCH and TESTING

Dr. Nerijus PEDIŠIUS
Head of the Laboratory of Heat-Equipment Research and Testing
Tel.: +370 (37) 401 863
*E-mail: **Nerijus.Pedisius@lei.lt***

MAIN DIRECTIONS AND RESULTS OF SCIENTIFIC RESEARCH AND APPLIED WORKS IN 2015

In 2015, the Laboratory performed research works significant for Lithuanian industry, business and science, actively cooperated with customers, taking into account general research and experimental development trends in other European Union countries, developed national liquid and gas flow standards as well as measurement services and further expanded research, created experimental basis for perspective research of various types of biofuel and its practical application.

SCIENTIFIC RESEARCH AND EXPERIMENTAL DEVELOPMENT

The most important event should be considered the significant direction of R&D toward solving the actual tasks formulated in new topic of 2013–2015 ***Research of gas flow mixing and its interaction with structured surfaces aiming at efficient use of biofuel in heat equipment with minimal pollution of the environment***:

- to investigate processes of air mixture, supplied to combustion zones in low capacity thermal devices, with the objective to determine optimum conditions, which would ensure efficient combustion of solid fuel, including biofuel, and minimum emissions into the environment;
- to assess and summarize the composition, calorific value and physical properties of solid biofuel, its mixtures and recovered fuel as well as the composition of their combustion products;
- to improve combustibility properties of biofuel and recovered fuel or to retrieve new materials by applying thermal processing technologies;
- to investigate the separation of solid particles and non-combustible components from combustion gas and gas obtained by gasifying biofuel with application of perspective technologies;
- to develop research of flow dynamics in micro-channels;
- to expand the application of the developed equipment and methods designed to investigate permeability of various materials and visualize flow structure in order to solve scientific and applied tasks in other fields.

This was preconditioned by the up-to-date flow structure and transfer process research equipment, purchased within the framework of ***Establishment of the National Open Access Scientific Research Centre for Future Energy Technologies***, and newly constructed experimental devices. This topic was also developed during research based on the projects and programs, which have begun and were implemented in recent years:

- Projects funded by European Social Fund Agency: ***Development of innovative thermal decomposition technology and its application for utilization of sewage sludge (INODUMTECH)***, project code No. VP1-3.1-ŠMM-10-V-02-009; ***Research of properties of different kind of prepared biofuel, produced from agricultural waste and processed products, and application of this fuel for small and medium capacity heat equipment (AGROBIOATENA)***, project code No. VP1-3.1-ŠMM-10-V-02-011;
- Long-term programs in 2012–2016: *Research of dynamics, heat and mass transfer processes of single phase and two-phase flows*, completing three tasks, and *Research of usage of renewable energy sources for efficient energy production and investigation of environmental impact,* completing two tasks;
- Economy development and increase of competitive ability program, which covers annually planned and implemented R&D works in accordance with the authorization of the Government of the Republic of Lithuania to maintain a base of four state standards for liquid and gas volume, volume flow rate and velocity units, and to ensure its appropriate operation and accounting of important energy resources and measurement accuracy of related sizes considering the demands of Lithuanian economy, business and science, as well as requirements of international exchange.

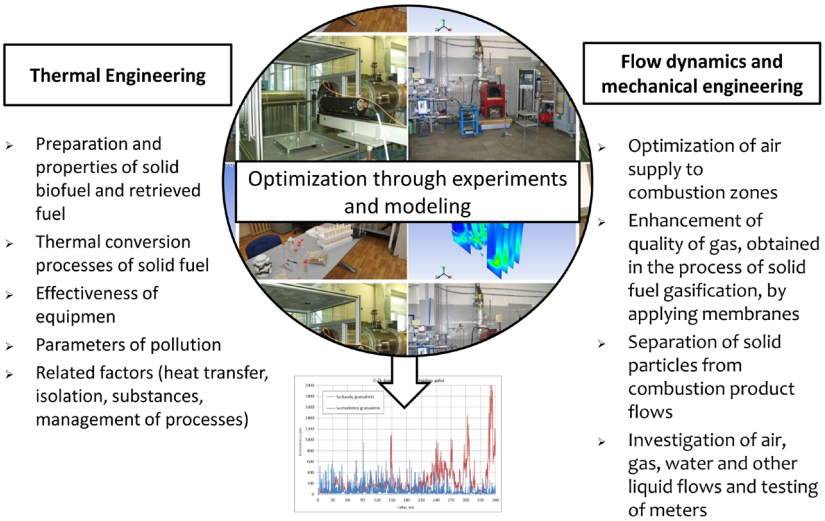

Fig. 1. Directions and fields of the research and applied works of the Laboratory

In this way, the Laboratory performed scientific research and applied works in two directions (Fig. 1) – energy and thermal engineering and measurement engineering; in the latter, the greatest attention was given to the investigation of dynamics of liquid and gas flows and their measurements.

THE MOST IMPORTANT RESULTS WHILE IMPLEMENTING R&D IN 2015:

- On December 4, 2015, final 2013–2015 report of the project financed by the government subsidies ***Research of gas flow mixing and its interaction with structured surfaces aiming at efficient use of biofuel in heat equipment with minimal pollution of the environment (B1-12-188.3.5)*** was successfully defended;
- The Laboratory carried on the investigations related to flow expansion and mixture in devices and channels of various types and shapes, at minimal surface roughness and structured surface, which cause additional disturbance phenomena, such as flow separation, and due to these reasons, energy efficiency of flows is lost;
- A prototype of biofuel pellet gasification device has been developed for conducting the research on low power biofuel-fired plants, the design of which allows using the device to explore the tasks of combustion efficiency and pollution reduction of different types of biofuel. The numerical simulation program that combines flow dynamics, energy transfer and chemical reaction equations to calculate flow dynamics and thermal parameters was developed. The initial results have shown that it could be effectively used in investigation, construction and improvement of devices, designed for biofuel combustion with minimum pollution of the environment;

Fig. 2. Device for investigation of flows in micro-channels

- The experimental devices for investigation of flow mixture and expansion, gas permeability through membranes, and flow in micro-channels (Fig. 2) by applying non-invasive laser anemometers and velocity measurement systems, based on visualization of particle movement, have been enhanced. The results of the conducted investigations were confirmed by comparisons with the theoretical calculation results and existing experimental results by other authors, and they present wide possibilities for carrying out perspective research on flow in channels and dynamics of flow expansion.

OTHER MOST IMPORTANT APPLIED WORKS AND SERVICES:

- Continuous maintenance of gas calibration laboratory equipment of SC *Lietuvos dujos* (from 2016 *ESO*) has been carried out. In 2015, a methodology of quality parameter control of natural gas transported in the distribution system was developed;
- In 2015, following the order of *METRON Fabryka Zintegrowanych Systemow Opomiarowania i Rozliczen Sp. z o.o., Torun*, Poland, the research of water meter type produced by this company was carried out in accordance with Directive 2004/22/EB module B, and type-examination certificates were issued;
- Organized by LEI interlaboratory comparisons of relative air humidity meters within 10–90% relative humidity range between three metrology centers, Lithuanian Hydrometeorological Service Metrology Laboratory and LEI Laboratory of Heat Equipment Research and Testing were performed;
- Experimental research and testing of SC *Axis Industries* created new generation heat meter QALCOSONIC HEAT1 and ultrasound water meter QALCOSONIC FLOW 4 were carried out;
- The Laboratory was reaccredited for calibration and carrying out investigations based on LST EN ISO/IEC 17025 standard;
- In 2015, the activity of the Laboratory as of an integral part of an open access Centre for Renewable and Alternative Energy expanded towards the tasks associated with scientific and applied research of biofuel exploitation processes. The volume of services provided to customers has significantly expanded.

Fig. 3. Issued type approval certificates by Laboratory in 2015

Funds received for applied research carried out under the projects, applied works and services to customers in 2015 amounted to over 0.5 million euros.

ACTIVITY ON THE INTERNATIONAL LEVEL:

- In 2015, the Laboratory, carrying out functions of the national reference laboratory, participated in the annual meeting of the international organization EURAMET TK "Flows" and prepared and provided information about indicators EURAMET TK "Quality" of the quality management system functioning;
- International comparison of flow measurements within gas flow rate range from 5 ml/min – 30 l/min was carried out (actual measurement were performed within the range (80 ml/min – 5 l/min), using laminar flow elements, based on EURAMET project **No. 1325**, which was organized by MIKES, Finland, and in which national measurement institutes of twelve European countries participated;
- International comparison of turbine gas flow meters G2500 and G6500 was carried out using reference low gas pressure devices within 1000–4000 m^3/h and 1000–10000 m^3/h flow rates, respectively, based on EURAMET project **No. 1333**, which was organized by VSL (Netherlands), and in which national measurement institutes of seven European countries participated;
- At the end of 2015, financing of the three-year project ***Baltic Energy Areas – A Planning Perspective (BEA-APP)*** of the Baltic region program 2014–2020 was approved. Project coordinator – *s. Pro – sustainable projects GmbH* (Germany). Estonian, Latvian Lithuanian, Polish, Finnish, Swedish and German institutions take part in the project.

PARTICIPATION IN INTERNATIONAL TRAINING

- PhD student Marius Praspaliauskas participated in training courses at summer school (Jyväskylä Summer School), University of Jyväskylä, Finland (Fig. 4);

Fig. 4. Advanced Environmental Chemical Analyses course group (first on the right M. Praspaliauskas)

- During the visit of the ILA GmbH (Germany) company executive Dr. Michael Dues, training for working with the updated 532 nm wave length 1D laser doppler anemometer (LDA) system and its software was held;
- Continuing cooperation with Polish Gdańsk Szewalski flow mechanics institute, an associate professor Dr. Janusz Podlinski was invited, who, on January 26–30, 2015, delivered a cycle of lectures *Flow visualization, application, and mathematical processing of processes*. During it, theoretical and practical capabilities of flow visualization techniques (PIV) were introduced, and experimental tests were carried out (Fig. 5).

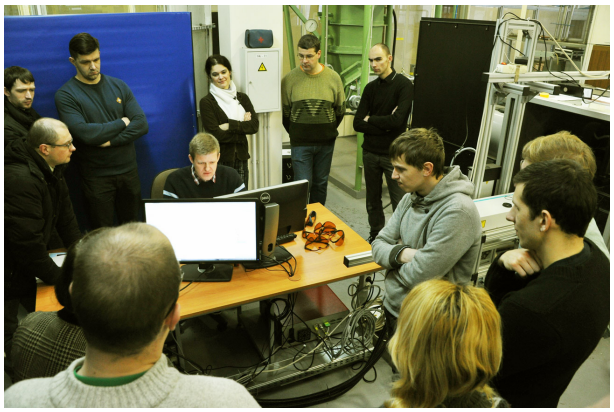

Fig. 5. Flow visualization workshops

RECOGNITION AND PUBLICATION OF THE ACTIVITY RESULTS

Defense and preparation of dissertations:

On November 7, 2015, A. Tonkonogovas defended doctoral dissertation ***Investigation of Pulsating Flow Effect on Meters With Rotating Parts*** (Fig. 6); PhD students P. Vilkinis and V. Zaleckas commenced their PhD studies, and PhD students M. Praspaliauskas, M. Valantinavičius and T. Vonžodas continued theirs.

Fig. 6. Conferring doctoral diploma to A. Tonkonogovas

Participation in international conferences:

- Chemistry and chemical technology, January 23, 2015 in Vilnius;
- 12th Annual International Conference of Young Scientists on Energy Issues (CYSENI 2015), May 27–28, 2015 in Kaunas;
- International Congress on Metrology CIM2015, September 21–24, 2015 in Paris;
- 7th Baltic heat transfer conference, August 24–26, in Tallinn;
- Conference on European industrial boiling houses and boilers, April 6–11, 2015 in Gaia (Porto), Portugal.

Awards:

The Laboratory developed a reference bell-type device that was awarded a gold medal in the *Machinery and equipment industry* group for the *Lithuanian Product of the Year 2015* nomination. The device is designed for calibration, verification and testing of air/gas meters and flow meters (Fig. 7).

Fig. 7. Moments of the award ceremony for ***Lithuanian product of the year 2015***

On December 11, 2015, Chief researcher of the Laboratory Dr. Habil. Antanas Pedišius was awarded the profession knight certificate by the Lithuanian Confederation of Industrialists (LPK).

LABORATORY of COMBUSTION PROCESSES

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THE MAIN AREAS OF LABORATORY SCIENTIFIC RESEARCH:

- improvement of efficiency of combustion processes;
- reduction of atmospheric emissions;
- development and improvement of burners and fuel atomizers;
- research of thermal destruction and gasification of solid calorific waste;
- numerical simulation of granular media and multi-particle systems;
- environmental impact assessment.

Research of combustion processes is carried out in the fields of fuel saving, reduction of environmental pollution, and thermal decontamination of materials.

RECONSTRUCTION OF WATER BOILER PTVM-50 NO. 5: UPGRADING OF BURNERS

In 2015, reconstruction of water boiler PTVM-50 No. 5 was completed in Panevežys boiler house RK-1. Lithuanian Energy Institute has participated in this reconstruction project in the part of burner upgrade: recalculation of burners' capacity for reduced boiler capacity (58.2 to 44±1 MW), by reducing a number of burners from 12 to 8 pieces; development of new burner gas rings and presenting parameters for their fabrication; supervision of burner

repair; development of new jet atomizers; boiler functional testing. Customer: UAB *Enerstena VS*.

During reconstruction of water boiler PTVM-50, its heating capacity was reduced from 58.2 to 44±1 MW. The capacity was reduced by reducing the number of installed burners from 12 to 8 pcs. After reconstruction of boiler water pipes, 4 points for installation of the upgraded burners were left in each of the two boiler side walls. Due to reduction of boiler heating load and the number of burners, fuel and air flows had to be recalculated for the rest of burners.

Burners of water boiler PTVM-50 are installed one in front of another. Due to this reason their design is non-standard – air swirls are retracted from the burner's throat deep into the burner's nozzle. Air swirled in the burners moves rather far and the main air mass is pressed to nozzle walls due to centrifugal forces. Thus the vacuum is generated in the burner's centre. Negative pressure draws hot combustion products from the boiler's furnace back to the burner's base part. The fuel oil atomizer which is installed in the middle of the burner functions as a flame stabilizer; part of unburned fuel is returned on it and, with time, coke sediment may accumulate preventing quality operation of the burner. Gas combustion (when fuel oil atomizers are removed) flame in certain cases may back flow up to the air swirlers and thermally damage them. Considering these technical deficiencies, LEI has proposed burner design modifications by inserting a tube in the middle of the burner in order to optimize the burner's operation. Such tube has two purposes: first, it acts as protection of the fuel oil atomizer against potential fouling, and, second, flame stabilization by retracting flame base part away from the air swirler. Air swirler is replaced in the burner to obtain swirled air flow. Such air supply is necessary to improve quality of fuel-air mixture and create internal recirculation inside a flame. 12 pcs. of blades were designed with angle adjustable during burner startup in order to obtain the optimal flame envelope corresponding to the combustion chamber. Burner natural gas supply was designed from the gas header installed in the burners' periphery. Natural gas inlets were designed so that gas penetrates perpendicularly into air flow uniformly through the entire cross-section.

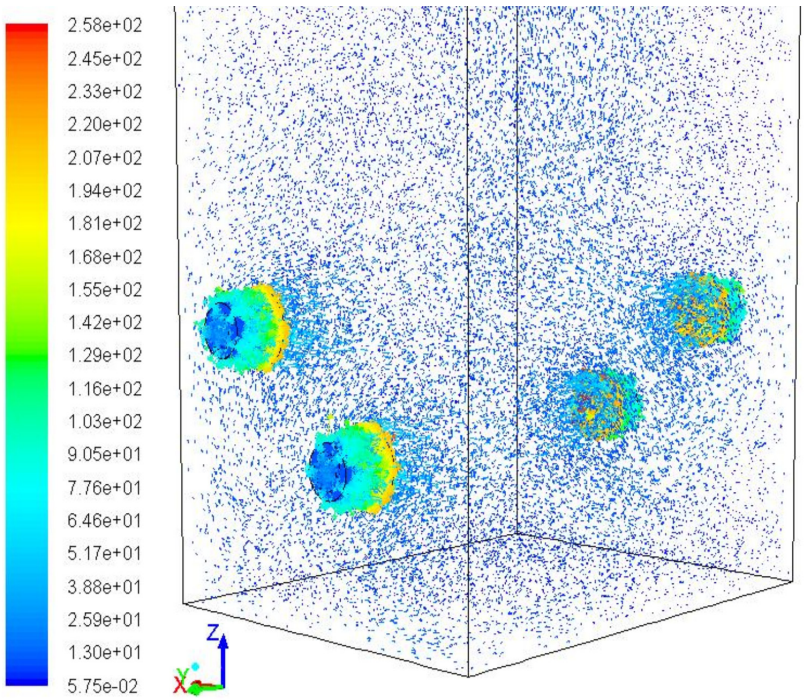
During functional testing in the entire loading range, the boiler was adjusted for ecological operation: in case of natural gas, levels of nitrogen oxides (NOx), depending on boiler load, have ranged 89 to 195 mg/Nm^3, and CO: 0 to 10 mg/Nm^3. In case of fuel oil: respectfully NOx: 237 to 344 mg/Nm^3, and CO: 0 to 20 mg/Nm^3. After the burner upgrade, significant reduction of nitrogen oxides was achieved both with gas and fuel oil.

Water boiler PTVM-50 burner upgrade was implemented by introducing new burner design solutions, preventing risk of overheating of air swirler metal parts and fuel oil atomizer coke fouling; new gas inlet rings were designed, new air swirlers were installed and new fuel oil jet atomizers were fabricated as well. This final report presents dimensional drawings of burner structural modifications and technical parameters. Operation principle of fuel oil jet atomizer is described; flow diagram and technical parameters are presented. Fabricated and installed upgraded burners were commissioned by adjusting the optimal fuel/air ratio for natural gas and fuel oil, the boiler's main technical and economical parameters were determined.

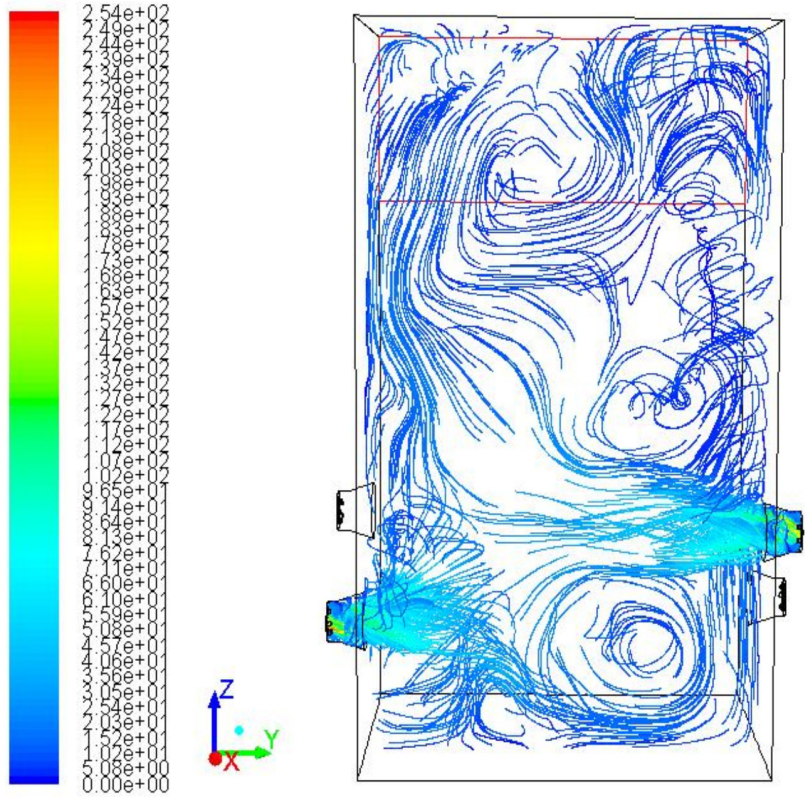
BURNERS' OPERATION OPTIMISATION FOR BOILER NO. 1 E-25/14 IN ORDER TO REDUCE NITROGEN OXIDE EMISSIONS

Since 2016, emission standard for nitrogen oxides (NO_x) in case of natural gas combustion has been reduced 3.5-fold, i.e. from 350 to 100 mg/nm^3, and in case of fuel oil combustion, NO_x standard is reduced 2.7-fold (from 400 to 150 mg/nm^3), sulphur oxide (SO_2) standard: 8.5-fold (from 1700 to 200 mg/nm^3), and particulate standard: 2.5-fold (from 50 to 20 mg/nm^3). This is a difficult task for the existing combustion units, requiring additional investments or scientific research and experimental development: the existing burners have to be replaced by low nitrogen oxide burners and/or secondary measures for nitrogen oxide emission reduction have to be implemented.

In 2015, representatives of AB *Nordic Sugar Kėdainiai* addressed the institute's scientists one more time asking for additional scientific research and experimental development in the area of NO_x emission reduction with intention of gradual approach to the requirements of directive 2010/75/EU. Taking into consideration features of burners D10, the customer was proposed to modify some components of the burner, which would enable NO_x emission reduction by 25–30%. The purpose of this work was to evaluate operation quality of the existing burners and implement required modifications in order to reduce NO_x level in combustion products. The following tasks were completed: boiler aerodynamic measurements to assess condition of the existing burners; designing and fabrication of new gas atomizer nozzles; adjustment of combustion air distribution; and functional testing.



Air flow velocity vectors in steam boiler combustion chamber – mathematical modelling results



Air flow lines in steam boiler combustion chamber – mathematical modelling results

Two burners D-10 of LEI design are installed in steam boiler furnace walls. These burners (fabricated according to the company's code No.1195521-01-98) are intended to burn natural gas, fuel oil or other liquid fuel in water and steam boilers and process heaters. The burner generates two swirled air flows: central and external. Such air flow distribution is required for stepwise fuel combustion with low nitrogen oxide emission. Both air flows are swirled by the individual axial blades. The angle of blades of external air flow is adjusted during burner startup by adjusting flame envelope to the combustion chamber. Gas is injected through lances with certain angle to the lance axis. Fuel is directed to the highest velocity points of external air flow. Each burner is equipped with 5 pcs. of gas lances. Each lance has 7 pcs. of gas outlet holes. The burner generates a stable zone of combustion gas recirculation (within load range), therefore, it is easily ignited and combustion is reliable. Gas igniter is used for ignition.

The burners are designed with capability to improve the structure of the central and peripheral air flows. Aerodynamic research of the burner flows shows that the structure of flame envelope does not fully comply with the current requirements – recirculation zone is wide and intensive. In this case, fast fuel ignition within a rather high volume takes place resulting in a local high temperature zone. Such high temperature zone always leads to the increased risk of thermal generation of nitrogen oxides. It was found that the burner generates too deep vacuum in the internal recirculation zone and it is feasible to enlarge this zone by increasing central air flow. Having adjusted air distribution, gas atomizer nozzles were replaced.

Lengthened internal recirculation of combustion products at the burner and modified atomization of gas flows resulted in decreased local temperature of flame envelope. For the modified flame envelope, it was determined that nitrogen oxide levels in the exhausted flue gas were reduced, depending on steam boiler load, from the range 220–270 mg/nm^3 to the range 180–209 ±5 mg/nm^3.

DEVELOPMENT OF INNOVATIVE THERMAL DECOMPOSITION TECHNOLOGY AND ITS APPLICATION FOR UTILIZATION OF SEWAGE SLUDGE (INODUMTECH)

The project ***Development of innovative thermal decomposition technology and its application for utilization of sewage sludge (INODUMTECH)*** funded by the EU structural funds under the measure VP1-3.1-ŠMM-07-K *Promotion of High-Level International Scientific Research* for implementation of the Priority 3 *Strengthening researchers' abilities* under the Human Resource Development Action Programme of 2007–2013 was completed in 2015. The project was administered by ESFA (European Social Fund Agency). The project was started in January 2013 and lasted for 30 months, i.e. up to July 2015. The amount of 2.259 mln. litas was allocated to LEI.

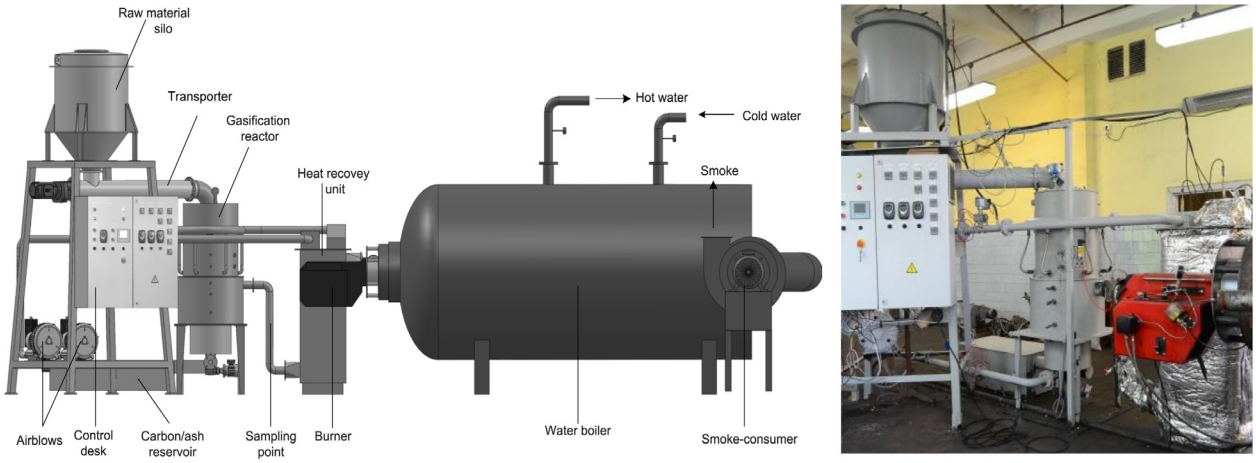
Sewage sludge is generated as waste in Lithuanian wastewater treatment plants. Increasing wastewater collection and treatment infrastructure leads to proportional increase of sludge volume. Annual amount of dry sewage sludge generated in Lithuania achieves 50 thousand tons of dry material. In 2007–2013, sewage sludge management infrastructure was developed in Lithuania. Its aim is utilization of 80% of sludge generated in Lithuania in sludge digestion, drying and composting plants. Dried and pelleted sewage sludge is obtained after sludge processing in digestion and drying plants implemented in the wastewater treatment plants of the major Lithuanian cities. The most feasible method of its utilization is gasification. This technology enables to generate the valuable product – flammable gas, which can be used to produce electricity or heat needed for sludge drying.

The aim of the project is development of innovative thermal decomposition technology and its application for utilization of sewage sludge. Downdraft fixed bed gasifier of 100 kW capacity. Raw material dries in the top part of the gasifier, then it moves through pyrolysis, combustion and gasification stages. Different process reactions take place in individual reactor zones. Temperature in the drying zone ranges 150 to 300 °C. Here the major part of water is evaporized. Temperature in the pyrolysis zone is 500 to 700 °C – here volatile compounds, resins and coke are generated. In the combustion zone, the presence of oxygen causes oxidation of pyrolysis products resulting in the required amount of heat to promote further gasification reactions. Reactions in pyrolysis zone of the downdraft fixed bed gasifier at temperature of ~500–700 °C produce gas with calorific value of 4–5 MJ/Nm^3, consisting mainly of CO, H_2, CO_2, CH_4 and other C_nH_m hydrocarbons, N_2. High ash content raw material – sewage sludge – contains ~50% of volatile compounds. The rest is carbon and moisture. Decomposition of residual carbon requires high temperature and time. Therefore, additional equipment or more intensive carbon oxidation process is required.

The Laboratory dried sewage sludge gasifier is designed for gasification of sludge or other organic waste. Raw material is fed from the top and moves downwards together with released gas flow. Raw material flowrate to the reactor is ~20–50 kg/h. Stoichiometric fuel/air ratio is ~0.2–0.4. Volume of produced gas ~60–120 m^3/h. Carbon residue after evaporisation of volatile compounds from the sludge is ~10% by weight from the raw material feed.

Gasifier system consists of three major parts: a gasification reactor, heat recovery unit, and combustion unit. Raw material to the gasifier is supplied by screw conveyor from the top and then slides down in a closed volume. Raw material level in the gasifier is maintained constant automatically by the mechanical level measurement. Required air is supplied radially around combustion zone, where the required temperature is maintained within a small height section. The residual carbon is additionally gasified by supplying secondary and tertiary air. Gasification residues, carbon and ashes are removed through moving grate and stored in a silo. Generated gas from the reactor flows through the carbon layer on the reactor bottom and through insulated pipes is supplied to the heat recovery unit where the air supplied to gasification process is heated. Partially cooled generated gas from the heat recovery unit is sent to the burner installed in the combustion chamber (in water boiler VK21). The boiler is equipped with *Bentone* liquid fuel burner B40A. Special openings are provided for gas injection into the burner.

Gasification process is fully automated, the main process parameters are

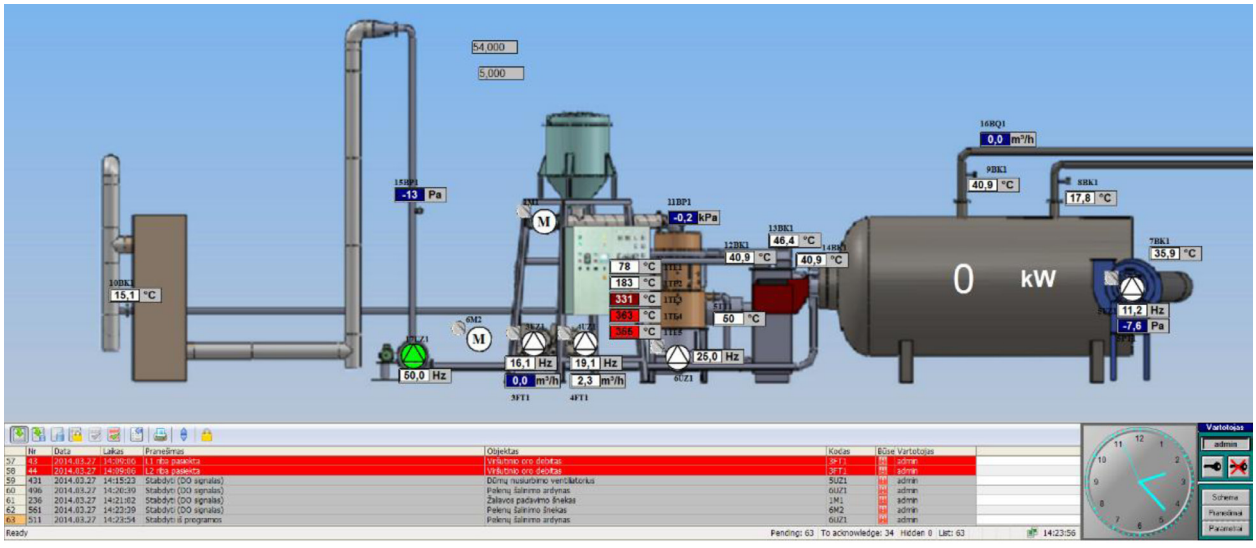


Prototype of sewage sludge gasification system

collected and stored in a computer. The process has to be adjusted individually for each biomass feed due to different characteristics of different investigated mixtures. The following parameters have to be adjusted depending on the determined feed material characteristics: primary and secondary air flow, grate movement cycle; and based on these parameters, the following parameters are adjusted automatically: fuel feed conveyor drive frequency, combustion air volume, boiler draft, water flowrate and temperatures.

Combustion products generated in the gasifier were treated in the modified unit. This unit consists of plasma generator (PG); plasma chemical reactor (PChR); electrical power supply, regulation and control system; cooling system; plasma gas supply and regulation system; measurement and monitoring system; auxiliary and ventilation equipment.

After testing of individual process components, all components were combined into the common process sequence intended for research of sewage sludge utilization technology. The main components of test bench: gasifier, plasma chemical reactor, cooler, electrostatic filter (ESF), and water boiler VK 21. The experiment starts by filling the silo with the prepared mixture. Considering limited volume of the silo, ~ 200 kg of prepared mixture is filled for one experimental test. This volume of mixture, taking into account capacity of the reactor, is sufficient for 4–5 hours of operation. The raw material from the sealed silo is supplied to the gasifier by the screw conveyor. The generated power gas ~500–600 °C is sent to the cyclone, where part of the carbon particles carried out with the gas is separated. Hot power gas from the cyclone further is supplied to the plasma chemical reactor, from which treated hot power gas ~ 1000 °C is sent to the water cooler. Gas is cooled down to ~300 °C in this cooler. The cooled



Gasifier control display in a computer screen

gas further is sent to the electrostatic filter, where particles are separated from the gas flow and collected.

The system of vertical pipes with sampling points is installed upstream and downstream ESF. At these sampling points, i.e. downstream plasma chemical unit and downstream ESF, composition and concentration of power gas and resins, concentration of solid particles, concentration of HCB in the gas are measured. Clean calorific synthetic gas after electrostatic fitter is further transported by the blower to burner B 40 A installed in water boiler VK 21. Combustible gas/air mixture is prepared in the burner, which then is burned in the boiler's combustion chamber. Combustion products are exhausted to the atmosphere by the draft fan. Sampling point is also provided in the flue gas duct downstream water boiler. Flue gas sample is analysed with the analyser Testo 350 XL for composition and HCB level.

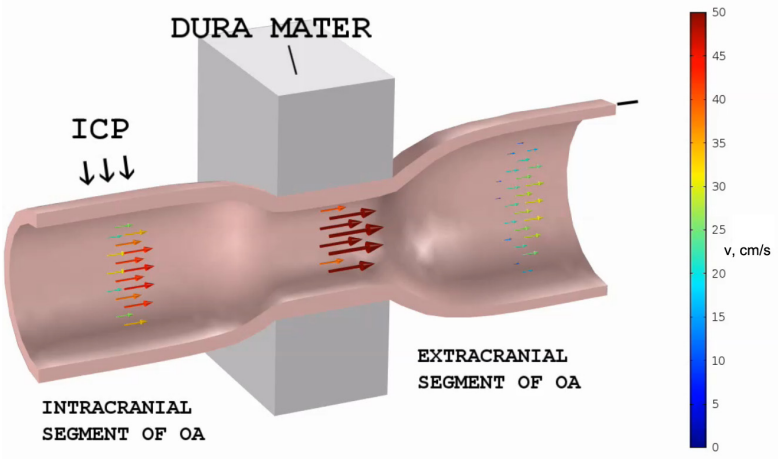
The thermal decomposition technology with gasifier applied in this research has shown that this technology not only allows reducing volume of accumulating sewage sludge waste, but also obtaining a useful product from the process – calorific power gas, which can be used to generate heat or electricity. The experimental research has revealed new scientific research findings about composition, heat value and physical properties of the generated gas, amount and composition of liquid products, residual amount and composition of solid material, distribution of sewage sludge heavy metals in gasification products, potential presence of toxic materials and their neutralization issue were evaluated. Characteristics of gasification of various mixtures containing dried sewage sludge and wood (70%/30%, 50%/50%, 30%/70%), as well as optimal conditions allowing generation of the highest calorific value gas were determined. Certain technology design solutions and control features were discovered. Further improvement directions were presented.

NUMERICAL RESEARCH OF EYE ELASTIC ARTERY BLOOD CIRCULATION

Intracranial pressure (ICP) is the pressure inside human skull and brain. Its deviation may be caused by pathologies or injuries; therefore, it has to be measured as part of diagnostics or treatment. Too high or too low ICP is dangerous to human life. Numerical modelling of liquid flow enables to detect correlation between eye artery pressure and skull pressure. Thus, having measured pressure in eye artery by non-invasive method, we can calculate the intracranial pressure. Eye artery for most people is unique – it can be divided into three sections: intracranial, bone and orbital. Such segmentation leads to assumption that intracranial pressure could be determined indirectly by applying measurements based on balance principle. Such non-invasive measurement is performed by putting a special mask on a head, which creates additional pressure Pe in the eye orbit. Using ultrasound technique, average blood velocities in the intracranial and orbital sections are measured. Taking into consideration that added additional pressure forces artery to shrink causing increased average blood velocity (flowrate is constant), we can reach such state, when velocity difference conforms to the natural differential pressure ΔP. Then the following condition should be met: $ICP = Pe + \Delta P$. The aim of the modelling was to determine if such condition is true; and if not, what the reasons are. It was determined that local external impact to the eye artery wall had significant influence on this condition. Different tensions in measurement points allow different expansion or shrinking of the artery, though common acting pressures may be equal. After introducing additional tolerance factor dU in the pressure equation, extreme cases and tolerance limits were determined.

SCIENTIFIC RESEARCH FUNDED BY THE STATE BUDGET

The scientific research ***Theoretical research of pelleted biofuel dynamics and combustion processes*** funded by the state budget was conducted in 2015. The two tasks related to solid fuel application for power generation were explored by experimental and numeri-



Eye artery sections and blood velocity – mathematical modelling results

cal investigation of solid fuel particle size change under heat exposure, as well as formation of larger structures in the granular matter, when parameters of individual particles are known from discrete element modelling.

Experimental research of wood and biofuel pellet size change during pyrolysis process

The simplest method to convert low quality biofuel to heat or electricity is to gasify pelleted biofuel by converting solid state fuel into gas. However, gasification process tests have revealed one issue of using wood pellets: fuel bed agglomerates into uniform structure when sliding from pyrolysis zone into oxidation zone, which stops a further process. Fuel bed agglomeration in pyrolysis zone is rarely analysed in scientific references and this process is most frequently observed during gasification of pellets produced from recycled waste. In order to determine causes of fuel bed agglomeration, wood pellet pyrolysis tests were conducted by filming wood pellet size change and recording sample centre temperatures in heating temperatures of 400–1000 °C. It was found that fuel bed agglomeration is caused by pellet expansion phenomena and experimental research was extended to the investigation of biofuel pellets of various composition.

Biomass particle fuel research in 400–1000 °C heating temperatures was conducted using horizontal electric tube furnace Nobertherm RS 80/500/13, by creating inert environment and filming sample size changes during pyrolysis process. A sillimanite tube heated both from top and bottom was inserted into the furnace. One furnace tube end was equipped with nitrogen supply system,

Electrical tube furnace Nabertherm RS 80/500/13 with temperature control unit

and the other furnace end was left open for sample insertion and for filming of sample size changes. When the required heating temperature was reached in the furnace, nitrogen flow controlled by rotameter was started. A special tray with sample was inserted through the open tube end into the middle of the furnace. A thermocouple was fixed to the tray to measure temperature of pellet centre and transfer the obtained data to the computer. During the test, variation of wood particle, wood pellet and straw pellet centre temperatures was monitored and sample size changes in a radial direction were filmed during pyrolysis process at heating temperatures of 400–1000 °C.

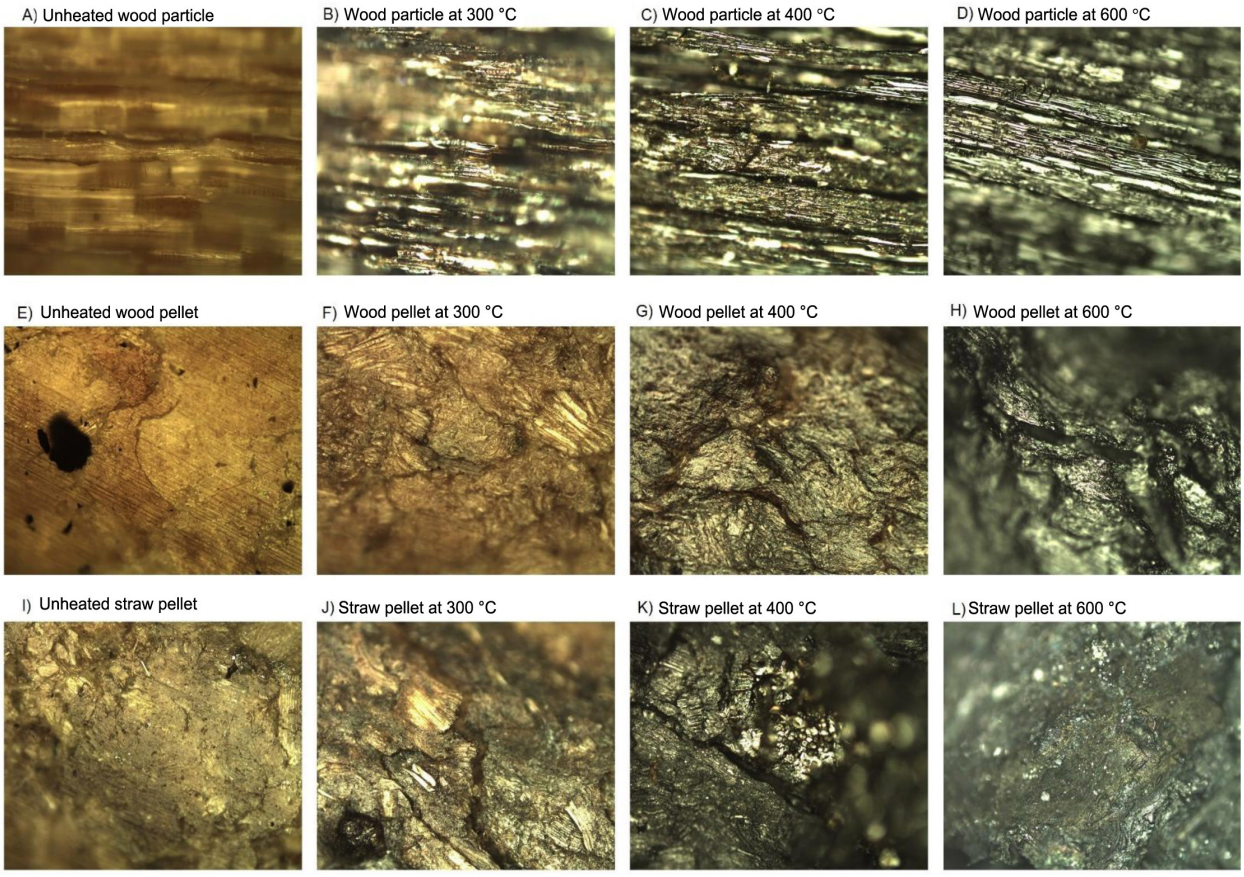
At low heating temperature (400 °C), due to the fastest overheating comparing to all samples, the wood particle begins to shrink after 60 sec. from the test start, when particle centre temperature exceeds 110 °C (the moment when water evaporation process is completed). Wood particle shrinking lasts 430 sec. and it losses approx. 12% of the original diameter. Meanwhile, diameter change of wood and straw pellet starts only after 120 sec. from the test start, and contrary to wood particle, they start expanding when centre temperature reaches 130 °C, which shows more complicated water evaporation process. Maximum expansion of pellet samples, reaching 1% of the original diameter was observed at 170th second when wood pellet centre was heated up to ~180 °C, and straw pellet centre was heated up to ~200 °C. Expanded pellets start to shrink. During shrinking process, more intensive straw pellet diameter shrinking is noticed, during which centre heating rate increases due to hemicellulose decomposition. Straw pellet stops shrinking at 380th sec. from the experiment start and losses 8% of the original diameter. Wood pellet shrinks by ~6% comparing to the original diameter. When heating temperature increases up to 600 °C, sample diameter changes become more intense. When wood particle centre heats up to 65 °C, intensive shrinking process is observed which lasts 130 sec. while particle centre heats up to 410 °C. Wood particle loses 44% of the original diameter. Contrary to wood particle, when centres of wood and straw pellets heat up to, respectfully, 71 °C and 66 °C, expansion phenomena is started in these pellets. Wood pellet within 60 sec. expands up to 3.25% of the original diameter, when centre heats up to 190 °C. Expansion of straw pellet is more intense (within 40 sec.) and

reaches 35% of the original diameter, when centre heats up to 175 °C. The expanded wood and straw pellets start shrinking after a few seconds. Wood particle diameter shrinks linearly 210 seconds down to 75% of the original diameter, and straw pellet shrinks in several stages.

The obtained results show that pellet diameter variation depends on pyrolysis temperature and heat transfer in particles. Increasing heating temperature leads to increase of the received heat amount resulting in changed intensity of wood degradation, during which intensive release of volatile compounds is taking place. In order to investigate a cause of diameter changes more deeply, a surface of pyrolysed samples was analysed using the optical microscope Olympus BX51 with high resolution digital camera Go-21. The obtained images show that the surface structure of wood particle unexposed to high temperature is regular, comparing to wood and straw pellets. The surface of the wood particle exposed to heating temperature of 300 °C is charred, which shows early and intensive particle degradation. In higher temperatures, these processes become more intense, causing appearance of cracks in surface due to release of volatile compounds. Wood and straw surface structure differs from wood particle at heating temperature of 300 °C. Due to slower heat transfer processes, slight melting and micro cracks in pellet surface are noticed. At higher temperature (400 °C), more intensive melting is observed, as well as larger cracks and pores appear on the melted areas. According to information found in references, pores on a surface appear due to impeded release of volatile compounds. It is also believed that expansion of wood and straw pellets is caused by accumulated water vapour and volatile compounds inside a pellet, which cannot evaporate due to condensation of resins, alkali on a surface which decreases porosity. Thus, water vapour and volatile compounds accumulate inside a pellet causing increase of internal pressure and pellet expansion. At critical pressure, surface structure is broken and accumulated water vapour with volatile compounds is released – shrinking process begins. Expansion process stops when heating temperature exceeds 900 °C. A pellet heats up rapidly, materials condensed on a surface are thermally destructed and so the passage for release of volatile compounds is opened.

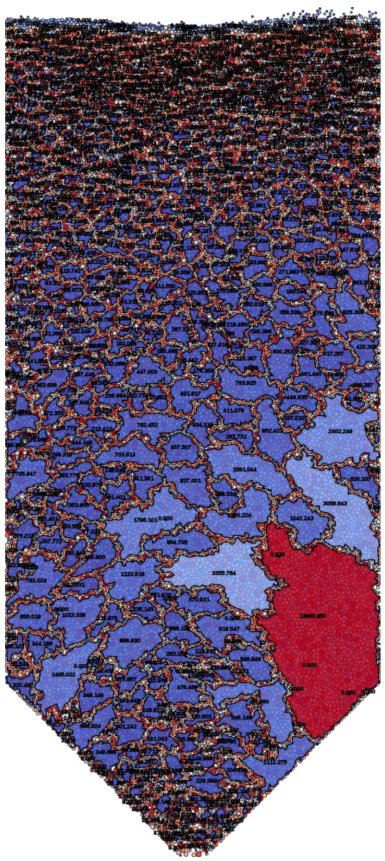
Modelling of mechanics of granular matter

Granular matter is widely spread in nature and many industrial areas;



Images of surfaces of wood particle, wood and straw pellets (zoom 10×) at different heating temperatures

solid fuel pellets also belong to this group of materials. Different mechanical phenomena can be observed within these pellets which are interesting both from a scientific and practical point of view. Discrete element model is widely applied for modelling of their mechanical behaviour when movement of each particle and mutual collisions of particles are described by common equations of mechanics. Mechanical properties of granular matter depend on interaction of individual constituent particles determining properties observed in macroscopic level, such as mechanical compression resistance. Parameters of individual particles are obtained by modelling granular medium using a discrete element (DEM) or molecular dynamics methods. In order to determine properties of high volume granular matter using modelling data, additional data processing is necessary. One of the methods is to display interaction of particles as the graph, where nodes mean particles, contacts or relations among particles are represented as edges, and edge weights are selected based on relations of interacting particles, such as similarity of given parameter, size of interaction force, etc., depending on a specific task. Such graph can be composed using methods and algorithms known from the graph theory. One of the graph analysis methods widely explored today which could be used to detect larger particle communities from DEM modelling results is community detection algorithms. It is assumed that particles within the same particle community have stronger mutual links comparing to the particles in different communities. Such communities are detected by analysing the structure of edges of a respective graph. Mechanical properties of granular medium in macroscopic level are highly influenced by force bridges. Quantitative analysis of such



bridges today is widely researched. Force bridges are usually detected by applying threshold method, i.e. the lowest threshold of forces among particles is chosen and interactions exceeding this force threshold are analysed. However, stability of such bridges is also influenced by side weaker forces, which stabilize these force bridges. This research analyses force communities, i.e. such particle communities where mutual interaction forces are stronger comparing to particles in different communities. Above mentioned community detection method is applied to detect these groups. Particle pouring from a silo is analysed as a model task. Such phenomenon is encountered in many areas related to research and technology of granular medium and loose materials. Pellet silos installed at solid fuel boilers is an example. This research deals with mechanical forces appearing in a granular matter pouring from a silo and their structure. It was determined that rather big structures of particles are created in different time above silo outlet, which possibly influence pouring process, and forces among particles at the top of the pile are relatively low. Size of such communities depends on particle friction factor. The obtained data shows that pouring process of granulated matter is influenced by the generated particle communities with mutual interaction forces higher than forces among particles belonging to different communities. Formation and disappearance of such communities determine uneven pouring process in time. Stability and alteration of such communities in time are analysed.

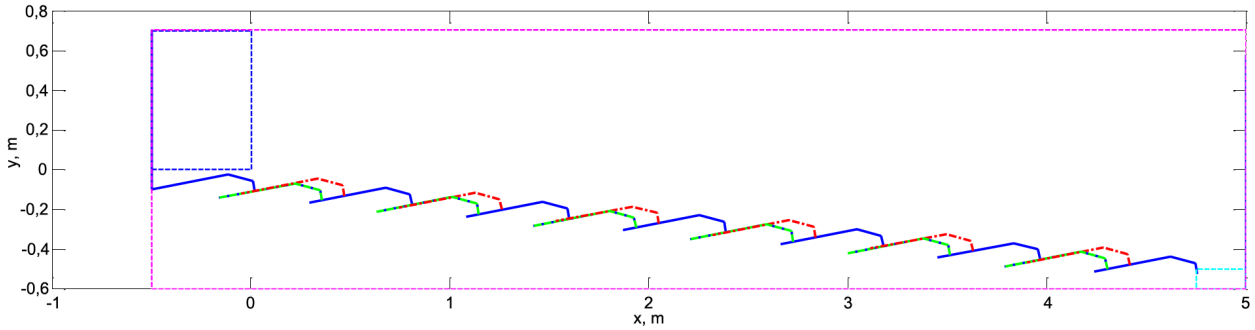
Particle communities connected by higher forces during pouring from a silo were detected by applying algorithms of the graph theory. Black lines show boundaries of detected particle communities. The colour of groups corresponds to the sum of force modulus in a certain community.

MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF LITHUANIA

Long-term institutional scientific research and experimental development programme
Experimental and numerical research of combustion and plasma processes for improvement of power generation technologies and reduction of environmental pollution

Research of combustion of fossil and renewable biofuels by optimizing boiler combustion chambers and combustion equipment in order to reduce levels of nitrogen oxides in exhausted flue gas

Work on reduction of atmospheric pollution was continued in 2015 by applying secondary optimization techno-



Biofuel combustion unit diagram for the numerical experiment; green bars are initial position of moving bars, red – maximum position of moving bars

logies for combustion process. Special test benches were not built, but actual applied scientific research was conducted in collaboration with operators of combustion plants. Experimental research was conducted in cogeneration power plant No. 2 of UAB *Vilniaus energija*. During testing, flue gas was injected upstream air blowers. Flue gas mixing with combustion air took place in the blower. The completed theoretical and experimental research has shown that injection of secondary gas has to be adjusted to geometry of a combustion chamber, and additional supply of flue gas could reduce NO_x level from 150 mg/nm^3 to <100 mg/nm^3 resulting in lower emissions. The research has shown that flue gas recirculation flow is minimal and does not exceed 10% of combustion air volume in water boiler equipped with burners of LEI design with stepwise implementation of secondary gas flows. Comparing to examples found in references, flue gas recirculation rate reaches even 30%. The results were published in an international publication and science popularization publications.

Numerical modelling of dynamics of granular matter by applying Discrete Element Method (DEM) and Computational Fluid Dynamics (CFD)

Numerical modelling research combined with experiment in biofuel combustion unit was conducted in order to study how biofuel combustion chamber grate movement rate determines behaviour of humid biofuel particles. Experimental results were compared to calculations. Calculation data has confirmed, supplemented and explained experimental data.

Biofuel combustion chamber grate consisted of 13 bar rows (every second row moving). The first row of bars is fixed and belongs to fuel feed zone. The rest 12 rows of bars are divided into 2 zones, each of 6 rows, with every second row of fixed bars. Fuel is fed on the first bar (left side). Bars of each zone move at their own preset period.

Pressure in air chamber above the grate increases with increasing bed thickness, i.e. additional pressure is required to force the same air volume through increased resistance. Different movement rate leads to biofuel bed thickness "break". Half grate is covered with thick biofuel bed with high resistance factor, while the other half is thin with relatively low resistance. Therefore, it is obvious that air tends to flow through the thin biofuel bed with low resistance, it is distributed unevenly, volumetric velocity through a bed is increased. The increased velocity through a bed may cause bed fluidization, arches, tunnels or similar effects. This can also lead to carry-out of light fuel particles into the boiler's flue gas passage. It should be noted that increased grate movement ratio has also resulted in a higher level of solid particles in exhaust flue gas.

Drying of humid biomass on industrial biomass combustion unit grate was modelled using the numerical DEM method. Results of the numerical experiment have shown that biomass particle drying model describes particle drying processes sufficiently well and it may be applied for calculation of industrial biomass combustion units. In order to increase accuracy of calculations and extend application of a numerical method to calculations of efficiency of industrial equipment, the adjusted model of interaction among particles and surrounding gas has to be used.

In 2015, 3 articles were published in scientific journals referred in *Thomson Reuters* data base *Web of Science Core Collection*, and 8 presentations in state and international conferences were delivered.

LABORATORY of MATERIALS RESEARCH and TESTING

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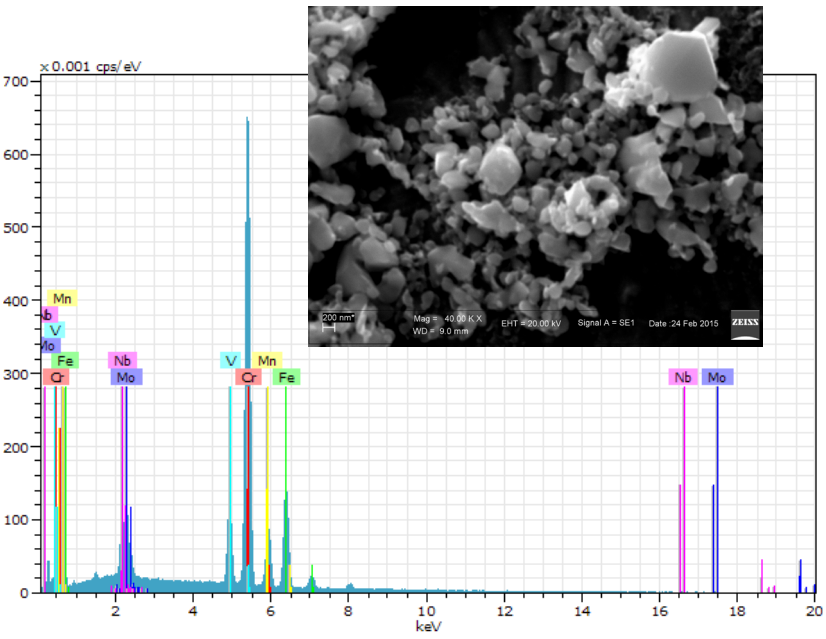
MAIN RESEARCH AREAS OF THE LABORATORY:

- reliability of power plant facilities: research of metal aging processes and degradation of properties due to the impact of operational factors;
- development and research of multifunctional materials and composites;
- testing of materials, assessment and analysis of their qualitative indicators.

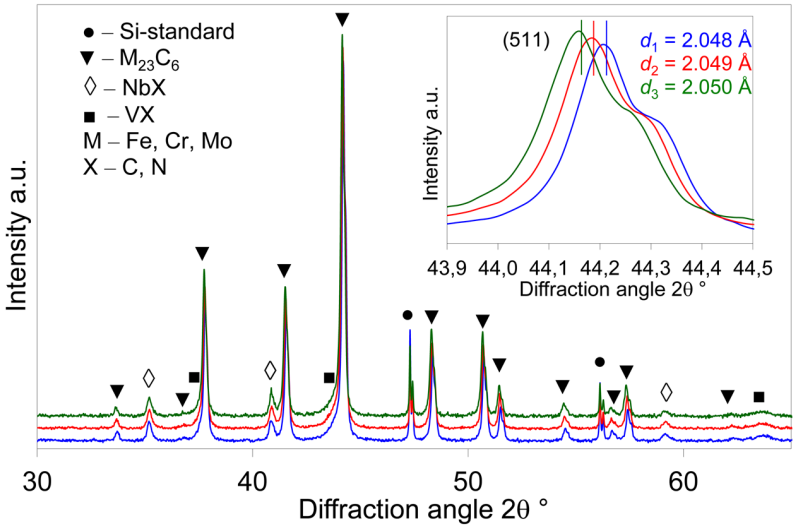
RELIABILITY OF POWER PLANT FACILITIES: RESEARCH OF METAL AGING PROCESSES AND DEGRADATION OF PROPERTIES DUE TO THE IMPACT OF OPERATIONAL FACTORS

The Laboratory carries out research aimed at the investigation of ageing processes of steel and special alloys that are used as the constructional elements for

power plants and at studying patterns of aging processes, solving issues concerning control of these processes and service life. Applying mechanical tests, X-ray Diffraction (XRD) and elemental composition analysis, as well as optic and scanning electron microscopy, structural and property changes of exploited steel and non-ferrous metal alloys are studied. Experimental and numerical methods are used to predict operational reliability taking into account material ageing processes and other operational factors. The implementation of the work focuses on the investigation of fundamental physical and chemical phenomena affecting structure and properties of metals. In this research direction, researchers of the Laboratory participate in long-term institutional scientific research and experimental development programs: ***Scientific research of safety important processes taking place in nuclear and thermal nuclear facilities*** and ***Research of processes of nuclear power plant operation decommissioning, nuclear waste and spent nuclear fuel management and radiation impact analysis***.



Research of martensitic ferritic steel aging processes: detection of composition changes of carbides extracted from the metal matrix



Research of martensitic ferritic steel aging processes: detection of changes of $M_{23}C_6$ carbide crystal lattice parameters using XRD method

Research Council of Lithuania

In 2015, the project **Service life assessment model for new generation steel** funded by the Research Council of Lithuania has continued. The objective of the work is to investigate regularities of structural changes in steel under high temperatures and their influence on the mechanical characteristics and degradation parameters. The structural changes are determined after the investigation of phase transformations of steel structure, related to diffusion processes occurring under the influence of temperature, by assessing the evolution of steel carbides and changes of parameters in their crystal lattice.

Carbide elemental composition and structure changes in steel due to the diffusion of chemical elements during steel aging were investigated by means of scaning electron microscopy and EDX methods. Johnson-Mehl-Avrami kinetic equation was applied for creating a kinetic model of carbide crystallographic parameter variation that describes steel structure changes taking into account temperature and time.

The Laboratory continued the research initiated by IAEA in 1998 related to degradation impact of hydrogen and hydrides on zirconium alloys. During 2011–2015, the Laboratory participated in the research project ***Analysis of Nuclear fuel Cladding Resistance to Hydride Cracking during Long-Term***

Storage coordinated by the International Atomic Energy Agency (IAEA).

The objective of this work is to develop experimental procedures in order to assess conditions of hydride cracking in zirconium alloy fuel cladding – threshold stress intensity factor values and temperature limits, under which failure of fuel cladding may occur. By applying controlled hydriding, special construction samples were made of zirconium alloy fuel cladding, in which by changing stress levels, hydride cracking process under given temperatures was studied. The research is important for solving the issues of ensuring safe operation of nuclear power plants and assessing the resistance of fuel cladding to the hydride cracking during long-term storage of spent nuclear fuel.

European Union 7th Framework Program project ***MATerials TEsting and Rules (MATTER)*** have been completed. The project was launched in 2011 together with the researchers of the Laboratory of Nuclear Installation Safety. Fifteen work packages were formed following the project tasks. The Laboratory participated in the activities of two working groups: *Manufacturing and welding* and *Testing activities in support of design*. Within the scope of the project, a new research on material behaviour in the operational conditions of IV generation reactors was initiated. One of the main objectives of the experimental research is to identify the allowable fatigue limits and weld joint coefficient values of heat resistant steel welding seams, operating under high temperature and obtained by applying up-to-date welding technologies. Taking into account the requirements for modern experimental procedures, a research methodology was developed for carrying out the experiments. Fatigue tests were performed at 550 °C temperature under strain controlled conditions using dynamic testing machine ***Instron*** (Model 8801, 100kN) with a special testing equipment and software for experiment control. The resulted data of this work, describing the behaviour of welding seams at high temperatures, are important for predicting their lifetime in the reactor components and for assessing the suitability of welding technologies in continuation of further research on welding materials and processes caused by operational factors in nuclear components. At the final stage of the project, the report related to methodology for evaluation of fatigue resistance of welding seams, their durability and determination of weld joint coefficients, taking into account the given strain values, was prepared. The results of the experimental data have been included in MatDB database.

In 2015, researchers of the Laboratory together with the team of the Laboratory of Nuclear Installation Safety launched the European Union financed programme **Horizon 2020** project **INcreasing Safety in NPPs by Covering gaps in Environmental Fatigue Assessment, INCEFA-PLUS.**

The objective of the project ***INCEFA-PLUS*** is to obtain new experimental data and submit recommendations by evaluating fatigue induced degradation in the nuclear reactor operating conditions. The impact of strain and stress mode, hold time, and the surface roughness on the fatigue life of austenitic steels will be investigated. Information about the possible fatigue degradation mechanisms will be obtained after conducting the microstructure and a fractographic research of the tested samples. The obtained experimental data will be standardized and presented in the online fatigue strength database.

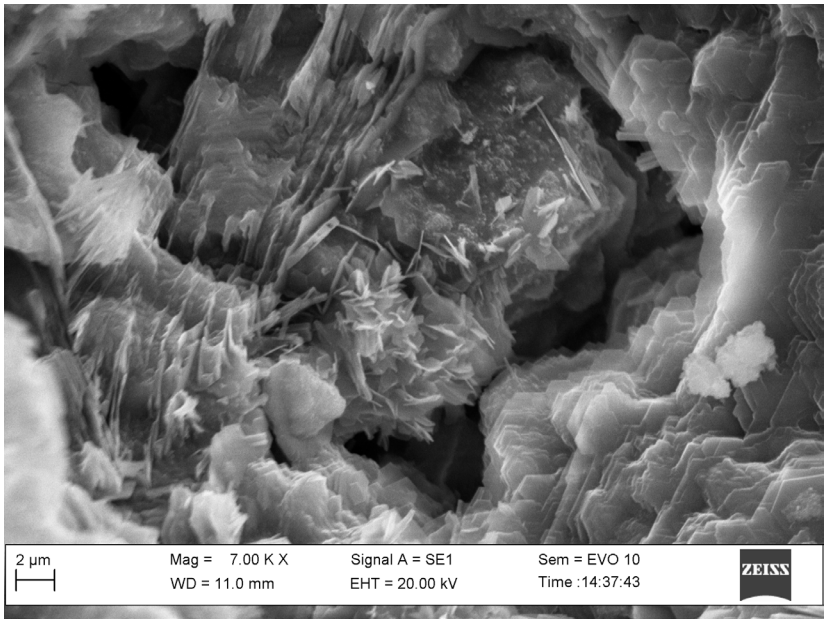
The research will seek to fill in the current gaps in the existing data: create fatigue assessment procedures that would as much as possible comply with the real NPP operational conditions. During the project, a modified environmental fatigue assessment procedures will be created, which will allow more accurate estimation of the mean strain, hold time and surface roughness influence. This will enable better management of nuclear facility components ensuring long-term safe operation of the NPP.

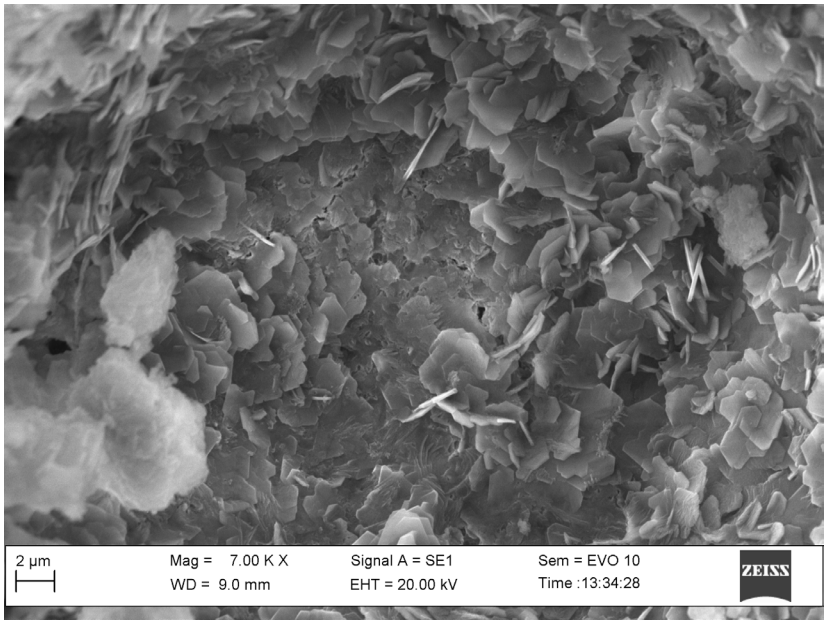
DEVELOPMENT AND RESEARCH OF MULTIFUNCTIONAL MATERIALS AND COMPOSITES

In 2015, a subsidy-funded scientific ***Research of impact of nano-sized modified admixtures on the structure of composite materials*** has continued. The work aims at investigating the structure of natural and synthetic layered nano silicates and optimizing the modification methodology; it also seeks to research the impact of modified silicates and complex nano-sized

admixtures on morphology of cement composite materials. This year's work objective was to investigate the dependence of structure changes of the cement composition with nano admixture – organically modified layered nano silicate – on several factors: nano silicate preparation, its concentration and concentration of the used organic modifier. Several modified montmorillonite dispersion methods have been investigated, as well as their influence on morphology of dispersed particles. Applying X-ray diffraction analysis, scanning electron microscopy, and nitrogen adsorption/desorption research methods, modifier and nano silicate concentration in cement matrix was optimized. Seeking to replace the part of cement in the composition by modified montmorillonite, an optimal ratio of concentrations of modifier and layered nano silicate montmorillonite was set.

The obtained results are an important step in the development of composite material, the components of which will be replaced by alternative and environmentally friendly materials, yet the structural properties of the material will remain unchanged.





SEM images of cement with modified nanofiller

TESTING OF MATERIALS, ASSESSMENT AND ANALYSIS OF THEIR QUALITATIVE INDICATORS

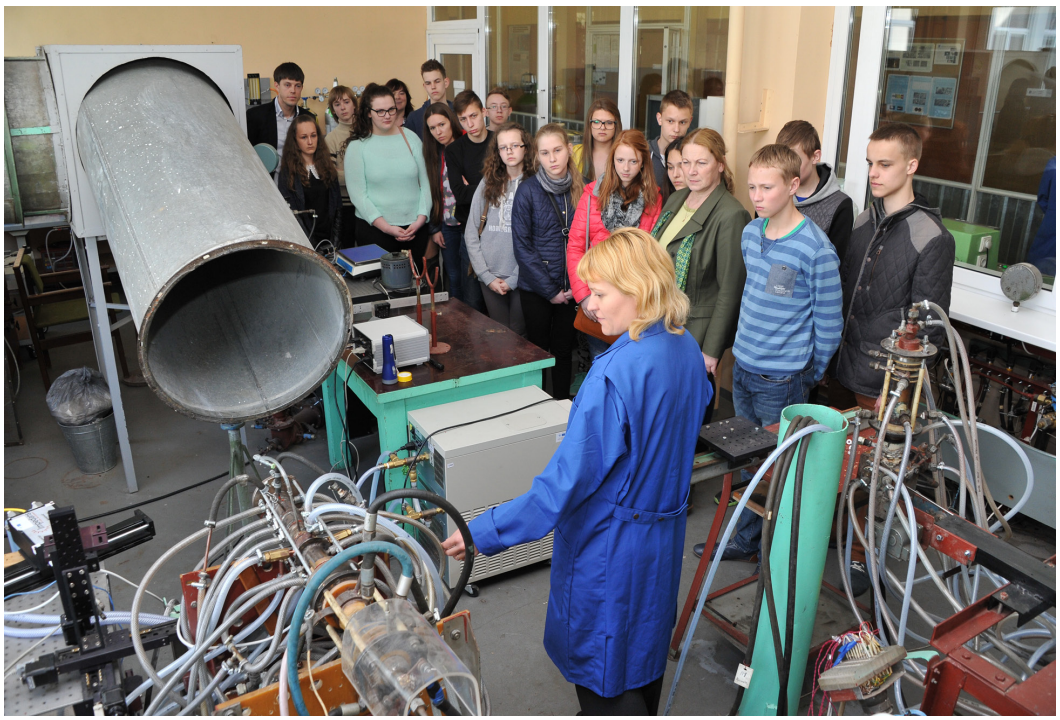
Researchers of the Laboratory provide accredited Laboratory services, and perform material testing and assessment of their qualitative indicators. In 2015, the Laboratory was reaccredited to comply with the LST EN ISO/IEC 17025 standard. As a result of successful collaboration with economic entities, the Laboratory conducts research and provides consults on the quality issues of product manufacturing.

Services to customers. Preparation of samples for plastic pipe testing

The Laboratory is accredited to carry out tests on:

- plastic pipes,
- insulated pipes,
- building mortars,
- fire-resistant materials and products.

In 2015, as a result of the investigations carried out by the researchers of the Laboratory, six articles were published in scientific journals referenced in *Thomson-Reuters* WoS database. The researchers participated at two international conferences.



LABORATORY of PLASMA PROCESSING

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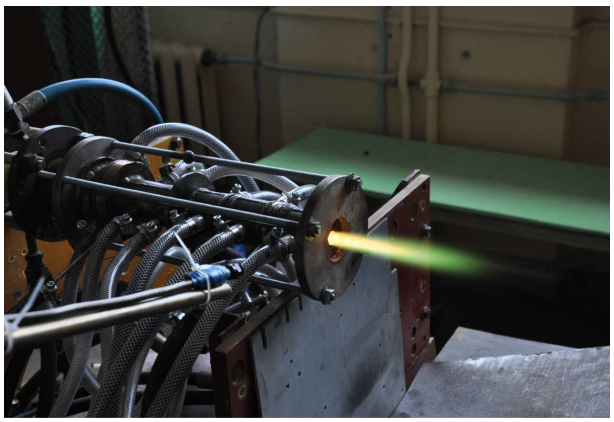
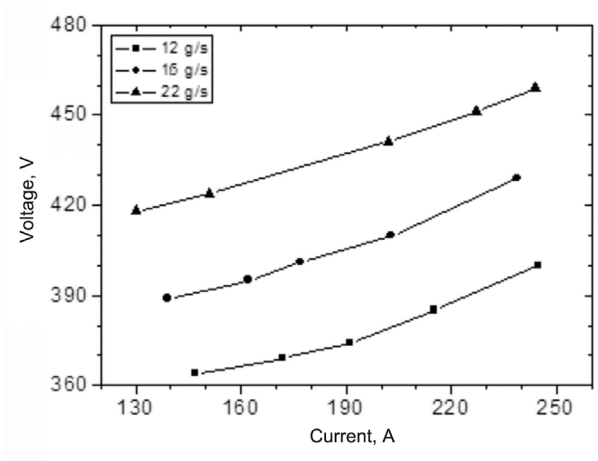
MAIN RESEARCH AREAS OF THE LABORATORY:

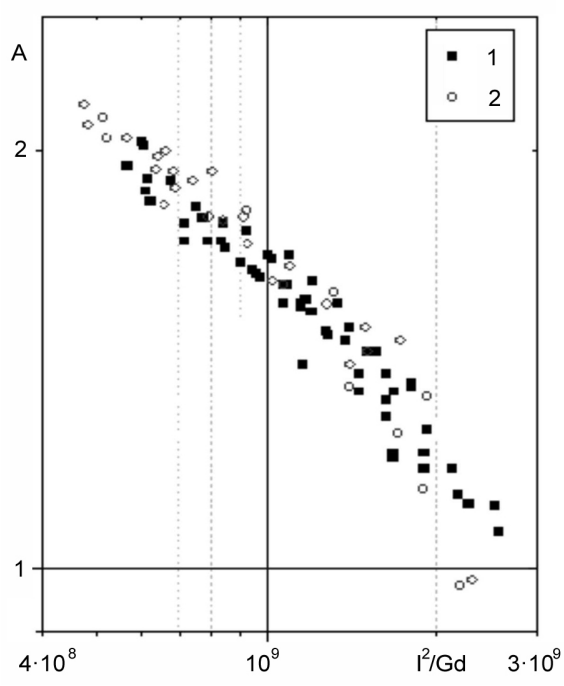
- development and research of DC plasma sources for wide range of applications;
- research of processes and phenomena taking place in discharge channels, exhaust plasma jets and flows;
- diagnostics of plasma and high-temperature flow and development of diagnostic measures;
- research on interaction of plasma jets and substances in various plasma-technological processes;
- research and implementation of plasma neutralization process of hazardous substances;
- synthesis of catalytic and tribological coatings in plasma ambient and analysis of their properties;
- research of thermal and heterogeneous processes for reacting product flowing around catalytic surface;
- formation and modification of constructional material surfaces in plasma;
- synthesis of micro- and nano- dispersed granules and mineral fiber from hardly meltable materials and analysis of their properties;
- generation of water vapor plasma and its application for fuel conversion and neutralization of hazardous waste.



Air plasma jet discharged from direct current linear plasma generator



Current–voltage characteristics of the plasma generator as a function of a heated air flow rate: 12, 16 and 22 (g/s)



Generalized current–voltage characteristics of the plasma generator. 1 – with the additional section, 2 – without the additional section. $A = (Ud_2/I)(G_1/G)^{0.12}(d_2/I)^{-0.5}$

Researchers of the Laboratory of Plasma Processing have over 40 years of experience working in different fields of development, scientific research and application of atmospheric and reduced pressure plasma and are able to successfully simulate new plasma technologies, using plasma equipment, designed in the Laboratory. Different composition gas and its mixtures are used for plasma jets formation. The Laboratory contains pilot production technological equipment, which is used to change and modify mechanical, tribological, chemical and optical properties of layers of different material surfaces. Constant updating of technical base, development and disposal of available analytic equipment enables to perform research of plasma sources, diagnostics of plasma flows and jets, analysis of gas dynamic characteristics and heat-mass exchange.

DEVELOPMENT OF PLASMA SOURCES AND RESEARCH OF PLASMA JET

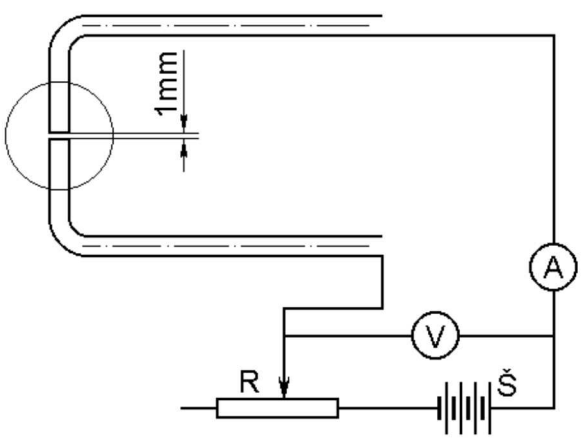
The Laboratory of Plasma Processing develops new plasma generators up to 200 kW of capacity and improves the existing ones. Recently, a new design water vapor plasma generator has been developed. Based on the knowledge of processes, occurring in the reactive discharge chambers, and by means of the theory of similarity of plasma processes, its volt-ampere and thermal characteristics were generalized and stable operation modes were determined.

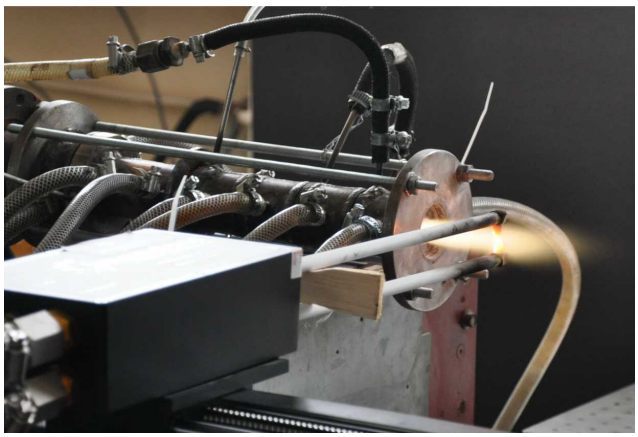
By means of water vapor plasma generator, conversion of gaseous, solid and liquid organic materials into hydrogen enriched synthetic gas was carried out.

DIAGNOSTICS OF PLASMA AND HIGH TEMPERATURE JETS

The Laboratory continues the investigations on heat transfer in plasmatron reactive arc zone, as well as variation of electric arc strength in laminar and turbulent flow regime, the impact of various factors on the characteristics of plasma flows and jets, specific features of arc radiation with different gas flows. Operating modes of linear electric gas arc heaters and reactors and their operating characteristics have been examined, conditions of increase of duration of operation have been determined, arc turbulence and new methods of energy application in plasma equipment have been analyzed.

Formation of high-temperature and plasma jet, its dynamics, heat exchange in the channels of different configuration, their cells, and in elements of heat exchangers are investigated in the Laboratory. Plasma diagnostics is performed in the Laboratory by applying numerical and experimental methods.

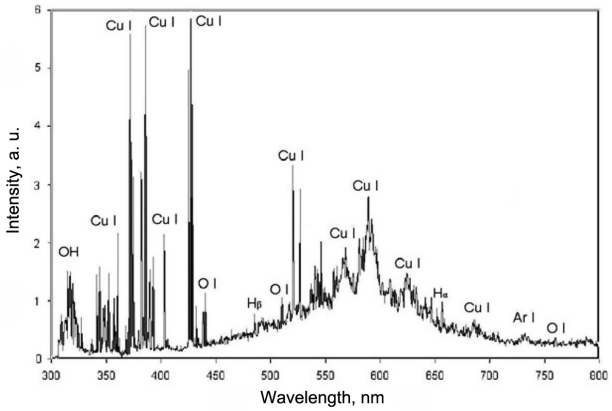




The scheme of electron and heavy particle temperature measurement by double Langmuir probe. Š – power supply, R – rheostat, V – voltmeter, A – amperemeter

A numerical research of heated gas jet in the channel was performed applying hydrodynamics software ANSYS Fluent. The calculation was performed to solve full Navier-Stokes and energy equations based on the dynamic k-ε model. However, the numerical research becomes especially difficult when multiphase jets are flowing, and the solid particles are injected into the jet. This occurs due to specific plasma properties; therefore, numerical research of two-phase plasma jets is performed applying software package Jets & Poudres, adjusted to modeling plasma jets.

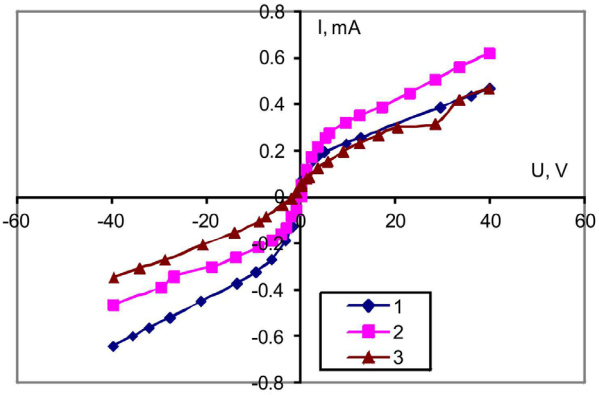
Recently, non-contact methods have been widely applied for plasma diagnostics in the Laboratory. For measurement of temperatures of electrons and heavy particles a double Langmuir probe was used. Chemical composition of plasma flow was analysed using optical spectroscopy method. Its main device is an optical spectrometer AOS-4. It is a very fast optical measurement system that may be used for the investigation of peaks of gas emission spectra in a wavelength range of 250–800 nm. The system is also used to examine



Elemental composition of argon and water vapor plasma jets discharged from 62 kW power plasma generator, identified using optical spectroscopy method

composition of plasma elements and emission spectra.

A high-speed optical camera with CMOS sensor, 1280×800 pixel matrix, which enables high-speed recording and capturing of moving objects at a very high speed, is used for multiphase plasma flow visualization and determination of some dynamic characteristics. The Laboratory uses Phantom Miro M310 high-speed camera.

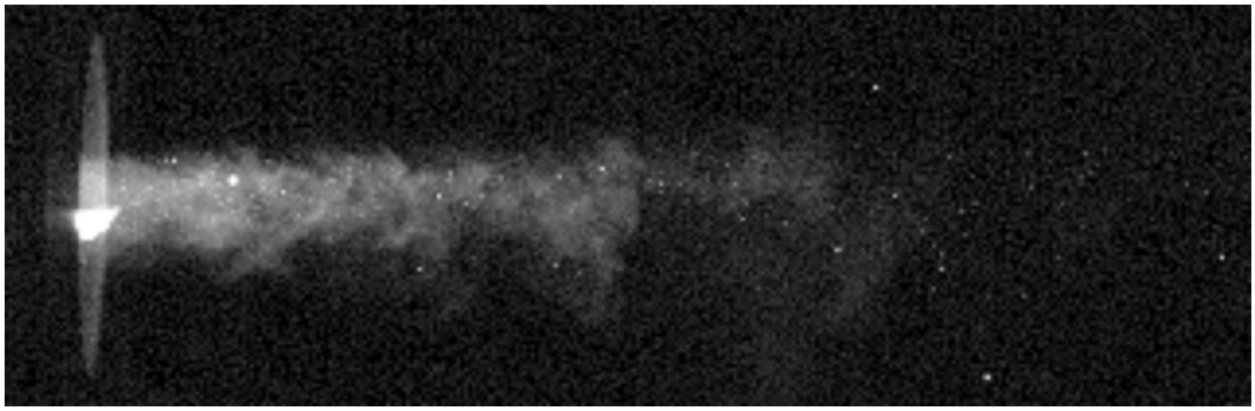


Radial distribution of the double Langmuir probe characteristics at 90 mm axial distance from the outflow nozzle of the plasma torch when the radial position 1 – y = 0; 2 – y = 5; 3 – y = 10 mm respectively

FORMATION OF SURFACE LAYERS OF CONSTRUCTION MATERIALS BY PLASMA TECHNOLOGIES

Synthesis of coatings in plasma flows

Plasma spray technology for surface formation, developed in the Laboratory, was applied for catalytic, tribological and protective coatings formation as well as for hard ceramic coatings, which are employed for improving the operational characteristics of constructional material surface layers in



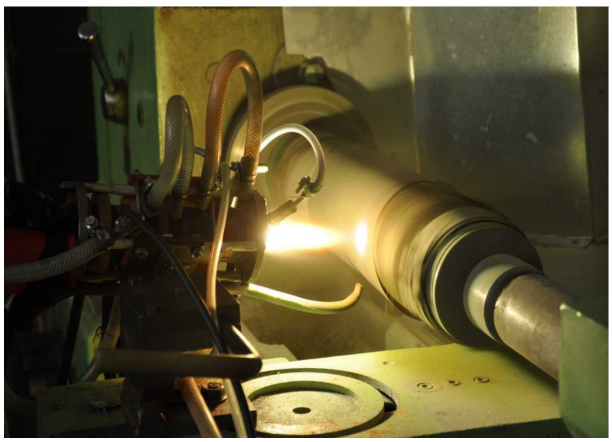
Movement of alloy and granules and the process of mineral fibre formation in supersonic plasma jet, observed by high-speed video camera

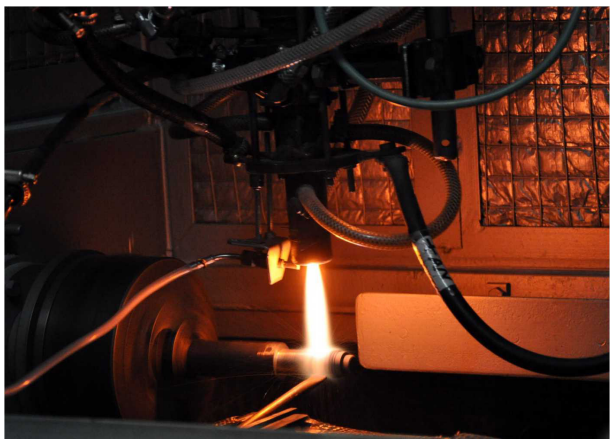
mechanics, chemistry, energy and medicine. These coatings improve the corrosion resistance up to 10^2–10^3 times, significantly decrease the friction coefficient and reduce the mechanical wear. The use of plasma technology decreases the demand for expensive constructional materials, since cheap materials covered with different thickness coatings replace large amounts of used expensive materials.

Having developed a non-equilibrium atmospheric pressure plasma jet with unbalanced temperature of individual components in the equipment presented in Fig., the activated and synthesized materials acquire different energies before reaching the treated surface. Necessary conditions for certain chemical reactions to combine into blocks in both plasma jet and the substratum surface are created. This enables the synthesis of γ phase Al_2O_3 coatings with highly active surface, which is especially relevant in the formation of catalytic coatings. The specific surface area of the coating was further enlarged by heating it at a certain temperature.

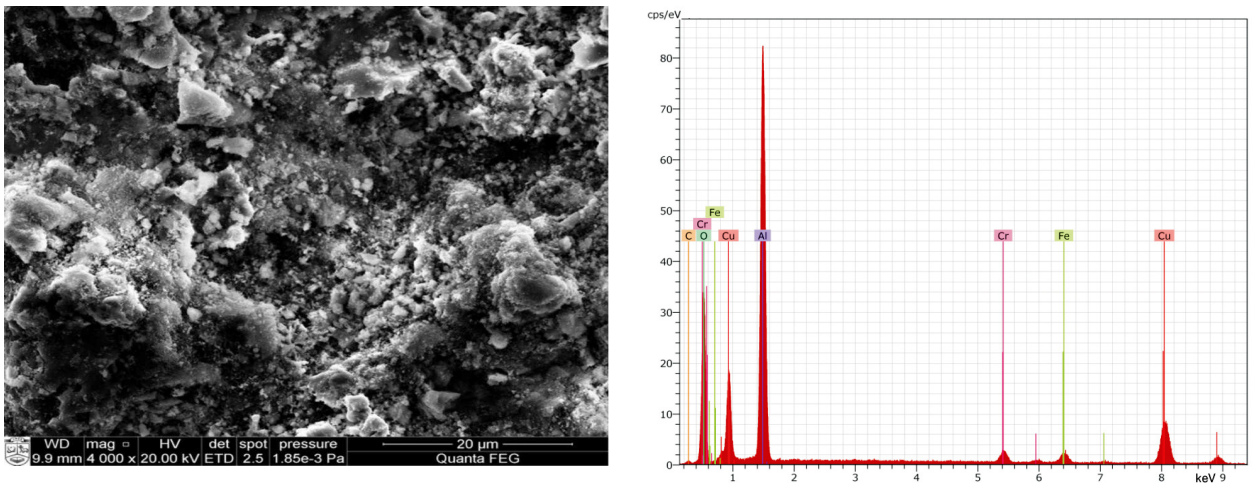
Catalytic coatings

In the fields of science and production, a worldwide attention has recently been given to the renewable energy technologies, hydrogen energy, programs of fuel synthesis and saving, issues related to the reduction of environmental pollution and their solution. All these areas require special purpose and composition catalysts that are used in approximately 70% of chemical reactions carried out worldwide. The production of the up-to-date catalytic reactors is a time and finance consuming chemical process performed by precipitating platinum group metals. For this reason, the catalytic reactors are expensive; their ceramic substrates are non-durable, and the meshes often melt and block the reactors due to poor thermal conductivity. In the new generation of catalytic neutralizers, a metal substrate is substituted for ceramic one, and noble metals are replaced by cheaper metal oxides, zeolites and other materials that are successfully used as effective catalysts.





Formation of various metal alloys in air plasma at atmospheric pressure



Catalytic Al_2O_3 + Cu+Cr_2O_3 coating (on the left) and its elemental composition (on the right)

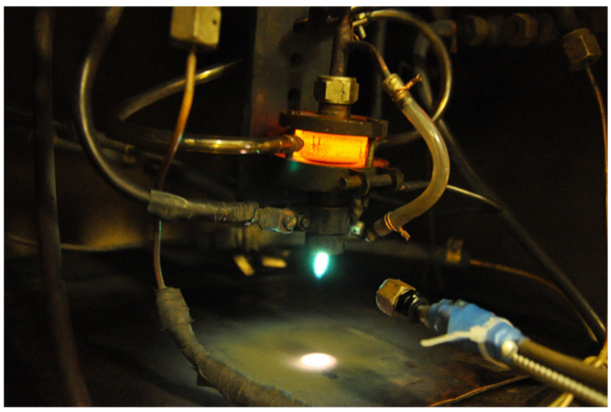
The mass and heat transfer processes taking place in the catalytic reactors made of coatings were examined using the equipment for studying catalyst coating characteristics developed in the Laboratory. Gas with CO concentrations, characteristic of internal-combustion engine, is emitted, and the temperature necessary for catalytic oxidation of the pollutant is reached when the combustion products mix with an oxidant in the air.

For the purpose of the work, the methodology for the research of dynamic and thermal characteristics of gas in the boundary layer zone was developed; the equipment and facilities for examining the jet structure were assembled. The distribution of velocity, temperature and substance concentration of the reactive gas next to the catalytic wall and the heat-mass exchange coefficients of the jet and the wall were established.

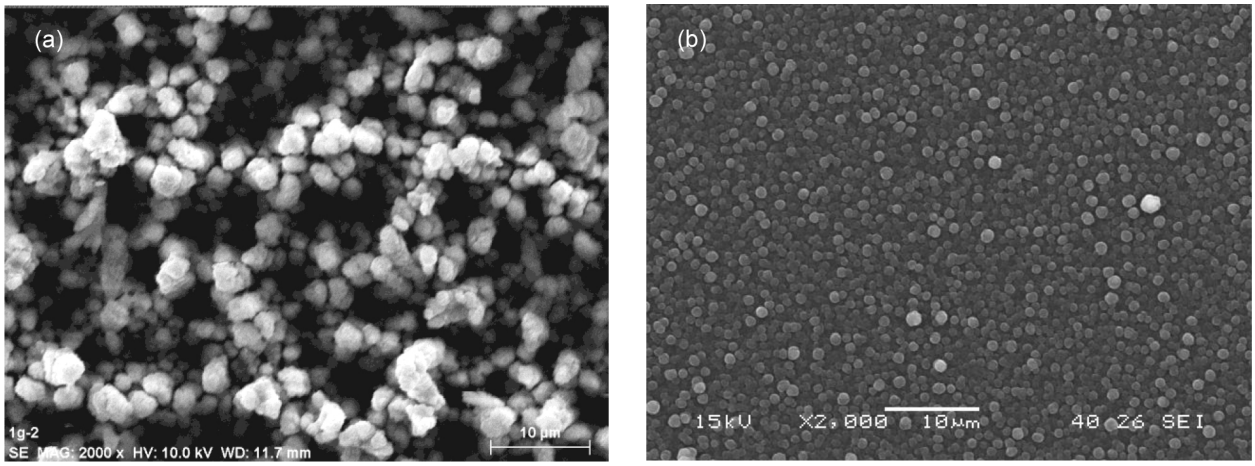
On the basis of metal oxide catalytic coatings, formed employing plasma method, catalytic reactors efficiently reducing the emission of CO, SO_2, NO_x, HC and other pollutants have been developed. By the catalytic combustion behavior, these reactors are very similar to the ones composed of noble metals. The work related to this issue continues in accordance with the project of the Baltic Sea Region Program 2007–2013. Presently, an innovative efficient catalyst for sulphur compounds oxidation is being developed on the basis of TiO_2.

Carbon derivative coatings

Technological modification of surface layers of constructional materials by forming multifunctional coatings is widely applied in surface engineering. One of the possibilities of using plasma technology is the synthesis of plasma polymers. Plasma polymers are thin membranes precipitated by plasma method that may be applied in a wide range of fields: microelectronics, medicine, biotechnologies, manufacturing of semiconductors, etc. Plasma polymers are usually synthesized in a vacuum, but their structures have not been thoroughly studied yet. Due to the low price and good mechanical properties (resistance to corrosion, strength, small autonomous mass, small irrigation angle), hydro, halocarbon polymers and hydrogenated carbon films or their groups compete with the best up-to-date materials and alloys. After evaluation of the situation in the field of plasma polymer synthesis and research, it should be noted that plasma polymerization process requires more detailed knowledge, especially about the influence of coating parameters on the obtained plasma polymer properties and the stability of their time and temperature. One of the plasma polymer groups is innovative materials composed of plasma polymers mixed with metals or ceramics. Such composite materials form a new class of



Operating carbon coating synthesis facility generating argon/acetylene plasma



Morphology of amorphous graphite-type coating surfaces after nanosecond long radiation exposure

coatings, made of composites and non-composites, and are characterized by a variety of electric, optical and mechanical properties. The developed plasma polymers are mostly used as solid and protective coatings. The application of carbon derivatives for polymer synthesis is currently expanding.

Although the plasma coating formation process in the atmospheric pressure has been widely used in practice for a long time, yet, it has not been fully investigated in terms of physics. It is claimed that the chemical, physical and mechanical properties of the coating as well as its composition and structure are affected by about 50 factors. The prevailing ones are the following: composition of initial materials, dislocation of materials introduced in plasma jet, construction of plasmatron, working characteristics, distance from plasmatron to substrate, temperature, pressure and the type of working gas. Currently, a great deal of attention is directed towards developing solid carbon coatings of various composition and properties on different surfaces (steel, Al_2O_3, quartz glass, etc.) and investigating their properties by available methods.

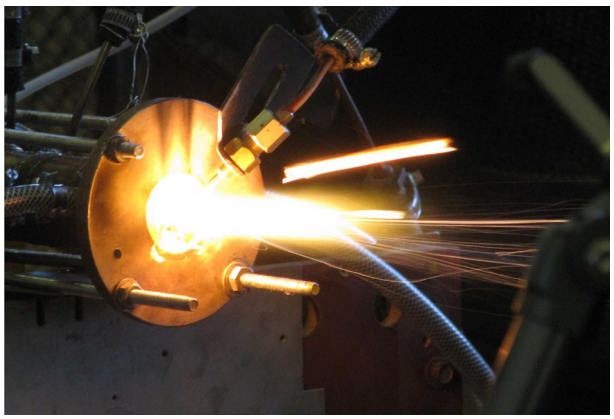
To carry out the mentioned work, two plasma systems for synthesis of solid ceramic and diamond coatings were developed. They are equipped with modified plasma generators that supply non-equilibrium plasma jet. The devices operate in the ambient at the atmospheric and reduced pressure of gas, such as nitrogen, argon, hydrogen, acetylene, propane-butane and their mixtures. The coatings on the surfaces of stainless steel, quartz glass and silicon, obtained during the process of synthesis, are characterized by good properties of adhesion. The SEM, XRD, IR and Raman spectroscopy methods were applied for determining the following factors: the coatings surface structure, the size, shape and composition of their particles, their dependence on the composition of gas, constituting and transporting plasma, as well as the place and means of gas introduction into the plasmatron. It was noticed that all spectra of IR photoconductance and reflection have relations common to CH_x, OH, CO, CO_2 and C=C groups.

Following the performed research, the synthesis of supercondenser electrode coatings was realized, and carbon derivative coatings were obtained by developing them in the atmospheric-pressure plasma in argon/acetylene ambient. The electrical characteristics of the coatings enable increasing the capacity of supercondensers presently used in practice.

MELTING OF CERAMIC MATERIALS AND SYNTHESIS OF HIGH-TEMPERATURE METAL OXIDE FIBER

Traditional technology and equipment presently used to produce mineral fiber require continuous operation process, complex and expensive alloying furnaces and insulation materials. The quality and composition of fiber produced traditionally are also limited by the melting-point of raw materials: this method does not allow for production of high-temperature thermal insulation fiber, which is more and more often used in various fields.

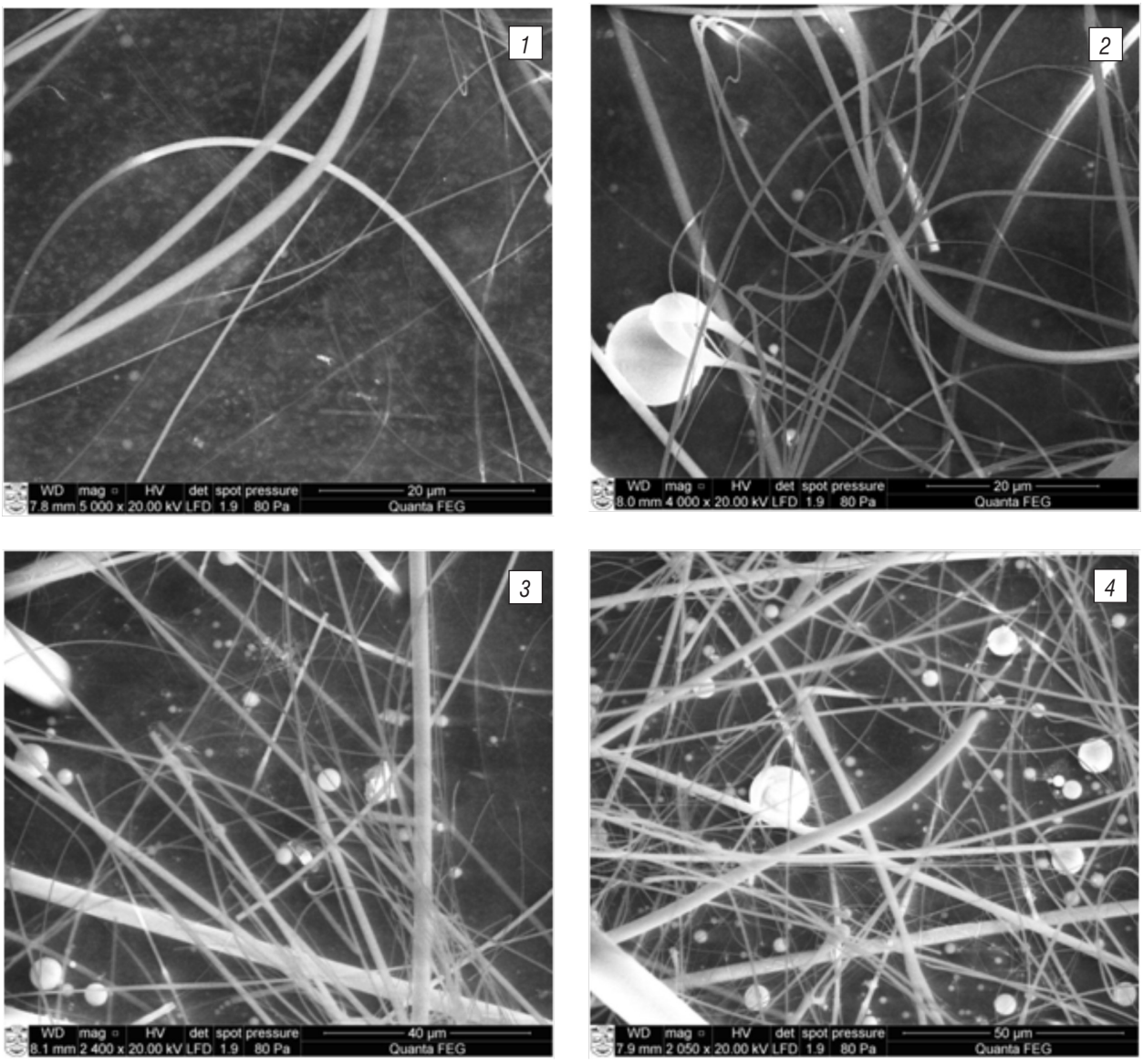
Plasma technology is the only alternative to obtain a high quality high-temperature fiber. Plasma deposited fiber has unique properties such as resistance to high temperature, low thermal conductivity, and high chemical stability. By melting and stringing ceramic materials and forming mineral fiber, an experimental plasma device with 70–90 kW capacity plasma generator has been developed at the Laboratory of Plasma Processing. It enables to form a splint from dispersed particles, using air as plasma forming gas and auxiliary gas mixtures. Cheap and widely spread in nature ceramic materials (quartz sand, dolomite, clay, aluminum oxide, industrial



Operating mineral fiber synthesis facility

ceramic waste, etc.) are used as raw materials for producing heat resistant ceramic fiber.

After conducting experimental and numerical research, it was determined that dynamic and energetic characteristics of plasma jet have major impact on the plasma process of pulping ceramic materials. Since melting temperature of ceramic materials reaches up to 2500 K, the temperature of plasma jet inflowing into the reactor should be 2500–3000 K, whereas velocity – 700–1000 m/s in order to completely melt and pulp dispersed ceramic particles. The average mass plasma jet temperature and velocity along the length of the reactor channel evenly reduces and changes at the end, respectively, by 14 and 10%, not taking into account plasma generator operating regimes. This enables to easily regulate plasma jet parameters in the reactor chamber. After getting physical explanation of the mechanism of ceramic fiber formation in plasma-chemical reactor, it was determined that melting of particles occurs in the reactor channel, whereas formation



SEM images of zeolite fiber gained at different plasma flow velocities: 1 – 1600 m/s, 2 – 1500 m/s, 3 – 1200 m/s, 4 – 1000 m/s

of fiber elements, which lasts 4–10 ms, occurs behind the reactor limits. After injection raw material and dispersed particles into the reactor, heat exchange occurs not only between plasma jet and reactor walls, but also among dispersed particles, which has impact on the reduction of plasma jet temperature. It was investigated that heat exchange of plasma jet and dispersed particles is more intensive the greater is the concentration of particles in the jet and the smaller their measurements are. With increase of concentration of mass cold dispersed particles in plasma jet from 6 to 24%, the heat flow into the reactor wall reduces from 6 to 31% due to intensive flow heat transfer to particles.

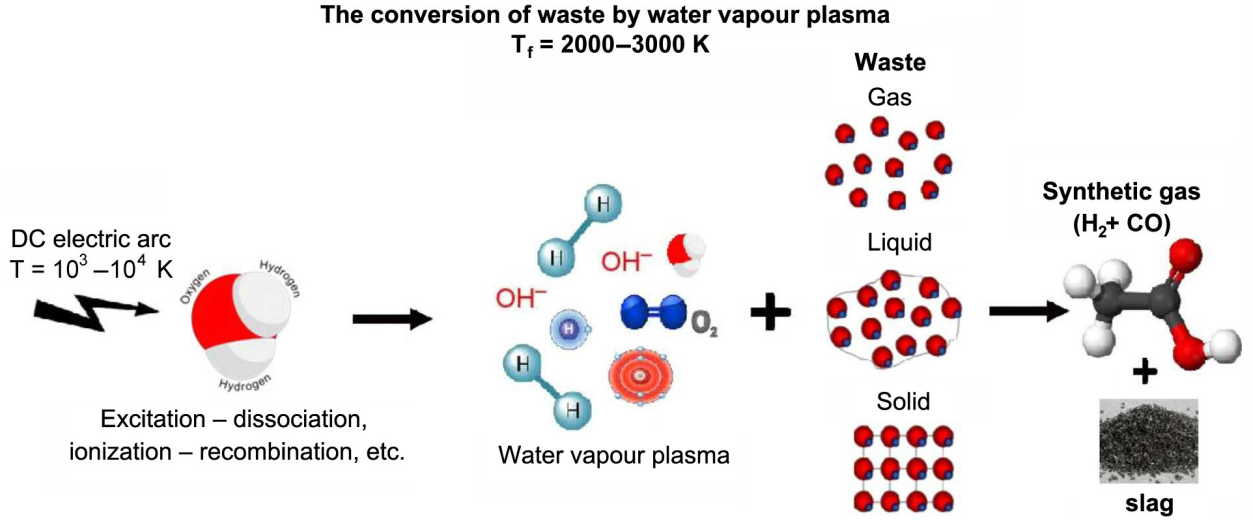
Plasma jet velocity is one the main factors conditioning the quality of ceramic fiber since with the increase of velocity of plasma jet discharge from the reactor by 60%, the developed fiber yield increases by 5%, whereas the fiber diameter comprising the splint and granular amount in it reduces.

The derived fiber is irreplaceable in the production of muffle furnaces, MHD generators and blast-furnaces, and due to splendid sound isolating properties – for sound isolation as well. The ceramic fiber can also be suitable in manufacturing of different filtrating materials, also as constructional, concrete solidifying material, whereas certain composition ceramic splint may serve as a catalyst.

WATER VAPOR PLASMA TECHNOLOGY

Rational exploitation of natural resources and environment protection from pollution by industries, household, medical waste are important tasks of the contemporary industry; it is likewise important to search for alternative energy resources. Decontamination of gaseous, liquid and solid waste is carried out by employing various methods. The hazardows waste can be disposed reducing the emission of pollutants into the environment, however the most rational way is to recycle them and get new useful products. Decomposition of different types waste with plasma method, due to unique plasma properties, it is characterized as an extremely environmentally friendly process. Plasma process uses water vapor, which is a coolant, and raw material, while in this plasma, practically all endothermic reactions can be carried out, the most persistent chemical compounds can be broken down to atoms; and by such water vapor plasma technology, synthetic gas ($CO + H_2$) can be derived by decomposing organic waste.

The process and efficiency are determined by the device structure, technical characteristics and plasma jet parameters. Scientific literature lacks data about heat transfer in plasma-chemical reactors, mechanism of electric and thermal processes and interaction of plasma flow with treated materials. Therefore, the tasks of performing research are to model and construct a plasma-chemical reactor, designed for gaseous, liquid and solid waste decomposition and reveal mechanism for jet interaction with decomposable materials, investigate elemental composition of the resulting products, assess efficiency of the process. When the temperature is high (starting at 4000 K), water vapor mass enthalpy is about 6 times greater than air enthalpy. At high temperature, water vapor decomposes into oxygen, hydrogen and their compounds, which react in plasma-chemical reactions. Extremely rapid chemical processes occur in water vapor plasma, when reactive elements

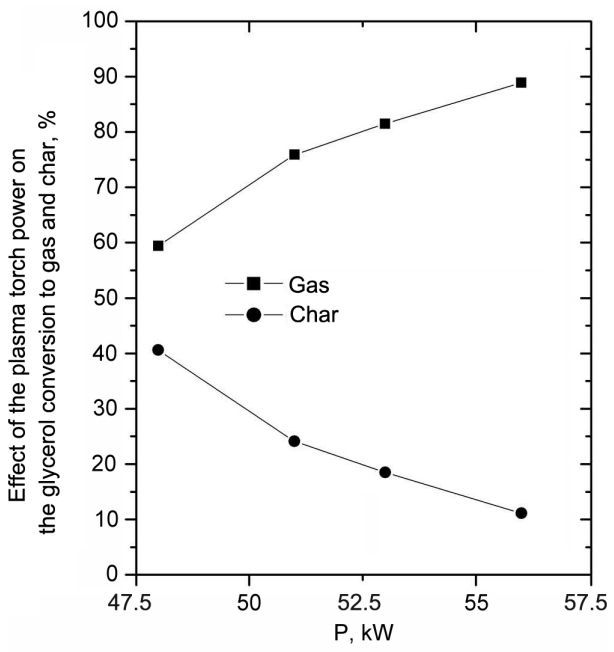


Simplified mechanism of organic waste conversion

Water vapour plasma torches for the organic waste treatment. A – the conversion of hydrocarbon gases, B – the conversion of liquid and solid wastes

Table. The composition of produced gas after the glycerol treatment

G_{H2O}, g/s	G_{C3H8O3}, g/s	$H_2O/C_3H_8O_3$	P, kW	Gas,%	Gas, (only H_2+CO), %	Solid substances, %	Water, %
2.63	2	1.3	48	54	38.9	16	29
3.51	2	1.75	51	58	40.6	8	33
3.71	2	1.85	53	59	42.4	6	35
4.48	2	2.2	56	57	40.3	3	39
3.71	4	0.9	53	64.8	45.8	18.5	17
4.48	4	1.1	56	61.8	43.3	17	21



Effect of the plasma torch power on the glycerol conversion to gas and char

H and O are formed. Due to this flow property, hydrocarbons introduced into water vapor plasma are decomposed very efficiently. This technology may be applied for decomposition of waste and environmentally hazardous materials or turn them into synthetic gas during the conversion.

Various experiments of organic material decomposition were carried out. Chosen gaseous substances – hydrocarbons, liquid materials – toluene, glycerol, and solid materials – wood granules were introduced into the plasma-chemical reactor to perform the conversion.

The obtained results and conclusions

Linear direct current water vapor plasma generator with step formed electrode was designed and manufactured. Plasmatron was tested at a variety of modes by supplying air and overheated water vapor.

Thermal and electric properties of water vapor plasma generator were determined. It was established that the flow of discharged from plasmatron jet is turbulent. Heat transfer

in water vapor plasmatron between electric arc, heated gas and electrode walls generally occurs by means of convection.

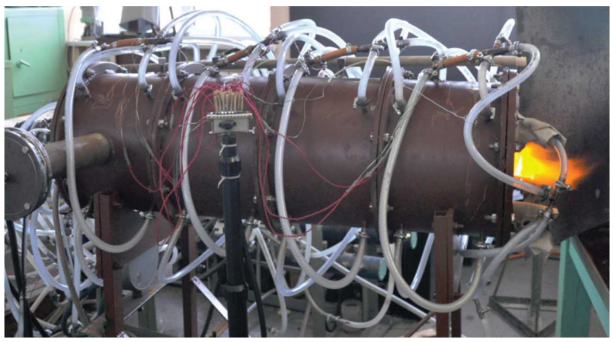
Parameters of plasma jet of gas heated in plasmatron were determined: flow of heated water vapor 2.63–4.48×10^{-3} kg/s, average temperature of plasma jet 2400–3300 K, average flow velocity 210–600 m/s, efficiency factor 0.7–0.78, Reynolds number 2750–6000.

After diagnostics of water vapor plasma jet performed by optical emission spectrometer, the results confirmed that water vapor in plasmatron discharge is dissociated and is comprised of OH, H_2, O (I), Ar (I) elements. Detected atomic hydrogen peaks H_α (656.2 nm), H_β (486.1 nm) and H_γ (434.1 nm) demonstrate that hydrogen atoms in water gas plasma are in excited state and are chemically very active. Spectral peaks of metal particles Cu and Fe are very intensive and demonstrate significant erosion of plasmatron electrodes, and care should be taken to reduce it.

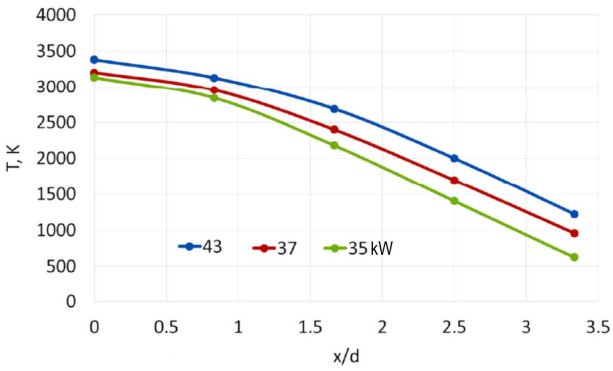
After analyzing formation of active radicals in water vapor plasma by numeric methods, it was determined that with the increase of temperature up to 4100 K, dissociation of water vapor occurs. Concentration of water vapor decreases to 1%, while concentration of atomic elements H and O comprising it constantly increases.

The tests of gaseous, liquid and solid material conversion showed that in the ambient of water vapor plasma, synthetic gas H_2+CO could be obtained. Its concentration in the general mass balance of the reaction products comprised over 55%.

After performing the tests on conversion of various organic waste, it was determined that the maximum efficiency (67% H_2) is achieved by decomposing gaseous waste. Decomposing liquid and solid waste, 34–27% of H_2 was obtained, since extra energy had to be provided for the gasification.



Plasma torch in operation



Distribution of plasma temperature depending on the power of the plasma generator

PROJECTS IMPLEMENTED IN THE LABORATORY

In 2015, researchers of the Laboratory participated in international projects and programs:

- EU support measure *Promotion of high international level scientific research* project ***Development of innovative thermal decomposition technology and its application for utilization of wastewater sewage (INODUMTECH)***. During the project, it is planned to develop a sample prototype of 100 kW power gasification process-technology designed to utilize the amount of sludge comprised in wastewater treatment enterprises of small Lithuanian towns. The project idea is implemented together with the Laboratory of Combustion Processes, Laboratory of Nuclear Engineering and Laboratory of Heat-Equipment Research and Testing.

- Started investigations of atmospheric plasma and high temperature gas flow dynamic and thermal characteristics.

- 2012–2016 long-term institutional scientific research and experimental (social, cultural) development program. The title of the work is: ***Experimental and numerical investigations of combustion and plasma processes for enhancement of energy generation technologies and renewable biofuel and for reduction of environment pollution;*** for implementation of the program, two work groups with separate goals, investigation of combustion and investigation of plasma processes, have been designated.

- 2013–2016 international activity *COST TD1208 Plasma in Liquids*. The researchers of the Laboratory implement an individual project in this activity ***Application of water vapor plasma for liquid waste processing***, through implementation of which, new plasma-chemical reactor

LEI representative Viktorija Grigaitienė presented a poster ***Water vapour plasma technology for liquid waste treatment***

will be developed for decomposition of organic materials of various composition and converting them into synthetic gas with increased amount of hydrogen. Researchers from 26 European countries participate in the activity.

The personnel of the Laboratory of Plasma Processing consists of 9 scientists with a doctoral degree, 1 junior researcher and highly experienced ancillary personnel: 3 engineers and 3 highly qualified foremen.

In 2015 the doctoral dissertation *Research on thermo-hydrodynamic processes and phenomena in water vapour plasma flow during the conversion of hydrocarbons* has been started by PhD student D. Gimžauskaitė.

In 2015, the scientific and technological production of the Laboratory was presented at international (4 papers) and national (2 papers) conferences, 5 scientific articles were published in the journals listed in *Thomson-Reuters* database ***Web of Science Core*** Collection.

CENTER for HYDROGEN ENERGY TECHNOLOGIES

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MAIN RESEARCH AREAS OF THE CENTER:

- research in the field of hydrogen energy technologies:
  - synthesis of hydrogen separation membranes and analysis of their properties;
  - hydrogen production using water activated metals and nanoparticles of their alloys;
  - synthesis and analysis of properties of metals and their alloy hydrides designed for hydrogen storage;
  - synthesis of hydrogen fuel cell elements anodes/electrolytes/cathodes applying physical vapour deposition technologies;
  - analysis of properties of NiMH battery electrodes.

In 2015, project ***Research on hydrogen production for portable energy storage devices, using water and plasma activated nanomaterials and metal/metal hydride reactions***, financed by state subsidies, has been launched.

This work is related to innovative hydrogen energy concept, when *in situ* hydrogen generation, if needed, is implemented during water reaction with metals with a more negative redox potential than hydrogen with regard to water:

$$M + xH_2O \rightarrow MOx + xH_2$$

$$M + 2xH_2O \rightarrow M(OH)_2x + xH_2;$$

where M – metal or metal alloys.

For this purpose, one of the potential metals is aluminum. This is a non-toxic, relatively inexpensive and widely available metal. Upon reaction of 1 g of aluminum with water, theoretically, the amount of released hydrogen is 1245 ml. Although aluminum-water reaction is thermodynamically possible, under normal conditions, it does not occur due to aluminum surface oxidation because of interaction with atmospheric oxygen. A thin 5–10 nm thick Al_2O_3 film forms on the surface, which passivizes the metal and prevents aluminum/water reaction. Water molecules do not penetrate through this barrier. One of the simplest ways to make aluminum react with water is a significant increase of the pH value. However, hydrogen generation in strong alkaline conditions may eventually damage and destroy fuel element membrane. One of the most effective methods designed for aluminum modification is forming alloys with other metals (Al + Ga, In, Sn, Bi, Ni, etc.); yet, this significantly increases the cost of the technology and causes additional impurities. Production of hydrogen, if needed, can also be realized through hydrolysis reaction of magnesium hydride (water reaction with magnesium hydride), during which magnesium hydroxide and hydrogen are formed, and heat is released.

The main originality of the research is related to the use of low temperature plasma technology applied to activate aluminum and to obtain Mg-MgH_2 nanocrystalline structures. The obtained materials due to their structural features (nanocrystalline or amorphous structure, a large number of defects, texture) have unique adsorption/desorption properties and are real candidates for development of the next generation of hydrogen-generating materials.

During the research, Al and Mg powders were modified in hydrogen gas plasma following the presented scheme (Fig. 1). In both cases, the powders were positioned in a vacuum chamber under magnetron, which was used as a plasma generation source. Rotary and diffusion pumps connected to the vacuum system allow achieving initial pressure 1.5×10^{-2} Pa in the chamber. The working pressure used in the chamber was 13 Pa.

Hydrogen gas is generated during the reaction of activated powder (Al or Mg/MgH_2) with water passing through

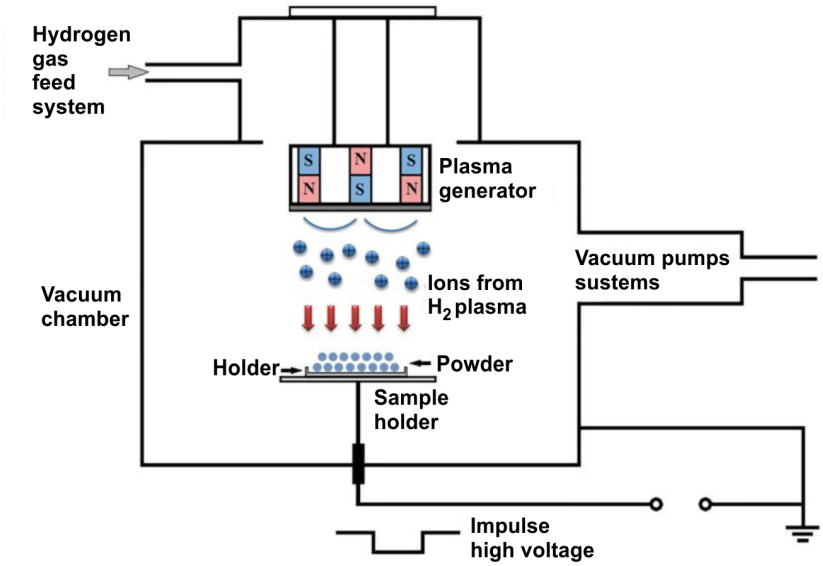

Fig. 1. Al powder modification and Mg powder plasma hydrogenation system

the filtering system (Fig. 2). Removal of undesirable substances from hydrogen gas does not only ensure a better fuel element performance, but also a more durable lifetime of electricity generating element. Measurements of basic parameters of generated electric energy are made by *Horizon Energy Monitor* energy meter, to which a known size (resistance) load is connected.

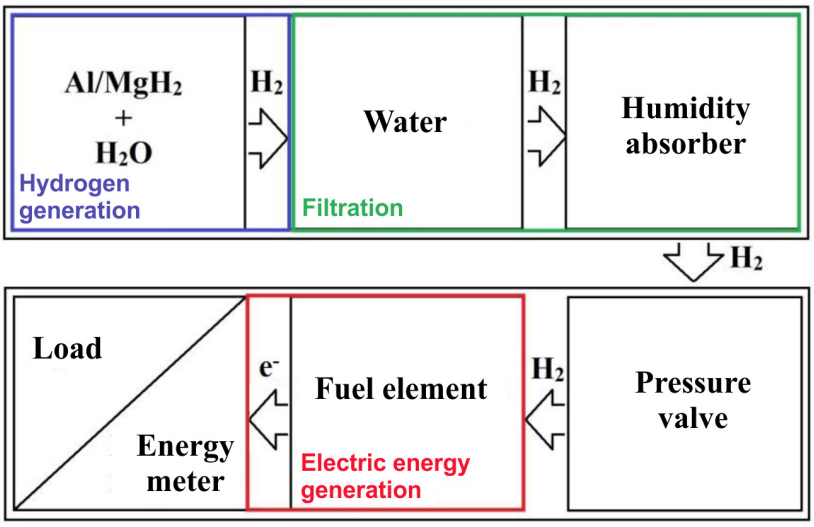

Fig. 2. Scheme of electric energy generation using Al/Mg reactions with water

Main conclusions of the works performed in 2015: the impact of low-temperature hydrogen plasma on aluminum and magnesium powders leads to structural changes in the surface of the analyzed samples. Even slightest plasma-induced defects and stoichiometric changes of a thin surface layer affect productivity of the investigated powder reaction with water. It is worth noting that after H_2 gas plasma exposure to XRD diffractogram, emergence of AlH_3 phase was not observed. However, hydrogenation of Mg powder is identified by a small MgH_2 peak. Thus, Al powder compared to Mg almost does not undergo any volumetric changes in the structure.

Efficiency of electric energy generation process does not only depend on modified surface structural features (in the case of Mg also content) of the materials used in the plasma, but also on other relevant environmental conditions (temperature of water used in the reaction, pH value, powder and water ratio). In this project, electricity generation works are carried out in cooperation with JSC *Inovatas*.

In 2015, the Center completed participation in EU COST MP1103 activities ***Nanostructured materials for solid-state hydrogen storage*** and actively participated in the research of 32nd group of International Energy Agency Hydrogen Implementing Agreement (IEA HIA) *Hydrogen based energy storage*. The Center continues joint work with the IFE (Norwegian Energy Institute) and the University of Stockholm (Sweden) researchers, characterizing and modifying metal hydrides used in NiMH batteries designed for integration of renewable energy sources into the grid.

In 2015, Center researchers have completed work on the project *Modification of expanded polystyrene surface properties using nanocrystalline oxide coatings* (NANOPUTPLAST; contract No. VP1-3.1-MES-10-V-02-019). During the research, nanocrystalline TiO_2 and SiO_2 coatings were synthesized on the expanded polystyrene surface (Fig. 3); three new technologies for nanocrystalline particle synthesis and feeding into the expanded polystyrene volume were developed, and three patent applications were submitted to the State Patent Bureau of the Republic of Lithuania.

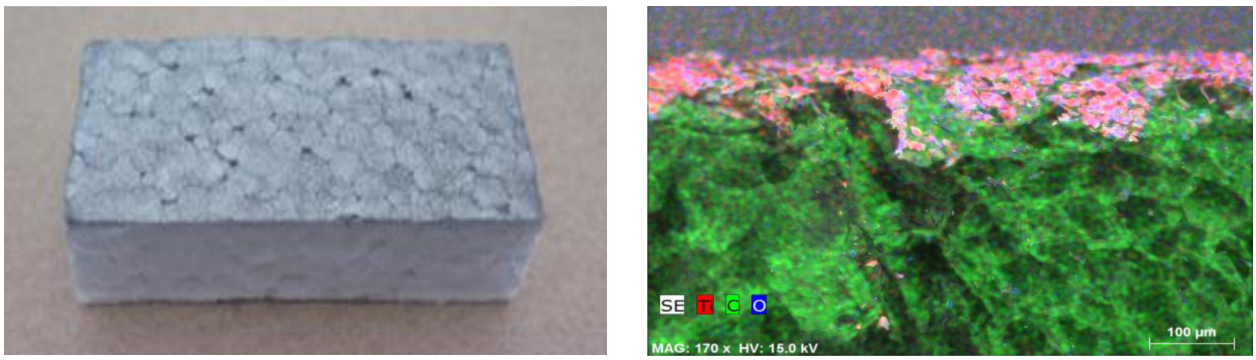

Fig. 3. a) – example of TiO_2 coating, deposited at low (10–11%) oxygen concentrations; b) – SEM/EDS images of TiO_2 coating on expanded polystyrene cross-section

The main conclusions of the work: during plasma activation, the polystyrene surface energy changes. Polystyrene surface turns from hydrophobic into hydrophilic, which makes it much easier to form a coating on the polystyrene surface. After plasma activation, main parameters were determined, with which surface adhesion and hydrophilic properties are preserved the longest (about 48 hrs.). Pressure $p = 1 \times 10^{-2}$ mbar, distance d = 40 mm, working gas – argon, voltage U = 400–450 V. The results of coating formation on the surface of expanded polystyrene showed that it was possible to form both TiO_2 and SiO_2 stoichiometric compounds. In both cases, after forming the coatings, elements uniformly distributed over the surface of the polystyrene. Carrying out experiments of resistance to direct flame, it has been observed that polystyrene without SiO_2 or TiO_2 coatings or in places, where these layers are rather thin, melting begins much faster than in polystyrene with coatings. By comparing resistance of these coatings to the flame effect, it was observed that the polystyrene with SiO_2 coating remains more stable under the same flame effect than that with TiO_2 coating. During the project, it was determined that crystalline anatase phase characterized by the highest photocatalytic activity of all TiO_2 forms can be formed by magnetron sputtering on the heat-sensitive EPS surface without causing damage and maintaining desired content features, while strength of photocatalytic properties of deposited nanocrystalline TiO_2 coatings can be maximized by selecting optimal O_2:Ar gas ratio during deposition process. During the project, three key technologies were developed; those related to the expanded polystyrene surface activation and shaping of oxide-based protective coatings, synthesis of nanoclusters on non expanded polystyrene and synthesis of nanoclusters on water-soluble substrates. All of it have been submitted as patent applications to the State Patent Bureau of the Republic of Lithuania. The third technology related to synthesis of nanoclusters is now under testing for synthesis of Ni clusters, designed for NiMH batteries (together with partners in Sweden); the obtained nanoclusters have also been presented to 3D printer users in Lithuania, and the possibility of trying more metal-based nanoclusters in real 3D printing processes was considered.

In 2015, the researches of the Center published two research articles in journals listed in Thomson-Reuters WoS database and presented three papers at the international conferences.

LABORATORY of NUCLEAR ENGINEERING

MAIN RESEARCH AREAS OF THE LABORATORY:

- Investigation of thermal processes in energy equipment components:
  - Research of heat and mass transport in the equipment of biofuel-fired objects; reduction of emission along with flue gases resulting from biofuel combustion using electrostatic precipitators;
  - Forced and mixed convection, turbulent and transition flow regimes, one and two-phase flows, influence of channel geometry, variable physical properties, roughness, effect of transient conditions and centrifugal forces;
  - Numerical modelling of heat transfer and transport processes in various channels and geological structures;
- Safety of spent nuclear fuel (SNF) management: modelling of fuel characteristics, safety and environmental impact assessment of storage and disposal facilities, normative and legislative base;
- Safety of radioactive waste management: safety and environmental impact assessment of treatment technologies and storage and disposal facilities, normative and legislative base;
- Evaluation of different factors related to decommissioning of nuclear power plants: planning and cost of decommissioning and dismantling; radiological characterization of the area, buildings, systems and equipment; safety and environmental impact assessment of individual facilities; normative and legislative base;
- Assessment of fire hazard at nuclear power plants and other important facilities;
- Research related to construction of new nuclear power plant in Lithuania.

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Researchers of Nuclear Engineering Laboratory together with other laboratories of the Institute coordinate and implement two long-term scientific research and experimental development programs, which were approved by the Ministry of Education and Science of the Republic of Lithuania in early 2012:

- ***Investigation of single-phase and two-phase flow dynamics, heat and mass transfer processes (2012–2016).*** The objective of the programme is to develop research methods and perform investigations of single-phase and two-phase flow structure, heat and mass transfer regularities in dealing with the efficiency of new heat energy production from biofuel schemes, energy and mass flow measurement and heat and mass transfer intensification tasks under transient flow conditions, flow in transition region, impact of physical features and buoyancy forces and vapour condensation processes.
- ***Investigation of nuclear power plant decommissioning and nuclear waste and spent fuel management processes and radiation impact analysis (2012–2016).*** The objective of the programme is to analyse and estimate radiation impact on humans and environment during management, storage and disposal of SNF and radioactive waste by applying numerical and experimental research methods and taking into account the peculiarities of Ignalina NPP decommissioning processes.

RESEARCH OF THERMAL PROCESSES IN ENERGY EQUIPMENT COMPONENTS

Biofuel is rather widely used in many countries for heat and electric power production. It (wood, straw, grain, etc.) is considered a renewable energy source causing the least environmental impact; this is why its consumption increases not only in the newly built, but also in the reconstructed boiler houses in Lithuania. However, one of the major drawbacks comparing biofuel combustion to gas or liquid fuel combustion is quite a large release of solid particles into the environment. With the growing number of devices burning biofuel, the emission of solid particles increases. Due to the harmful impact to the human health, the amount of solid particles in the flue gas of the combustion devices is limited, i.e., various filters that capture these solid particles are installed. The efficiency of cyclone and other mechanical devices capturing solid particles usually used in Lithuania is too small for capturing small particles streaming with the flue gas; by means of electrostatic precipitators, a very high efficiency of gas (flue gas) cleaning can be achieved. While burning fuel, different sizes of solid particles are emitted, and the composition of flue gas changes; due to this, the efficiency of electrostatic precipitators changes. An exhaustive analysis of these factors enables solving relevant issues related to upgrading technologies in the Lithuanian energy sector.

Researchers of the Laboratory in the frame of the project ***Research of local fuel thermal decomposition processes by developing efficient and ecological technologies (2012–2014)***, financed by national research program ***Future Energy*** of the Research Council of Lithuania together with other laboratories of the Institute conducted investigations on cleaning flue gas. During the project, an experimental device was manufactured, and a research was performed. A prototype of the electrostatic precipitator manufactured at the Laboratory was used for the research. Relative concentration of the particles was determined taking into consideration voltage supplied to the electrostatic precipitator when the discharge electrode is positive or negative. The conducted research enabled to determine the efficiency of the electrostatic precipitator.

Researchers of the Laboratory together with other laboratories of the Institute also implemented another project ***Development of Innovative Thermal Decomposition Technology and its Application for Utilization of Sewage Sludge (2013–2015)*** based on the measure of the third priority ***Strengthening Capacities of Researchers Promotion of High International Level Scientific Research*** of the program for the development of the action of human resources approved by the Ministry of Education and Science. Sewage sludge is retrieved as waste in Lithuanian wastewater treatment enterprises. While the infrastructure of wastewater collection and treatment expands, the amount of sludge generated during wastewater treatment increases proportionally. Vast amounts of sludge stored in sludge sites begin to evoke hazard for the environment and contradict sustainable development principles. Therefore, the most effective methods are searched to treat wastewater sludge. One of the most innovative methods

for utilization of waste sludge is its gasification. Applying this technology, a valuable product is released from sludge during thermal decomposition – flammable gas, which may be used in heat and electricity production. Gasification enables to reduce not only the volume of the generated sludge and obtain additional energy, but also to reduce the environmental pollution. During the project, a technological device model of gasification process of up to 100 kW was developed. The model allows operation in automated mode.

During implementation of this project, an experimental research of flue gas purification was performed. The research results demonstrated that when burning biofuel (wood pellets), the greatest part of solid particles with diameters ranging from ~0.4 μm to ~20 μm dominate in untreated flue gases. The largest amount of particles is with the diameter up to ~4 μm. Solid particles from flue gases are cleaned using electrostatic precipitator. When voltage applied to the precipitator was 12 kV, the obtained results showed that the decrease of concentration of solid particles was ~99 %. Experiments with synthetic gases showed that during the experiment, the amount of solid particles gradually decreased, and the lowest concentration was recorded at the end of the experiment. During these experiments, efficiency of 75 % in electrostatic precipitation was achieved in the case of wood gasification, and efficiency of 60 % in electrostatic precipitation was achieved in the case of wood-sludge gasification.

The Laboratory also carries out investigations of heat transfer and hydrodynamics in energy equipment for different purposes (in elements of nuclear reactors, various heat exchangers, etc.). In both laminar and turbulent flow cases, surface roughness, centrifugal and buoyancy forces (mixed convection) can impact heat transfer in many energy installations, which under certain conditions can become a reason for an accident in different installations. Therefore, in order to analyse such problems in depth, the Laboratory performs experimental mixed convection investigations in various channels. In parallel, a numerical investigation is also performed using ANSYS CFD code (ANSYS, USA), which is widely applied in the world for modelling fluid movement and heat transfer in complex two and three-dimensional systems. Taking into consideration the flow mode, various models of laminar, transitional and turbulent transfer are used. Additionally, such research was initiated in geological structures while analysing the possibilities of Ignalina NPP spent nuclear fuel disposal.

*R. Poškas made a presentation at the international conference **Baltic Heat Transfer** (23–27 August, 2015, Tallinn, Estonia)*

In 2012, the Laboratory participating in activity of the project ***Santaka Valley*** by the open access scientific research and experimental development (R&D) center obtained LDA and PIV equipment, designed to investigate flow structure in gas and liquids in a wide range of velocity variation. This equipment can measure flow velocities, pulsations, and vortex rotational frequencies, and it can visualize them, etc. Furthermore, the Laboratory obtained liquid crystal thermography equipment enabling to measure temperature of various objects and variation of temperature of an individual visual part of the analysed object in a remote non-invasive way.

In 2013, according to the European Union structural fund support measure ***Innovation Vouchers LT*** administered by the Agency for Science, Innovation and Technology, researchers of the Laboratory improved the efficiency of UAB Wilara beebread dryer. After experimental research and numeric modelling of air flow distribution, non-uniformity of drying airflow was resolved.

In 2015, conduction of fundamental experimental and numerical research of one-phase flow mixed convection heat transfer and flow structure in a flat channel in turbulent and transitional flow areas continued, and a fundamental numerical research of two-phase flow in a tube bundle

using the ANSYS CFD (USA) software has started.

On September 16–November 1, 2015, A. Gediminskas participated in an internship program at Lund University (Sweden), where he broadened his experience of two-phase flow modelling with supervision of Swedish experts. During the internship, the ANSYS Fluent software was used. The most attention was devoted to the Volume of Fluid method and usage of User Defined Functions.

RESEARCH ON SAFETY OF SPENT NUCLEAR FUEL MANAGEMENT

After the decision to use dry storage facility for spent nuclear fuel (SNF) at the Ignalina NPP in CASTOR and CONSTOR type casks, back in 1997, researchers of the Laboratory started performing studies related to the safety assessment of SNF management, storage and disposal. The Laboratory carried out criticality assessments for casks with SNF under normal operational and accident conditions, variation of radionuclides activity during the storage period, radiation doses on the cask surface and at the specific distance from it as well as temperatures.

Implementing the research on SNF disposal in Lithuania, the Laboratory experts with the assistance of Swedish experts proposed the concepts of deep geological repository in clay and in crystalline rocks for SNF and long-lived intermediate level waste in Lithuania. The concepts on disposal are constantly defined more precisely and optimized taking into account international experience and physical, chemical, thermal and mechanical properties of a specific repository site. While analysing the possibilities of SNF disposal in Lithuania, the cost assessment of geological repository installation was carried out, and generic repository safety assessment was initiated.

The Laboratory together with consortium GNS – NUKEM Technologies GmbH (Germany) implements an extensive project ***Design and Installation of the Interim Storage Facility for RBMK Spent Nuclear Fuel Assemblies from Ignalina NPP Units 1 and 2*** (2005–2015). This project comprises the analysis of all activities related to the design, construction, installation, commissioning, operation and decommissioning of the new SNF storage facility and the performance of all necessary works related to SNF removal, packaging, sealing and transfer as well as operation of the appropriate equipment for implementation of chosen design concept. It is planned to store approximately 200 new type CONSTOR casks with intact and damaged SNF in the new storage facility. Researchers of the Laboratory prepare Environmental Impact Assessment and Safety Analysis Reports of this SNF storage facility (operational time no less than 50 years) and offer support in licensing the storage facility. In 2007, *Environmental Impact Assessment Report* was approved by the Ministry of Environment; in 2009, *Preliminary Safety Analysis Report* (PSAR) was prepared and agreed upon, and the license for construction of the new SNF storage facility was issued by VATESI. In 2010–2011, PSAR Addendum, which presents the evaluation of safety aspects of management and storage of damaged RBMK-1500 nuclear fuel assemblies, was prepared. In 2015, taking into consideration certain changes in the technical design made during construction works of SNF storage facility, the *Updated Safety Analysis Report* was prepared.

In 2015, while implementing the provisions of Directive 2011/70/EURATOM by the EU Council of July 19, 2011, the Laboratory researchers prepared a Strategic Environmental Assessment (SEA) for the program of Radioactive Waste Management Development (RWMD) by Radioactive Waste Management Agency (RATA). The SEA report identifies, describes and assesses the potential significant RWMD programs involving the management of spent nuclear fuel and radioactive waste, and the implementation impact on the environment. The RWMD programme and the SEA report were publicly presented to the civil society in 2015; representatives of the civil society and the responsible state institutions were being consulted. Based on these documents and the conclusions drawn, the Government of the Republic of Lithuania approved the *Radioactive Waste Management Development Programme* by Decree No. 1427 of December 23, 2015.

In 2015, the Laboratory researchers prepared and published the final report *The siting programme for a geological repository and the repository development plan: preparation* (Client: Radioactive Waste Management Agency). The report contains a review of earlier investigations in the field of geological repository implementation in Lithuania. On the basis of the provisions of international and national documentation and recommendations of the IAEA expert mission, the researchers prepared proposals for the plan of geological repository implementation in Lithuania, prepared a program for geological repository siting investigations 2016–2021.

A side product of some companies, organizations and institutions in Lithuania are spent sealed ionizing radiation sources and solid radioactive waste. According to the requirements presently in use, this waste of small-

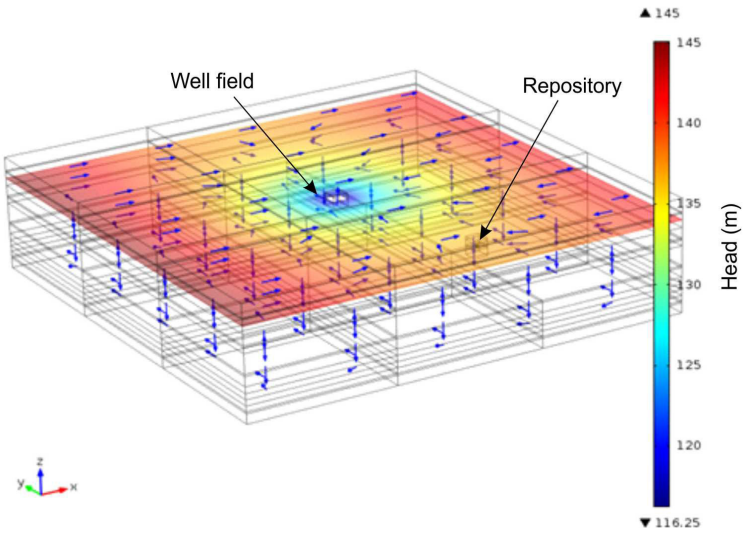
scale radioactive waste producers is managed at Ignalina NPP storage facilities. Radioactive Waste Management Agency, which collects radioactive waste from small-scale producers, and the Ignalina NPP have concluded an Agreement that names the annual quantities of the transferred waste, packaging requirements and fees for the services. The necessity to revise the service fees has appeared because of a growing range of services after the Ignalina NPP Radioactive Waste Management Facility started operating, and because of the waste planned to be disposed off in repositories. In 2015, researchers of the Laboratory investigated various stages of management, storage, and disposal of solid radioactive waste and spent sealed sources, evaluated expenses and labour costs incurred during these stages, and other information and prepared ***Calculation methodology for service rate applied to Ignalina NPP small-scale radioactive waste producers for separate classes and types of solid radioactive wastes***.

IAEA
International Atomic Energy Agency
Atoms For Peace

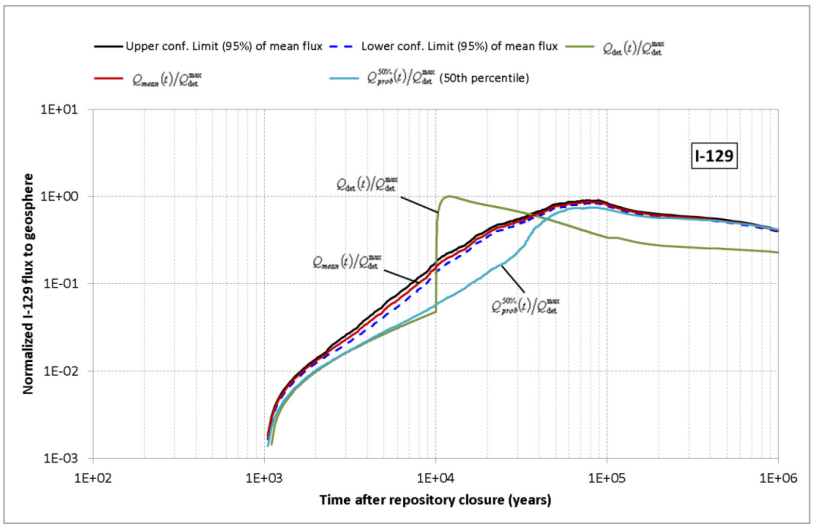
Researchers of the Laboratory constantly participate in research projects and programs coordinated by the IAEA. The following projects have already been completed: ***The Use of Numerical Models in Support of Site Characterization and Performance Assessment Studies of Geological Repositories*** (2005–2010) and ***Treatment of RBMK-1500 irradiated graphite in order to meet disposal requirements in Lithuania*** (2010–2014). In 2015, another IAEA project ***Investigation of RBMK-1500 Spent Nuclear Fuel and Storage Casks Performance during Very Long Term Storage*** (2012–2016) has been carried out. This project has been implemented within the framework of the general project ***Demonstrating Performance of Spent Fuel and Related System Components during very Long Term Storage*** coordinated by the IAEA. In 2015, numerical investigations of radiation characteristics and construction material neutron activation of Ignalina NPP spent nuclear fuel dry storage containers CASTOR® RBMK-1500 and CONSTOR® RBMK-1500 during long-term storage were carried out.

In 2015, a scientific study financed by the budget subsidies ***Integrated research on generation of radioactive contamination, its impact and migration upon termination of RBMK-1500 reactor operation and storage and disposal of radioactive waste*** (2013–2015) was completed. In this study, the researchers of the Laboratory by means of numerical methods evaluated the way the nuclide content of the RBMK spent nuclear fuel, radiation characteristics, dissipation of residual heat in the long-term storage change, and the way these parameters depend on the load of the reactor, density of coolant and cross-section libraries used in modelling. This assessment is important for estimating the impact of ionizing radiation on the environment and ensuring safe operation of SNF storage facilities. Fuel with different U-235 enrichments was used during Ignalina NPP operation; however, as the assessments of gamma and neutron emission spectra reveal, the initial fuel enrichment has insignificant influence on the radiation characteristics.

Moreover, this scientific research financed by the budget subsidies conducted the study of radionuclides, gas and heat migration in engineered and natural barriers of geological repositories. Taking into consideration the geological conditions of the Ignalina NPP region, conceptual and numerical models for groundwater flow and radionuclide transport in a geological repository implemented in crystalline rocks were developed. Assessment of the influence of natural barrier properties on the radionuclide I-129 migration showed that the uncertainty of hydraulic conductivity had a more significant impact on radionuclide concentration than the uncertainty of the diffusion coefficient and porosity.



Groundwater flow directions in the Ignalina NPP region assessing radionuclide release from geological repository (using software COMSOL)

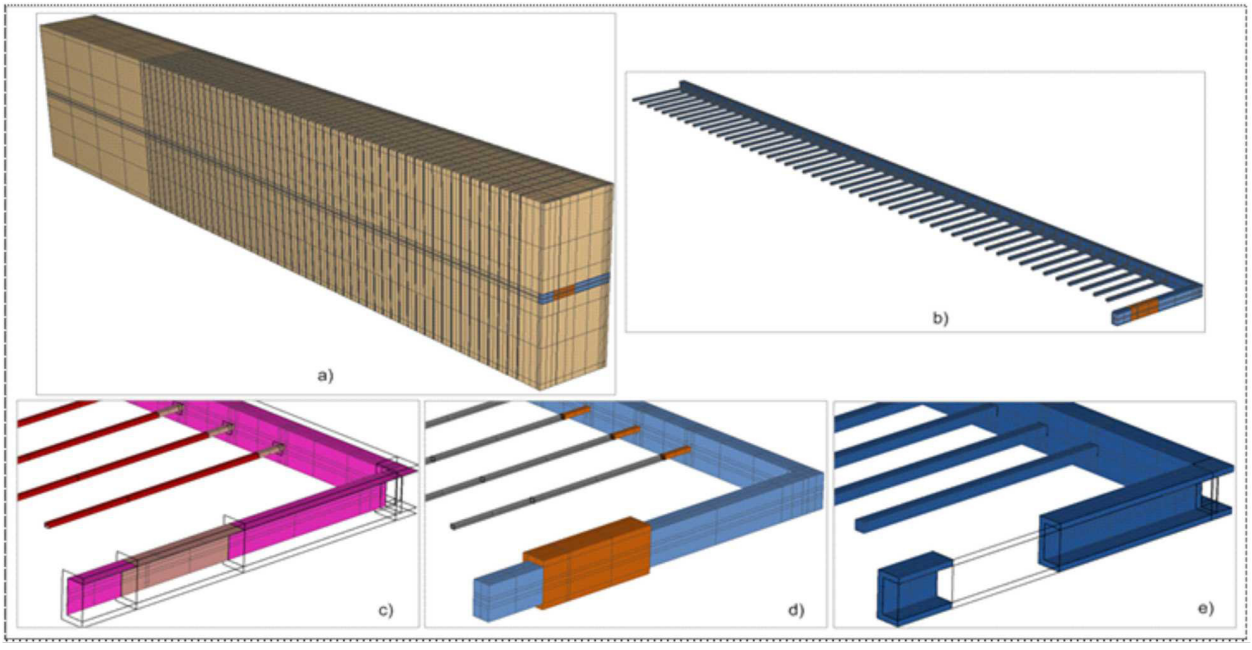


Results of probabilistic and deterministic analysis of radionuclide I-129 flux into the geosphere

Probabilistic and deterministic evaluation of radionuclide migration through the engineered barriers as well as uncertainty and sensitivity analysis of the results were carried out after the assessment of the revised data on I-129 initial activity, flow conditions probable in the Ignalina NPP environment, and uncertainty of dispersion parameters.

Based on the results, while continuing the research on I-129 migration within the environment of the Ignalina NPP region, the priority should be given to the research on justification of equivalent flow rate as well as on the assessment of RBMK-1500 spent nuclear fuel-specific parameters: instant release fraction and dissolution rate.

After the numerical assessment of gas migration in the module of a geological repository, situated in clay formation, it was determined that engineering interfaces, tunnel filling material and the excavation disturbed zone (EDZ) are the main migration and accumulation materials of gaseous hydrogen generated due to corrosion of steel SNF containers. The sensitivity analysis that evaluated the influence of characteristics of engineering interfaces on gas migration showed that the maximum gas pressure in the module (in cases of reference and local sensitivity analysis) did not exceed the lithostatic (geological environment) pressure at a depth of 500 meters, thus it is not sufficient to disturb mechanical stability and functionality of the system of engineering barriers. Compared with the uncertainty of the permeability coefficient of the EDZ, the uncertainty of the permeability coefficient of engineering interfaces is more relevant to the value of maximum pressure in the module and the amount of gaseous H_2 exiting the module.



Representation of the module of a geological repository in a numerical model: a) module and the surrounding clayey rocks; b) tunnel system of the repository and the EDZ; c) engineering interfaces; d) engineered barriers; e) EDZ

Researchers of the Laboratory use software codes SCALE and MCNP (USA) for modelling fuel characteristics (assessment of criticality), for assessment of nuclide content of spent nuclear fuel and evolution. PETRASIM (USA) and GOLDSIM (USA) software tools are used for assessment of safety of radioactive waste repositories. Using this software, modelling of radionuclide/gas transfer (one-phase/two-phase flow) in porous and fractured medium is performed. Software codes COMSOL (USA) and COMPASS (GRC, the United Kingdom) are used for evaluation of influence of thermal-hydro-mechanical processes on groundwater migration in geotechnical environments.

SAFETY RESEARCH OF RADIOACTIVE WASTE MANAGEMENT

Since 1994, the Laboratory has been actively involved in the analysis of the radioactive waste management problems at the Ignalina NPP. Laboratory experts together with the experts from SKB International (Sweden) carried out several projects, which assessed the existing Ignalina NNP waste storage facilities and the possibilities to transform them into repositories.

In 2002, the Laboratory together with Framatome ANP GmbH (Germany) participated in performing the environmental impact and safety assessments for Ignalina NPP cement solidification facility and an interim solidified radioactive waste storage facility.

In 2004–2005, together with French companies Thales Engineering and Consulting, ANDRA and the Institute of Physics, PHARE project ***Safety Assessment and Upgrading of Maišiagala Repository*** in Lithuania was implemented. The Laboratory specialists participated in preparation of Safety Analysis Report, developed the database containing information on radioactive waste, which is stored in the Maišiagala storage facility, and performed a comprehensive nuclide composition analysis.

In 2002–2005, a great deal of attention was given to the siting of a new near-surface repository for radioactive waste in Lithuania, scientific research related to the radionuclide migration from radioactive waste repositories and its impact on safety. With the assistance of Swedish experts, researchers of the Laboratory determined the criteria for choosing a near-surface repository site, improved the reference design of a near-surface repository and prepared the implementation program. The impact of *heterogeneous* (uneven) waste activity distribution on radionuclide migration from model near-surface repository was investigated.

In 2006–2009, researchers of the Laboratory implemented the project ***Reconstruction of Ignalina NPP Bitumen Radioactive Waste Storage Facility (Building 158) into Repository***. A long-term safety assessment of the planned repository was prepared; it was based on the possible engineering solutions of storage facility reconstruction into repository, components of disposal system. To be more precise, radioactive waste, storage facility and surface engineering barriers planned to be installed over storage facilities and site characteristics were taken into consideration.

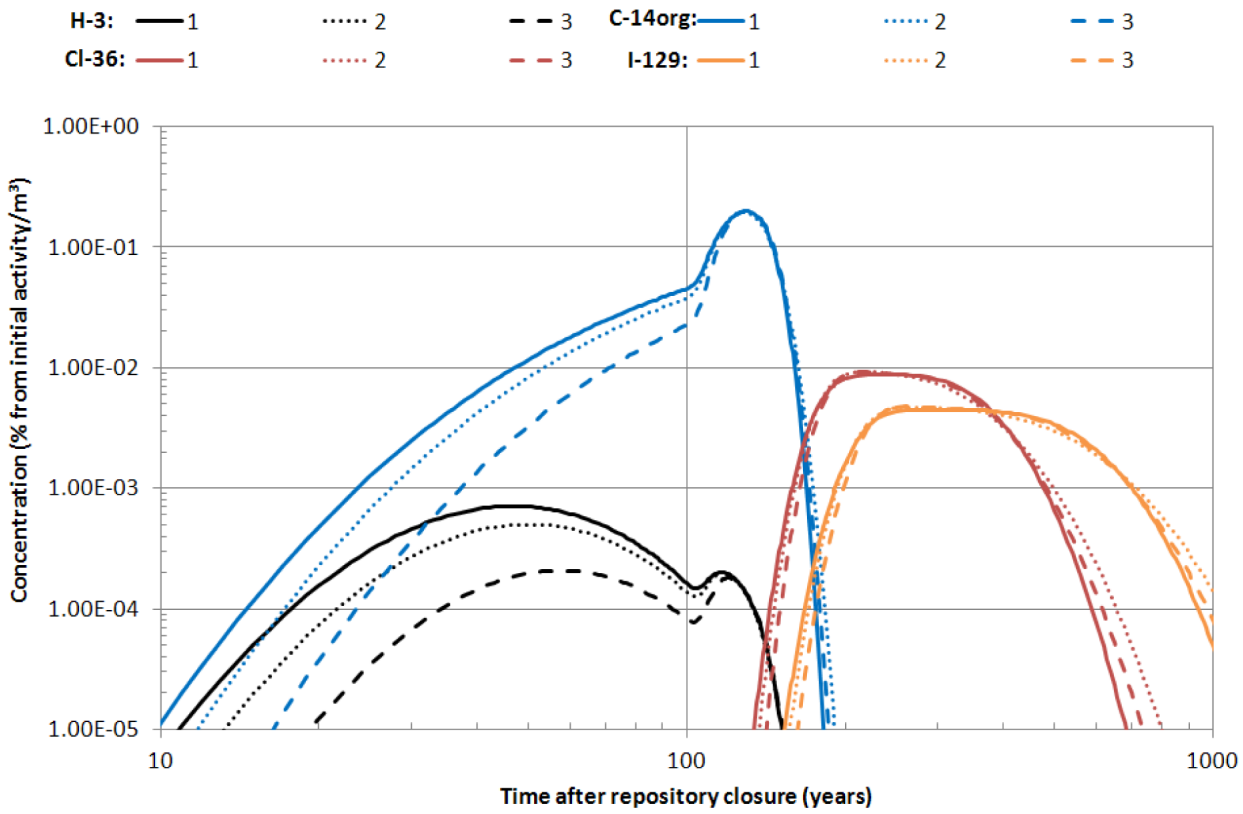
In 2008–2013, the Laboratory, as a partner of Lithuanian consortium (UAB *Specialus montažas-NTP*, LEI, AB *Pramprojektas*, UAB *Vilstata*) implemented the project ***Installation of Very Low Level Radioactive Waste Repository (Landfill)***. *Landfill* repository is intended for disposal of very low-level radioactive waste generated during the Ignalina NPP operation and decommissioning. The entire *Landfill* facility will be comprised of three repository modules and a buffer storage, where waste will be stored until its disposal. In 2009–2013, researchers of the Laboratory prepared *Environmental Impact Assessment Report* for the planned economic activity, two preliminary safety analysis reports (for buffer storage and waste disposal units), two general data sets, final safety analysis report and waste package description of the radioactive waste packages intended for disposal.

In 2015, the Laboratory together with NUKEM Technologies GmbH (Germany) continued implementing the project ***New Ignalina NPP Solid Waste Management and Storage Facility*** (2006–2018). This facility is intended for solid radioactive waste retrieval, sorting, transportation, treatment (following envisaged technologies), packaging, characterization and storage. The entire facility will be comprised of several facilities located at two sites: the solid waste retrieval facility at the existing Ignalina NPP solid waste storage buildings, and new facility located nearby Ignalina NPP for solid waste treatment and storage. In 2008, *Environmental Impact Assessment Report* was agreed upon and approved at the Ministry of Environment. Also, two Preliminary Safety Analysis Reports (PSARs) were prepared: *New Solid Waste Treatment and Storage Facility at Ignalina NPP* and *New Solid Waste Retrieval Facility at Ignalina NPP*. The first PSAR was approved in 2009, and VATESI issued a license for the construction of the storage facility. In 2009, two more PSARs *New Solid Waste Retrieval Facility for Retrieval Unit 1 and Retrieval Units 2–3 at Ignalina NPP* were prepared. In 2010, both PSARs

were submitted to the institutions for review. The first PSAR was updated following the recommendations by the institutions, and at the end of 2010 was approved by VATESI, while in the middle of 2011, the permission to build the facility was received. In 2011–2014, the second PSAR was updated considering the recommendations of the institutions. In the late 2014, VATESI approved documents justifying safety for *Waste Retrieval Units 2-3*. An updated PSAR is currently prepared for release. In 2017–2018, the *Final Safety Analysis Report* will be prepared.

In 2015, the Laboratory together with partners from French companies *AREVA TA* and *ANDRA* and Lithuanian partners JSC *Specialus montažas-NTP* and *Pramprojektas* continued the project ***Low and Intermediate-Level Short-Lived Radioactive Waste Near-Surface Repository (Design)*** (2009–2015). The repository is intended for disposal of low and intermediate-level short-lived radioactive waste generated during Ignalina NPP operation and decommissioning. In 2010–2011, the specialists of the Laboratory made a considerable contribution to the preparation of Design Options Report, Waste Inventory Report and Site Revalidation Report, which were submitted to the Customer and approved. In 2012, Basic Engineering Design Report for ***Low and intermediate-level short-lived radioactive waste near-surface repository*** was prepared and submitted. For this report, the experts of the Laboratory prepared four chapters: waste inventory, long-term safety assessment, waste acceptance criteria and waste package specification as well as environment monitoring and surveillance overview. In 2014, researchers of the Laboratory finished the preparation of preliminary safety analysis report and submitted it to the Customer. The conducted safety assessment covers the operational period and long-term safety (period after closure of the repository). In 2014, repository environment monitoring program was prepared and submitted to the Customer. In 2015, the preliminary safety analysis report and the environment monitoring program were reviewed taking into consideration the comments from the Customer.

In 2015, researchers of the Laboratory finished the scientific research financed by the budget subsides, in which they performed investigations of impact of waste zone inhomogeneity evaluating radionuclide migration from the near surface radioactive waste repository. For this purpose, three models of waste zones with various complexities were developed: homogenous, layered and two-dimensional.



Comparison of volumetric concentrations of leached radionuclides below the repository: 1 – homogenous model; 2 – layered model; 3 – two-dimensional model

The results of the investigation revealed that assessing migration of short-lived radionuclides, the homogenous model is conservative (an overestimated impact of radionuclides is obtained). Therefore, in order to optimize the repository design and still preserve the necessary safety level, more complex models of waste zone should be used.

The experience came from participation in IAEA coordinated investigation projects, such as ***Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities (ISAM)*** (1998–2001), ***Application of Safety Assessment Methodologies for Near Surface Radioactive Waste Disposal Facilities*** (2002–2005), and ***Disposal Aspects of Low and Intermediate Level Decommissioning Waste*** (2002–2006).

Researchers of the Laboratory for modelling migration of radioactive and non-radioactive contaminants in the environment use software AMBER (Quintessa, the United Kingdom). For modelling water balance, forecasting underground water level, evaluating scenarios of climatic change software GARDENIA (BRGM, France) is used. Geochemical research is being carried out using software EQ3/6 (Lawrence Livermore National Laboratory, USA) that enables to compile models for the assessment of chemical processes taking place in the analysed water/solid phase systems, designed for modelling chemical changes of contaminants (radionuclides), solubility and sorption in water/solid phase systems.

EVALUATION OF DECOMMISSIONING

Back in 1998, researchers of the Laboratory initiated research related to Ignalina NPP decommissioning. Our experts participated in PHARE project preparing ***Preliminary Ignalina NPP Decommissioning Plan*** as well as ***Final Ignalina NPP Decommissioning Plan***. In 2004, researchers of the Laboratory in accordance with the order of the Ministry of Economy of the Republic of Lithuania prepared projects for Ignalina NPP decommissioning program and its implementation measures plan for 2005–2009. In 2005–2008, together with the Institute of Physics the project ***Development of Radiological Characterization Programme for Equipment and Installations at Ignalina NPP*** was implemented.

Since 2007, Laboratory of Nuclear Engineering has actively participated in Ignalina NPP dismantling projects. Lithuanian Energy Institute, as a partner of consortium Babcock (former VT Nuclear Services Ltd) (the United Kingdom) – LEI – NUKEM Technologies GmbH (Germany), implemented the project ***Ignalina NPP Building 117/1 Equipment Decontamination and Dismantling*** (2007–2010). With the same partners, they implemented the project ***Ignalina NPP Building V1 Equipment Decontamination and Dismantling*** (2009–2012). In 2009, specialists of the Laboratory prepared and coordinated with the institutions the *Environmental Impact Assessment Report*; in 2010, *General data collection on waste disposal* was prepared. Specialists of the Laboratory participated during preparation of the *Basic design*, which in 2010 was coordinated and transferred to the Customer, and *Detail design* and *Safety justification*, which were coordinated with the institutions. Researchers of the Laboratory analysed the equipment in Building 117/1, the amount of accumulated waste and their characteristics and carried out the assessment of the planned economic dismantling and decontamination activity. On December 1, 2010, employees of the Ignalina NPP, based on the prepared documentation, began dismantling and decontamination of the equipment in Building 117/1, which were completed in October 2011.

Researchers of LEI Laboratory of Nuclear Engineering also as partners of consortium Babcock (the United Kingdom) – LEI – NUKEM Technologies GmbH (Germany), implemented the project ***Ignalina NPP Building V1 Equipment Decontamination and Dismantling*** (2009–2012). In 2010, specialists of the Laboratory finished preparation of *General data collection on waste disposal*. In 2011, specialists of the Laboratory prepared and coordinated with the Ministry of Environment *Environmental Impact Assessment Report*. In 2012, *Basic design* and *Safety justification* were coordinated, and *Detail design* was submitted to the Customer. In 2012, employees of Ignalina NPP, based on the prepared documentation, began dismantling and decontamination works of the equipment in Building V1. At the end of 2013, dismantling stage D1 was completed, during which about 640 tons of equipment were dismantled. During 2023–2028, it is planned to implement dismantling stage D2 of Building V1.

In 2015, Laboratory of Nuclear Engineering, as a partner of international consortium (JSC *Specialus montažas*-NTP – FTMC – LEI – ATP (Bulgaria) – INRNE (Bulgaria) continued the project ***The Evaluation of the Material Backlog and Radiological Inventory of Kozloduy NPP Units 1 to 4 (2012–2016)***. The objective of the project is to carry out a detailed evaluation of the radiological status of the equipment, structures, compartments and the radioactive waste and assess the total radiological inventory and material backlog of the Kozloduy (Bulgaria) NPP

Junior researcher G. Poškas with other participants of the project DACCORD (20–24 April, 2015, Daejeon, South Korea))

Units 1–4 (WWER). In 2015, experts of the Laboratory completed the verification calculations of neutron activation and dose rates for the structures of Unit 3 WWER-440 reactor and participated in preparation of the reports on the verification calculations of neutron activation and dose rates and well as on detailed evaluation of the radiological status of the compartments, structures and the surrounding territories.

In 2015, researchers of the Laboratory further improved ***DECRAD*** software, developed by them in 2009. The main objective for the application of DECRAD software is the analysis of decontamination and dismantling of nuclear power plants, planning the demand for expenses, costs and personnel, calculation of the personnel radiation doses, planning radioactive waste disposal and the assessment of other parameters related to the decommissioning. The software may be applied for planning and analysing decommissioning of different power plants, their individual buildings or units. Also, using DECRAD software a *Multi-criteria Decision Analysis* may be performed, the AHP (*Analytic Hierarchy Process)* method used in parallel with the DECRAD software is one of the most relevant methods for selecting the alternatives for dismantling nuclear facilities.

The DECRAD-ACT software, developed since 2013 to expand the functionality of DECARD, is designed to store and process the data on radioactive components of nuclear reactors. This newly created DECRAD-ACT software has been completed already and used in the above-mentioned ongoing Kozloduy NPP project.

In 2015, researchers of the Laboratory were invited to participate as experts in an IAEA coordinated project ***Data Analysis and Collection for Costing of Research Reactor Decommissioning (DACCORD)*** (*2012–2016*). Its focus is representative input data and benchmarking data needed for the costing of research reactor decommissioning at preliminary planning stages.

In 2015, researchers of the Laboratory finished a scientific study financed by the budget subsidies. The following tasks were completed during the study while applying modern methods of numerical investigation:

- Investigation of radiological contamination of water purification and cooling system (PCS) of Ignalina NPP Unit 1; the investigation provided results on general activity of deposits in PCS sub-

systems and components and radionuclide composition of the deposits during the final shutdown of the reactor as well as change in time of deposits of most contaminated components and their overall dose rate. The contamination of PCS subsystem components was compared to a main circulation circuit specific component. Also, probabilistic sensitivity and uncertainty analyses of the activity of the deposits that form on the walls of a PCS specific component were carried out.

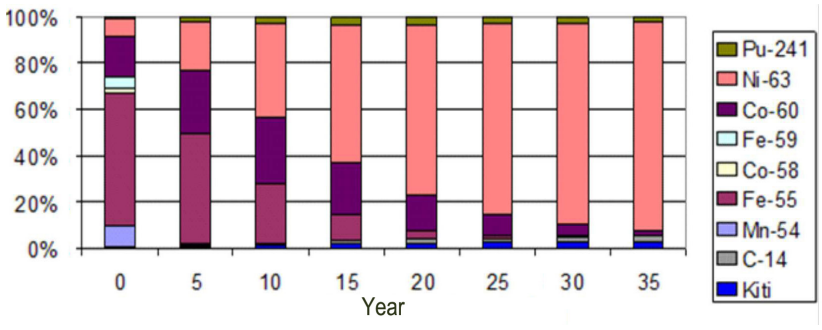
- Investigation of the ionizing radiation effect on workers during the Ignalina NPP decommissioning; the investigation analysed the ionizing radiation effect on workers during dismantling of the pressured tanks from the Ignalina NPP reactor emergency core cooling system (ECCS). Eight dismantling strategies were analysed, and the most suitable of them was determined. The parameter sensitivity analysis was also carried out, i.e., standardized regression coefficients to a general effective dose were determined.
- Assessment of radionuclide migration into the environment during Ignalina NPP decommissioning and its effect on people; the assessment showed that evaluation of the effect of some radionuclides discharged into the environment lacks accuracy. In order to evaluate the effect of these radionuclides, it is reasonable to use the corrected dose factors. It is recommended to take into consideration the significance of the environmental impact of separate radionuclides while optimizing the analysis of numerical modelling uncertainties and further revision of releases impact assessment models.

Modelling of neutron, photon and electron (radiation) transfer is performed using the MCNP-MCNPX (Los Alamos National Laboratory, USA) software. Assessment of scattered gamma radiation from nuclear facilities (e.g., radioactive waste storage and disposal facilities) is performed using the MICROSKYSHINE software. Effective dose to workers is assessed using VISIPLAN (SCK-CEN, Belgium) and MICROSHIELD (GroveSoftware, USA) software. Modelling of dispersion of emissions from various contamination sources is performed by means of AERMOD VIEW (Lakes Environmental Software, USA) software.

FIRE SAFETY ASSESSMENT IN NUCLEAR POWER PLANTS AND OTHER IMPORTANT OBJECTS

Fire in nuclear facilities (NF), especially in nuclear power plants, causes danger to safety, efficiency of important systems and serious unpredictable losses. Thus, it is a worldwide practice to analyse fire hazard in nuclear facilities. The key aim of such analysis is demonstration that the arrangement of systems important for safety and existing fire safety measures ensure the safety of a NF and comply with requirements of the national legislation as well as the IAEA recommendations and good practice of other countries.

Since 2002, the Laboratory carries out fire safety assessment at nuclear power plants and other important facilities. Researchers of the Laboratory consulted by Swedish experts assessed fire safety of reactor Unit 1 and Unit 2. Moreover, they assessed fire safety of some renewed Ignalina NPP rooms with changed designation and newly designed Ignalina NPP SNF and radioactive waste storage facilities. An external fire impact on the new Ignalina NPP Solid Waste Storage and Treatment Facility was assessed, and the analysis of fire hazard in the most dangerous areas in case of an internal fire in the facility was performed. In 2009, the impact of fire during the implementation of dismantling and decontamination of Ignalina NPP Building 117/1 was evaluated; also, fire safety of newly designed buffer storage and disposal units of *Landfill* repository was assessed. In 2010, the impact of fire during the implementation of dismantling and decontamination of Ignalina Unit V1 was assessed. In 2012, based on Detail design documentation, the fire hazard impact in very low activity radioactive waste repository was estimated, and in 2014, during preparation of documents justifying safety of low and intermediate activity radioactive waste repository, fire hazard analysis of this facility was performed.



Change in time of deposit activity of a water purification and cooling system component at Ignalina NPP Unit 1 (other < 1 %)

In 2015, researchers of the Laboratory completed a research work ***Fire hazard analysis of bitumen radioactive waste storage facility*** (2014–2015). In order to completely ensure fire safety at the bitumen radioactive waste storage facility, it was necessary to perform fire hazard analysis and demonstrate the protection of this NF structures, systems and components against fire and its effects without disturbing the performance of systems important to safety. The fire hazard analysis was carried out applying engineering assessment methods and carrying out a wide scope numerical investigation. The released report provides conclusions and recommendations, the implementation of which will improve the fire safety of the bitumen radioactive waste storage facility and reduce the negative impact caused by fire and its consequences.

Fire modelling is performed using PYROSIM (USA) software.

DEVELOPMENT OF NUCLEAR ENERGY IN LITHUANIA

In 2007–2009, at the consortium, researchers of the Laboratory together with Pöyry Energy Oy (Finland) conducted research related to the construction of a new nuclear power plant in Lithuania. The *Environmental Impact Assessment Program for New Nuclear Power Plant* and *New Nuclear Power Plant Environmental Impact Assessment Report* were prepared. In the EIA Report, possible environmental impacts of the construction and operation of the new NPP were assessed in cooperation with other Finish and Lithuanian institutions (Institute of Botany, Institute of Ecology and National Public Health Surveillance Laboratory). According to the EIA Report of 2009, positive conclusions of the competent authorities were made concerning the planed economic activity; therefore, following this EIA Report, the Ministry of Environment made a motivated decision on the construction possibilities of a new nuclear power plant in Lithuania.

LABORATORY PARTICIPATES IN **EU FP7** AND **HORIZON 2020**

Since 2008, researchers of the Laboratory actively participate in the EU 7th Framework Program funded scientific research and coordination and support activity projects. The following projects have already been implemented: ***Treatment and Disposal of Irradiated Graphite and Other Carbonaceous Waste (CARBOWASTE)*** (2008–2013), ***Fate of Repository Gases (FORGE)*** (2009–2013), ***New MS Linking for an Advanced Cohesion in EURATOM Research (NEWLANCER)*** (2011–2013), ***Sustainable network of Independent Technical Expertise for radioactive waste disposal (SITEX)*** (2012–2013). In 2014, researchers of the Laboratory continued work in three EU 7th Framework Program funded projects.

In 2015, researchers of the Laboratory continued participation in three 7FP funded projects and, together with scientists from other countries, started two activities in coordination and support projects of the EU program **Horizon 2020**:

- ***CArbon-14 Source Term (CAST)*** (2013–2018). This project aims to develop understanding of the generation and release of C-14 from radioactive waste materials under conditions relevant to waste packaging and disposal to underground geological disposal facilities. The project will focus on releases from irradiated metals, ion-exchange resins and graphite. The project is implemented by 33 partners from 12 EU countries and 3 non-EU countries. In 2015, information about radiocarbon inventory in and its releases from the reactor RBMK-1500 irradiated graphite and about handling of radiocarbon in safety analyses in Lithuania was revised. Development of new models for radiocarbon inventory evaluation in and release from the Ignalina NPP graphite has also begun. Researchers of the Laboratory participated in the CAST work package 6 (WP6) meeting in March 2015, in Madrid (the Kingdom of Spain) and at the second general assembly meeting in October in Bucharest (Romania).

- ***Assessment of Regional Capabilities for New Reactors Development through an Integrated Approach (ARCADIA)*** (2013–2016). The objective of the project is to support and develop nuclear scientific research in new EU states related to the development of IV generation reactors, devoting the main attention to ALFRED (lead cooled reactor) demonstrator. The project is implemented by 26 partners from 14 EU states. Researchers of the Laboratory participate in this project together with the Laboratory of Nuclear Installation Safety.

• ***Building a platform for enhanced societal research related to nuclear energy in Central and Eastern Europe (PLATENSO)*** (2013–2016). The objective of the project is to enhance the capabilities of social research institutions in Central and Eastern European countries to take part in EU research with respect to governance, social and societal aspects linked to nuclear energy. The project is carried out by 19 partners from 12 EU states. In 2015, two PLATENSO partner meetings took place (in Stockholm and Budapest) where the project achievements were presented and future works were discussed. A national strategy on social, societal and governance (SSG) issues for nuclear energy was developed in 2015.

• ***Sustainable network for Independent Technical EXpertise of radioactive waste disposal: Interactions and Implementation (SITEX-II)*** (2015–2017). This Horizon 2020 program Euratom Project, funded by the EU, is carried out by the Laboratory researchers and 17 organisations from other EU countries and Canada. A high level of scientific and technical expertise is necessary in order to evaluate the decisions, especially those based on the results of scientific research, ensuring the geological repository safety. In this context, the aim of the project is to demonstrate the cooperation means and possibilities identified during the previous project (EC 7FP SITEX, 2012–2013) that would allow creating a sustainable network for independent technical expertise of radioactive waste disposal in Europe. Activities of such network are based on scientific cooperation using equipment present is different institutions, present potential of knowledge and improving the specialists' skills that are necessary not only for interpretation of scientific research results but also for execution of independent technical expertise. The independent specialists (network) are a tool to develop a dialog for technical issues between regulatory institutions, organisations carrying out implementation of a geological repository, and the public. In 2015, the Laboratory researchers started this Project together with the Consortium partners and provided proposals for joint Scientific Research Agenda, collected and systematised information on the needs for preparation of specialists with technical expertise, and the strategy and the practice applied within the participating organisations, took part in preparation of recommendations for geological repository safety assessment expertise, and prepared the project documentation for quality assurance.

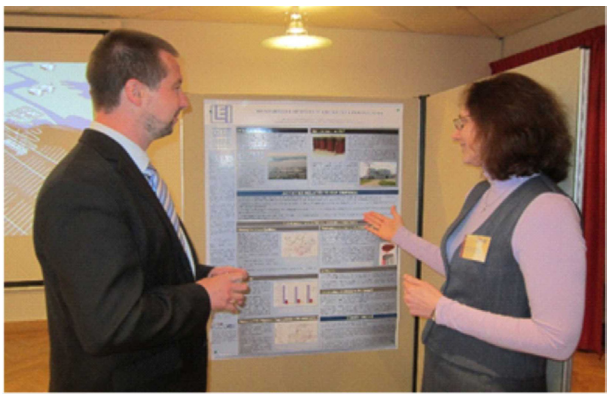
Dr. A. Narkūnienė in the underground Tournemire research laboratory during a SITEX-II Project meeting (17 November, 2015, Millau, France)

• ***Joint Programming on Radioactive Waste Disposal (JOPRAD***) (2015–2017). The aim of this Project is to prepare a proposal based on which a joint programming on radioactive waste disposal could be developed. The Joint Programming would bring together at the European level, those aspects of research and development activities implemented within national research programmes, where synergy from Joint Programming is identified. The Laboratory researchers participate in the Project as an interested group of researchers that provides proposals and information on the scientific investigation needs related to radioactive waste disposal in Lithuania. Two JOPRAD meetings took place in Paris and Nantes in 2015. The meetings invited for discussions about identification of priority scientific investigations in radioactive waste management that are necessary

for implementation of national radioactive waste management programmes; a Strategic Research Agenda was prepared.

- On May 26, 2015, the urge to improve the level of qualification in planning, the need of preferential research, and implementation of the geological repository led Dr. Darius Justinavičius to participating in a seminar *Planning geological disposal of radioactive waste in Europe* (PLANDIS) organised by *Implementing Geological Disposal of radioactive waste Technology Platform* (IGD-TP) in Romania. During the seminar, the researcher gained knowledge about the experience in implementation of geological repositories of the most advanced countries and participated in discussions on how to pass this experience to less advanced countries (Lithuania as well). On 3–4 November, 2015, Dr. Justinavičius took part in the 6th IGD-TP Exchange Forum in London, during which previous as well as ongoing research projects were presented, and the EC approved cooperation possibilities were introduced.

- On 2–4 June, 2015, Dr. Dalia Grigaliūnienė took part in a conference and workshop "*Full-scale demonstration tests in technology development of repositories for disposal of radioactive waste*" organised by ***LUCOEX*** (*Large Underground Concept Experiments*) project in Oskarshamn (Sweden).



Dr. D. Grigaliūnienė presenting a poster on spent nuclear fuel management in Lithuania (2–4 June, 2015, Oskarshamn, Sweden)

The participants of the conference and workshop presented concepts of repositories, shared their practical experience and the challenges that they face during construction of geological repository tunnels for SNF disposal. The participants also visited the Äspö underground research laboratory constructed in crystalline rock down to a depth of 450 m under the Baltic Sea.

ACTIVITIES IN THE IAEA EVENTS

In 2015, the Laboratory researchers improved their qualification levels and took part in various technical meetings, workshops, conferences and trainings organised by the IAEA.

On 26–28 January, Dr. E. Narkūnas took part in a Technical Meeting on *Methodologies for Source Term Assessment for Decommissioning* in Vienna (Austria). During the meeting,

Dr. D. Justinavičius together with other PLANDIS participants (25–27 May, 2015, Pitesti, Romania)

a preliminary IAEA technical document *Methodologies for Source Term Assessment for Decommissioning* was being prepared/reviewed.

Dr. E. Narkūnas with the participants of the IAEA technical meeting (26–28 January, 2015, Vienna, Austria)

On 4–8 May, Dr. A. Šimonis took part in a Technical meeting on Learning from International Experiences of Stakeholder Involvement in Radioactive Waste Management in Vienna.

On 18–22 May, Dr. V. Ragaišis took part in a Regional Workshop on Decommissioning of Soviet RADON-type radioactive Waste Disposal Facilities and on Estonia's experience while dismantling the repository at the Tammiku site.

On 31 May–5 June, Manchester, UK, G. Poškas participated in a Workshop on Selection of Adequate Technologies to Address Specific Waste Processing Needs. The researcher got acquainted with radioactive waste management investigations during decommissioning of nuclear objects in other countries. The participants of the workshop visited the cold testing facility of radioactive waste management technologies in NNL, Workington.

Dr. D. Grigaliūnienė took part in the Third Technical Meeting on the Application of the Practical Illustration and Use of the Safety Case Concept in the Management of Near-Surface Disposal Project (PRISMA), which was held in Vienna on 7–13 June.

On 14–20 June, also in Vienna, Dr. A. Šmaižys participated in an International Conference on Management of Spent Fuel from Nuclear Power Reactors: An Integrated Approach to the Back End of the Fuel Cycle and made a presentation *Evaluation of Radiation Characteristics of Spent RBMK-1500 Nuclear Fuel Storage Casks during Very Long Term Storage*.

On 22–26 June, Warsaw (Poland), Dr. A. Narkūnienė took part in a Technical meeting on Generic Concept, Data and Modelling Needs to Develop a First Iteration Safety Assessment.

On 24–28 August, Visaginas, the Laboratory researchers participated in a Workshop on Development of specific decontamination techniques for RBMK dismantlement and/or highly active material from contaminated areas from accident conditions.

On 7–11 September, Baku (Azerbaijan), Dr. A. Šimonis took part in a Regional Workshop on Closure and Long-Term Care and Maintenance of Sites after Remediation. During it, presentations were made on recommended safety, organisational and financial means and methods for communication with the public during long-term care and maintenance of the

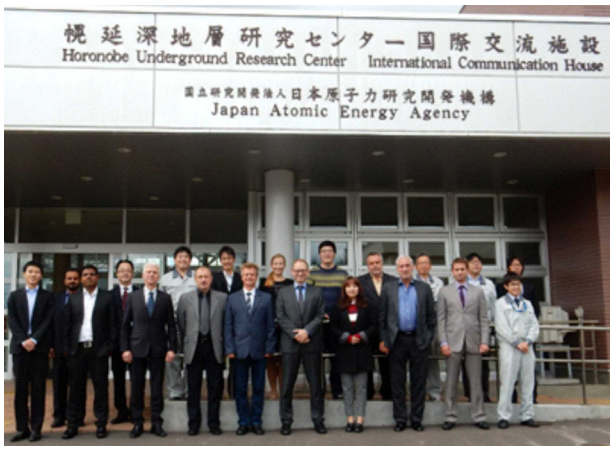
Dr. V. Ragaišis with the participants of the IAEA workshop (18–22 May, 2015, Tallinn, Estonia)

*Dr. A. Šimonis with other participants of the IAEA workshop in the territory of the radioactive waste repository of the special industrial complex **Isotope** (7–11 September, 2015, Azerbaijan)*

sites of such objects as nuclear facilities, radioactive waste repositories or mineral resource mines after their remediation. Participants of the seminar visited the site of the radioactive waste repository of the special industrial complex Isotope and the remediated site of Surakhany of the iodine factory.

On 20–26 September, Saint Petersburg (Russia), Dr. D. Justinavičius took part in a joint workshop *III International School on Power Reactor Spent Nuclear Fuel Management,* jointly organised by *Rosatom* and the IAEA.

On 9–15 October, Dr. R. Kilda participated at a technical meeting on *Underground Research Facilities Network on the Fundamentals of Geological Disposal Concepts* in Japan, where new IAEA recommendations on research for preparation to dispose of spent nuclear fuel as well as high-level radioactive waste in deep geological repositories were provided. Some special exercises were performed in the scope of the meeting in order to demonstrate the understanding and practical application of the proposed recommendations. During the meeting, the participants visited Horonobe Underground Laboratory. They were introduced to geological-hydrogeological research and to the research on bentonite properties performed in the Laboratory.



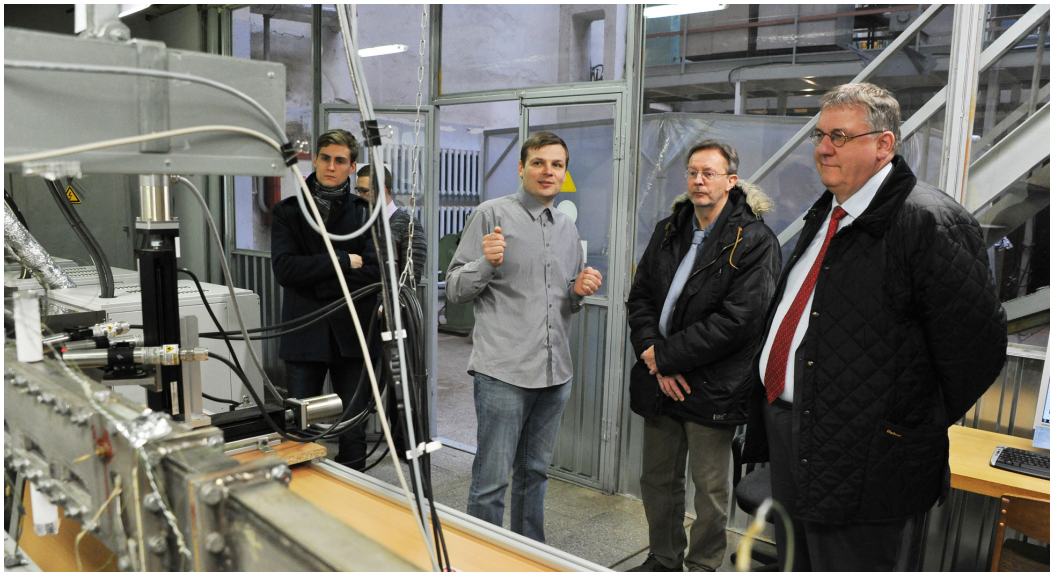
Dr. R. Kilda in the IAEA's technical meeting (9–15 October, 2015, Horonobe, Japan)

On 22–28 November, Dr. A Sirvydas took part in a workshop on *Management of Waste from Decommissioning* in Karlsruhe (Germany), where he got acquainted with new IAEA recommendations and visited the radioactive waste management facility of Karlsruhe Technology Institute.

Dr. A. Sirvydas together with other IAEA workshop participants (22–28 November, 2015, Karlsruhe, Germany)

MAIN RESULTS

In 2015, the researchers of the Laboratory implemented two long-term research and experimental development programs, finished the scientific study financed by the budget subsidies, carried out three EU **7FP** projects and stared two new projects of the program **Horizon 2020**. They also carried out nine applied works and got approx. 730 thousand Euros of income. The researchers actively developed their expertise in various technical meetings of the IAEA, seminars, completed internship at Lund University, delivered eight presentations at international conferences (in Sweden, Switzerland, Slovakia, China, Austria, Estonia, and Lithuania) and three presentations at national conferences, published six scientific papers in journals listed in *Thomson Reuters data base Web of Science Core Collection*.



LABORATORY of NUCLEAR INSTALLATION SAFETY

MAIN RESEARCH AREAS OF THE LABORATORY:

- safety assessment of nuclear power plants;
- safety analysis of thermonuclear fusion reactors;
- analysis of new nuclear power plants;
- analysis of thermal-hydraulic accident and transient processes;
- assessment of change of thermal-hydraulic parameters in NPP containments and other premises;
- simulation of transport of radionuclides and aerosols in premises;
- analysis of reactivity initiated accident processes of nuclear reactor and justification of modifications in reactor core;
- safety assessment of decommissioning and dismantling of nuclear installations;
- reliability estimation and control of energy systems;
- level 1 and level 2 probabilistic safety assessment of NPPs;
- strength analysis of structures, piping and components in complex technical systems;
- failure analysis and engineering assessment for complex technical systems;
- risk and hazard assessment of industrial objects;
- assessment of security of energy supply;
- modelling and reliability assessment of processes in energy supply networks;
- probabilistic modelling and analysis of unusual events;
- analysis of sensitivity and uncertainty of modelling results;
- fundamental research in thermal physics.

Prof. Dr. Habil. Eugenijus UŠPURAS
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In 2015, researchers of the Laboratory together with other national and foreign subjects have been implementing 30 projects: three budget subsidy funded research works; one long-term institutional scientific research and experimental development program; 24 international projects (five projects in both FP7 and *Horizon 2020*); two projects ordered by Lithuanian economic subjects.

1. LITHUANIAN REPUBLIC GOVERNMENT FUNDED PROJECTS

LONG-TERM SCIENTIFIC RESEARCH AND EXPERIMENTAL DEVELOPMENT PROGRAMS

The objective of this five-year long-term institutional research and development program ***Research of important for safety processes occurring in nuclear and thermonuclear devices***, initiated in 2012, is to prepare a complex safety assessment methodology for deterministic and probabilistic analysis of nuclear and thermonuclear installations with regard to uncertainties and severe accident scenarios. Currently, there is no unified safety assessment methodology, whereas deterministic and probabilistic safety analyses separately employed for safety assessment do not estimate the aspects of interrelations. The performed work is complex; here, integrated deterministic and probabilistic analysis methodology is developed and applied for safety assessment encompassing the fields of neutron kinetics, thermal-hydraulics, strength analysis, material science, mathematical modelling.

In 2015, investigation on suitability of tools used for deterministic accident analysis of new generation nuclear reactors and nuclear fusion facilities has continued. Features of software codes RELAP5, ASTEC and COCOSYS application processes for thermonuclear device internal structures in cooling circuits and vacuum (plasma) vessels have been discussed. Impact of features and construction modelling of division of internal vacuum (plasma) vessel into separate volumes on the course of the processes in case of an accident when coolant flows into the vacuum vessel was demonstrated. In 2015, the research of hydrogen mixing and combustion in nuclear power plant containments has continued. The influence of differences in scenarios and hydrogen combustion modelling on the final research results was examined; results of the uncertainty analysis were summarized. At the same time, the research of aerosol and radioactive nuclide transfer and deposition in the reactor cooling circuit and containment was conducted. In 2015, using COCOSYS software code, the analysis of PHEBUS FPT-3 experiment numerical study of aerosol and radionuclide deposition in containment was performed by assessing the experience of previous years while examining FSS-1 and the FSS-2 experiments.

In the field of the strength analysis, the method of evaluation of the main circuit structural integrity of nuclear power plants was prepared; specific features of the structure of thermonuclear fusion facilities were overviewed. Also, the integrity analysis of facilities with defects, occurring during the operation of the aging mechanisms, was carried out. In 2015, using best-estimate software code Cast3M, welded P91 steel sample fatigue load at high 550 °C temperature was modelled. In addition, assessment methodology of structural integrity of reinforced concrete structures under static loads, in case of an earthquake, internal and external incidents was prepared. In the field of material science, weld fatigue at high temperature under controlled deformation conditions was carried out. All the above-mentioned works and numerical studies will be later combined and used to develop an umbrella complex (deterministic and probabilistic) safety analysis methodology.

During implementation of the program, the research was carried out and experience accumulated, important for improving the competence of Lithuanian researchers working in the field of nuclear energy, which is necessary seeking to estimate safety of nuclear power plants constructed or to be constructed both in Lithuania and neighbouring countries during all NPP lifetime stages: selection of NPP, design, construction, operation, its shutdown and management of radioactive waste. Participation in design and analysis activities of nuclear fusion facilities will enable the Laboratory to keep up with the most up-to-date technologies and retain high-level scientific potential.

STATE FUNDED RESEARCH

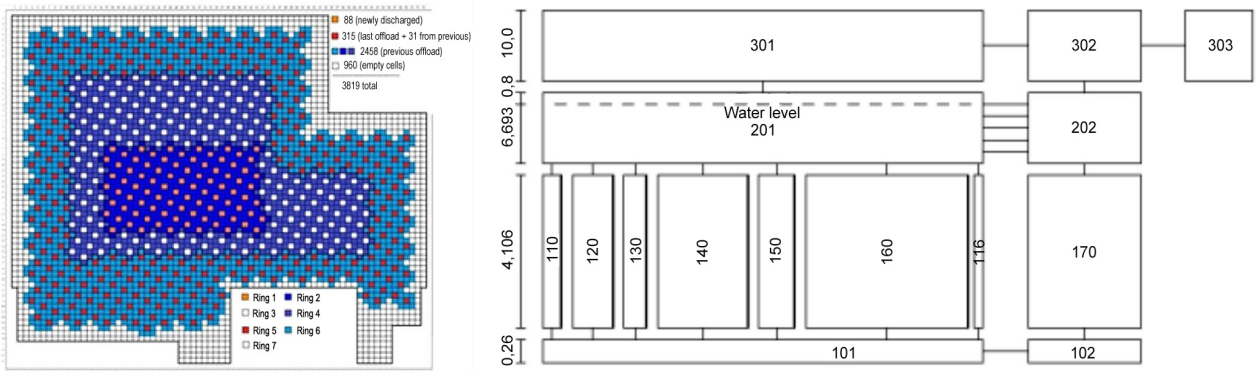
In 2015, three-year work ***Application of best-estimate method in the analysis of thermal-hydraulic processes in nuclear and thermonuclear devices*** was completed. The work's objective was to demonstrate suitability of best-estimate method for the assessment of severe accidents in nuclear devices and thermal-hydraulic processes in thermonuclear fusion

devices. Moreover, systemic software code RELAP/SCDAPSIM for the analysis of thermal-hydraulic processes with integrated possibility to assess the uncertainty of calculation results was tested. Four best-estimate method application cases were analysed in the work:

- While modelling experiments that investigate phenomena occurring during severe accidents at the nuclear reactors;
- While modelling processes in spent nuclear fuel pools (design basis and severe accident cases);
- While modelling design basis accidents at ABWR reactors;
- While modelling thermal-hydraulic processes in thermonuclear fusion devices.

In the work's final year, i.e., 2015, thermal-hydraulic processes in spent nuclear fuel pools at BWR4 Mark I in case of heat removal disruptions have been modelled. A thermal-hydraulic model was developed using systemic software code RELAP5. The results have demonstrated the extent, to which model development features (model nodalization) can affect modelling results. Furthermore, by means of software code RELAP5, a numeric model of ABWR fuel assembly was developed. By applying GRS developed best-estimate methodology, the analysis of boiling crisis sensitivity and uncertainty calculation was carried out.

This work, financed by the Republic of Lithuania budget subsidies, is a preparation for future projects, the implementation of which is aimed at gaining modelling experience. The accumulated knowledge and experience are applied in other ongoing works, aimed at investigating processes in thermonuclear fusion devices, spent fuel storage facilities and ABWR reactor.

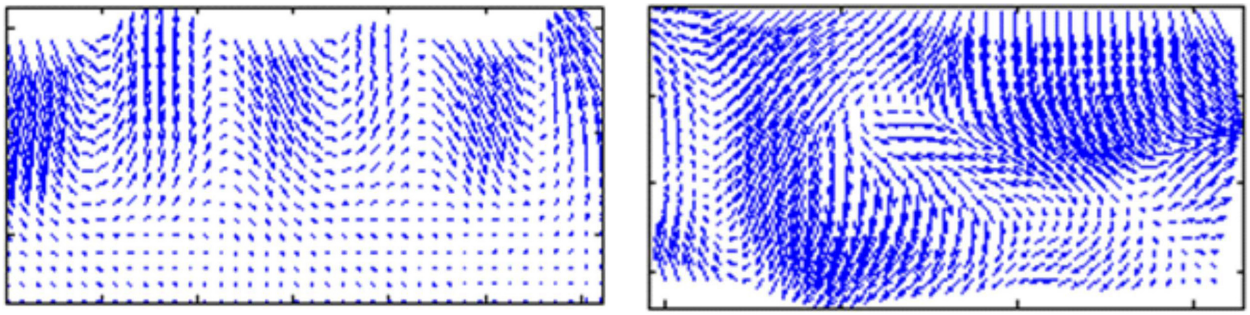


Models of BWR4 Mark I spent nuclear fuel pool, developed by means of three-dimensional and one-dimensional software codes

In 2015, implementation of a new research work ***Risk assessment of critical infrastructures*** financed by the budget subsidies has begun. Infrastructure assessment at a critical object is a constituent part of any state's national safety. EU members are obliged to conduct risk assessment and ensure protection of critical infrastructure objects based on EC published green book *European program on CI object protection* and later adopted *European Council Directive* 2008/114/EC *On the identification and designation of European Critical Infrastructures and the assessment of the need to improve their protection*.

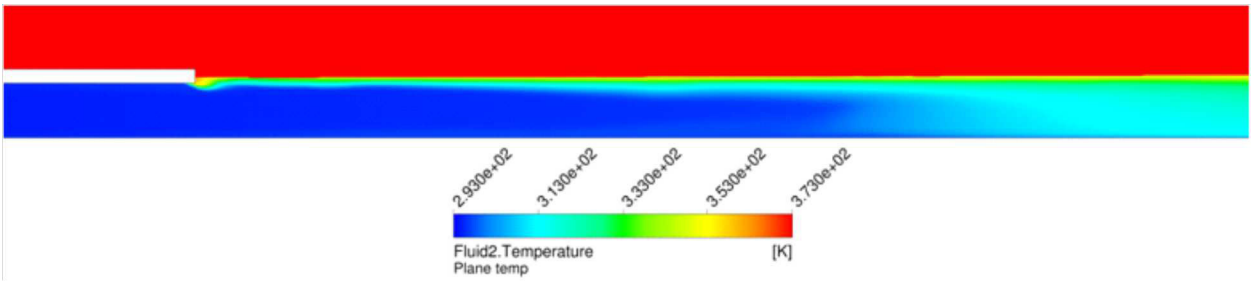
The objective of the conducted research is to develop a methodology for critical infrastructure risk assessment, which is based on the probabilistic risk assessment analysis, statistical and probabilistic data analysis, system reliability analysis, uncertainty and sensitivity analysis, application of Bayesian and optimization methods. The proposed methodology will allow simultaneous modelling of various critical infrastructures, taking into account their physical, functional and logical interconnections, technical and reliability characteristics of the individual system elements. Risk assessment of the analysed critical infrastructures will include a variety of internal and external infrastructure interferences. The developed methodology for critical infrastructure risk assessment can be applied to energy, transport, information technology and other sectors important for the country's economy and national security.

In 2015, budget-funded work ***Study of turbulence self excitation in the condensed two-phase flow*** has been launched. During the research, a digital method for optical flow analysis of temperature field variation has been applied, based on which, turbulence in water is estimated and based on generated thermal field images sequence.



Surface and cross-sectional turbulence in water induced by interphase interaction

In order to facilitate the interpretation of measurement results of temperature and velocity fields of natural experiments, two-phase flow model ANSYS CFX is further developed by means of computational hydrodynamics code. Separate two-phase velocity and temperature fields, and momentum transmission through the interphase surface were simulated. The development of the model aims to incorporate heat and mass transfer between phases.



Two-phase flow simulation assessing the interphase heat transfer

Ministry of Energy of the Republic of Lithuania

NATIONAL ENERGY STRATEGY

In 2015, researchers of the Laboratory together with the Laboratory of Energy Systems Research, following the agreement with Energy Ministry of the Republic of Lithuania, implemented ***National Energy Strategy Upgrade Project***. The main objectives of the work: to propose development goals and strategic initiatives for the Lithuanian energy sector until 2030; to present and evaluate (also in terms of energy security) development scenarios for achieving the above goals by determining the optimal structure of country's primary energy resources for each of these scenarios; to present the National Energy Strategy Project based on comprehensively analysed scenarios. Researchers of the Laboratory of Nuclear Installation Safety carried out tasks encompassing energy security analysis.

The main objective of this analysis is the assessment of development scenarios of the Lithuanian energy sector in terms of energy security. Moreover, by performing energy security analysis in the entire capacity, not only the mentioned scenarios are evaluated in terms of energy security, but also identification and analysis of hazards for the Lithuanian energy sector, and the assessment of integrated Lithuanian energy security level based on previous data, and its comparison to other EU states energy security level are performed. All the mentioned parts constitute the comprehensive analysis of the Lithuanian energy sector security, which has been performed while implementing the National Energy Strategy Upgrade Project.

The applicable methodological principles include the definition of the concept of energy security, energy security indicators, which determine the integrated energy security level, the methodology for the analysis of energy sector development scenarios in terms of energy security. The analysis consists of the assessment of internal and external hazards and disruptions for the energy sector, their modelling and determination of consequences due to the occurred disruptions and assessment of energy security coefficient from the consequences of disruptions as a measure of energy security. The performed study presents the results of the analysis of energy security for the Lithuanian energy sector. Emerging hazards and their sources were identified and assessed for the Lithuanian energy sector and its separate systems; possible disruptions,

manifesting due to potential occurrence of hazards, and their parameters were identified; the integrated level of Lithuanian energy security was assessed; it was compared to the Latvian and Estonian energy security level; development scenarios for Lithuanian Energy sector analysed in terms of energy security were modelled; the obtained research results were summarized, and conclusions were formulated.

2. HIGHEST LEVEL SCIENTIFIC RESEARCH FINANCED BY THE EUROPEAN COMMISSION

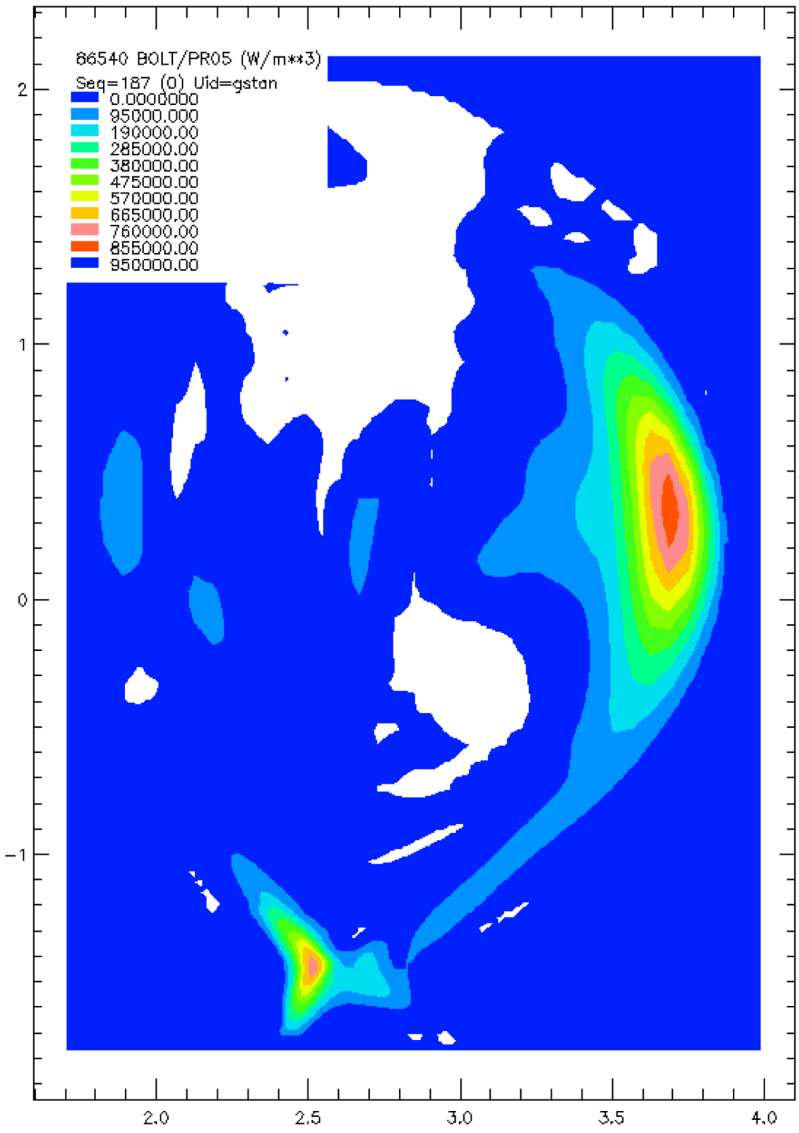
THE EU PROGRAMME FOR RESEARCH AND INNOVATION *HORIZON 2020*

Scientific research of thermonuclear fusion

EUROfusion

In 2015, during implementation of **EUROfusion** project, researchers of the Institute were in charge of coordination and execution of several tasks. The project activity involved PhD students and young scientists. LEI contributes the most to works in WPSAE work package, designed for safety assessment of nuclear fusion reactors. During implementation of the work plan, software codes intended for safety analysis were reviewed; quality assurance program for safety analysis and the analysis of DEMO reactor systems were initiated. The activation, nuclear decay heat and radiation dose rate are important measures describing nuclear processes. These calculations were performed under **EUROfusion** project JET3 and SAE work packages, where these processes were analyzed applying the newest neuronics methods in order to ensure safe nuclear fusion reactor operation and decommissioning. These works describe activation and decay heat calculations carried out according to the ***European Power Plant Physics and Technology (PPPT)*** program for DEMO Water Cooled Lithium-Lead (WCLL). Activation calculations were performed by means of coupled transport and activation programs MCNP/FISPACT. Furthermore, potential alternative structural materials were assessed. For the research, high temperature ferritic and martensitic (HT-FM) and SS-316 (LN) steels were selected. In formwork module, Eurofer steel has the largest influence on fission heat and activation, and the analysis of other steels determined that the lowest activity within 200-year period after the reactor shutdown is characteristic of SS-316 steel. Later, Eurofer and HT-FM steel activity decreases more rapidly. Lately, the activity of both materials is by approximately one order lower than SS-316.

In 2015, LEI got engaged in activities of another work package (ENS – Early Neutron Source), which include neutron and activation analysis of the projected neutron source. It is planned



Plasma power distribution in a JET tokamak vacuum vessel

that this source will be used to irradiate nuclear fusion reactor construction materials by 14 MeV neutrons.

In 2015, in JET (Joint European Thorus), preparation for deuterium-tritium (DT) plasma campaign has begun; therefore, LEI extended works in JET1 work package, which is designed for works, related to currently largest in Europe operated nuclear fusion reactor. Plasma power distribution in a vacuum vessel, which is monitored by bolometer devices, has an important role in the analysis of experimental data. LEI along with other partners analyses data by carrying out tomographic analysis of the analogous bolometer device signal by drafting a plasma power map in a tokamak vacuum vessel.

BRILLIANT
Baltic Region Initiative for Long Lasting InnovAtive Nuclear Technologies

SCIENTIFIC RESEARCH OF NUCLEAR SAFETY

Baltic Region Initiative for Long Lasting InnovAtive Nuclear Technologies

In July 2015, a joint Polish, Lithuanian, Latvian and Swedish organizations programme *Horizon 2020* EURATOM project **BRILLIANT** has been launched. The objective of the project is to determine the actual obstacles faced by nuclear energy development and try to overcome them. Universities, research institutes and a business partner JSC ***VAE SPB*** participate in the project, the aim of which is to prepare for the construction of Visaginas NPP in Lithuania. Project participants agree that it may be easier to overcome individually complex obstacles for each party by cooperating on a regional level. Project covers the following issues: relatively low power systems; influence of nuclear power programs on macro economy and energy security; strengthening nuclear power research and development capabilities in the region; regional cooperation in development of nuclear waste management and nuclear fuel closed cycle technologies; informing the society about benefits of strengthening nuclear energy and national and regional capabilities in the fields of new technology development and application.

In July 2015, European Commission held the first project meeting. During the meeting, work plans and project implementation issues were discussed with EC representatives. In November 2015, at the Ministry of Energy of the Republic of Lithuania, project objectives and tasks were presented to the interested Lithuanian institutions, and in December, introductory visit to Oskarshamn NPP operated in Sweden took place. During the visit, radioactive waste storage infrastructure was introduced, and Swedish experience on how organizations operating nuclear energy

BRILLIANT project meeting at the Ministry of Energy of the Republic of Lithuania

Visit to Oskarshamn NPP (Sweden)

infrastructure and local residents can successfully cooperate was presented.

In-Vessel Melt Retention Severe Accident Management Strategy for Existing and Future NPPs

The activity of EU research and innovation program *Horizon 2020* project **IVMR** has been officially launched in June 2015. In this four-year project, LEI participates together with 23 partner institutions from 14 European countries. Retention (stabilization) of the melted core in the nuclear reactor housing is recognized as a very important measure in order to stabilize the situation in the nuclear power plant in the case of severe accident. This measure reduces the amount of generated hydrogen, allows avoiding melt reaction with concrete and is very effective measure in reducing failure risk of the reactor containment. This measure has already been implemented in several VVER-type nuclear reactors and is included in some new nuclear power plant desings. The objective of the IVMR project is to evaluate the expediency of application of this measure to various operating and planned to build nuclear power plants in the European Union.

In this project, researchers of the Laboratory of Nuclear Installation Safety participate in project work group for reactor modelling and IVMR strategy application to accident management. Together with experts from KTH (Sweden), GRS (Germany) and HZDR (Germany), it is foreseen to simulate severe accidents in BWR by applying numeric methods; in this way, the impact of IVMR strategy will be assessed.

FAST Nuclear Emergency Tools

The activity of *Horizon 2020* programme project **FASTNET** has been launched in October 2015. The objective of the project is to develop a methodology that would cover the assessment of accidental release of fission products and emergency preparedness planning issues. All types of nuclear power plants operated or planned to be operated in Europe, such as pressurized water reactors PWR, EPR and VVER, boiling water reactors BWR, heavy water reactors CANDU and others will be investigated under this project. Moreover, possible release of fission products in case of an accident at the spent nuclear fuel pool will be considered. First, database of accident scenarios will be compiled, which will also include the assessment of possible release of fission products. This database will be compiled based on deterministic and probabilistic safety analysis results, which will be carried out by the organizations participating in the project. Later, also harmonized methods will be developed that will allow performing a fast prediction of the fission products release into the environment. The obtained results would help the responsible institutions in each country to have a tool, enabling to perform a fast prediction of the course of the emergency and to make necessary decisions notwithstanding in which world's nuclear power plant the event took place. Moreover, the developed prediction tool will not only cover the events related to the nuclear reactor, but also the events in the spent fuel pools.

This four-year long project is coordinated by French organization IRSN. The project is implemented by 22 organizations, among which there are not only European research institutes, but also such organizations as IAEA, USA Nuclear Regulatory Commission (USNRC), Canadian Nuclear Safety Commission (CNSC), Russian Scientific and Engineering Center for Nuclear and Radiation Safety (SEC NRS). Researchers of the Laboratory will contribute the most to the first work package *Scenarios Database* by processing and classifying information on accident situations at nuclear power plants in various countries and by compiling a database of parameters characteristic of selected main representative scenarios.

INcreasing Safety in NPPs by Covering gaps in Environmental Fatigue Assessment (INCEFA-PLUS)

In the beginning of 2015, EU programme **Horizon 2020** project **INCEFA-Plus** ***INcreasing Safety in NPPs by Covering gaps in Environmental Fatigue Assessment*** was signed. The implementation of the project has begun on July 1, 2015; LEI Laboratories of Material Research and Testing and Nuclear Installation Safety participate in it.

INCEFA-PLUS delivers new experimental data and new guidelines for assessment of environmental fatigue damage to ensure safe operation of European nuclear power plants. For this purpose, austenitic stainless steels (main circulation circuit steel) will be tested for the effects of mean strain, hold time and material roughness on fatigue endurance. INCEFA-PLUS also develops and disseminates a modified procedure for estimating environmental fatigue degradation. Testing will be in nuclear Light Water Reactor environments. The data obtained will be collected and standardised in an online fatigue database.

Most advanced EU research centers engaged in research in the nuclear energy field participate in **INCEFA-Plus** project. The project consortium consists of 16 organizations. Based on the project tasks, four work packages have been formed. LEI staff participates in two work packages: the first *Project Management* and the second *Test program*. During the project, Institute researchers will carry out experimental studies of austenitic steel fatigue in the air environment at room and operating temperatures. Furthermore, microstructural analysis of the tested specimens will be conducted. In 2015, regulatory documents and references related to fatigue tests were studied; first version of the fatigue test matrix was coordinated with all participating organizations. Coordinators of WP 2 *Test Program* will assess capabilities of all organizations to carry out experimental studies and will prepare a final matrix of fatigue tests.

EUROPEAN UNION SEVENTH FRAMEWORK SCIENTIFIC RESEARCH, TECHNOLOGICAL DEVELOPMENT AND DEMONSTRATIONAL ACTIVITY PROGRAM

Establishment of ASTEC software code as a means for management of severe accidents in Europe

EU FP7 programme project **CESAM** ***Code for European Severe Accident Management*** has been launched on April 1, 2013. Project objective is to establish ASTEC software code as a main means for management of severe accidents in all II and III generation NPPs in Europe (PWR, BWR, CANDU). Duration of the project is four years; it is divided into four work fields:

- Scientific support of ASTEC software code, i.e., inclusion of new models into software code,
- Development of new models by assessing knowledge about latest existing physical models,
- *Validation* of software code using experimental data and performance of comparative calculations,
- Application of ASTEC software code for power plant analysis and during enhancement of efficiency of severe accident management and creation of *reference* input sets for European power plants with PWR and BWR type reactors.

18 institutions from EU states participate in the project. LEI researchers participate in EC Joint Research Center JRC coordinated work package *Plant Applications and Severe Accident Management*. Using software code ASTEC, during the project, LEI together with partners will create a model of a nuclear power plant with GE BWR4-Mark type I reactor and will carry out comparative calculations of spent fuel pools at the chosen BWR type power plant using software codes ASTEC and RELAP/SCDAPSIM for that.

In 2015, Laboratory specialists applied a part of created earlier initial GE BWR4-Mark I type power plant model, using ASTEC-V2.0R3p2 software code module MEDICIS for ASTEC V2.1 version. This module was expanded using RUPUICUV and CORIUM modules. The developed numeric model was presented to the Joint Research Center. By means of MEDICIS module, processes of emissions of concrete ablation, melt oxidation and non-condensable gases (H_2, CO, CO_2) into the containment may be analysed. CORIUM module is applied for transporting melt particles from the core to the containment under direct containment heating. By means of this model, heat flux between melt particles and inner systems inside the containment is calculated. Applying RUPUICUV module, melt fall down to the bottom of the core and possible melt reactions

with metals are simulated.

In 2015, Laboratory researchers carried out the simulation of water loss in the spent nuclear fuel pool at a BWR type power plant applying V2.0R3p2 version of ASTEC software code. In V2.1 version of ASTEC software code, developed under CESAM project, the designation of ICARE module changes (it no longer contains a thermal hydraulic modelling part, and new models for modelling spent nuclear fuel assemblies of BWR type reactors are implemented). Therefore, Laboratory experts created a model of spent nuclear fuel pools for BWR type power plant using ICARE and CESAR modules. CESAR module is intended for modelling thermal hydraulic processes, occurring in the reactor core and cooling circuit. During implementation of the project, initial calculations of water loss accident in spent nuclear fuel pool of GE BWR4-Mark I type power plant have been performed using RELAP/SCDAPSIM software code. The initial calculations of water loss in nuclear fuel pool of GE BWR4-Mark I type power plant have been performed using RELAP/SCDAP-SIM software code.

NUGENIA +
AIR-SFP

Behavior of spent fuel pools in case of loss of coolant accident

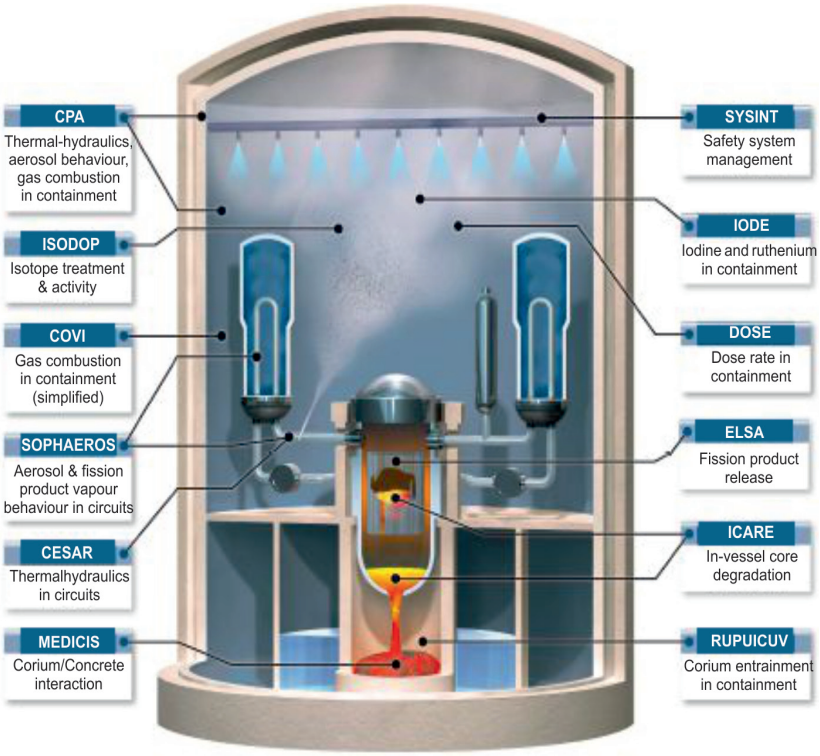
EU FP7 programme project NUGENIA-PLUS, **AIR-SFP** ***Preparing NUGENIA for H2020: Spent fuel pool behavior in loss of cooling or loss of coolant accidents*** has been launched on March 1, 2015. Project duration is 18 months. Project is managed by IRSN (France); 14 organizations from EU countries participate in it.

AIR-SFP project is divided into two work packages:

- *Benchmark of SFP transients with SA codes*,
- *Roadmap for further R&D on SFP accidents* – coordinated by NRG.

LEI participates in both work packages. In the first work package, benckmark calculations of heat removal disruptions and loss of coolant at a similar to Fukushima NPP spent fuel pool will be conducted. Laboratory specialists will carry out calculations using software codes ASTEC and RELAP/SCDAPSIM. After performing these calculations, criticality phenomenon will be preliminary assessed by analysing situations that might cause power increase. Laboratory specialists have also previewed participation in investigations of the criticality phenomenon. After performing benckmark calculations, guides for future research of accidents in spent fuel pools will be prepared. This work will be carried out by all project participants.

In 2015, Laboratory experts together with project partners collected necessary information for creating models of a spent nuclear fuel pool. The collected information is summarized in the report published by Swiss partners (PSI – Paul Scherrer Institut). For benckmark calculations during implementation of the project, two accidents have been chosen: water evaporation due to boiling and loss of coolant. Laboratory experts created an initial model of a spent nuclear fuel pool using ICARE module of ASTEC V2.0 software code, which during the project will be replaced by a model created by CESAM and ICARE modules of ASTEC V2.1 software code. The initial model of the spent fuel pool of the same type was also created using RELAP/SCDAPSIM software code. Since used software codes do not always apply the same correlations for modelling processes occurring during severe accidents, in 2015, the sets of initial, boundary conditions and applicable correlations



ASTEC program code structure

in models created by ASTEC and RELAP/SCDAPSIM software codes were discussed. While modelling processes in spent fuel pools, the uncertainties are inevitable. Therefore, Laboratory experts discussed modelling uncertainty and its possible influence on the results of the numerical research.

NUGENIA + REDUCE

Justification of Risk Reduction Through in-Service Inspection

A part of project **REDUCE of** EU FP7 programme NUGENIA-PLUS (while preparing NUGENIA H2020) ***Justification of risk reduction by applying operational control,*** with additional funding from the Agency for Science, Innovation and Technology, has been launched in the second quarter of 2015. As it has been planned, the following activity was implemented:

- The Laboratory participated at the meeting of project REDUCE part and at the meetings related to project and NUGENIA-PLUS activities; some of the meetings were organized as teleconferences;
- The Laboratory participated in preparation of the report on definition of initial calculation conditions;
- The Laboratory participated in determination of initial calculation limiting conditions;
- The Laboratory participated in determination of sensitivity assessment conditions.

Besides the mentioned activities, the Laboratory also participated in preparation of guidelines for the assessment of risk reduction by inspections.

In 2015, work meeting of the participants of project **NUGENIA-PLUS REDUCE** part was organized, and the Laboratory participated in the work meeting of the eights technical area TA8 (ENIQ) of the risk area (SAR) of NUGENIA association (UJV Rez, Prague, Czech). After launching the project, it was provided that project meetings were to be coordinated with meetings of TA8 (ENIQ) area of NUGENIA association. At these meetings, the objectives of envisaged activities and applicable research methodology were reviewed.

In the first work package (coordinated by VTT), it is foreseen to collect the initial data, based on which, various types of pipeline welding failure risk and inspection program calculations will be carried out. For the analysis, BWR and PWR pipeline weld parameters were selected. It is foreseen that cracks resulting from the impact of intergranular corrosion and failure will be investigated. Experimental and final data for the basic and sensitivity analyses were prepared before the start of the main activities in the second package.

Within the scope of the second work package (coordinated by Inspecta), in 2015, the envisaged basic calculation goals have been determined; plans for the pipeline failure risk calculations performance have been revised. It is planned that with separate software, these calculations will be performed by VTT, Inspecta and LEI. LEI researchers will carry out calculations applying their developed software code AutoPifrap. In this program, for the part of calculation of failure probability, Inspecta developed software Pifrap_solver is used. In this project, LEI will modify the mentioned calculation tool AutoPifrap and will participate in the topic structural reliability mechanics (SRM) and uncertainty research.

In the activity of the third work package (coordinated by CEA), by conducting sensitivity calculations with variable parameters, it is also planned to use various probability of detection curves.

In scope of the fourth work package (coordinated by LEI), it is planned to prepare risk reduction assessment manual (guidelines) *Guideline for assessment of risk reduction achieved by ISI* based on operational control. This guideline will be prepared in accordance with the results obtained in other work packages and NUGENIA/ENIQ methodological document *European Framework Document for Risk-Informed In-Service Inspection*.

ASAMPSA_E

ASAMPSA-E Advanced Safety Assessment Methodologies: Extended PSA

Since 2013, LEI participates in the Consortium, managed by the Institut de Radioprotection et de Sūreté Nucléaire (IRSN), by implementing new EU FP7 programme project ***Advanced Safety Assessment Methodology: Extended PSA***. The project activity began on July 1, 2013; the duration of the project is 36 months. 28 organizations from 18 European countries are partners of the project; several associate members from the USA and Japan also take part in the project: US-NRC, JANSI, and TEPCO.

The project particularly focuses on various extreme external hazards (meteorological, human induced and other events) for probabilistic safety analysis. In 2015, activities in all five major project work packages have continued:

- WP10: Relationship with End-Users;
- WP21: Initiating events (internal and external hazards) modelling;
- WP22: How to introduce hazards in L1 PSA and all

possibilities of event combination?;

- WP30: General issues regarding extended PSA scope and applications;
- WP40: 2 Specific issues related to L2 PSA.

Laboratory researchers, by participating in the activities of all project work packages, in 2015 mostly focused on the activities related to identification and analysis of the initial events (internal and external hazards). The largest contribution of LEI is to WP21/WP22 work packages. In them, LEI coordinates preparation of the report related to meteorological hazards and their impact (emphasizing extreme winds, including tornadoes, extreme temperatures and snow covering hazards). Earlier, in the relevant working package, the information for the interdisciplinary work field "Link between external initiating events of the PSA and the NPP design basis conditions" was presented.

In November 2015, at ASAMPSA_E project technical meeting and work package sessions/workshops that took place at IRSN, LEI representative coordinated a separate meeting session, reviewed the preparation progress of the relevant report "Extreme weather hazard" and presented reports "Probabilistic modelling and uncertainty analysis of the extreme snow weight" and "Assessment of potential construction sites in respect of external events." In 2016, the results of this meeting and the project with a new questionnaire will be sent for the external review.

Participation in such international projects allows immediate access to the latest ideas on risk assessment and probabilistic analysis performance and application, and allows contributing to new scientific and applied research in the field of safety analysis. Future plans are to actively develop bilateral cooperation with ASAMPSA_E project participants.

NC2I-R
Nuclear Cogeneration Industrial Initiative – Research

Initiative of nuclear energy cogeneration in industry – coordination of scientific research and development

In 2015, EU FP7 Euratom initiated international project **NC2I-R** ***Initiative of nuclear energy cogeneration in industry – coordination of scientific research and development*** has been completed. Strategic objective of NC2I-R project is to structure scientific research and development capabilities of European public and private sector by presenting to the public a demonstrative industrial facility for nuclear energy cogeneration that fully meets the market needs. During the project, the possibility to use nuclear reactors not only for electricity, but also for heat production has been evaluated. High temperature nuclear reactor was chosen as the main research object. The environmental aspect of this research, i.e., reduction of carbon compound emissions into the environment, is very important. The main activity of the Laboratory researchers included the works, envisioned in project task 3 *Safety and licensing*.

Assessment of Regional CApabilities for new reactors Development through an Integrated Approach

In 2015, the works of EU FP7 **ARCADIA** project have continued. This project covers two nuclear energy implementation areas foreseen in Strategic research and innovation plan of SNETP technological platform:

1) ESNII through support of construction of Generation IV liquid lead-cooled nuclear fast reactor in Romania and
2) NUGENIA through support in dealing with the remaining safety issues of Generation III nuclear reactors.

ARCADIA

26 organizations from European countries take part in the project, which is coordinated by Romanian company RATEN-ICN. The project covers seven work packages, and LEI participates in five of them. The Institute is the coordinator of two of those (*WP5 – Cooperation and dissemination of results* and *WP6 – Research Reactors Networking for LFR Technology and Improved LWR Safety*). In 2015, two meetings took place: the first one on April 15-17, 2015 in Kaunas, during which introductory meeting with other European organizations working in the field of nuclear energy took place (ENEN, IGD-TP, ETSON, etc.). The second meeting was held on September 29-October 1, 2015 in Warsaw (Poland). The objective of this meeting was the discussion of the project progression.

3. SCIENTIFIC RESEARCH CARRIED OUT FOLLOWING AGREEMENTS WITH EU AND LITHUANIAN ECONOMIC SUBJECTS

Modifications or replacement of auxiliary maintenance systems for spent nuclear fuel casks at Ignalina NPP spent fuel pool halls

In 2015, works under the contract

ARCADIA project meeting in Lithuania

with GNS (Gesselshaft für Nuklear-Service mbH, Germany) ***Modification or replacement of auxiliary maintenance systems for spent nuclear fuel casks at Ignalina NPP spent fuel pool halls*** have continued. The work is performed under cooperation with SC *TECOS* and machinery plant SC *ASTRA*. During implementation of the project, it is planned to manufacture and install six absorbers at the INPP fuel storage pool halls (three different absorbers at each Ignalina NPP Unit) and other equipment for maintenance of spent nuclear fuel casks. The designation of the main components of this equipment, i.e., absorbers, is to absorb energy in case of accidental drop of casks loaded with spent nuclear fuel or an earthquake, and ensure that the loads on the building and cask structures will not exceed the permitted limits.

In 2015, the three remaining absorbers out of six were successfully manufactured and assembled. All manufactured absorbers were successfully transported and installed in Ignalina NPP Unit 2 spent nuclear fuel storage pool and in the transport corridor. Furthermore, all the remaining works related to modifications or replacement of auxiliary maintenance systems for spent nuclear fuel casks were successfully completed. Although all the project works have been completed, the project will continue for another year and a half, i.e., within the period envisioned in the agreement for warranty works.

Absorbers for Ignalina NPP Unit-1 spent nuclear fuel pool

A.L.A.R.A.
As Low As Reasonably Achievable

Preliminary studies for the decommissioning of the reactor compartments of the former Paldiski military nuclear site and for the establishment of a radioactive waste repository

In 2015, works under the contract with the company of the Republic of Estonia AS A.L.A.R.A ***Preliminary studies for the decommissioning of the reactor compartments of the former***

Paldiski military nuclear site and for the establishment of a radioactive waste repository have been successfully completed. The work is executed through cooperation with the company JSC *EKSORTUS* and Federal Centre of Nuclear and Radiation Safety (FCNRS) in Russia. The objective of the project is to choose the optimal concept for dismantling two nuclear reactors at the Paldiski site, offer the best concept for radioactive waste management, and perform economic assessment of the mentioned works.

In 2015, together with partners, the analysis of legal regulatory documents of the Republic of Estonia was performed, and modifications and improvements of regulatory documents regulating decommissioning of nuclear facilities and radioactive waste management was proposed. Furthermore, four possible options for the dismantling reactor vaults were chosen. Out of mentioned dismantling options, one satisfying the customer expectations at most was selected. For the selected dismantling option, risk safety analysis was performed, and safety of the planned works was assessed. Together with partners, the amount of radioactive waste accumulated at the Paldiski facility was recalculated, and its increase while performing the mentioned reactor vault dismantling works was assessed. Based on the obtained results, radioactive waste acceptance criteria have been prepared, and most suitable for the Republic of Estonia types of radioactive waste repositories were proposed. Together with partners, price calculation methodologies for dismantling of reactor vaults at the former military nuclear facility Paldiski and radioactive waste management were developed and presented.

Former military nuclear facility Paldiski, Republic of Estonia

Safety assessment of Maišiagala radioactive waste storage facility

In 2015, the agreement was signed with JSC *EKSORTUS* regarding preparation of ***Periodical safety assessment report for Maišiagala radioactive waste storage facility***. The work has been implemented in cooperation with the Institute of Physics of the Center for Physical and Technological Sciences. During the project, it is planned to carry out a periodical safety assessment and justification, and to prepare a periodical safety assessment report. The objective of the report is to determine whether, considering legal regulations and

Maišiagala Repository

Collection of geomembrane sample buried near Maišiagala repository

changes of the storage facility site and (or) its environment, aging of structures, systems and components and other factors that may influence safety, safety of the storage facility is ensured. During periodical safety assessment, the condition of storage facility components important for safety was assessed (e.g., geomembrane, limiting water access inside the storage facility, study of physical and mechanical features).

Optimization of heat supply main networks to the Ignalina Nuclear Power Plant

In 2015, LEI and JSC *Specprojektas* signed an agreement to carry out the ***Analysis of optimization of heat supply main networks to SE Ignalina Nuclear Power Plant***. This work has been initiated, because currently existing heat supply main networks to the Ignalina NPP had been installed while constructing the Ignalina NPP, and they were designed to supply heat from the Ignalina NPP to Visaginas town.

After final shutdown, the NPP became from heat supplier a consumer. Now, via those 800 mm diameter pipes, the heat is supplied from Visaginas boiling house to the Ignalina NPP. Due to the large diameter of the pipeline, which is currently unnecessary, there are considerable heat losses along approximately 6 kilometer pipeline. Moreover, heat demand at the Ignalina NPP will decrease with time; therefore, part of the heat loss will only increase. For this reason, the objective is to carry out the analysis of possible substitution of the main heat supply pipeline.

Experts of the Laboratory of Nuclear Installation Safety and Laboratory for Renewable Energy and Energy Efficiency:

- carrying our the analysis of thermal hydraulic main heat pipeline networks, assessed changing demands of heat consumers at the Ignalina NPP and determined optimal diameter of main heat pipeline networks. They also determined heat loss from pipelines both for overground and underground main pipeline heat network;
- carrying our economic analysis of reconstruction options, when heat supply main pipeline networks are overground, and when they are directly burned at the existing pipeline place, assessed dismantling works of old heat supply network pipelines. Moreover, heat energy savings and reconstruction payoff indicators were calculated.

The performed thermal hydraulic and economic analyses enabled calculating the necessary investments and allowed drawing conclusions on how to optimize the reconstruction of main pipelines to the Ignalina NPP. This work has also received additional funding from Agency for Science Innovation and Technology based on call to promote contract R&D works of economic subjects.

Main pipelines from Visaginas boiling house to the Ignalina NPP

Expertise of aboveground liquid fuel storage tanks

In 2015, the work ***Expertise services for compliance with the requirements of Reference document for this type of installations for the status of aboveground liquid fuel storage tanks MR-2, 31, 32, 33 installations and their related infrastructure*** according to the agreement signed with *Lietuvos Energijos Gamyba* Company has been completed. During the work, design, technical and operational documentation of fuel tanks located in the territory of Elektrenai Power Plant and their engineering networks were assessed. A report was prepared, where the compliance of the condition of this equipment and organizational control measures to the requirements in the EU document *Emissions from Storage* for this type of installations was assessed. The results of the analysis were presented and discussed at the work meetings; recommendations and suggestions for enhancement of the state of these installations and their engineering networks, to eliminate the identified incompatibilities, were presented.

4. TRANSFER OF KNOWLEDGE ON NUCLEAR SAFETY AND TRAINING ORGANIZATION

European Nuclear Safety Training and Tutoring Institute (ENSTTI) was established in 2010. The Institute is closely related to the European Technical Safety Organization Network ETSON and technical safety organizations participating in this EU community. The objective of ENSTTI is to provide training, consulting and practical services in the assessment of nuclear and radiation safety. It is intended for technical support organizations to share their experience on enhancing nuclear safety, dissemination of news and practical experience in the field of nuclear safety culture.

In 2015, ENSTTI organized a three-week introductory preparatory training course on nuclear safety that took place on June 8-26 at Garching GRS research center in Germany. The researchers of the Laboratory delivered lectures on the strategies and issues of dismantling nuclear power plants equipment. From 2013, specialists of the Laboratory of Nuclear Installation Safety also participate in the implementation of a two-phase training project ***Training and tutoring for experts of the Nuclear Regulatory Authorities and their technical support organizations*** ordered by the European Commission.

For the first part of the project (LOT1) *Nuclear safety regulation, licensing and enforcement*, a consortium consisting of institutions regulating nuclear safety and technical safety organizations has been established. Besides the four afore-mentioned organizations constituent of ENSTTI, consortium involves: FANC (Belgium), ASN (France), CSN (Spain), BBM (Austria), RCR (Czech Republic), SSTC (Ukraine). For the second part of the project (LOT2) *Nuclear safety assessment and inspection*, another consortium consisting of technical safety organizations that besides ENSTTI includes CIEMAT (Spain), ENEA (Italy), RCS (Czech Republic), VUJE (Slovakia) and SSTC (Ukraine) has been established. The trainings are aimed at developing countries and countries developing (or planning on developing) nuclear energy: Tunisia, Indonesia, Malaysia, Jordan, Belarus, Georgia, Vietnam, Morocco, Philippines, Ukraine, Armenia, Egypt, Mexico and Brazil. Audience from other countries can also attend the course upon paying the participation fee. During the course, specific issues on nuclear installation safety are addressed; the courses are aimed at experienced audience, and the specialists delivering the lectures to them have to be experts in respective fields.

On May 18–22, 2015, LEI, lead by the specialists of the Laboratory of Nuclear Installation Safety, hosted *Probabilistic Safety Assessment* training course. At the same time, *Heat Hydraulics* course prepared by combined ENEA and LEI efforts was held at the Brasimone research center, Italy.

In 2015, ENSTTI started implementing European Commission Energy Directorate DG ENER project ***Feasibility study for development of the European Union technical safety organizations and nuclear safety regulating bodies.*** According to this project, two PhD students from the Laboratory of Nuclear Installation Safety A. Gražević̆ius and M. Drūlia participated in ENSTTI training course *Legal framework and regulatory processes of nuclear and radiation safety* (May 4–8, 2015) in Stockholm, Sweden, and on June 8–26 in Garching, Germany that took place during preparatory nuclear safety course. Moreover, during this project, these PhD students had a three-month internship organized for them at the work place. The internship was intended for the analysis of short-

PhD students and professor of the Laboratory of Nuclear Installation Safety at preparatory ENSTTI nuclear safety course (Garching, Germany, June 25, 2015)

ENSTTI training ***Probabilistic Safety Assessment*** *(LEI, Kaunas, May 18–22, 2016)*

term and interim storage processes in spent nuclear fuel assemblies. After the internship, the PhD students reported on their accomplished work. This project initiated by EC Energy Directorate will finish in 2016.

At the end of 2015, ENSTTI won a contract to implement a new training project organized following the order of the European Commission ***Development of national regulatory institutions and their technical support organizations, strengthening of regulatory and technical feasibility by training and preparing their experts***. The beginning of the project is in 2016.

Active participation of LEI specialists in the activities of all these training projects helps gain experience in organizing similar courses and enhance their qualification.

Transfer of the European Regulatory Methodology and Practice to the Nuclear Safety Authority of Belarus

In 2015, works of BY3.01/09 (BE/RA/07-A) project ***Development of technical cooperation in nuclear safety in the field of assistance to regulatory authorities,*** initiated and financed by the European Commission, have continued. The objective of this project is to support Regulatory Body of Republic of Belarus *Gosatomnadzor* in nuclear safety regulation activities, in licensing construction for Belarus NPP, also training Belarusian experts to properly perform the review of documents related to nuclear activity. In 2015, LEI executed works under task 2.2 *Review of selected safety issues addressed in the preliminary safety analysis report.* Besides LEI, this work involved experts from IRSN (France), GRS (Germany), STUK (Finland) and SSTC (Ukraine). The representative of IRSN was in charge of the works. BE/RA/07-A agreement was extended until February 28, 2017. During the project, participating at ENSTTI, training courses *VVER accident analysis and emergency preparedness* were organized for Belarus *Gosatomnadzor* staff. On November 9–13, at the courses held near Minsk, a representative of the Laboratory of Nuclear Installation Safety also participated and delivered lectures on issues of emergency preparedness.

LEI cooperates with RISKAUDIT IRSN/GRS INTERNATIONAL also by conducting another similar project, funded by the European Commission, in providing assistance to Belarus *Gosatomnadzor*: ***Support in strengthening Belarusian nuclear safety inspection workforce by monitoring and licensing Belarusian NPP construction***. This project was launched in the beginning of 2014; the end is planned for February 2018. Nuclear Installation Safety Laboratory participates in the work group that helps nuclear safety inspectors carry out inspections, assess and review the licensing documents – to conduct an independent review of the safety analysis report. On September 14–18, in Minsk, this group organized a workshop for review of selected safety issues of the preliminary safety analysis report. At the meeting, cases of accidental dilution of non-heterogeneous boron compound enriched coolant were considered. A representative of the Laboratory delivered a paper on LEI experience, gained at the Ignalina NPP – additional shutdown system design and safety justification of this system.

Such support to the neighbour country is necessary in order to ensure timely and effective supervision of the constructed nuclear power plant by Belarus nuclear regulation institutions. This is very important not only for Belarus, but also for Lithuania (at the border of which this power plant is constructed) and for the entire Europe.

5. PARTICIPATION IN EU RESEARCH ORGANIZATIONS AND COMPETENCE NETWORKS

ETSON EUROPEAN TECHNICAL SAFETY ORGANISATIONS NETWORK

European Technical Safety Organizations Network

Since 2009, the researchers of the Laboratory of Nuclear Installation Safety have participated in the activity of ***European Technical Safety Organizations Network*** (ETSON). Presently, ETSON consists of ten member organizations: Bel V (Belgium), INRNE BAS (Bulgaria), CV Rez (Czech Republic), LEI (Lithuania), IRSN (France), VTT (Finland), PSI (Switzerland), JSI (Slovenia), VUJE (Slovakia), GRS (Germany), and three associated member organizations: JNES (Japan), SEC NRS (Russia) and SSTC (Ukraine). In 2015, new ETSON president was elected, BelV director general Benoît De Boeck. The main objectives of ETSON are as follows:

- stand for an exchange forum on scientific research and development of nuclear energy safety;
- contribute to fostering the convergence of nuclear safety practice in Europe and beyond;
- plan nuclear safety scientific research programs and promote their implementation;
- speed up the application of the EU Directive on nuclear safety;
- cooperate in implementation of safety assessment and research projects.

Fourteen expert groups were established in ETSON network in key nuclear safety research areas.

In 2015, the activity of one of such groups *Electrical systems* was suspended; research group *Processes in reactor core* was renamed into *Processes in nuclear fuel*, and it was decided to direct the activity of *Emergency preparedness and response* more at the kind of help Technical safety organizations can provide organizing emergency preparedness and response.

LEI representatives actively participate and have their representatives in all the main structures and groups of ETSON organization. Specialists of the Laboratory participate executing all the group activities (with the exception of electrical system analysis). Working in these expert groups, specialists prepare Technical Safety Assessment Guides. These documents present recommendations on how the institutions performing the expertise should assess safety issues related to the nuclear activity. The goal of such documents is to achieve that independent technical analysis in every ETSON member state is performed following the same approach/methodology. In this way, it is sought to coordinate and maintain a high level of nuclear safety practices in ETSON member countries. In 2012–2013, all ETSON member countries (with active participation of LEI), coordinated and approved three Technical Safety Assessment Guides:

- Review of events and analysis of precursors;
- Deterministic analysis of severe accidents;
- Analyses of human and organization factors of construction of nuclear facilities and modification processes.

In 2014, new Technical Safety Assessment Guide *Transients and design basis accident analyses* was prepared and approved. In 2015, *Manual for assessment of heat carrier safety systems* was completed and officially published.

With the participation of specialists from the Laboratory of Nuclear Installation Safety, working in *Probabilistic Safety Analysis* expert group, a document was prepared on the methodology of probabilistic safety analysis. The document will be put on the ETSON website, where it is also foreseen to put a document covering experience of ETSON members countries that conducted "stress tests" following the accident at the Fukushima Nuclear Power Plant. This document, which was prepared with the participation of the Laboratory specialists, discusses the best safety ensuring practices in cases of flooding, earthquake, complete loss of electricity and heat removal.

LEI participated in **EUROSAFE** forum organized by network of ETSON organizations, which was held in Brussels on 2–3 November. The forum was dedicated to the implementation of European Directive of 2014 *Nuclear safety and associated future tasks*. LEI representatives presented two papers and co-authored one paper. Moreover, the poster presentation about LEI has been exhibited. In 2015, specialists of the Laboratory of Nuclear Installation Safety prepared two publications for ETSON journal *EUROSAFE Tribune*: about project ***H2020 FASTNET*** (FAST Nuclear Emergency Tools) launched this year and the benefits that LEI obtained by participating in Severe Accident Network of excellence SARNET.

In the meetings of ETSON experts and coordinating groups, the participation of ETSON members in planned, and ongoing EU projects, e.g., Horizon 2020, are constantly discussed. At these meetings one can learn about the latest ideas of performance and application of deterministic safety, risk assessment and probabilistic analysis and contribute to the implementation of new research and applied works in the field of nuclear safety analysis. There-

fore, participation in ETSON network helps to get involved in new international projects and promote LEI.

NUclear GENeration II & III Association

Lithuanian Energy Institute has participated in the activity of **NUGENIA** association, encompassing activities of Sustainable nuclear energy technology platform (SNETP) and competence networks NULIFE and SARNET, since its very establishment in 2011. **NUGENIA** association unites industry, research and safety organizations, executing general research and development projects in the field of nuclear energy. The association initiates and coordinates relevant research for the II and III generation nuclear reactors operated in EU states. The activity of NUGENIA is organized for eight research directions:

1. Nuclear power safety and risk assessment.
2. Severe accident research.
3. Enhancement of reactor operation.
4. System integrity assessment, structure and components.
5. Development of new nuclear fuel, waste and spent fuel management, decommissioning.
6. Innovative projects and technologies for light-water reactors.
7. Alignment.
8. Operation inspections and testing without disassembling.

NUGENIA association has developed an open innovation platform, where all the projects implemented by members of the association are stored. In this way, due to joint efforts of members of the association, the projects are brought to perfection, and project proposals prepared for *Horizon 2020* calls may be submitted for evaluation only after obtaining NUGENIA label of the Board that guarantees the quality of the project.

LEI is a member of NUGENIA association and along with other participants is actively involved in all eight NUGENIA association research and developments areas.

In 2014–2015, using open access innovation platform, LEI joined the activity of a variety of projects under preparation. Seven out of ten project proposal applications for *Horizon 2020* EURATOM 2014–2015 call, in preparation of which specialists of the Laboratory of Nuclear Installation Safety took part, were prepared due to the open access innovation platform. Three of those received EC financing and are currently implemented.

The association additionally organized call for projects NUGENIA+. The purpose of this call was to additionally support the NUGENIA association by strengthening its role and coordinating European research in the area of safety of nuclear devices of II and III generation, also to initiate international cooperation. For this call, LEI together with other members of the association prepared and submitted another two research projects proposals. Both proposals received NUGENIA+ financing and are currently implemented.

European Safety, Reliability & Data Association ESReDA

ESReDA is a European association, providing a possibility to communicate and exchange information on the issues of safety and reliability in the field of scientific research. LEI is a part of this association. ESReDA constantly organizes seminars and initiates projects aimed at preparation of publications (books) in the relevant fields of scientific research on reliability and safety of energy and industrial objects. LEI contributes to this activity. In 2015, the project *Reliability-based Optimization of Life Cycle Cost of Structures*, ROLCCOST, in which researchers of the Laboratory also took part, has been completed. As a result, a book *Reliability-based Optimization of the Life Cycle of Structures* has been prepared. Currently, LEI participates in a new ESReDA project *Critical Infrastructure Preparedness and Resilience: Modelling, Simulation and Analysis – Data, CI PR/MS&A Data*. It should be noted that this topic is related to the funded research being implemented at the Laboratory: *Risk assessment of critical infrastructures.*

In 2015, three researchers of the Laboratory participated at the 48th ESReDA seminar *Critical Infrastructures Preparedness: Status of Data for Resilience Modelling, Simulation and Analysis (MS&A).* At the seminar, two papers were delivered on the subject of the assessment of the rupture of natural gas transmission pipeline, where the consolidation of theresults on the structural integrity analysis and failure data were investigated in order to assess more accuratelythe probability of the natural gas pipeline rupture. In another paper, the topic of criticality assessment of aggregated energy sector infrastructure is analysed.

FUSENET the European Fusion Education Network

FUSENET association is the European Fusion Education Network, uniting European universities, research centers and industrial organizations

participating in fusion research. ITER international organization also belongs to this network. Since mid 2013, LEI has been a member of this association. Participation in the association activity enables PhD students and junior researchers to take a more effective part in different trainings and exchange programs in all organizations of Fusenet association. On February 3, 2015, the 4th Fusenet General Assembly meeting took place in Culham Research Center (England), where business and financial reports of the year 2014 and work plans for 2015 were discussed; new Fusenet council members have been approved.

On November 15–17, 2015, the event dedicated to PhD students participating in nuclear fusion research took place in Prague (Czech Republic), where LEI PhD student A. Tidikas participated as well and delivered a paper *Investigation of DEMO construction material characteristics affected by neutron irradiation*. Tidikas' participation in the event was financed by Fusenet Association.

6. TRAINING OF SCIENTISTS AND PUBLICATION OF SCIENTIFIC RESULTS

In 2015, six PhD students studied at the Laboratory of Nuclear Installation Safety. One doctoral dissertation in the field of energetics and thermal engineering was defended ***The criticality Assessment of Energy Systems Critical Infrastructure*** (B. Jokšas). Young PhD doctors together with experienced scientists presented the investigation results obtained in 2015 in science research reports and 50 scientific articles (21 out of those in the journals referred in *Thomson-Reuters Web of Science Core Collection database*); 33 papers were presented at scientific conferences. The researchers of the Laboratory participated in the events related to nuclear topics and presented papers at all main international conferences, where safe operation of nuclear power plants and physical phenomena occurring in them were analysed.

At the end of summer 2015, at a prestigious international conference NURETH-16 organized by American Nuclear Society, LEI researchers presented a paper *Integrated Assessment of Thermal Hydraulic Processes in W7-X Fusion Experimental Facility* (authors T. Kaliatka, E. Ušpuras, A. Kaliatka) that was recognized as one of the best (among 680) and was awarded a commemorative letter.

In fall 2015, young PhD Doctor Tadas Kaliatka gone for a six-month internship at the Japan Nuclear Engineering Research Institute and the University of Fukui, where he improved his skills in the field of ABWR reactor beyond design basis accidents. On October 7, 2015, a meeting with the Mayor of Tsuruga City took place, where Dr. Kaliatka delivered a speech and passed greetings and handed Kaunas Mayor Visvaldas Matijošaitis courtesy letter. The meeting drew the journalists' attention and was rather broadly advertised in press.

The researchers of the Laboratory also actively participated in different international and national training programs, IAEA seminars, committee and coordinating meetings, activity of FUSION development committees and other organizations and scientific institutions.

All the above works contribute to strengthening the expertise of Lithuanian specialists in nuclear energy field, which is necessary for each state that has nuclear energy installations (nuclear power plants, nuclear fuel and radioactive waste storage facilities and repositories, etc.) and that carries out the county's nuclear program.

Dr. T. Kaliatka's meeting with Tsuruga City Mayor

LABORATORY of ENERGY SYSTEMS RESEARCH

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MAIN RESEARCH AREAS OF THE LABORATORY :

- Analysis of macroeconomic development scenarios, modelling and forecasting of energy demands;
- Analysis of medium- and long-term energy supply scenarios using widely approved optimization models;
- Evaluation of environmental impact of the energy sector, analysis of pollution reduction technologies and implementation of environment protection policies;
- Energy management and marketing research;
- Research of efficiency of support means for renewable energy sources;
- Generalization of the energy sector restructuring and liberalization experience in the European Union and Central and East European countries and its application while implementing reforms in the Lithuanian energy sector;
- Development of energy information system, collection of statistical data on the energy sector development in Lithuania and foreign countries.

In 2015, implementation of a long-term program of institutional research and experimental (social, cultural) development ***Economic and sustainability analysis for the energy sector development*** has continued in co-operation with the experts of the Laboratory for Renewable Energy and Energy Efficiency and the Laboratory of Systems Control and Automation.

In the long-term perspective, an ambitious objective was set to solve the following tasks:

1) to develop a theory of harmonious progress in the energy sector on the basis of sustainable development and interrelations with knowledge-based economy concepts;
2) to analyse possibilities of perspective development in the Lithuanian energy sector and prepare recommendations related to rational directions of perspective technical development of the energy sector, changes in fuel and energy balance, environmental factors;
3) to form methodological basis for the assessment of efficiency of sustainable energy development promotion measures in municipalities, to evaluate the efficiency of already applied and proposed new support measures;
4) to investigate possibilities of synchronous operation of the Lithuanian power system with ENTSO-E, taking into account the perspective development of generating capacities.

During implementation of the second task in 2015, the investigations aimed at expansion of modelling base for the energy sector development and solution of specific tasks were continued in the Laboratory. At this stage of the research, the structure of a mathematical model for analysis of the energy sector future development and exploitation was formed; it assessed internal and external relations, energy policies, environmental restrictions, and external factors. An important step for improving the research base is a newly developed tool for processing and analysing modelling results. The main results enabling to perform a comprehensive analysis of the Lithuanian energy sector development in a long-term perspective are as follows:

- An updated mathematical model was prepared for the analysis, which integrally describes development of power system, district heat supply system and fuel supply system as well as the change of the final energy demand in a long-term perspective, assessing their seasonal, weekly, and daily variations;
- The model allows determining economically most efficient district heating production technologies in individual cities (selecting them from a large number of the existing, undergoing modernization, and new ones), types of used fuel and their rational amounts, capacity of heat and electricity production, without violating environmental restrictions;
- The model allows determining optimal structure of the generating capacities in the power system and their utilization, ensuring reserve capacities necessary for the system operation, and at the same time, evaluating expedience of electricity and reserve capacity exchange with individual foreign countries, which is determined by the needs of electricity markets in neighbouring countries (export from Lithuania), possibilities of supply to the country's consumers (import to Lithuania), electricity prices, capacity of interconnections, etc.;
- Fuel supply to power plants and heat plants is modelled taking into consideration the existing and feasible in the future supply infrastructure (capacities of pipelines and terminals, natural gas storage, etc.), prices of the supplied fuel and volumes of the consumed fuel. The rationality of usage of local and renewable energy sources for individual heat and electricity supply technologies is established taking into consideration their potential and prices of these sources;
- Newly developed tool for processing and analysis of modelling results allows presenting significant information for making decisions about the optimal structure of power generation plants, electricity and heat production volumes, amounts of investment and operation and maintenance costs, fuel and energy flows, comprehensive perspective fuel balance, deployment of renewable energy sources, amount of funds for their installation, amounts of discharged contaminants, etc.
- The information input database was updated and expanded: the recent information on consumption of primary energy sources in Lithuania, EU countries and worldwide and, in particular, tendencies in changes of prices

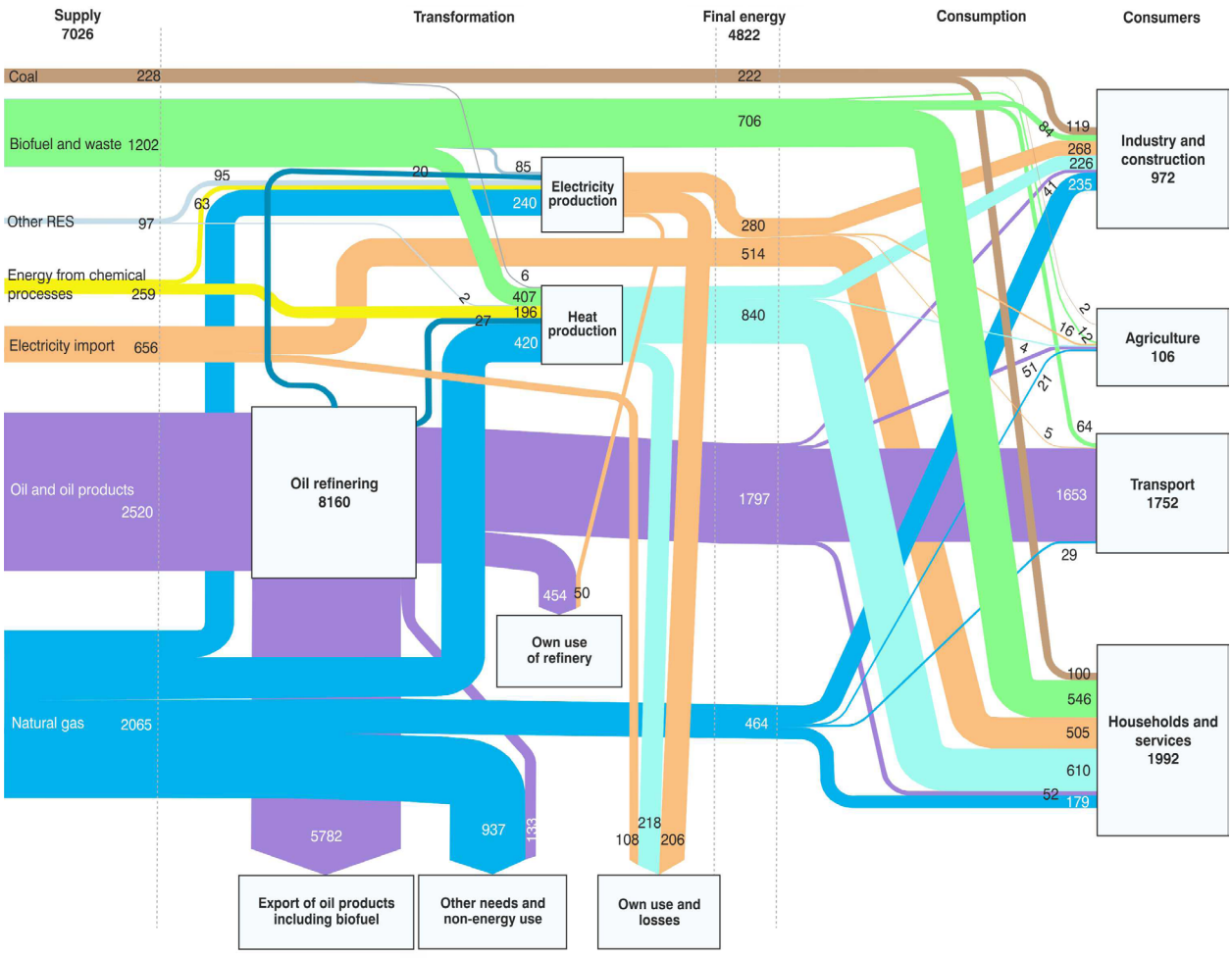
of electricity and natural gas, development of technologies for electricity and heat production, their accessibility, technical and economic indicators are accumulated.

An optimization model prepared by applying MESSAGE software code enables researchers to determine from the set of all available and probable future technologies such structure and amounts of energy sources that satisfy estimated final energy demand in a long-term perspective with the least total expenses, and at the same time, at lowest prices for the final consumers.

In order to justify development directions of the country's energy sector, renewal and update of the information database were also useful. After performing the analysis of the indicators existing in the database of the Lithuanian Department of Statistics, indicators defining tendencies of sustainable development of the country's energy sector were updated. A comparative analysis of the data published in the Eurostat database showed that indicators of primary and final energy efficiency in Lithuania characterizing the changes decreased faster that in the majority of the EU countries. A comprehensive analysis of the use of renewable energy sources, supported by energy flow diagrams, proves a stable growth of their role: in 2014, the part of renewable energy sources in the primary energy balance comprised 18.2 %, in the gross electricity consumption – 12.6 %, and in the gross final energy consumption – 23.8 %.

In order to choose energy and climate change policy tools, designed to promote advanced energy production technologies, it is necessary to perform their multi-criteria analysis and select packages of the best tools based on a variety of important criteria that reflect priority goals of the energy policy. Carrying out such analysis, multi-criteria decision methods may be applied, which differ both in principles of explanation of preferences and in principles of aggregation of information on the criteria. A question, which method is the most appropriate for the solution of specific problems, remains pertinent. In order to choose the most suitable alternatives in the field of energy and climate change, the following methods may be applied:

1) multi-criteria value (useful-



Main fuel and energy flows in Lithuania 2014, thousand toe

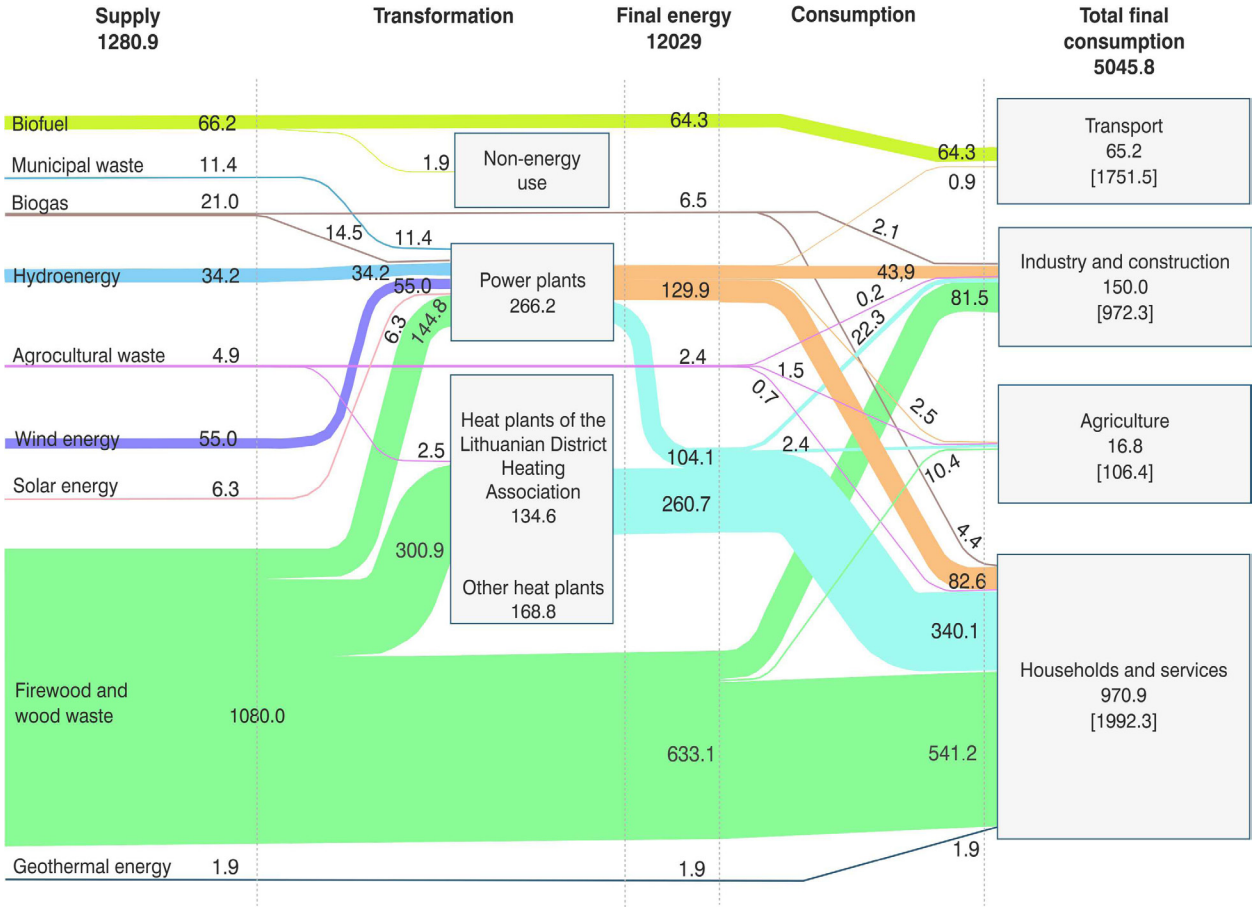
ness) methods, which are based on the comparison of quantitative criteria and the assumption that it is possible to balance out the negative sides of one criterion by the advantages of another criterion. Qualitative criteria may be compared providing them a quantitative disguise by applying methods of analytical hierarchy and undefined sets;

2) ranking methods that follow the concept of non-compensated value and deny the possibility of mutual compensation of the criteria;

3) integrated multi-criteria methods, combining several various methods, thus seeking to solve the issue of reducing uncertainty.

Taking into consideration the existing original data, an appropriate method or a package thereof can be selected to solve specific multi-criteria tasks. When applying several methods to evaluate the same alternatives, the layout of alternatives in a priority line is not always the same. Then, it is necessary to investigate, which method is more sensitive to possible initial data errors, using the widely applied Monte Carlo method for sensitivity analysis. The advantage of this method should be emphasized: it may be applied not only to determine the significance variations ranges of the analysed alternative indicators, but also to evaluate the probabilities for alternatives in their variation ranges.

Multi-criteria analysis is related to the uncertainty of solutions, which may be determined by the lack of expert experience or their subjective opinion in assessing the initial data (values of indicators and, especially, the significance of indicators). In such case in practice, it is appropriate to apply contingent multi-criteria methods intended for the analysis of the indicator values expressed in contingent numbers. In practice, a problem of comparing indicators with each other is often faced due to their great variety. In order to sort the compared alternatives by applying multiple criteria, expressed in different units of measurement, and the selected number of indicators, it is appropriate to apply the data envelope analysis method. This method allows



Flows of renewable energy sources 2014, thousand toe

evaluating and comparing technical efficiency of multiple alternatives with many efficiency measures, such as energy prices, dependence on energy import, energy intensity, part of renewable energy sources in the final energy consumption, emissions of greenhouse gases and other atmosphere contaminants and so on.

Research Council of Lithuania

The project ***External economic effects of development of energy sector: quantitative assessment*** launched in 2014 according to the task of the ***Projects by groups of scientists*** of the ***Research Council of Lithuania*** has continued. Its objective is to prepare a system of quantitative assessment of external economic effects of perspective development of the energy sector, to assess external economic cost and benefits of the Lithuanian energy sector development scenarios and possibilities of their internalization. During implementation of the project, theoretical investigations were carried out, modelling methods were developed, analysis tools were prepared and tested, energy research and economic data database, social accounting matrix, and other information necessary for economic modelling were prepared.

The developed system for the assessment of external economic effects of energy development includes the assessment of direct effects in the partial economic equilibrium model, used for preparation of energy scenarios, and assessment of net effects in the general equilibrium model. In order to realistically reflect possibilities of the energy sector development, more complete supply of resources, recycling and consumption networks were included into the partial economic equilibrium method used for energy planning, simultaneously representing alternative exploitation of these resources, also evaluating the expedience of import/export. These uncharacteristic model elements can be represented as technologies used in energy development models in the form of oriented graphs and can be described by normal equations. In 2015, an interim report on the project results was submitted and approved; while continuing the research envisioned by the project, recommendations will be prepared on rational internalization of external economic effects and planning processes for integration into the energy economics.

SCIENTIFIC RESEARCH PAPERS FOR COUNTRY'S ECONOMY

Ministry of Energy of the Republic of Lithuania

National Energy Strategy

Under the agreement with the Ministry of Energy of the Republic of Lithuania, a study ***Analysis of the development of the Lithuanian energy sector*** was prepared. The final report presents general characteristics of the country's energy sector, discusses essential features defining the state of individual energy systems, presents the assessment of possibilities of the energy sector development and significant factors that influence it, presents the concept of the energy sector development and operation analysis. Prospective development directions of the Lithuanian energy sector and scenarios of rational energy sector development in the long-term perspective were justified by the analysis of the results of the mathematical modelling, and the main factors defining the energy sector development were summarized.

Development of the energy sector was modelled by a detailed assessment of operating conditions of different types of energy facilities and cost-effectiveness of various operating modes, by adequately balancing heat and power production and consumption in Lithuania and electricity flows imported from Scandinavian countries and Continental European networks, as well as third countries or exported to neighbouring markets.

For the analysis, scenarios that differ in terms of the existence or absence of Visaginas NPP, different installed capacity of power plants, or local electricity production level, volumes of imported electricity and indicators of the role of renewable energy resources in the country's energy balance, i.e., factors that are very important for national energy security, were chosen. These scenarios have effectively illustrated potential limits for change of internal and external conditions. After the analysis of the obtained results for modelling of future development of the energy sector, main rational and stable technological solutions were identified.

A thorough analysis of optimization results enabled to establish the main objectives of the Lithuanian energy sector development and operation, to define state provisions and directions of their implementation in the period until 2030, and guidelines until 2050. These provisions and directions are based on the economic efficiency, energy security, environmental protection and the improvement of management aspects by fully coordinating those with the state needs and the recent EU directives and the country's international commitments. According to the comprehensive analysis, project of an updated *National Energy Strategy* was prepared and submitted to the Ministry of Energy of the Republic of Lithuania.

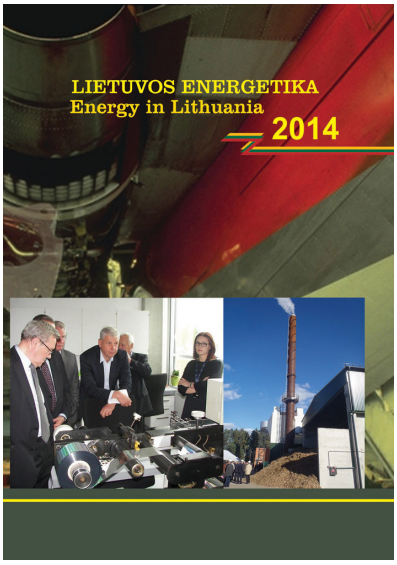
Following the agreement with the Ministry of Energy of the Republic of Lithuania, a scientific research ***Assessment of the statistical possibilities for transfer of the amount of renewable energy sources from Lithuania to other member states*** was carried out. The final report presents: forecast of final energy demand, forecast of the part of renewable energy sources in the gross final energy consumption, recommendations for Lithuania regarding possibilities of transfer to other EU member states the justifiably statistical amount of renewable energy sources that corresponds to the actual trends of the country's energy sector development and undertaken commitments. Also, the assessment on sales price limits due to such statistical transfer and recommendations for the use of the obtained funds in the energy sector were presented.

NACIONALINĖ LIETUVOS ENERGETIKOS ASOCIACIJA

According to the agreement with the National Lithuanian Electricity Association, a scientific study ***Assessment of social and macro-economic impact of energy development scenarios*** was carried out. Energy development is related not only to energy transformation technologies, their role in the energy sector and impact on energy sources prices, but also to larger effects that affect the entire country's economy. Such effects need to be taken into account both when determining country's energy sector development directions and when shaping energy policy.

These effects significantly depend both on energy (generating technologies, energy supply infrastructure) and on economy structure. Energy structure determines sources to be used in power industry in order to produce and supply energy to consumers, whereas economy structure defines energy consumption, inter-sectorial links and other factors that determine formation of social and macro-economic factors. Assessment of these factors is a rather complex task. For this reason, an original dynamic general equilibrium model has been developed. It includes four power industry products, nineteen other products and types of economic activities, companies, government and household sectors and foreign trade. The model in an aggregated way reflects tax system and other transactions including social security charges. Specific features of the model: consumption of electricity, district heat, natural gas and biofuel in economic branches and end-use segments is modelled in detail; a variable component of production of energy products is modelled using coefficients that characterize the structure of energy product costs in each given year; a particular emphasis is laid on modelling the energy infrastructure. For practical application of the model, initial data and result processing tools were developed.

By applying the developed model, social and macro-economic influence of the Lithuanian energy development until 2050 was assessed, including the impact on value added and gross domestic product created in economic sectors, various types of taxes, social security contributions, and international trade. The final research report presents: the results of modelling of social and macro-economic impact of energy development scenarios; methodological principles and assumptions used for the assessment; general characteristic of the analysed scenarios from the social and macro-economic impact point of view also qualitative assessment results of social and macro-economic impact of Lithuanian energy development scenarios. Social and macro-economic indicators were completed by the assessment results of the impact on country's research, innovation and technology development system, and national infrastructure.



The annual issue of statistical data ***Energy in Lithuania 2014*** was prepared, published, and transferred to the Ministry of Energy. The publication presents the most recent information characterizing development trends of the Lithuanian energy sector and its branches in the period 2010–2014, fuel and energy balances, and provides main indicators of the country's energy sector. Lithuanian energy and economic indicators are compared with the respective Estonian and Latvian indicators (in 2013 and 2014). The publication also presents the most recent, of 1990 and 2012, amounts of greenhouse gas emissions and their structure by sectors in the United Nations Framework Convention on Climate Change and the Kyoto Protocol signatory countries of Annex 1.

The publication provides a comparative analysis of 2012 and 2013 of European Union, the largest states in the world, countries of the Organization for Economic Co-operation and

Development (OECD) and summarized general world economic and energy indicators (GDP, energy consumption per capita, energy efficiency, etc.). This analysis was performed based on the most recent International Energy Agency data published in 2015 and methodology, according to which losses in networks are not assessed in electricity consumption of all countries, while in the final energy consumption, energy sources used for non-energy needs are included.

The Lithuanian economy after a dramatic decline in 2009 (14.8%) has been recovering – in 2010–2014, GDP has increased on average by 4.1% per annum. In 2014, GDP chain-linked volume comprised 32.9 billion EUR (base year 2010) or 11.2 thousand EUR/per capita. Primary energy consumption in 2014 increased by 0.7% and comprised 7.03 million tne. Final energy consumption in economy branches increased by 2.1% and comprised 4.82 million tne; final electricity consumption increased by 3.1% and comprised 9.24 MWh. Primary energy consumption per GDP unit in 2014 decreased by 2.3%, and the efficiency of final energy directly consumed in economy branches decreased by 0.9%.

GDP created in Lithuania (calculated based on purchasing power standards) in 2003–2008 has increased by 46.6% (EU-28 – 23.8%, respectively); however, due to economic decline in 2009, this indicator in EU-28 countries has decreased by 5.7%, and in Lithuania by 16.3%. GDP per capita in 2014 comprised 74% from the average of the EU-28 (in 2010, this indicator was 60%).

Following the agreement with the ***Ministry of Environment***, a scientific research ***National greenhouse gas emissions inventory in the energy sector for2015*** has been performed.

Carrying this research, National greenhouse gas inventory in the energy sector for 1990–2013 was prepared based on European Parliament and Council decision 280/2004/EB on greenhouse gas emission monitoring mechanism in the Community and requirements for implementing the Kyoto Protocol and methodology of the Intergovernmental Panel on Climate Change. Dr. I. Konstantinavičiūtė, as a member of the National Greenhouse Gas Emission Inventory Preparation Commission and National Climate Change Committee, actively contributed to finding solutions in this field of research.

PARTICIPATION IN INTERNATIONAL PROGRAMMES

Project ***Resource Efficient cities implementing ADvanced smart citY solutions*** (READY) funded by the EU Seventh Framework Program for research, technological development and demonstration has been launched; it aims to determine perspective of innovative technologies in Lithuania, such as:

- assess possibilities of smart kitchen implementation,
- assess possibilities of implementation of innovative energy systems,
- identify potential technologies, which can utilize excess industrial energy and which are appropriate for application in Lithuania,
- assess possibilities of application of innovative cooling technologies in district heat supply systems,
- assess possibilities of replication of integrated energy systems in urban areas.

Horizon 2020 project of the program ***Baltic Region Initiative for Long Lasting InnovAtive Nuclear Technologies*** (BRILLIANT) funded by the European Commission has been launched. The objective of the project is to determine obstacles, preventing nuclear energy development in the Baltic Region states and prepare recommendations for their elimination. In the

project that is coordinated by the Lithuanian Energy Institute, researchers of the Laboratory together with partners from the National Centre for Nuclear Research in Poland, University of Latvia, University of Tartu, Royal Institute of Technology in Sweden, Centre of Physical and Technological Sciences and JSC *VAE SPB* will have an important role in modelling energy development scenarios and in evaluation of social and macro-economic consequences of the implementation of various technologies. On 21–22 October, 2015, at the seminar dedicated to implementation of this project that was held at the Lithuanian Energy Institute, researchers of the Laboratory presented to the 3rd work package partners: experience in implementing research on sustainable development of energy systems; mathematical modelling and application principles of energy system analysis tool (MESSAGE); demand of initial data necessary to model development of energy systems and specific requirements for their preparation; possibilities of MESSAGE model application for solution of various energy development problems. In the discussions, possible problems while implementing this project were analysed, and tasks for all the project partners were envisioned.

According to the agreement with the Institute for Energy and Transport of the Joint Research Centre of the European Commission, a scientific study ***Research of consequences of failures at compressor stations*** has been carried out. The main attention of the conducted study was given to the analysis of how to ensure gas supply and satisfy the needs of the country's gas consumers in case of failures at compressor stations located in Lithuania. Moreover, other external conditions were rather broadly studied, those that influence operation modes of Lithuanian main gas supply network, such as pressures maintained at the Minsk compressor station, gas flows at the Kotlovka and Šakiai gas metering stations, volumes of gas supply via Klaipeda liquefied natural gas terminal, exploitation possibilities of gas pipeline interconnection Lithuania-Latvia, etc. The research report provides recommendations for the stability of operation of the country's gas pipeline system at different combinations of possible disturbances.

Issues of the energy sector development relevant for Lithuania, as well as aspects of wider use of renewable energy sources and increase of efficiency of energy consumption, are addressed in international program *Intelligent Energy-Europe* projects. In 2015, two projects ***Policy Dialogue on the assessment and convergence of RES policy in EU Member States (DIA-CORE)*** and ***Monitoring of energy consumption efficiency in EU states (ODYSEE MURE 2012)*** were implemented.

By the project ***Policy Dialogue on the assessment and convergence of RES policy in EU Member States (DIA-CORE),*** it is aimed to ensure the continuity of the assessment of RES support schemes and to develop a productive discussion on future support policy for the use of RES in electricity generation, heat production, and transport sectors. The project coordinator is the Fraunhofer Institute for Systems and Innovation Research ISI (Germany). Project partners: Vienna University of Technology, Energy Economy Group (Austria), Ecofys (Netherlands), Eclareon (Germany), National Technical University of Athens (Greece), CEPS (Belgium), DIW Berlin (Germany), Utrecht University (Netherlands), and AXPO (Austria).

During implementation of the project ***Monitoring of energy efficiency in the EU (ODYSEE MURE 2012)***, it is aimed to conduct a thorough monitoring of energy consumption efficiency and policy measures for increasing the efficiency of energy consumption in all EU countries and in all economic sectors. Project coordinator is ADEME (France). 32 partners from all EU countries participate in this project.

Experience gained at the Laboratory was widely applied on the international scale:

- On June 2–5, 2015, at the IAEA headquarters in Vienna, Dr. Galinis participated in a technical meeting, where methodologies used by the Agency and analytical tools for the analysis of sustainable energy development were addressed, as well as compliance of training programs and packages with the needs of today's member countries, improvement needs and directions of the applied measures were discussed, and recommendations for further activity of the Agency were proposed. Galinis also participated in another consultation that took place on 30 June–3 July, where IAEA experts-lecturers from all over the world shared their experience in organization and hosting training in the field of sustainable energy development held by the Agency, discussed various ways to improve specialist training and increase the interest of those who learn;

- On August 9–22, 2015, Dr. Galinis participated in training organized by the IAEA on the issues of the analysis of perspective energy development at the Royal Institute of Technology in Sweden. There, he delivered lectures and was in charge of practical training for experts in energy sector modelling, who are trained to become lecturers during training on regional energy modelling;
- In November 2015, Dr. Konstantinavičiūtė participated in the 11th meeting of the Intergovernmental Panel on Climate Change of the experts of Emission Factor Database in Hayama, Japan. Konstantinavičiūtė presented national carbon dioxide emission factors, which are used in preparation of Lithuanian national greenhouse gas inventory in the energy sector. During the meeting, it was decided to include the presented Lithuanian carbon dioxide emission factors into Emission Factor Database of the Intergovernmental Panel on Climate Change;

- Dr. Štreimikienė participated in the meetings of Energy advisors group of the European Commission scientific research and innovation program ***Horizon 2020***, where priority financial areas were established, assessing also the first and the second stages of the program projects.

In 2015, researchers of the Laboratory improved their qualifications:

- From January 12 till April 11, 2015, Dr. Dalia Štreimikienė participated in an internship programme in Kiev, where during implementation of EU FP7 project ***Pro-ecological restructuring of workplace***, she was assigned an important task: to present the assessment of aspects of workplace greening, energy saving and the impact of greenhouse gas emissions;
- On June 6–19, 2015, engineer Eimantas Neniškis improved his qualification at the courses organized by the Royal Institute of Technology and Linnaeus University in Sweden. Neniškis attended twenty lectures related to spent nuclear fuel waste management policy, technologies, also social, economic and environmental impact, got acquainted with the ongoing procedures and existing processes of spent nuclear fuel storage at wet fuel storage, laboratory and its tunnels;
- On August 10–21, 2015, Dr. Norvaiša participated at IAEA organized course, intended for instructors, applying IAEA analysis means in preparation of sustainable energy strategies. The course was held at the Royal Institute of Technology in Sweden, Stockholm. Its objective was to introduce to the participants the mathematical model applied by IAEA for the analysis of the energy sector and preparation of experts, capable of becoming teachers at the future trainings. Norvaiša got acquainted with specific features of the MESSAGE model, its mathematical formulation, specific issues and modelling of energy objects, modelling of various energy policy achievements, etc. He had a chance to model and analyse different objects of the energy system. Norvaiša prepared and delivered several papers to other course participants.

In 2015, the researchers of the Laboratory presented research results in eight papers at the international and national conferences, published fifteen scientific articles in Lithuanian and foreign journals, in proceedings of international conferences, etc. (five of those in journals listed in *Thomson-Reuters Web of Science Core Collection* database).

LABORATORY for RENEWABLE ENERGY and ENERGY EFFICIENCY

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THE MAIN RESEARCH FIELDS OF THE LABORATORY:

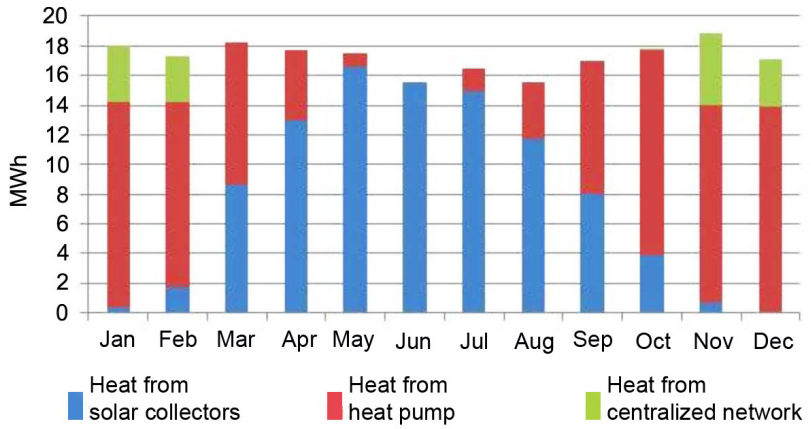
- research and modeling of wind flow variation in different regions of Lithuania;
- development and research of models and methodologies for forecast of variation of wind power plant capacity;
- research of the aspects of performance efficiency and environmental impact of industrial and small wind power plants, preparation of feasibility studies of wind power plants;
- research of development of solid biomass sources, fuel preparation and combustion technologies;
- research of biogas and biofuel production processes and environmental problems;
- analysis and research of use of sustainable development of renewable energy sources;
- analysis and promotion of advanced energy production technologies using local and renewable energy sources, compilation of databases, services and consultations to users, dissemination of information to the society.

RESEARCH OF DEVELOPMENT OF RENEWABLE ENERGY TECHNOLOGIES

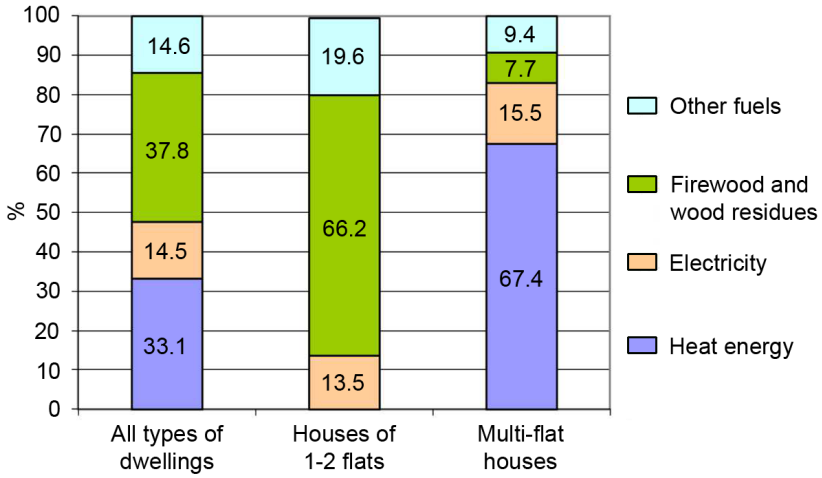
The Laboratory conducts research on the use of wind, solar and biomass energy as well as research related to the development of technologies to ensure the sustainable development of renewable energy sources (hereinafter RES) in the country, facilitate the development and implementation of new technologies, and reduce the dependence on imported energy sources.

In 2015, a scientific research project ***Integration of renewable energy technologies into building energy supply systems*** was launched, financed by the state grant.

Statistical analysis was performed to identify energy needs in buildings used for different purposes, energy consumption regularities were described, measures ensuring efficient use of energy in buildings were analysed, the regulating legal acts were reviewed, typical building characteristics were identified, which will be used in the feasibility study on the integration of renewable energy source (RES) technologies into buildings, methodology was developed for the assessment of technical and economic efficiency of the use of RES technologies in buildings.



Heat generated by solar collectors and heat recovery equipment under optimal solar collector area



Average consumption of fuel and energy in Lithuania by type of dwelling and kind of fuel and energy used in percent

An overview of the latest methods used to forecast the power of wind farms and analysis of precision of the forecasting models used in Lithuania were performed, and methodology for designing a wind power forecasting model was developed. It was identified that the precision of forecasting is affected by the change in wind speed during various seasons and also by the quality of the applied numerical weather prediction (NWP) model data.

The study, performed in 2015, confirmed that good building heat insulation system and compliance with all energy efficiency requirements for the building are the most important conditions for the efficient use of RES in the building. Only this can ensure economic exploitation of RES technologies which pays off fast.

While conducting research of wind conditions, wind speed and direction measurements are performed on the roof of the institute building, investigating the impact of meteorological conditions and surrounding buildings upon the formation of wind gusts and operation of small scale wind energy plant.

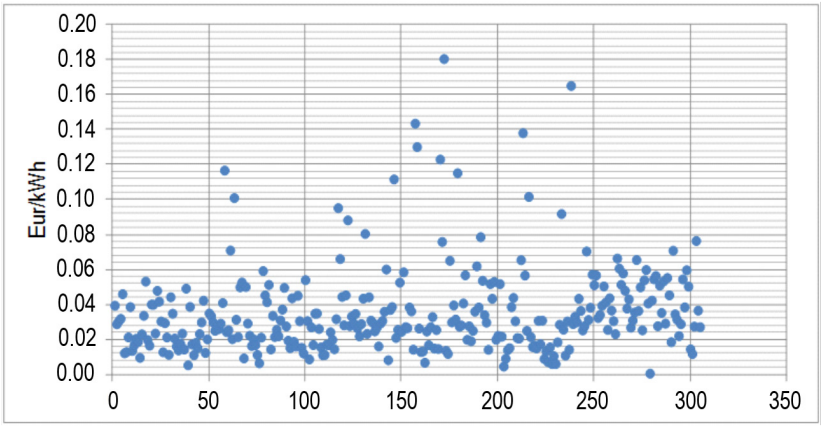
Since 2013, while conducting research on small scale wind energy plants, a doctoral dissertation ***Investigation* of *renewable energy technologies and their application in urban environment*** is being prepared. Research of wind power forecasting methods was also performed while preparing another doctoral dissertation – ***Impact of meteorological and topographical conditions upon wind power prediction.***

A doctoral dissertation ***Investigation of icing influence on wind turbines performance*** was started in 2015, which aims at a comprehensive exploration of environmental factors that exert impact upon the efficiency of wind energy plant.

A state funded scientific research project ***Investigation of the effectiveness of sustainable energy measures implemented on municipality level*** continued in 2015. A lack of systematic approach was identified with regard to the assessment of effectiveness of energy efficiency and renewable energy measures implementation, as well as shortage of methods and assessment criteria. The availability of information on the sustainable energy projects implemented on municipal level, their substantiation, monitoring and financial indicators were analysed.

Assessing the intensity of RES development measures, periods of simple pay off for biomass boilers and CHP plants were analysed for projects: a) with EU support, b) without the EU support and c) under the existing difference in fuel prices in 2015 without the EU support. The results show that the majority of the supported projects, when generated energy is supplied to the final heat consumers, would have paid off without the EU support during less than a 10-year period due to the difference in natural gas and biomass fuel prices. Having received the financial support, the average simple pay off for the implemented projects was only up to 3.2 years. On the other hand, the EU support provided an opportunity to reduce heat tariffs for the final consumers. The support provided for the projects can be considered asa positive social aspect in reducing heat tariffs for final consumers and reduction of compensations for families with low income.

Financial-economic mechanisms that facilitate the use of RES technologies and possible funding sources were also classified in the work. Although the functions of preparing RES action plans for municipal energy sector and zoning of RES technologies are rather precisely defined in the Renewable Energy law, but in practice RES action plans are only at the outset of being developed. The problem here is financial support via grants of EU Structural Funds which is currently perceived in a narrow way with the orientation towards biomass mainly.



Price of energy saved in public buildings, having implemented building renovation projects on national level in the period of 2007–2013

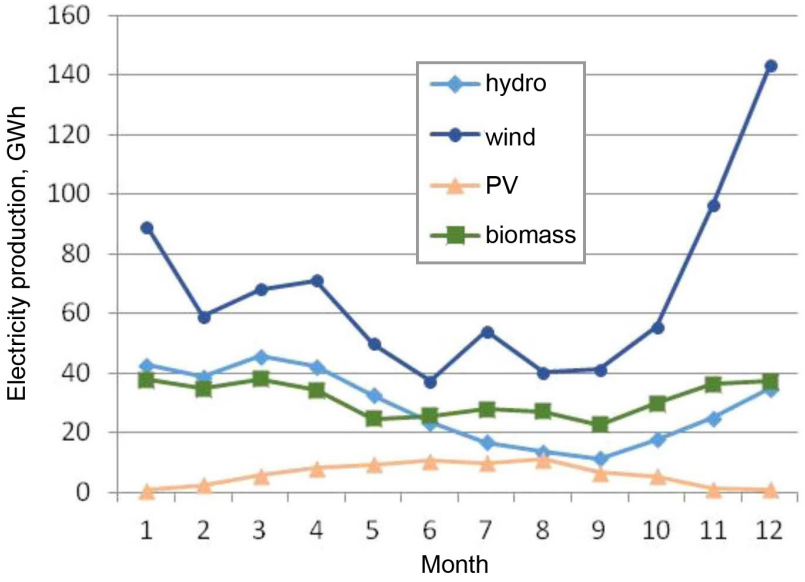
Since 2014, a doctoral student of the laboratory has been preparing a dissertation on the topic ***Effectiveness of renewable energy source support measure development.***

Research Council of Lithuania

In 2015, together with other units of the institute, a long term institutional research and development programme project ***Investigation of the use of renewable sources for efficient energy production and environmental impact*** was further implemented. In 2015, exploring the possibilities to increase biomass sources in production of solid biomass fuel, biogas and biofuels, technologies of growing and using water based biomass (algae) in energy sector were overviewed, estimating production costs and analysing the possibilities of using these sources in Lithuania. Almost all life cycle assessment research confirmed the necessity to increase the advancement of technologies to make algae fuel commercially perspective.

Measurements of wind characteristics were performed and data measured by the Lithuanian weather stations in 2014 were analysed, describing it by the Weibull probability density function. It was determined that a large number of probability density function calculation methods yield reliable results. However, taking into account the geographical location, height from the surface and impact of other factors upon the density of wind power, some methods are unacceptable as they determine rather high (up to 30%) relative biases. Therefore, while identifying wind energy resource distribution and calculating Weibull function parameters, it is necessary to take into account the reliability of the methodology.

An overview of the situation in electricity production from renewable energy sources was performed: in 2015, approximately 16% of the totally consumed electricity was produced from RES, including the greatest part (50%) produced in wind farms, 23.5% – in biomasspower plants, 21.5% – in hydropower plants, 4.5% – in solar power plants.



Electricity production from different kinds of RES in Lithuania in 2015

ANALYSIS AND RESEARCH OF SUSTAINABLE DEVELOPMENT OF THE USE OF RENEWABLE ENERGY SOURCES

This is a very broad area of the researches which are being provided by scientists of Laboratory.

It should be noted two already performed projects of the long-term institutional scientific research programme ***Lithuanian challenges of long-term economic competitiveness***. Projects that were on the topics *Assessment of RES and acquisition of energy saving technologies in wide scope on GDP and foreign trade balance in order to make economic presumptions for justification of the state's support* and *Identification of assessment principles for the use of state budget and available structural funds and various fiscal-financial measures for advanced energy technologies* were successfully performed. On the basis of these projects a monograph ***Justification of long-term economic policy of renewable energy sources*** was prepared and published.

The territorial aspect is the main dimension of the latest investigations concerning the implementation of RES at large scale.

Two doctoral dissertations have been prepared in the frame of territorial aspect of implementation of RES technologies. K. Bieksa has defended a dissertation ***Energy economic model for green settlements***. The problem is related to the direction of the development of modern energy economy and the issues of sustainable development when long-term and continuous development of the society does not have to confront the primary life status, which continuously maintains self-regulated mechanisms. Energy is needed for operation of the cycle of the ecosystem, and this energy comes mostly from the Sun. In the society of material flow where one lives, one element is lacking: these are decomposers, which can break down useful components closing the material cycle and create a waste-free cycle

The research object is the production of materials, products and energy in a "closed" cycle, where there is almost no waste, and where the produced waste is recycled. Therefore, not only the efficient use of products and materials is important, but also the ecology of components used in the production of these materials and the recycling possibilities. A systematic aspect is important in the circular economy cycle, where there is a need to analyse the resources and the amount of energy and its flow in order to manage and control energy distribution in an attempt to decrease the amount of waste and to turn waste into useful materials.

Lina Murauskaite will defend her dissertation ***Diversification of renewable energy sources for district heating system*** in October 2016. District heating infrastructure is suitable for reaching strategic energy goals of the state, such as integration of local and renewable energy sources, utilization of municipal waste for generation of heat and electricity, diversification of fuel sources due to the security of energy supply, implementation of district cooling for buildings, integration of industrial waste heat to district heating networks, efficient production of electricity in cogeneration power plants, reduction of environmental pollution and GHG emissions, etc. District heating enables the use of diversified fuel sources, and this could be the basis for security of energy supply and stabilisation of energy prices. The main issue in Lithuanian DH sector is based on dominant position of only one type of fuel source, which has to dominate in DH balance due to the lowest price in a short term. Therefore several times during the last decade there have been dramatical changes in prices, which affected massive implementation of new installations in district heating systems.

The main result of the research is created methodology for the integration of diversified RES (on the example of solar and geothermal energy) technologies into DH systems on the producers and consumers sides in terms of sustainable development of cities, which will enable

to reach the state's long-term goals of energy security, energy efficiency, and social problems for the long-term energy planning.

PARTICIPATION IN INTERNATIONAL PROGRAMMES

The kick-off meeting of MultEE project partners in Kaunas in April 2015

In 2015, a **Horizon 2020** project ***Facilitating Multi-level governance for energy efficiency*** (***MultEE***) was launched. The project is realised together with partners from nine European countries (Germany, Denmark, Latvia, Lithuania, Slovakia, Austria, Croatia, Macedonia and Greece). The project is coordinated by an organisation from Germany GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH).

The overall objective of "MultEE" project is to improve planning of measures to increase the efficiency of energy sources and energy consumption and their implementation in project beneficiary countries.

While implementing the directive 2012/27/ES of the European Parliament of 25 October 2012 on energy performance efficiency, various measures are implemented in Lithuania, which lead to increasing the efficiency of energy sources and energy consumption. The measures include household, service, industry, energy and transport sectors.

Aiming at better exploitation of funds allocated for preservation of energy resources and energy, it is very important to assess the final outcome of the implemented measures, i.e. the factual layaway of energy resources or final energy. Therefore, it is necessary to perform monitoring of the implemented measures, which would allow determining the implementation quality control and obtaining reliable data on not only energy savings after the implementation of the planned specific measures but also the summative outcome on national level.

At present, the collection of such data is mainly performed using a survey method on the basis of the data presented by the Lithuanian Department of Statistics, energy enterprises, various agencies, other institutions and organisations.

It is necessary to establish a unified computerised data collection, verification, assessment and presentation system on national level which embraces the organisations listed above. Furthermore, a good coordination system, balancing the actions of various organisational structures, is important which ensures reliable coordination of the above mentioned actions.

Recently such innovative systems have been established and implemented in Germany, adapted in Croatia and Macedonia.

The saved energy sources or amount of energy are estimated in these systems by applying bottom-up calculation methods which ensure a more precise and reliable identification of the efficiency of the implemented energy sources and energy saving measures. Such data will allow to considerably improve planning of these measures.

During the project development, information is being collected and summarised about the best practices in data collection, verification, assessment systems and coordination schemes in all the EU countries. On the basis of the collected data and using special assessment criteria, the best practices will be mapped, analysed and suggested to all participating countries.

Project participants will be acquainted with an innovative computerised system implemented in Germany; they will undergo training; the innovative system will be transferred to the specialists of participant countries.

The results obtained during the project will facilitate and allow for more precise calculation of the saved energy sources and amount of energy both for separately implemented energy saving measures and for various programmes which are currently performed on national level. The project implementation is performed in close cooperation with

employees of the PI Energy Agency who conduct calculations of the layaway of energy on the national level.

In 2015, the EU Intelligent Energy Europe Programme project ***Transparense – Increasing transparency of Energy service markets*** – was completed. The 3-year project was realised together with partners from 20 European countries, coordinated by the Czech Energy Efficiency Center (SEVEn).

At present, in order to fund energy efficiency projects the *Energy Performance Contracting* – EPC – model has been applied in a number of European countries, which allows to achieve good energy saving results. The essential feature of energy performance contracting, i.e. a contractual agreement between the beneficiary and the service provider (Energy service company - ESCO), is that the service provider ensures (by its financial resources) the amount of energy saving indicated in the contract, which will be achieved having implemented energy saving measures at the client's place. The beneficiary (client) pays for the provided services (fully or partly, depending on the contractual agreement) during a certain period of time (rather than straight away) from the income received for factually saved energy or energy sources.

The application of this model and its development has also been fostered by the new Directive 2012/27/EU of the European Parliament and of the Council. This directive projects a general energy efficiency enhancement system in the European Union which aims at achieving the objective of saving 20 % of the European Union's energy consumption by 2020 and creating conditions to further increase energy consumption efficiency. In Lithuania, this model has not been launched so far.

During the period of project implementation, the information about the activity of energy service companies in the EU countries was collected and analysed, evaluating legal acts which concern the application of the "Energy Performance Contracting", financial schemes of projects aimed at increasing energy consumption efficiency, their support, strategies, and etc.

During the project implementation the Energy Performance Contracting Code of Conduct was developed for energy service providers. Adherence to this code of conduct increases the transparency of energy service company activities and allows maintaining high quality of the provided services.

Seminars were organised and training programmes provided on the implementation of Energy Performance Efficiency while implementing the projects which increase energy consumption efficiency in Lithuania.

Moment of training for the basics of application of the ESCO model for the implementation of efficient energy consumption projects

In 2015, another EU Intelligent Energy Europe co-funded project was completed: ***SDHplus – New Business Opportunities for Solar District Heating and Cooling.*** The project was coordinated by partners from Germany - Research Institute for Solar and Sustainable Thermal Energy Systems, SFZ Solites, and lasted for 36 months. 18 partners from 12 EU countries participated in the project. The project ***SDHplus*** was oriented to broader integration of solar thermal plants in centralised heating networks and supplying heating in buildings.

The aims of the ***SDHplus*** project were to promote a broader use of solar energy in centralised heating provision systems by describing and disseminating successful practices of solar energy integration into CHP systems, developing and implementing new pilot business models and focusing on situations, when RES use is attributed to measures of energy efficiency increase and also developing and realising new market strategies in solar energy CHP sector (e.g., green tariff, purchasing models).

Dissemination of information is a particularly important area. Dissemination was provided in international SCHP seminars and during the centralised heating provision market participant visits to SCHP plants. Two documents were prepared in 2015; one of which is an information material – a project brochure in all project participant national languages where success factors in SDH are defined, highlighting its advantages with regard to other heating systems, implemented projects of various levels are presented, market situation in the European countries, business models, best practices and international cooperation opportunities described. The second document is a specialised report for heating system developers about the opportunities of solar energy use in CHP systems while planning cities, which presents possible business models, their technical possibilities, experience of European countries, relationship with city planning, solar energy integration decision making process, inclusion of solar energy into urban development plans, transition and correction of legal system.

Project participants also participated in the final project meeting in Tolouse (France) which was organised together with ***SDHplus*** scientific conference.

More information on project activities is presented on the website www.solar-district-heating.eu

Since March of 2014, the Laboratory scientists have been participating in the COST programme activity ***Wind energy technology reconsideration to enhance the concept of smart cities (WINERCOST)***. This activity aims at collecting and systematising the information on the experience of the European countries in the development of wind energy technology in urban environment and assessing opportunities for successful wind energy technologies adoption in Smart Future Cities. Technical, economic and social barriers as well as the most efficient measures which foster the development of wind energy plants in urban built environment are analysed. The activities involve working group meetings, international conferences and summer schools organised for specialists of various levels. 28 countries participate in the activity. For more information please see: http://wincercost.com

Partner meeting of COST program activity WINERCOST in Coimbra (Portugal) 30 March – 1 April 2015.

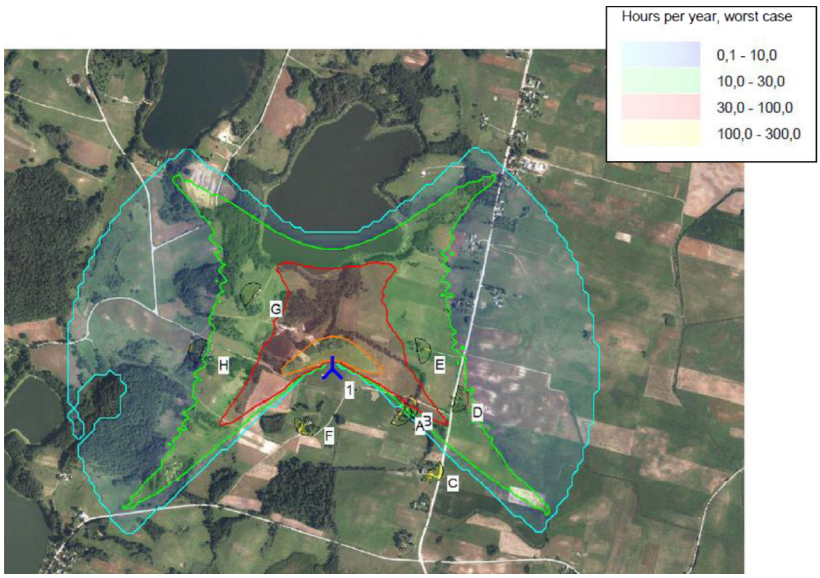
In 2015, two partner meeting were organised: in Coimbra (Portugal) in March and in Belgrad (Serbia) in August. The Head of the Laboratory M. Marčiukaitis made a presentation in the international strategic seminar *Trends and challenges for wind energy harvesting* in Coimbra.

APPLIED SCIENTIFIC RESEARCH

In 2015, the cooperation with 2 business enterprises continued: applied research was performed, funded by the Agency for Science, Innovation and Technology (MITA) according to the support measure **Innovation Vouchers**. During the projects wind energy plant noise and shadow zones were modelled and analysis of wind conditions was performed.

Successful cooperation with enterprises creates added value for them: in 2014, in cooperation with PE *Entiumas* and JSC *Aedilis,* a mobile wind speed, direction and wind turbine *Vejo fabrikas* was created, its power data registration and accumulation facilities have been used up to now. Monitoring of wind speed and energy produced by wind energy plants provides useful information on the efficiency of the wind energy plant under real life conditions; consequently, this leads to higher trust of its clients in the enterprise production and provided services.

In January of 2015, a 2009–2014 European Economic Area Financial Mechanism LT03 programme *Biodiversity and Ecosystem Function* project ***Development of Wind Energy and Important Areas for Biodiversity (VENBIS)*** was launched. The project coordinator is Lithuanian Ornithological



Results of wind turbine shadow flickering zone modelling

Society; the project partners are Coastal Research and Planning Institute and LEI.

The overall aim of the project is to reduce decline of biodiversity in Lithuania.

The main objectives of the project:

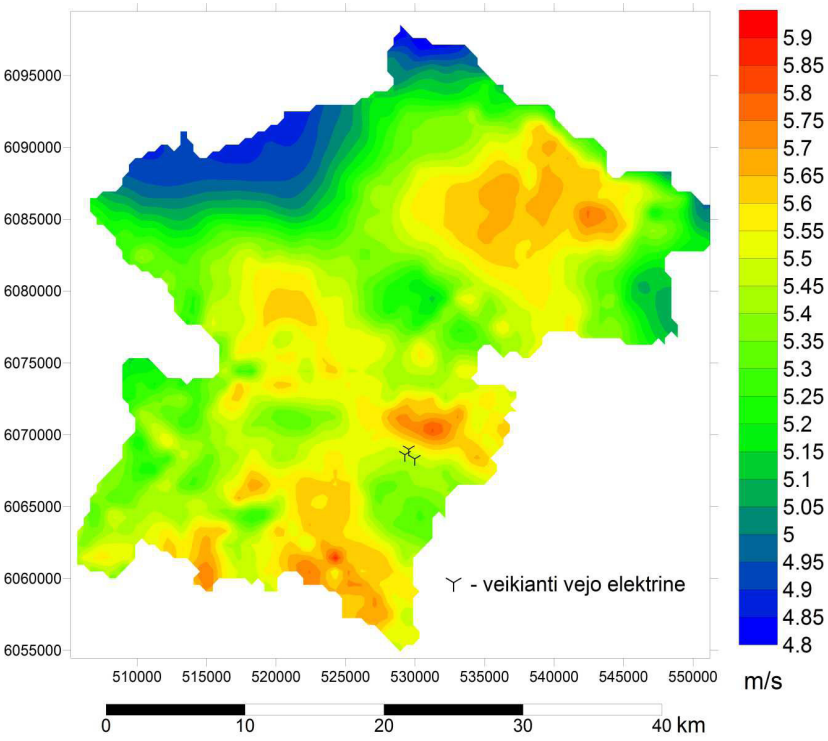
- to identify territories important/ sensitive to and in conflict with biological diversity protection with regard to wind energy (WE) development;
- to prepare mechanisms for protection of such territories and WE sustainable development conflict management;
- to present recommendations with regard to WE development conflict management in territories sensitive to biological diversity on national and local level.

Laboratory scientists performed the assessment of the present state of WE development, gathered information on all wind power plants operating in Lithuania, analysed general and special wind farms distribution plans approved by municipalities. Wind resource modelling in 53 Lithuanian municipalities is also currently performed; methodology to identify the suitability of the territory for WE development has been created.

On the basis of the obtained modelling results and according to various criteria (natural and technical) the most perspective WE development territories will be identified and visualised via GIS software.

In 2015 an applied research work was performed – ***A feasibility study on the use of renewable energy technologies in a multi-flat building (Tuskulėnų str. 37 Vilnius)***. In this work, an overview of statistical data on the apartment building's heat and electricity consumption was presented, the physical-technical state of the building constructions and energy systems was assessed, expected and factual energy consumption were compared, energy efficiency class of the building was determined, feasibility analysis on reduction of energy consumption and efficient energy consumption in the building was presented, technical possibilities for RES technologies implementing in the building were investigated and economic indicators were estimated. It was identified that the least cost heat can be provided for this building using heat pump installed on the roof, which could return the heated air flow from ventilation holes to hot water preparation system.

VENBIS project partner meeting at the Institute in July 2015



Map of wind speed distribution in Kaisiadorys district municipality (100 m)

SCIENCE PROMOTION ACTIVITY

While conducting scientific research and implementing international projects, society is acquainted with scientific ideas and findings of the performed research, which enhance societal interest in the diversity of renewable energy sources and opportunity of practical application.

In 2015, in the **Wind Energy Information Centre,** established in the Laboratory, practical seminars were organised for the 3rd year students of the Departments of Physics and Environmental Science at the Natural Science Faculty of Vytautas Magnus University, where the students explored peculiarities of power production in wind turbines and got acquainted with

Visit of schoolchildren from Vilnius Jesuit gymnasium Erasmus exchange programme at LEI

Practical seminars for VMU students: research of photovoltaic module efficiency

Interactive lecture for schoolchildren at the camp PAPARTIS

Visit of schoolchildren from Alytus Vidzgirio basic school at LEI

A 3rd year student of KTU performs wind turbine model research during practical training

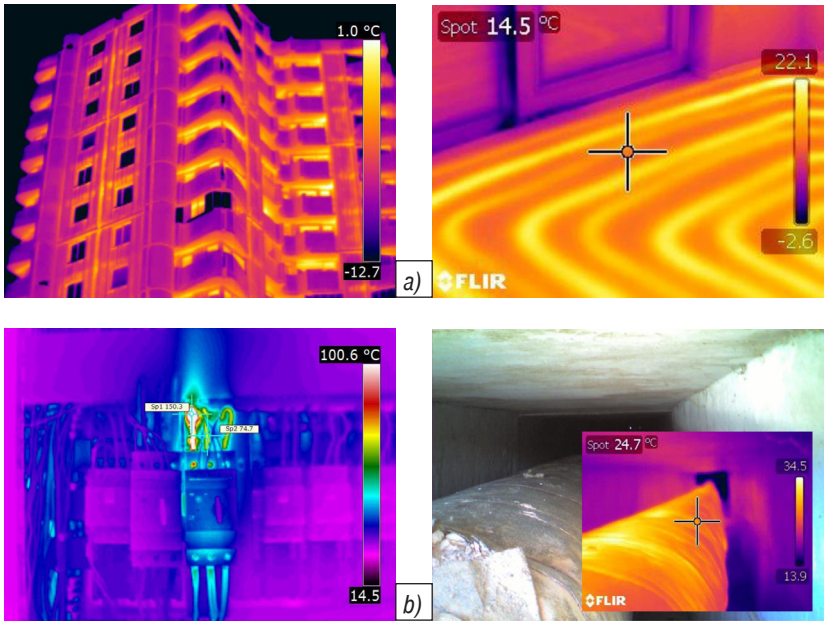
the principles of photovoltaic module efficiency. Furthermore, 9 excursions for schoolchildren from various schools in Lithuania were organised. During the seminars and excursions the participants learnt about the possibilities of application of small wind turbines, investigated practical samples, and improved their calculating, constructing and scientific test performance skills.

Students exhibit an active interest in RES consumption development, perform their practical training in the laboratory, and prepare their course and diploma papers, supervised by the Laboratory scientists. In 2015, the Laboratory scientists supervised the Master final thesis *Investigation of autonomous renewable energy supply systems*, prepared by a student of the Department of Physics at the Natural Science Faculty of VMU. Two 3rd year students performed their practical training at the Laboratory – one of them investigated the efficiency of the educational wind turbine models and the other elaborated the design of wind tubine model blades. In the future, with the help of Laboratory scientists, students are planning to conduct more comprehensive research and choose study fields related with the use of RES technologies.

SERVICES PROVIDED BY THE LABORATORY

Consultation activity

Laboratory employees disseminate their scientific competence and experience widely by providing consultations for municipality employees, business enterprises and state institution employees, give lectures in qualification development courses for public institution specialists and office workers.



Thermovisional research of buildings (a) and the electricity sector and heating pipelines (b)

Thermovisional diagnostics of buildings, electricity sector and technological processes

Thermovision is a non-contact surface temperature measuring technology based on measuring heat radiation intensity. Thermovisional analysis is used to investigate and supervise residential and industrial premises, their roofs, pipelines, electricity sector, chimneys, mechanical facilities, liquid drain problems, level of filling in tanks/vessels, process observation and quality monitoring. Thermovisional research is performed using a thermovisor **Flir B400**; its range of surface temperature measurement is from -20 °C to +350 °C.

Certification of building energy efficiency

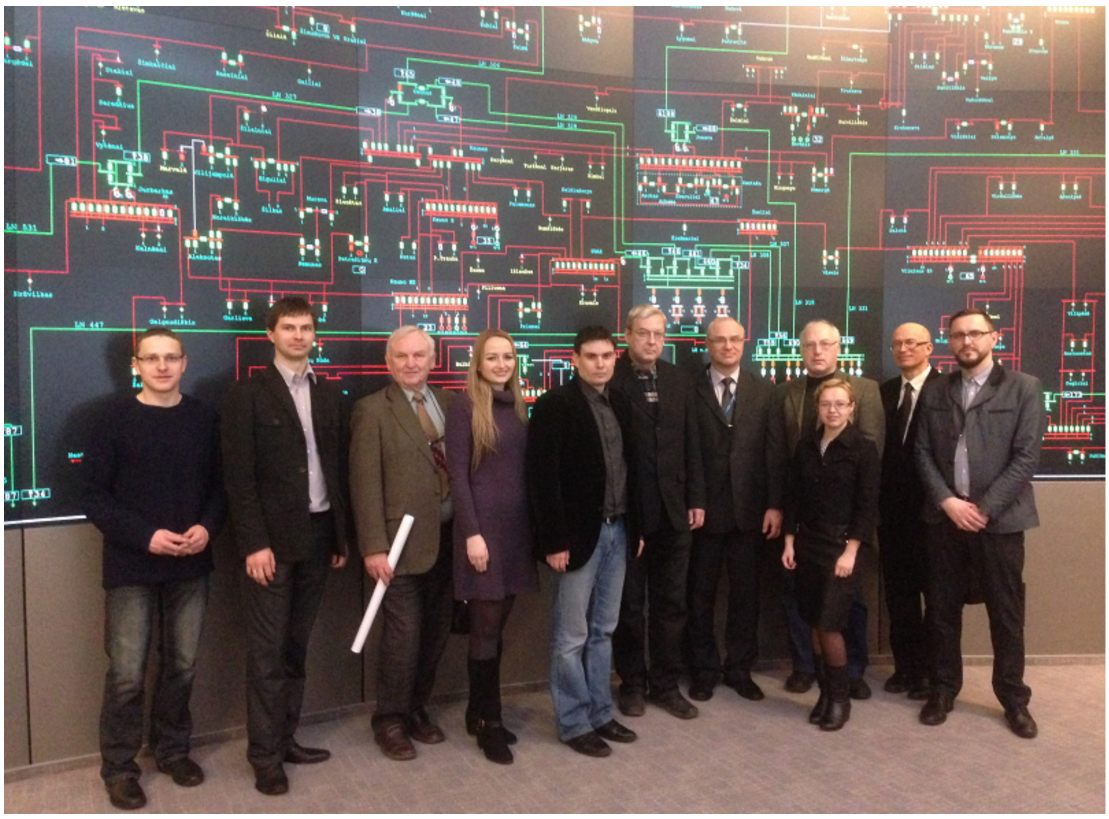
A Laboratory expert performs the certification of building energy efficiency. It is the process regulated by legal acts during which the building's consumption of energy is identified, energy efficiency of the building is estimated, attributing the building to a certain energy efficiency class, and the certificate of building energy efficiency is issued.

Energy audits

In 2014, the Laboratory expert S. Masaitis was awarded the qualification of an auditor by the PE Energy Agency, which grants him the right to perform the audit of energy consumption in facilities and technological processes.

Dissemination of scientific research findings

In 2015, the Laboratory researchers published 3 scientific articles, prepared 1 scientific monograph, gave 6 presentations in scientific conferences and published 1 science promotion article.



LABORATORY of SYSTEMS CONTROL and AUTOMATION

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MAIN RESEARCH AREAS OF THE LABORATORY:

- mathematical modelling of power systems and networks, investigation of their control issues;
- modelling and optimisation research of ICT-based control systems of power systems.

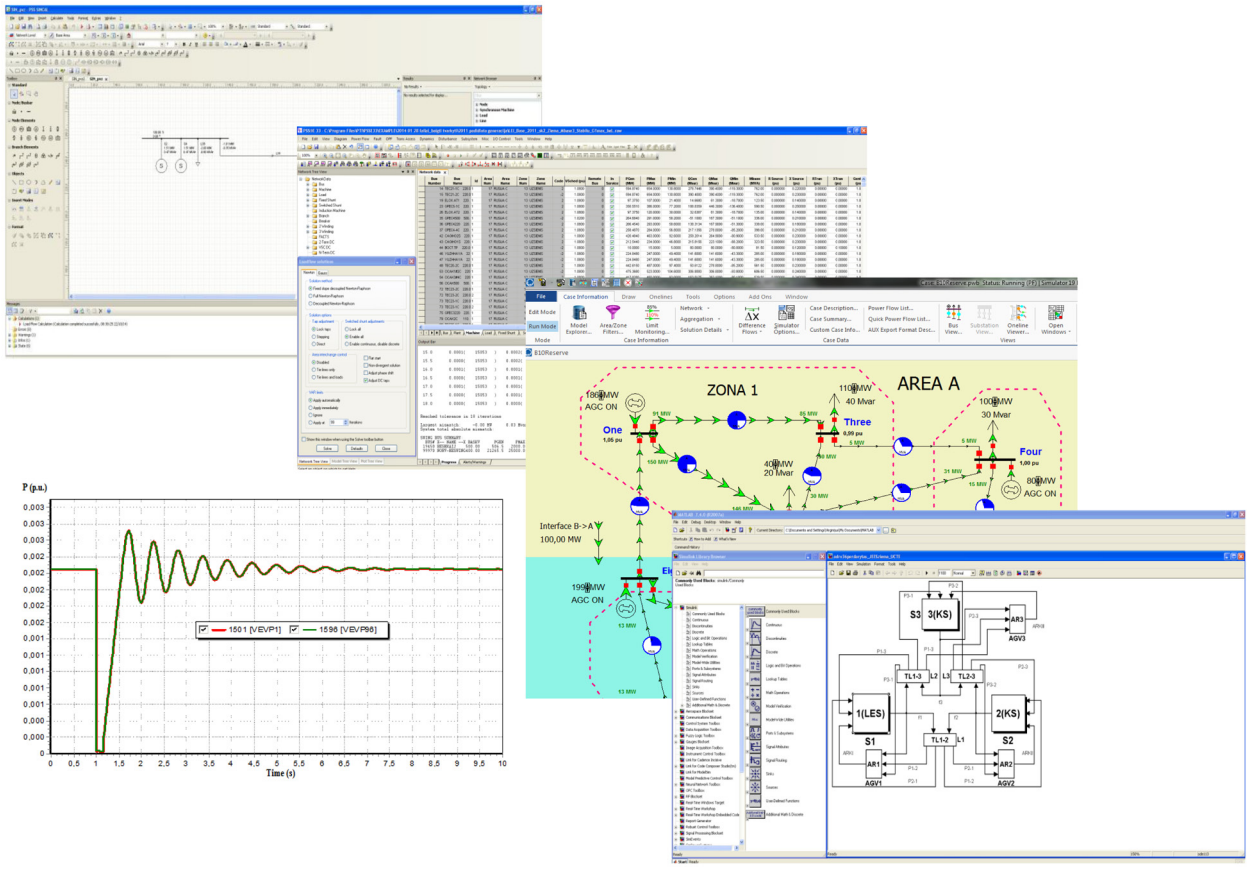
Power system (PS) is one of the most complex technical and organizational systems covering generators, power networks and consumers, which operate synchronously, i.e., under the same mode and with the same current frequency in large areas. The operational modes of PS, specified by energy, powers, currents, voltages, phase angles and other parameters, are characterized by continuous change. All the modes should be kept within the pre-determined parameter limits, and this is the major responsibility of the PS operator. Control is a rather complex task even under normal operation; however, systems often get into stressed modes, sometimes emergency and post-emergency modes, the control of which is more complicated. Out-of-

control operational modes may lead to loss of stability, voltage collapses, and failures of individual parts or total blackout. System and preventive automatics with protection relays and multiple digital controllers, as well as data communication systems, connecting generators and network substations with dispatch control centers, help the dispatchers to operate the systems and networks and protect them from emergencies.

Operators prepare control measures (equipment switch-over plans, settings of automatics, dispatch control signals) based on modelling, i.e., on calculations. This is an activity requiring a great deal of scientific knowledge and methods: adequate algorithms, assessment methodologies and analysis procedures need to be developed.

Laboratory of Systems Control and Automation *carries out research and offers services* in the following fields:

- mathematical modelling of power systems, analysis and assessment of their parameters;
- investigation of PS control issues and development of respective algorithms to deal with frequency regulation, active and reactive power control, static and dynamic stability, minimization of transfer losses, electric power quality, emergency prevention;
- investigation of advanced PS control methods and application of new automatic control devices and information and communication technologies (ICT);
- analysis and assessment of PS reliability, security and risks;
- optimisation of PS operation in competitive market environment, development of competitive balancing mechanisms and ancillary service mechanisms;
- research on the integration of renewable energy sources (wind, solar, etc.) and distributed generation into PS;
- legal regulation of PS control and use-of-electricity issues;
- economic efficiency analysis related to PS control and extension, and use of electricity;

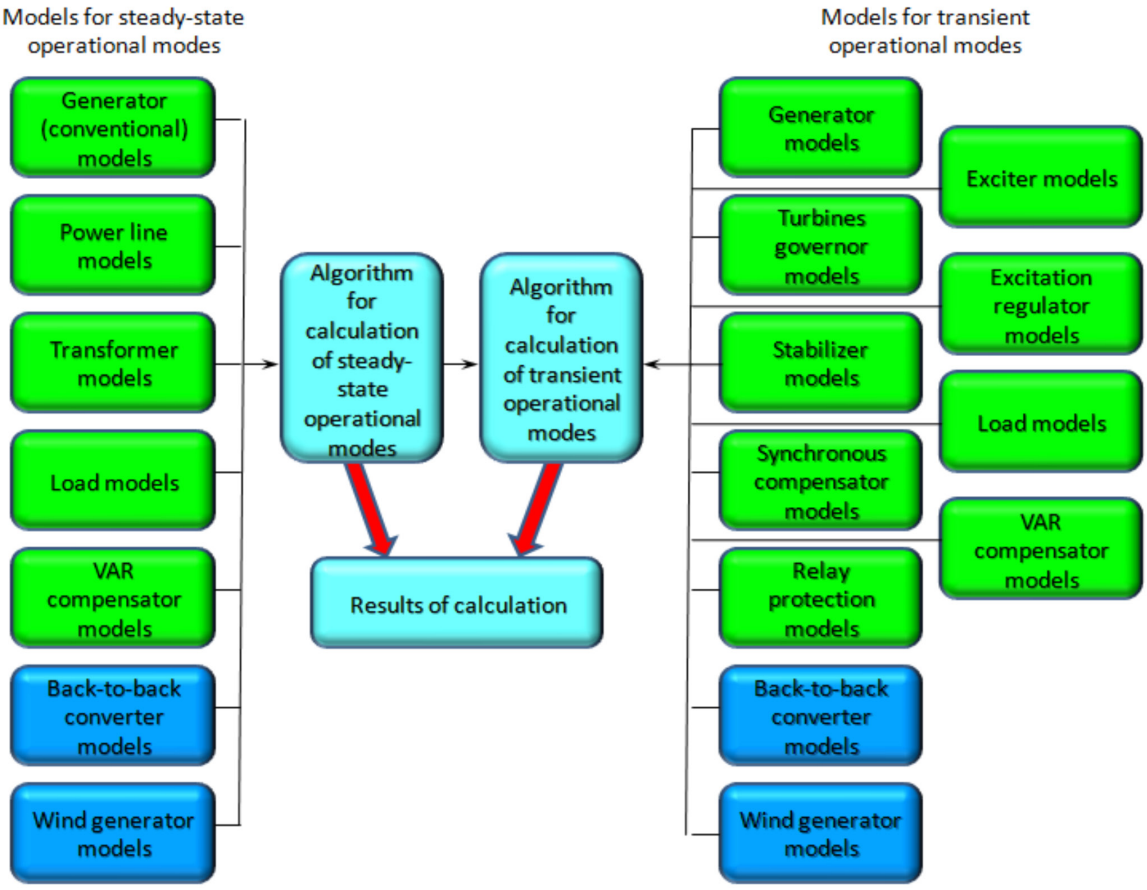


Software used in the Laboratory

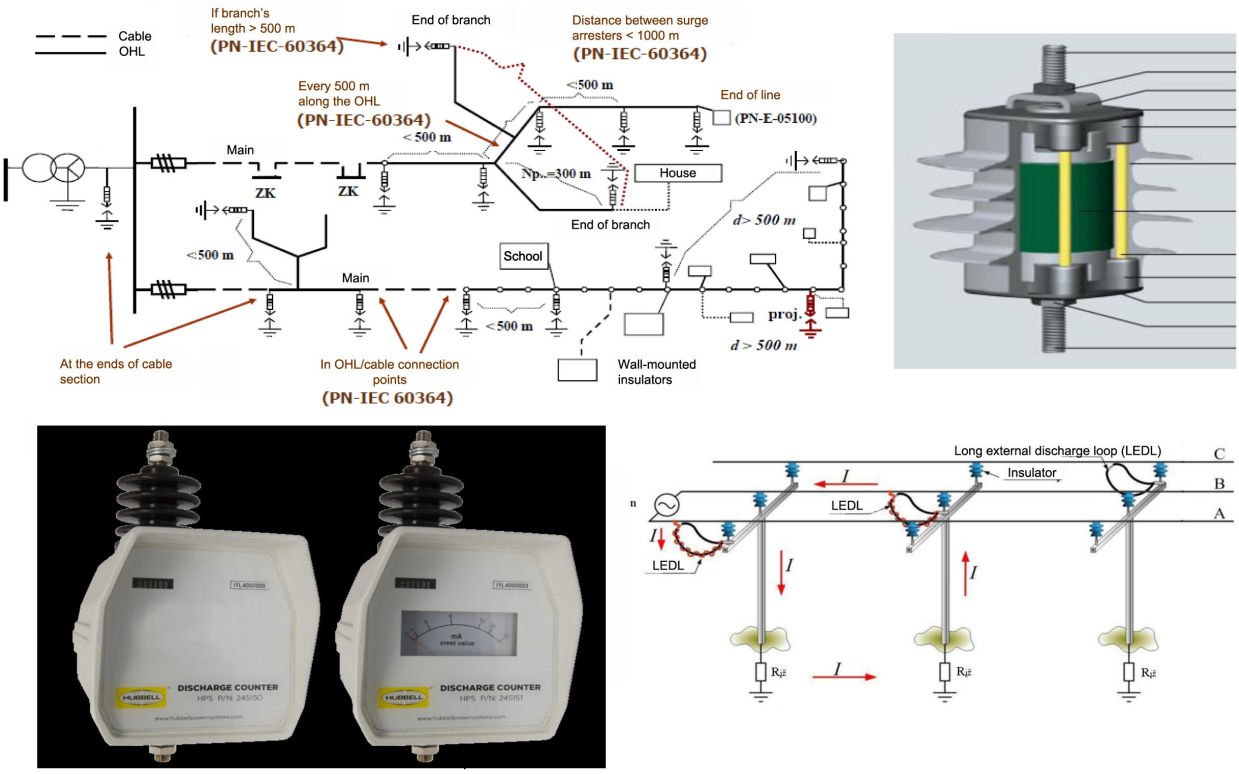
Development of modern power systems features significant changes. "Inter-system" electricity trade is expanding both geographically and in scope of various products of the electricity market (active power reserves and other ancillary services, forward financial transactions). Users and small generators are included into electricity trade and supply of ancillary services. Electricity is becoming "greener" due to increase of generation from renewable energy sources and also, if any, due to development of nuclear energy. Resistance of power systems to accidents will increase; reliability of power supply and power quality (more regular form of the voltage sine curve, less voltage flicker, etc.) will improve. Enablers for such changes are mostly the smart technologies, based on information and communication technologies. The result of their implementation is described by new concepts like *smart generation*, *smart grid, smart relay protection, smart metering*, and even *smart house*. The smartness component is achieved by computer logic devices (controllers with microprocessors) and their communication with each other and with the dispatchers of the power grid. Smart technologies help operators to control the power grid in a more efficient and reliable manner in real time, and in some cases even make this work simpler (since smart controllers perform a part of the control and monitoring functions without human intervention). On the other hand, control is becoming more complicated for the operators since many additional algorithms and programmes have to be installed into controllers, which requires integration of their interaction, coordination and reprogramming of controllers for addressing the detected faults of operation.

In 2015, the Laboratory completed the project ***Development of the Solutions for the Mitigation of Impacts of Voltage Surges on the AB LESTO Electrical Distribution Network,*** under the contract with *LESTO*, AB (currently ***Energijos skirstymo operatorius*, AB, abbr. – ESO).**

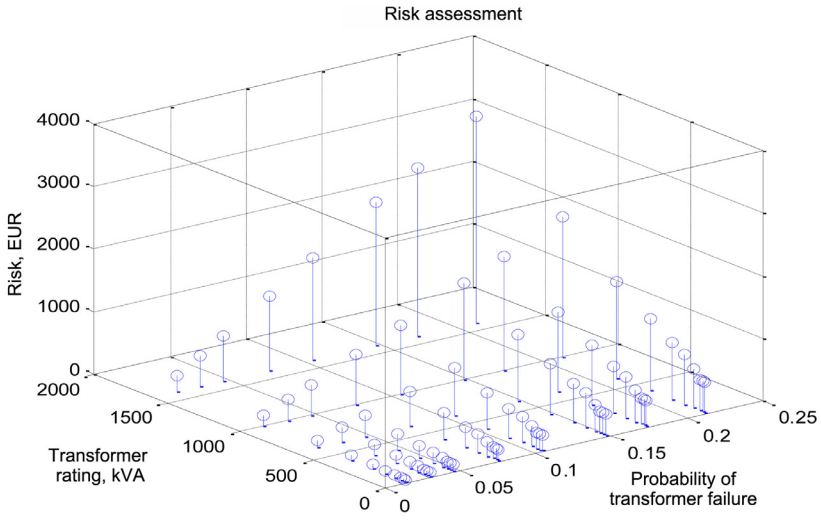
This study contains a survey of technical characteristics of surge protection measures, used in power distribution grids – spark gaps, surge arresters, recorders, as well as comparative analysis of foreign practice. Technical-economic evaluation of measures for minimisation of overvoltages was provided together with recommendations for limiting the surges in Lithuania's power distribution grid.



Structural chart of a mathematical model for calculation of electric power system operating modes



Suppression of voltage surges in the power distribution grid



Medium-voltage 10 kV grid risk dependence on transformer rating and probability of failure

Comparative characteristics of foreign solutions for protecting electrical devices from overvoltages.

Technical-economic evaluation of measures for minimisation of overvoltages and recommendations for limiting overvoltages.

The sector of power distribution grids is currently undergoing significant changes. The distribution grid is getting smart. A major part of smart technologies in the electric energy sector is installed in distribution grids. Statistics shows that distribution grids have a clear majority against transmission grids in the Smart Grid Catalogue of Projects carried out in Europe over the period of 2003–2014 (it should be noted that smart technologies, in particular information and communication technologies, were introduced into the transmission grid earlier, even before an emergence of the concept of smart grid). A distribution operator applies new technologies for controlling the grid, but on the other hand, this increases voltage unstabilities, amounts of transmission and processing of information flows, as well as the scope of coordination of controllers, sensors, monitoring and protection devices based on computer technology.

Distribution grids are being increasingly integrated into the transmission grid. The new European network codes (ENTSO-E), aimed at operational control of electric power systems, provide for active involvement of operators of distribution grids in:

- planning and controlling transmission operational modes;
- ensuring stability of the transmission grid;

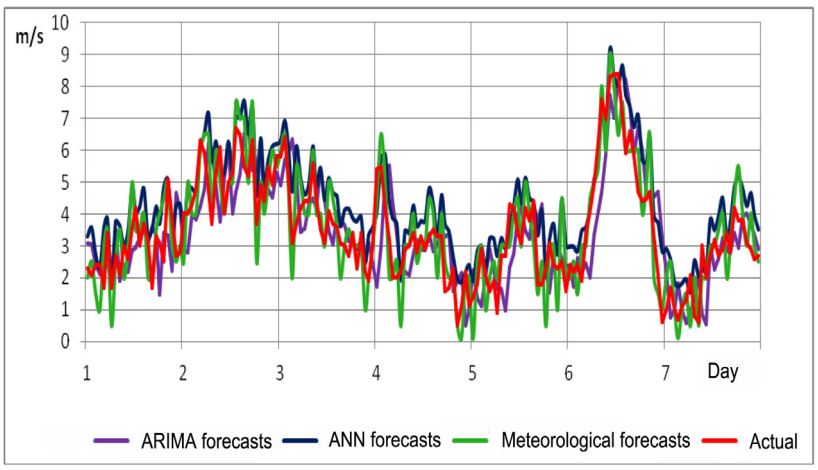
- bringing users closer to controlling the transmission grid through demand response and demand-side management technologies;
- bringing distributed generation closer to control of the transmission grid.

Deployment of distributed generation changes the nature of distribution grid. As generation changes in real time, voltages and currents change as a consequence thereof. Respectively, grids can undergo overloads and individual lines might get disconnected, thus leaving a part of users without power supply. Here, RES power plants – wind and solar – should be noted since they are characterized by intermittency of generated power due to fluctuations of solar radiation and wind speed. However, even generation of such power plants may be planned, i.e., estimated. Estimates allow more accurate calculations of scheduled modes, identification of more complicated ones and correction and optimisation measures. These include measures for voltage adjustment, loading of transformers or modification of grid topology.

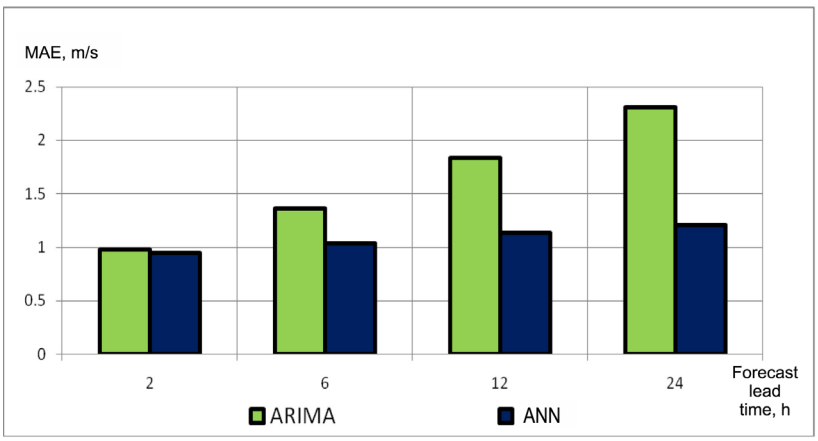
The role of wind generation will continue increasing in the future, and a significant part of it will be connected to the distribution grid. The on-going wide scale integration of wind power plants in the EU member states will contribute to the increase of cross-border exchange of power flows. This poses the challenges for transmission system operators (TSO) of better planning and controlling the varying loads and generations and transit them in a transparent, reliable and optimal way. Large capacities of wind power (as compared to system load) will be connected in the Baltic States before 2023: approximately 800 MW in Lithuania, up to 500 MW in Latvia and up to 1,000 MW in Estonia. This increases the demand for short-term wind forecast. Good forecast enables both distribution grid operator and TSO to match generation and loads, thus reducing the emergence of related imbalances on cross-borders ties.

In the last 20 years, a number of methods and models (statistical, physical, intelligent) for short-term wind speed forecasting were suggested globally, aimed at forecasting generation. However, there are still no universal methods or models with sufficient reliability. There is a tendency for development of hybrid models when two models are coupled. This often results in more accurate forecasts. It can be concluded that most forecasting models are aimed at forecasting operation of power plants connected to the transmission grid. In order to develop methodology suitable for Lithuanian conditions, a budget project ***Planning of smart electric power distribution grid operating modes***, focussing on forecasting power generated by power plants, has been started by Laboratory in 2015.

As a part of the budget project, an auxiliary tool was worked out – a short-term wind speed forecasting model, aimed at planning of operating modes of distribution grids. It has a forecast cycle of one hour. The accuracy of forecast for various lead times (2, 6, 12, 24 hours) was measured by three overall (statistical) indicators – errors MAPE, RMSE and MAE. This total was implemented using MATLAB software.

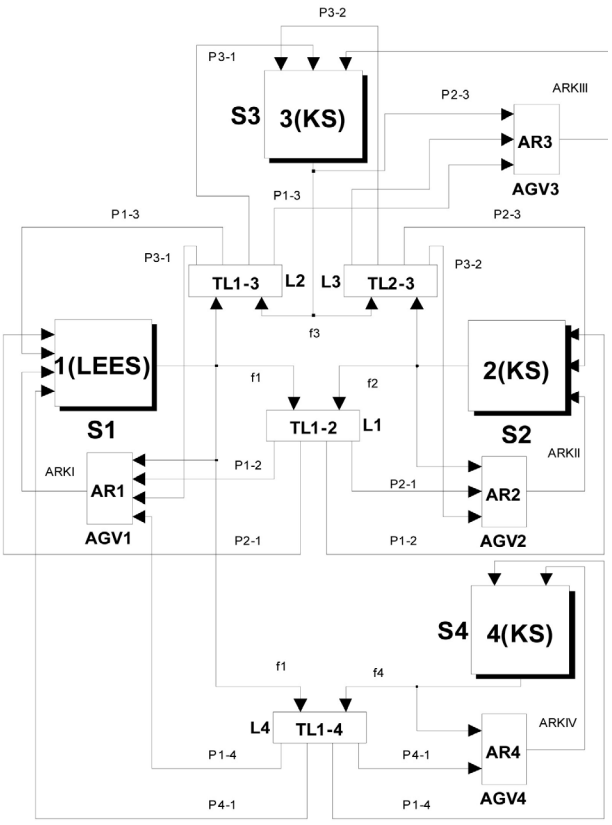


Expected and actual change of wind speed



Comparison of ARIMA and ANN mean absolute errors MAE

Lithuanian electrical energy system



Structural scheme of the interconnected EES mathematical model, aimed at analysis of active power and frequency regulation processes

A doctoral thesis *Planning of operating modes of electric power distribution grid taking into account the power generated from renewable energy sources* which is related to this topic is being written in the Laboratory.

Research project under the institutional programme **Economical and sustainability analysis of development of the energy sector** titled ***Perspectives of synchronous operation of Lithuanian electrical energy system with ENTSO-E, taking into account the expected development of generated power*** was carried out in 2015. It relates to the methods of regulation of frequency and power in the Lithuanian electrical energy system (EES), taking into account the perspectives of synchronous operation with ENTSO-E with wide adoption of renewable energy technologies.

The work was carried out in two directions:

a) effectiveness of methods of frequency and power regulation in Lithuanian electrical energy system (EES), with the view of synchronous operation with ENTSO-E and wide integration of wind and solar power plants;

b) development of market concept for trading frequency and power regulation reserves.

Numerical analysis of methods' performance was carried out using real wind data of two-hour intervals. In one case, it is assumed that the wind speed is similar in all wind farms (high wind correlation between wind power plants); in another case, the wind power plants were at a considerable distance in between; therefore, the variations of the total power generated by wind power plants will be minimised by the decreased mutual correlation due to different wind speed. Regulation of the secondary frequency and speed was carried out by methods of inter-system power balance and network power frequency characteristic.

The investigation showed that regulation is more efficient in economic terms when inter-system load balance method is applied in Lithuanian EES. However, in such case Lithuania would only minimally contribute to frequency containment in the entire Continental European network (CEN), and a part of regulation burden would be transferred to neighbouring systems. By applying an economically more expensive method as network power frequency characteristic, Lithuanian EES would "jointly" contribute to the operational security of the entire CEN and maximisation of its reliability. The minimal deviations from scheduled cross-border flows and frequency could be achieved if two generators (G1, G2) of Kruonis hydro-pump plant were used for secondary regulation of Lithuanian EES, irrespective of the regulation method.

Within the scope of the project of the long-term institutional programme **Economical and sustainability analysis of development of the energy sector**, development of the market concept for frequency and power regulation reserves (hereinafter – active power reserve or reserve) for electrical energy system (EES) of the Baltic States was finished in 2015, involving two periods of application:

1. from this day to 2025, in case of asynchronous connection (link LitPol Link1) between the EES of the Baltic States and CEN (ENTSO-E);
2. 2025 to 2030–2035, in case of synchronous connection (through links LitPol Link1 and LitPol Link2).

The concept was based on conclusions of an earlier research, presented in the 2014 report of this programme, on 1) inter-system trade of reserves and 2) reliability of reserve supply. The established concept considered the reliability reserve providers (generators), inter-system links, and individual EES.

Each period is divided into two subperiods of market development.

The 1st period would see development of the Baltic region of balancing services, including EES of Lithuania, Latvia, and Estonia. The systems balance their power individually in hourly intervals. They use reserve capacity and energy to cover unplanned *n-1* type unbalances, expected power deficit in repair modes and deficits caused by emergencies.

The first method (according to ENTSO-E grid codes) of reserve trade, described as the **TSO-TSO** model, is assigned to the first subperiod. Accordingly, operator of the transmission system (e.g., Lithuanian) purchases reserve from own generators (connected to Lithuanian EES) and other operators (e.g., Estonian operator ELERING). The Baltic region can also buy reserves through asynchronous links from the third countries. Such operators would be connected to EstLink, NordBalt and LitPol Link1 links. However, the IPS/UPS system, operating with the Baltic region in a synchronous BRELL ring and controlling the flows passing through the Baltic EES, should not be considered as a third party.

The second method of reserve trade, described as the **TSO-BSP** (balancing service provider) model, is assigned to the second subperiod. By applying this model, the system operator (e.g., Lithuanian) acquires reserves directly from generators of other systems in addition to its "own" generators. This allows expanding the number of market participants and competition in the region. Individual auctions of separate operators are organized and the generators voluntarily submit bids of reserve services in terms of (EUR/(MW/h) and EUR/MWh).

During the *2nd period of the market development*, starting around 2025, two subperiods are also foreseen. The first will continue with the **TSO-BSP** trade model; however, Baltic EES will start synchronous operation with the continental Europe grids, and its power flows will no longer be regulated by IPS/UPS dispatchers in Moscow.

During this stage, the Baltic region of balancing services will be expanded in the direction of synchronous connections to Poland and its neighbours, thus the reserve transmission routes will be extended, and the number of balancing service providers will increase. Therefore, a separate Baltic region operator will not be able to estimate a number of applying generators and the reliability of the transmission route of their reserve service. This will require development of an information support platform for reserve trade in the extended Baltic area of balancing services, including Poland (and its neighbours).

The second subperiod has two options:

a) TSO-BSP trade model may be transformed into TSO-balancing

services platform model, which would be derived from the information support platform applied in the first subperiod. TSO submits its auction conditions to the platform, which calls for the auctions, recalculates the bid values and automatically determines the winning bids;

b) TSO-BSP trade model may be transformed into **Baltic EES-BSP**, **Baltic EES-TSO** or **Baltic EES-Platform** model. In this case, the systems comprising the Baltic EES (Lithuanian, Latvian, and Estonian) would not balance their powers. Balancing would be carried out by the Baltic EES coordinator, which would purchase reserve services for addressing the imbalances against the external systems.

A doctoral thesis *Economic evaluation of efficiency of power regulation in the electrical energy system* is being written on this topic.

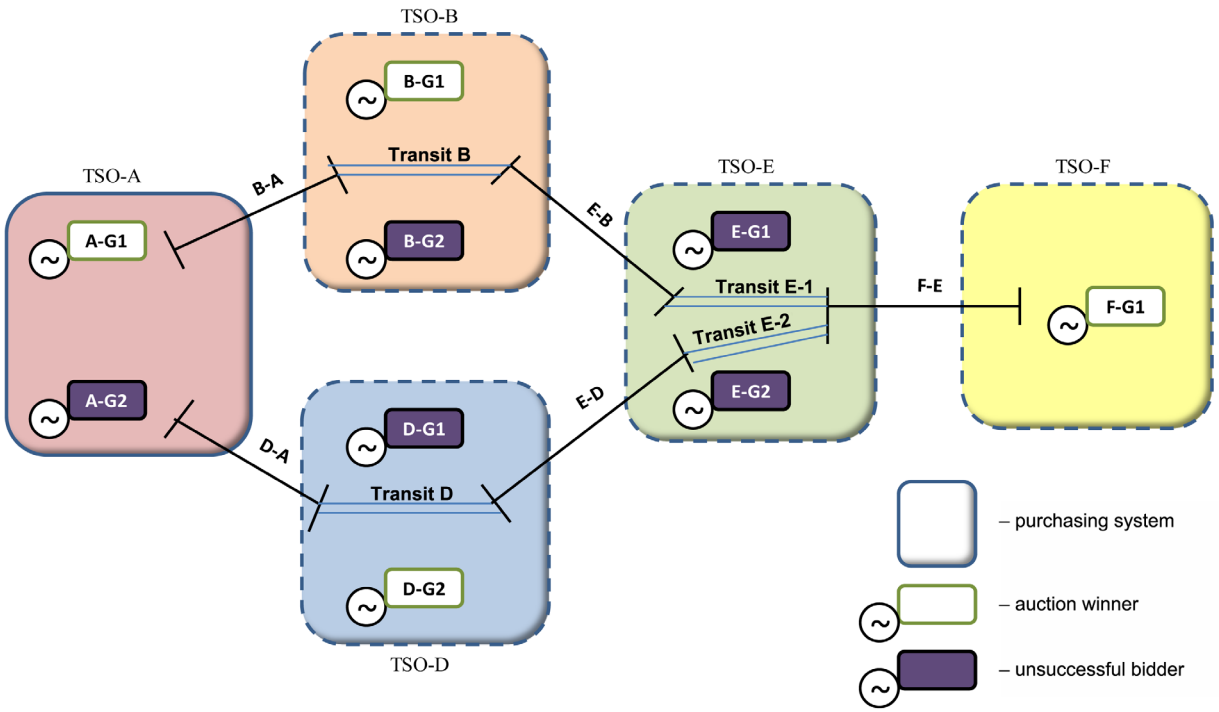
In 2015, the Laboratory continued research on improving energy efficiency in smart city planning in cooperation with international and Lithuanian partners, in particular with the Association of Smart Technologies. The research was carried out within the framework of the EU FP7 project ***Planning of Energy Effective Cities, PLEEC***.

The goal of the project is to prepare an integrated planning model, which could later be used to "re-plan" mid-sized cities in Europe in a way to allow more cost-effective, more efficient and environment-friendly use of energy.

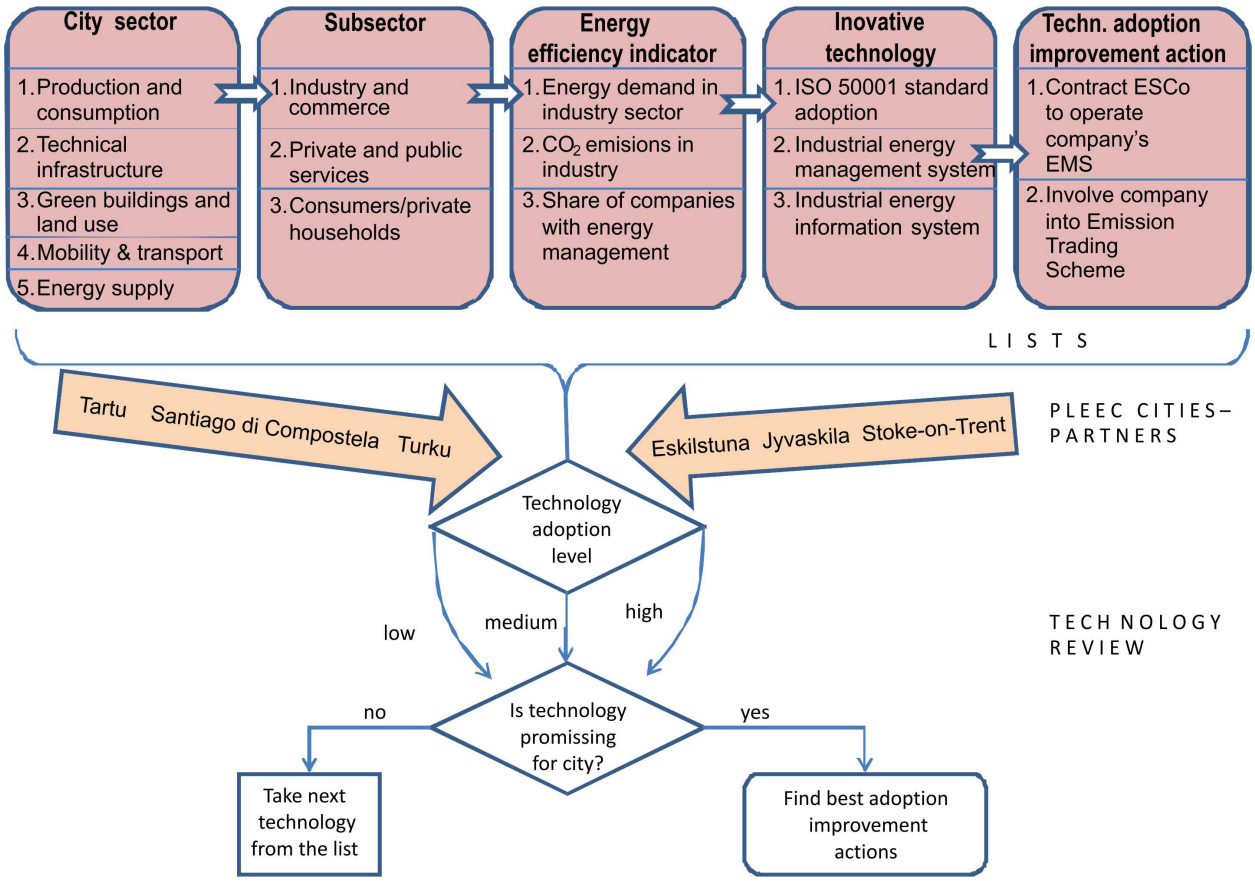
Scientists of the Laboratory and other experts went through the lists of innovative energy technologies (173 technologies) compiled in 2014 to select the indicators of energy efficiency for city planning. The indicators involved five sectors of city economy:

1) "green" buildings and use of land;
2) production activities and individual homes;
3) technical infrastructure;
4) mobility and transport;
5) energy supply.

Experts helped the representatives of municipalities participating in the project with evaluation of perspectives for application of technologies in partner towns, which have already done their homework – completed research of the energy efficiency of their towns. Tartu (Estonia), Santiago de Compostela (Spain), Turku (Finland), Stoke-on-Trent (the United Kingdom), Eskilstuna (Sweden) and Jyvaskyla (Finland) suggested measures for faster implementation of promising technologies. When concluding the set of recommended measures, the promoters of the project



Active power reserve trade



took into account the suggestions of municipalities and included the most suitable ones. Based on the list of innovative energy technologies and the recommended measures, the municipalities should prepare flagship energy efficiency action plans for their cities.

The results of research carried out in 2015 were published in a journal referred in *Web of Science Core Collection* in the **Thomson Reuters** database, as well as presented in an international conference.

LABORATORY of HYDROLOGY

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MAIN RESEARCH AREAS OF THE LABORATORY:

- analysis of climate change and river run-off variation;
- research of extreme hydrological phenomena in the context of climate change;
- research of wave, hydrodynamic, and sediment processes in water bodies;
- research of environmental impact of energy and transport objects;
- collection and analysis of data on Lithuanian water bodies (rivers, ponds, the Curonian Lagoon, and the Baltic Sea).

RESEARCH OBJECTS AND TASKS

The most significant research objects of the Laboratory are Lithuanian rivers and lakes, the Curonian Lagoon, and the Baltic Sea. The state of these water bodies is determined by extreme natural phenomena such as storms, floods, and anthropogenic activity

(energy production, navigation, ponds). Therefore, the assessment of the change of state of water bodies is one of the most important research tasks.

Using the information collected in the hydrographic and hydrometeorological database and applying the latest digital modelling methods, the Laboratory solves the following tasks:

- impact assessment of climate change on water bodies;
- analysis of change of extreme hydrological phenomena of water bodies;
- digital modelling of waves, hydrological and hydrodynamic processes, and sediment transport in water bodies;
- environmental impact assessment of anthropogenic activities on water bodies and justification of environmental protection measures;
- environmental impact assessment of new sea ports and ports under construction;
- exploitation of sea harbours and waterways, ensuring the nautical depth;
- modelling of pollution dispersion in water bodies;
- sensitivity and uncertainty analysis of hydrological and hydrodynamic processes.

The Laboratory of Hydrology carries out fundamental and applied research in the environmental engineering field. The basis of the research are numerous hydrographic, hydrologic, morphometric, and meteorological data collected by the Laboratory of Hydrology over the years as well as innovative digital modelling software (MIKE 21 system, developed by the Danish Hydraulic Institute for modelling of wave, hydrodynamic, and sediment transfer processes and pollution dispersion, hydrological process model HBV, developed by Swedish Meteorological and Hydrological Institute, as well as geographical information system). This enables solving the most important environmental tasks by assessing the impact of anthropogenic activity and climate change on the environment and justifying environmental protection measures.

In the past decade, the Laboratory has been carrying out research related to the assessment of the impact of climate change on water resources. In the period of 2013–2015, a state funded research project ***Research of Extreme Hydrological Phenomena of Lithuanian Rivers*** (leader Dr. J. Kriaučiūnienė) has been implemented. The research of extreme hydrological phenomena (floods and droughts) is relevant for design and operation of the most important infrastructure objects, such as polders, bridges, and culverts in addition to general flood risk management and planning in order to avoid human casualties and material loss. The preparation of such measures for Lithuanian rivers is based on observation, analysis, and digital simulation of river run-off. An overview of the research on extreme hydrological phenomena and modern flood forecasting methods in different countries was carried out. An original methodology for spring and flash flood assessment during a multi- year period and a methodology for forecast of extreme hydrological phenomena (climate change models and hydrological simulation) were developed. An analysis of conditions for formation of extreme hydrological phenomena of Lithuanian rivers was performed and the change of extreme parameters of river runoff over time was assessed along with a forecast of these phenomena following the latest climate change scenarios in the twenty-first century (Fig. 1). After the analysis of formation genesis and the change of extreme hydrological phenomena (the maximum flood discharge and 30-day mean discharge) in the twenty-first century, the issues of hydraulic structures and pond exploitation, design, and strategic planning were discussed.

In 2015, the Laboratory together with other divisions of the Institute continued the long-term institutional research and experimental development (further R&D) program ***Analysis of usage of renewable resources for efficient energy production and environmental impact***. The research objectives of the Laboratory of Hydrology in 2015 included:

1) calculation of wave parameters

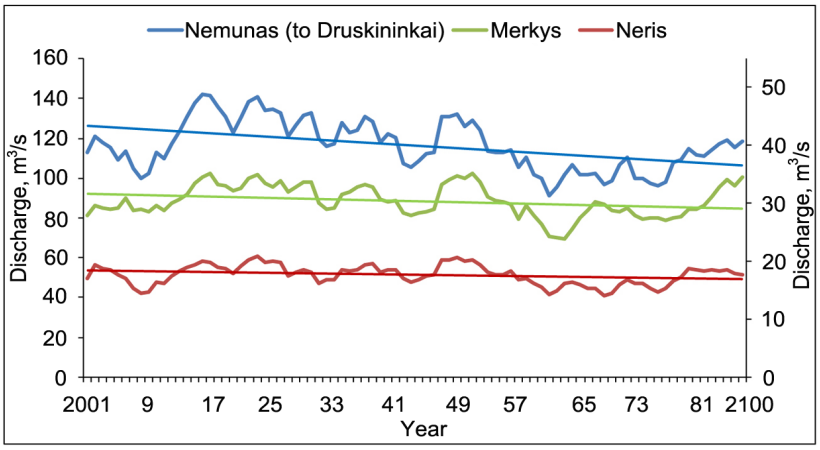


Fig. 1. Minimum 30-day discharge change of the Nemunas (up to Druskininkai), the Neris and the Merkys from 2011 to 2100

and assessment of wave energy potential in the territorial waters of Lithuania by applying the developed wave dispersion model for the Baltic near-shore,

2) evaluation of capabilities of river potential and technical hydrokinetic resources and determination of the river sections favourable for use and their distribution across the territory of Lithuania.

A wave dispersion model for the Baltic near-shore was created using the worldwide-recognized digital modelling system MIKE 21, developed by the Danish Hydraulic Institute. The NSW (Near-shore Spectral Wind-Wave Module) wave model of this system was applied to simulate parameters of wind-induced wave scattering for the Baltic near-shore. The modelled wave parameters (wave height and period) with South-West, West, and North-West direction at 5, 10, 15, and 25 m/s speed winds were used to assess wave energy potential in the territorial waters of Lithuania. Based on the hydrographic, river-bed morphological, and hydrological database of Lithuanian rivers, the hydromorphological dependencies of rivers (dependence of river-bed width, river depth, and flow speed on the average multi-year discharge, low and high river-bed) were created. The river sections with the flow rate of at least 95% probability meeting the following conditions were selected: 1) the maximum speed in the river-bed is over 0.4 m/s, 2) the flow depth is over 0.5 m. These conditions were met by only 328 river sections (22.1%) out of all 1487 analysed river sections. Maps of kinetic energy distribution of the rivers (except the Nemunas and the Neris) across the territory of Lithuania were drafted (Fig. 2).

NATIONAL RESEARCH PROGRAM *AGRO-, FOREST AND AQUATIC ECOSYSTEM SUSTAINABILITY* PROJECT ***IMPACT ASSESSMENT OF CLIMATE CHANGE AND OTHER ABIOTIC ENVIRONMENTAL FACTORS ON AQUATIC ECOSYSTEMS***

The main objective of the project is to identify environmental factor changes (water temperature, hydrological regime, and water quality elements) and their impact on aquatic ecosystem animal diversity and productivity and to carry out a comprehensive impact assessment in accordance with the multi-year data and climate change scenarios. The period of project implementation is 2015–2018. The first task of the project has been already completed: methods for assessment of climate change impact on the state of aquatic ecosystem were developed. According to the work plan, LEI together with the project partners (Aleksandras Stulginskis University, Vilnius University, and Nature Research Centre) completed the tasks planned for 2015:

1. An overview of the impact of climate change on the status of aquatic ecosystems in Lithuania and abroad.
2. The creation of the methods for assessment of the impact of climate change on the status of aquatic ecosystems.
3. Compilation of a database of environmental factors and aquatic ecosystems and the evaluation of data homogeneity.

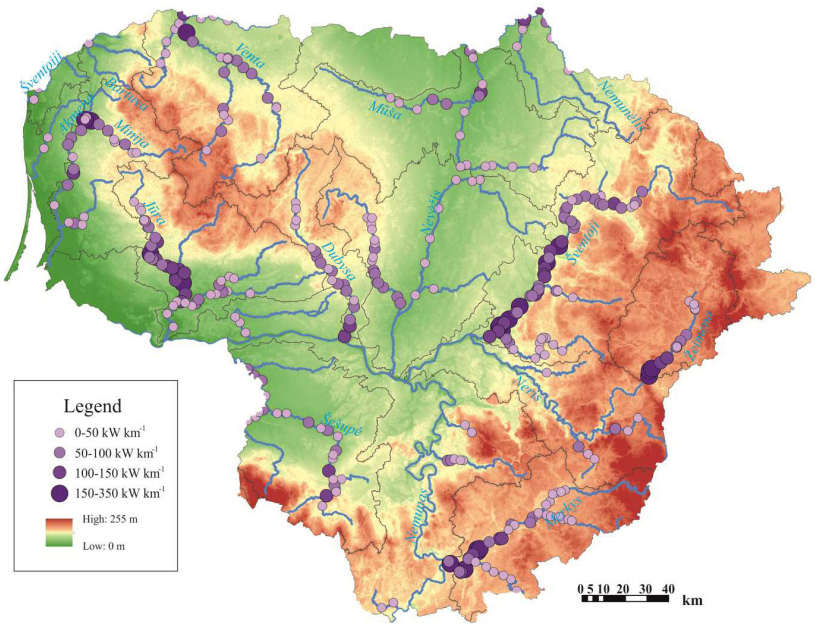


Fig. 2. Hydrokinetic resources of Lithuanian rivers (except the Nemunas and the Neris)

EUROPEAN NETWORK OF FRESHWATER RESEARCH ORGANISATIONS,

http://www.euraqua.org

In 2008, LEI Laboratory of Hydrology joined the ***EurAqua*** organization which consists of the most influential scientific institutions of 24 European countries conducting research of water resources.

EurAqua has the following main objectives:

1. To participate in the formation of water research policy in the European Union;
2. To formulate and propose the most significant and actual themes on water resource research which could be included into Horizon 2020 calls for projects;
3. To form consortiums of the ***EurAqua*** scientific institutions by preparing joint proposals for **Horizon 2020** projects;
4. To prepare scientific articles and technical reviews on problematic areas in European water resource research;
5. To organize conferences on pertinent topics (the impact of climate change on water resources, flood analysis and forecast in Europe, etc.)

On November 11–12, 2015, the 45th meeting of ***EurAqua*** members took place in the Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde) in Koblenz, Germany. The most important issues of European water policy were discussed there, including future climate scenarios, implementation of Water (Framework) Directive in the context of climate change, and analysis of uncertainties when predicting changes of water resources. Relevant issues of the **Horizon 2020** projects and possible groups of researchers from ***EurAqua*** institutions were also discussed.

COOPERATION WITH SCIENTIFIC INSTITUTIONS

The Laboratory of Hydrology closely cooperates with the Institute of Environmental Engineering of the Kaunas University of Technology and has been publishing a scientific journal ***Environmental Research, Engineering and Management*** since 1995. The researchers carry out complex environmental investigations together with the Nature Research Centre. Aiming at the development of up-to-date infrastructure for the common needs of scientific research and technological development of the Lithuanian sea sector, the Laboratory of Hydrology began contributing to the activity of the association ***Baltijos slėnis*** (the Baltic Valley). One of the main objectives of the Integrated Science, Studies, and Business Centre regarding Lithuanian sea sector development is to unite institutions and departments of maritime science. The initiators of the establishment of the Valley are Klaipeda University, Nature Research Centre, Lithuanian University of Health Sciences, Lithuanian Energy Institute, and maritime business companies. Two directions of scientific research and experimental development are planned: sea environment and maritime technologies. In pursuance of integration of the diffused national scientific potential, working in the field of maritime science, and effective use of modern scientific research equipment and ships, it is planned to establish a National Maritime Science and Technology Centre. The partners of the Baltic Valley (Klaipeda University, Nature Research Centre, Lithuanian Energy Institute, PE Space Science and Technology Institute, and State Scientific Research Institute Center for Physical Sciences and Technology) bring together their experience, professional knowledge, capacities and business reputation, and human, labour and technical resources to participate in the implementation of the 2007–2013 Human Resource development operational program of priority 3: Strengthening the capacities of researcher means VP1-3.1-ŠMM-08-K *Implementation of research and development activities under the national complex program topics* of the project **Development of Lithuanian marine sector technologies and environmental research (2013–2015)**. Researchers of the Laboratory together with Klaipeda University researchers actively participated in the activity of the subtopic **Simulation of Hydrodynamic and Litodynamic Processes in the Baltic Sea Nearshore**.

MAJOR APPLIED WORKS OF THE LABORATORY

The Laboratory carries out applied research work on the environment and prepares hydrotechnical construction projects following agreements with enterprises and organizations:

– Under the agreement with JSC *Sweco Lietuva*, the study ***Creation of technical concept of Klaipeda State Seaport Southern entrance*** was prepared.
– Under the agreement with the *Nature Research Center*, ***The Assessment of the impact of water level fluctuation on fish and water bird population in Kaunas hydro power plant reservoir*** was carried out.
– Under the agreement with JSC *Ekotektonika*, the study ***Hydrodynamic Modelling of the Dane River Flow for Construction of Boat Pier*** was prepared.
– Under the agreement with *Klai-*

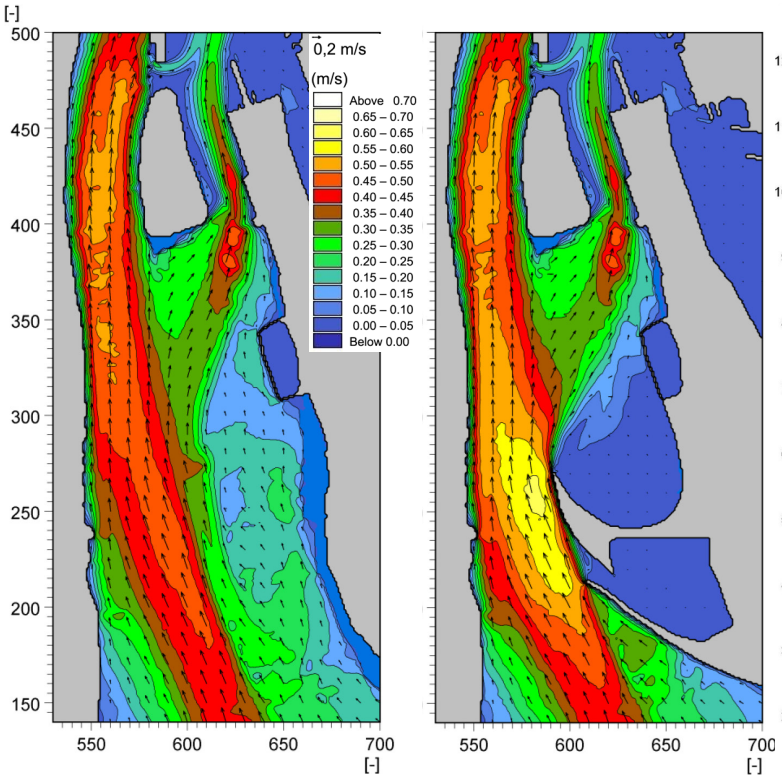


Fig. 3. Flow structure according to "0" (a) and 3 (b) alternatives when the water discharge of 1,600 m³/s in the Strait flows from the Curonian Lagoon to the Baltic Sea

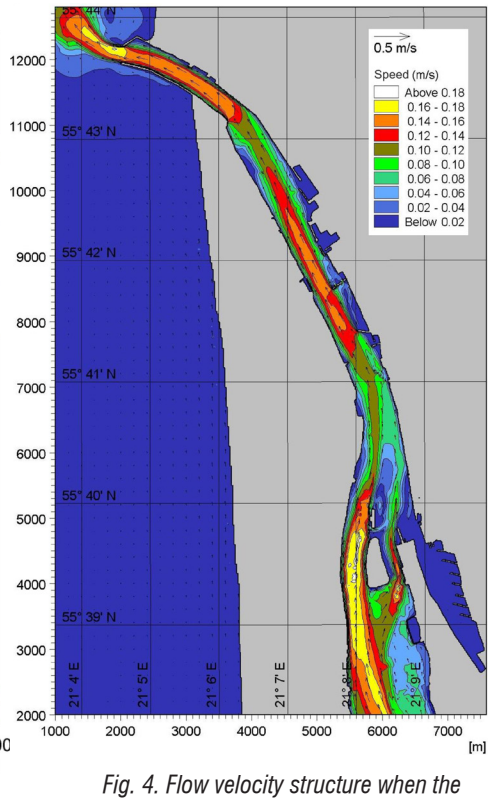


Fig. 4. Flow velocity structure when the water discharge of 75% probability (544 m³/s) in the Klaipeda Strait flows from the Curonian Lagoon to the Baltic Sea

peda State Seaport Authority, ***The Klaipeda Port Stream Atlas*** was prepared.

MIKE 21 model system was applied for the development projects of Klaipeda Seaport in estimating their impact on the environment and navigation conditions. For improvement of navigational conditions of Klaipeda port waters and deepening of the port fairway from 14.5 to 17 m, it is necessary to choose environmental protection measures that could be used to avoid negative consequences for the ecosystem of the Curonian Lagoon. In 2015, researchers of the LEI Laboratory of Hydrology in collaboration with researchers of JSC *Sweco Lietuva* and *Sweco Hydro Project* prepared the study ***Creation of Technical Concept of Klaipeda State Seaport Southern Entrance.*** In this study, the concept of the Southern port entrance based on hydrodynamic modelling results was presented. After the analysis of three alternatives for the southern entrance, the most suitable alternative was chosen, which allows avoiding the changes of Klaipeda Strait permeability and additional Curonian Lagoon coast erosion hotspots. It was proposed to implement the third concept (alternative) of Southern port entrance that satisfied the environmental requirements and met the targets of long-term development of the port (Fig. 3). After the implementation of the third alternative of the Southern entrance concept, the Strait permeability is planned to increase by up to 0.6% for the flow direction from the Curonian Lagoon to the Baltic Sea and by up to 1.3% for the flow direction from the Baltic Sea to the Curonian Lagoon as compared to the "0" alternative. These permeability changes are very insignificant and will not affect the ecosystem of the Curonian Lagoon.

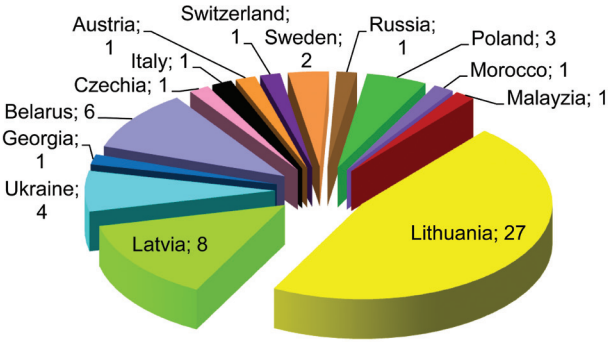
The development of the Klaipeda port (installation of the fairway with new dimensions and the port gate reconstruction) changes flow structure. With increased water depth in the fairway, changes occur in sediment transport and accumulation conditions as well as wave regime. In the future, the conditions for navigation and mooring of ships at the docks in deeper port water area will be more complex, because vessels of increasing tonnage will be serviced. The flow structures in the Klaipeda Strait are formed by natural factors (riverbed morphological parameters and flow rates) which are affected by the seaport hydrotechnical constructions. Therefore, the flow structure (flow velocity and direction) under increasing ship traffic and servicing of larger vessels is becoming an important factor in determining the safety of navigation. In the study *Klaipeda Port Stream Atlas*, the distribution of flow velocities and directions of the Klaipėda Strait was drawn up for navigators (Fig. 4). This measure will allow a better assessment of Klaipeda port navigation conditions for navigators. At the same time, this atlas will provide information about the potential sediment accumulation and

bottom erosion zones in the Strait in different water flow regimes. The Klaipeda Port Stream Atlas was prepared based on the current state of the harbour water territory bathymetry, including the deepening of the port navigation channel to 14.5 meters, the completed widening works, and the installation of the LNG terminal.

In 2015, the Laboratory researchers collaborated with researchers from foreign countries to publish three scientific research articles in journals referenced in *Thomson-Reuters WoS database*, three science promotion articles, and three scientific papers at three international scientific conferences. On December 18, 2015, A. Jurgelėnaitė (photo) defended doctoral dissertation *Warm season thermal regime of Lithuanian river water and its forecast in the context of climate change.*

12th INTERNATIONAL CONFERENCE of YOUNG SCIENTISTS on ENERGY ISSUES CYSENI 2015

On May 27–28, 2015, Lithuanian Energy Institute (LEI) hosted an International Conference of Young Scientists on energy issues (CYSENI 2015). This year's conference is the twelfth conference organized by the initiative of young scientists of the Lithuanian Energy Institute. 76 abstracts were submitted for the conference, 58 of which have been accepted for presentation at the conference. From the submitted scientific publications, experienced reviewers selected 55 that were appropriate for publishing in the conference material. The objective of the conference is to bring together doctoral students and young scientists from various countries to share experience in solving energy issues and problems, introduce colleagues to ongoing research and the latest research results; conference participants were also given a chance to learn to review and evaluate peer articles, relevance of the analysed topic and importance of the obtained results. At this year's conference, presentations were delivered by doctoral students and young scientists from Lithuania, also young scientists from neighbouring countries, i.e., Austria, Belarus, Georgia, the Czech Republic, Italy, Latvia, Malaysia, Morocco, Poland, Russia, Sweden, Switzerland and Ukraine, actively supported the idea of the conference.



Division of the participants of the Conference 2015 by countries

The Director of the Lithuanian Energy Institute Dr. Sigitas Rimkevičius opened the 12th international conference and delivered a welcome speech to the participants of the conference. The conference participants were also greeted by the Minister of Energy of the Republic of Lithuania Mr. Rokas Masiulis and a Counsellor of Member of Parliament of the Republic of Lithuania Ms. Diana Korsakaitė. The conference organizer Dr. Viktorija Bobinaitė thanked the Lithuanian Energy Institute doctoral students and young scientists for their sincere assistance in organizing the conference and teamwork

Director of the Institute Dr. S. Rimkevičius, Ms. D. Korsakaitė, Minister of Energy R. Masiulis and Dr. V. Bobinaitė

during the conference.

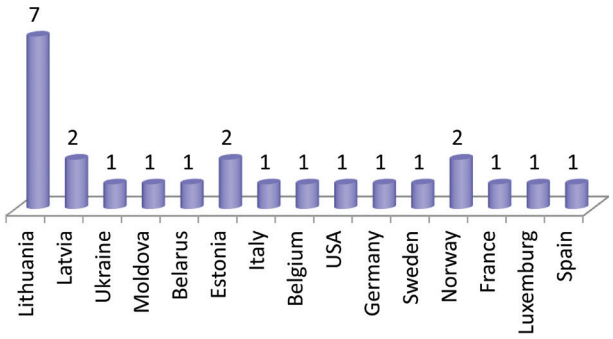
Conference participants were invited to attend four plenary session paper presentations – by the European Commission representative Dr. Philippe Schield (topic of the presentation – *The Energy Dimensions in EU*), the representative of the Latvian Institute of Physical Energetics, Dr. Gunta Šlihta (topic of the presentation – *Role of Energy Research in EU*), Tartu Regional Energy Agency representative Mr. Marek Muiste (topic of the presentation – *Implementing European Energy and Climate Change Policy on Local Level*) and the Italian National Agency representative Dr. Giacomo Grasso (topic of the presentation – *Nuclear Research in an Evolving Energy Scenario*).

Parallel sessions assembled conference participants to listen presentations by young researchers conducting various energy-related science field investigations. Paper reviewers, recognized experts in technology and social sciences, also participated in parallel sessions. They were given an opportunity to get acquainted with the submitted papers by doctoral students and young scientists and instructed to carry out the evaluation of papers based on a number of criteria, including the evaluation of scientific novelty and relevance, consistency and novelty of the methodology, accuracy and reliability of the results, completeness of the findings and other. During the conference, reviewers asked questions, commented on the papers of young scientists and conducted discussions.

Moments of parallel sessions

In order to improve business communication skills of the doctoral students and young scientists, the parallel sessions were chaired by the young participants of the conference and board representatives of the LEI Young Scientists Association. During the two days of the conference, more than 50 papers were delivered.

Doctoral students and young scientists are invited to present their papers on the following topics: Hydrogen and fuel cells; Renewable energy sources; Smart energy networks; Energy efficiency and reliability; Knowledge for energy policy making; Investigations in the fields of thermal physics, fluid mechanics and metrology; Material sciences and Technology; Investigations of combustion and plasma processes; Global change and ecosystems; Fusion energy; Nuclear fission and radiation protection; Cross-cutting energy issues. In 2015, the scientific committee of the conference consisted of 24 members from Lithuania and 14 foreign countries.



Division of the members of the Conference Scientific Committee by countries (2015 data)

Scientific publications and abstracts prepared by conference participants are published in proceedings of the conference issued in electronic format (ISSN 1822-7554). Published material will reach the main national research centres and libraries, as well as some foreign libraries and research centres.

As every year, authors of the best scientific works were announced upon evaluation of the relevance of scientific issues of the articles, proposed solution methods, the importance of the obtained results and effective public speaking skills. Given the experience of the conference participants in conducing scientific work and skills, the assessment was carried out in two groups. Director of the LEI Dr. Sigitas Rimkevičius congratulated the winners and handed diplomas marking the achievements and sponsor gifts.

After the official part of the conference, a cultural program was offered. Folk dance group *Rasa* introduced participants of the conference to Lithuanian traditions and created good mood.

In 2015, the initiative to organize a conference as always was supported by the Institute's management that allocated financial and technical support. Substantial financial support and gifts to participants of the conference were provided by the conference sponsors Linde Group member AGA, *Hnit-Baltic* UAB and JSC *REO Investment* UAB.

Conference organizers seek that this conference becomes an annual event for young scientists working in the field of energy; therefore, they constantly look for well-known, highly experienced scientists conducting research on the conference topics and wishing to contribute to developing strong young scientists and invite them to become members of the editorial board of the conference. If you are interested, please do not hesitate to contact the conference organizers via e-mail: ***info@cyseni.com.***



Authors of the best scientific works with the Director of the Institute and organizers

FINANCIAL HIGHLIGHTS

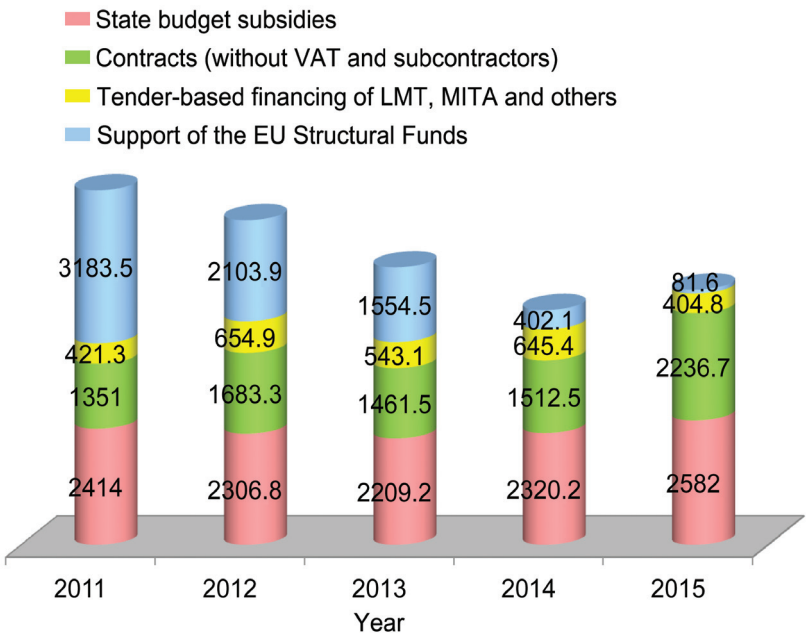
THE FINANCIAL SOURCES OF THE INSTITUTE CONSIST OF:

- State Budget subsidies;
- Financing received from Lithuanian, foreign and international funds and organizations;
- Financing for scientific research from competitions in programmes;
- Financing received from Lithuanian and foreign enterprises and organizations for contract work, realisation of products and services;
- Funds received for participation in the international research programmes;
- Funds received as support under the Law on Charity and Sponsorship of the Republic of Lithuania;
- Subsidies received from enterprises and associations for participation in joint activities and training of specialists;
- Support of the EU Structural Funds (SF);
- Other Income.

Structure of Income and Total Expenses (thous. Euro)

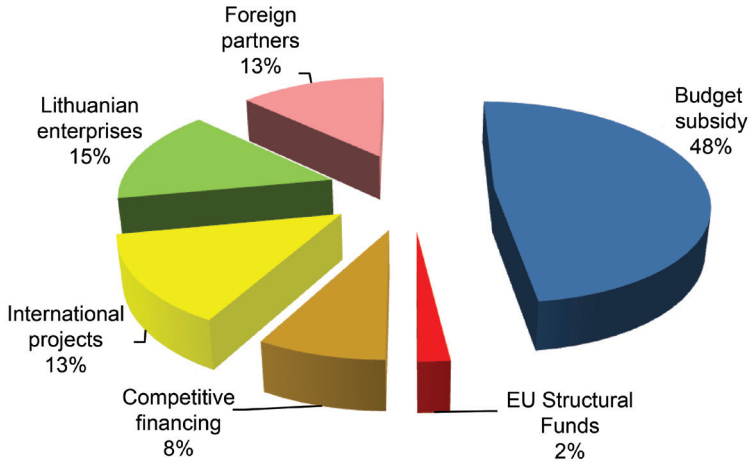
	2011	***2012***	***2013***	***2014***	***2015***
Income:					
State Budget Subsidies	*2414.0*	*2306.8*	*2209.2*	*2320.2*	*2582*
Contracts	*1757.3*	*2309.9*	*1965.4*	*2107.7*	*2613.6*
SF Support	*3183.5*	*2103.9*	*2273.7*	*402.0*	*81.6*
Other Income	*27.7*	*28.5*	*30.2*	*50.2*	*27.9*
Total:	*7382.5*	*6749.1*	*6478.5*	*4880.1*	*5305.1*
Expenses:					
Salaries (soc. ins. incl.)	*4133.8*	*3944.1*	*3971,6*	*4005.2*	*3867.3*
Operating and oth. Expenses	*994.8*	*737.9*	*1729.9*	*913.4*	*1007.2*
Capital Funds	*3146.1*	*2205.8*	*871.8*	*75.3*	*89.9*
Total:	*8274.7*	*6887.8*	*6573.3*	*4993.9*	*4964.4*
Long-term Projects Assets	*650.9*	*512.2*	*417.4*	*303.6*	*664.3**

** – A financial claim in the sum of 263.49 thous. € for the liquidated bank **Ūkio bankas AB***

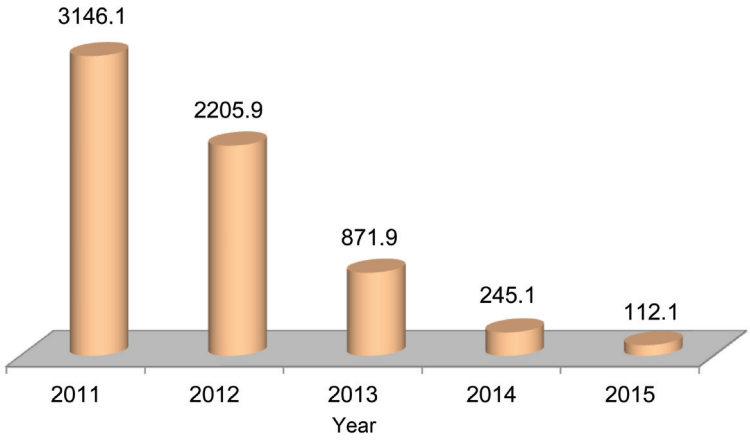


Evolution of financial recourses, thous. €

LMT – Research Council of Lithuania;
MITA – Agency for Science, Innovation and Technology.



The structure of finances obtained from the contractors of LEI for year 2015



Dynamics of assets devoted for equipment purchase, thous. €

Financial Reports may be found on **http://www.lei.lt** (About LEI: Financial Reports).

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20. **Krečius M.** Support measures for renewable energy assessing the development effectiveness. *12th Annual international conference of young scientists on energy issues (CYSENI 2015)*, Kaunas, Lithuania, May 27-28, 2015. Kaunas: LEI, 2015. ISSN 1822-7554. p. 61-72.
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2. **Galinis A., Alėbaitė I., Neniškis E.** Šalies centralizuoto šilumos tiekimo sistemos plėtra. *Šilumos energetika ir technologijos-2015: konferencijos pranešimų medžiaga*, Kauno technologijos universitetas, 2015 sausio 29-30 Kaunas. LEI. 2015. ISSN 2335-2485. p. 70-78.

3. **Galinis A., Lekavičius V.** Biokuro tiekimo energetikos sektoriui grandinės modeliavimas. *Šilumos energetika ir technologijos-2015: konferencijos pranešimų medžiaga*, Kauno technologijos universitetas, 2015 sausio 29-30 Kaunas. LEI. 2015. ISSN 2335-2485. p. 64-69.

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7. **Perednis E., Katinas V., Savickas J.** Biologiškai skaidžių atliekų panaudojimo energetikoje tyrimas.

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12. **Savickas J., Katinas V., Tamašauskienė M.** Biodegalų panaudojimo Lietuvoje aspektai ir poveikio aplinkai analizė. *Šilumos energetika ir technologijos-2015: konferencijos pranešimų medžiaga*, Kauno technologijos universitetas, 2015 sausio 29-30 Kaunas. LEI. 2015. ISSN 2335-2485. p. 51-54.
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ARTICLES OF SCIENCE POPULARISATION

1. **Gaigalis V**. Startavo ES programos „Horizontas 2020“ projektas „Energijos vartojimo efektyvumo daugiapakopio valdymo spartinimas (multEE)“. *Energetika.* (Kronika) ISSN 0235-7208. 2015. T. 61. Nr. 2. p. i-iii.
2. **Gaigalis V., Markevičius A., Savickas J.** Tvarios energetikos strategijos – Lietuvos regionų vystymosi prielaida. *Structum*. ISSN 2335-2108. 2015 vasaris.
3. **Kriaučiūnienė J., Gailiušis B.** Klaipėdos uosto plėtra sąsiaurio hidrodinamikos aspektu. *Mokslas ir technika*, ISSN 0134-3165. 2015. Nr. 1/2. p. 18-21.
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THE MAIN EVENTS in 2015

8 January.
Dr. Egidijus Babilas conferred Engineering Industries Association of Lithuania (LINPRA) honorary award

26–30 January.
Series of lectures *Flow visualization, application and mathematical treatment of the processes*

10–11 February. Visit of experts of MOSTA (Research and Higher Education Monitoring and Analysis Centre)

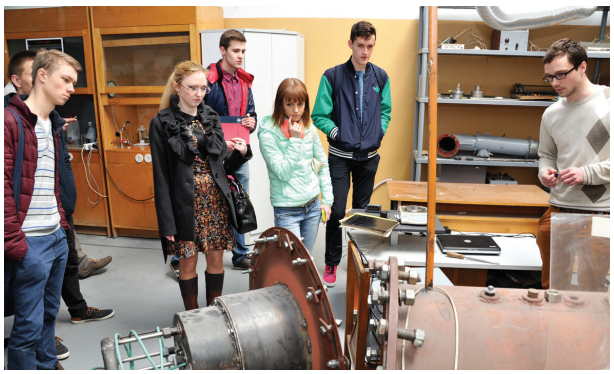
19 February. Conference *District heating development security in Kaunas city*

3 March. Visit of representatives of Tokyo University of Technology and HITACHI Company

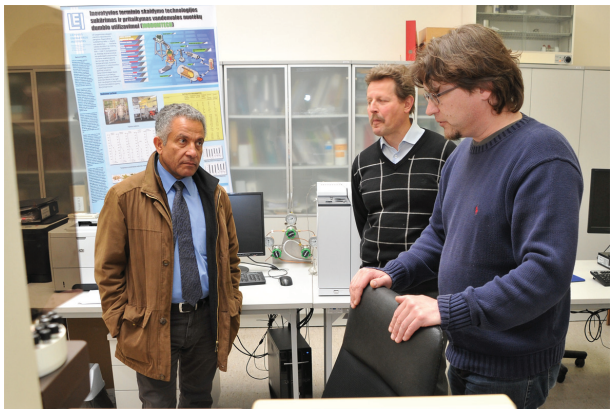
20 March.
Visit of Dr. Kiyonobu Yamashita (Japan)

1 April. Visit of academicians of Lithuanian Academy of Sciences at National Open Access Scientific Research Centre

15–17 April.
The event of the EU 7 FP project ARCADIA



23 April. Open Doors day at the Lithuanian Energy Institute



4 May. Visit of Dr. Mohamed Eid (Alternative Energies and Atomic Energy Commission, France)

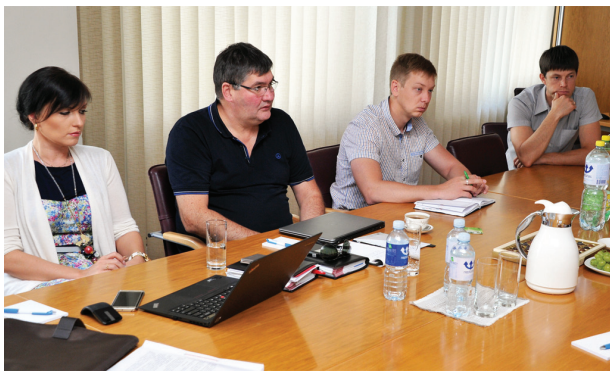
18–22 May. ENSTTI Training Module *Probabilistic Safety Assessment* in LEI

27 May. Visit of Minister of Energy Mr. Rokas Masiulis

27–28 May. 12th International Conference *CYSENI 2015*

17 June. Visit of Prof. Henrik Madsen from Technical University of Denmark

23 June. Visit of adviser of Ambassador of Japan Mr. Shinici Yamanaka



2 July. Meeting of VENBIS project partners

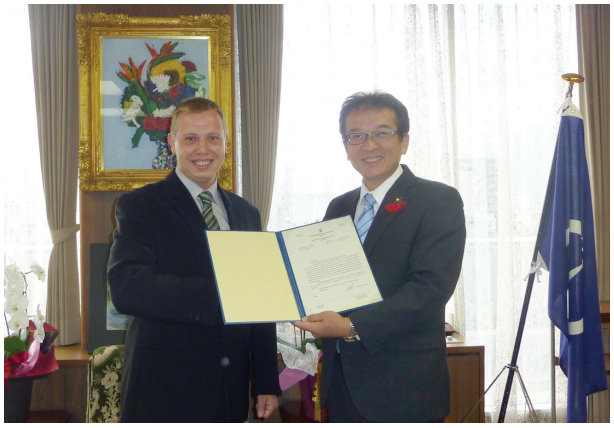
28 August. Anniversary lecture of Academician Prof. Dr. Habil. E. Ušpuras *Has the nuclear energy the future in Europe?*

7 September. Paper *Integrated Assessment of Thermal Hydraulic Processes in W7-X Fusion Experimental Facility by* T. Kaliatka, E. Ušpuras and A. Kaliatka was awarded as one of the best papers

18 September. Visit of Prof. Krzysztof Kolowrocki (Gdynia Maritime University)

2 October. Visit of representative of German Embassy in Lithuania

5 October. Visit of representatives of HITACHI Company



7 October. Visit of LEI representative Dr. Tadas Kaliatka at Mayor of Tsuruga city (Japan)

16 October.
75th anniversary lecture of Dr. Habil. Antanas Pedišius

21 October. Guests from Azerbaijan Ministry of Economy and Industry at the Institute

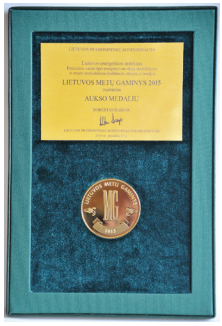
21–22 October. Meeting of representatives of H2020 project *BRILLIANT*

3 November. Representatives of Hazardous Waste Management Association visit to Institute

4 November. Guests from Nuclear Chemistry and Technology Institute (Poland)

11 November. Association *Santaka Valey* general assemby and board meeting

30 November – 1–2 December. Defense of scientific works financed by the state subsidies



11 December. LEI granted a gold medal in the competition *Lithuanian Product of the Year 2015*

17 December. Cooperation agreement signed between LEI and UAB *Altecha*

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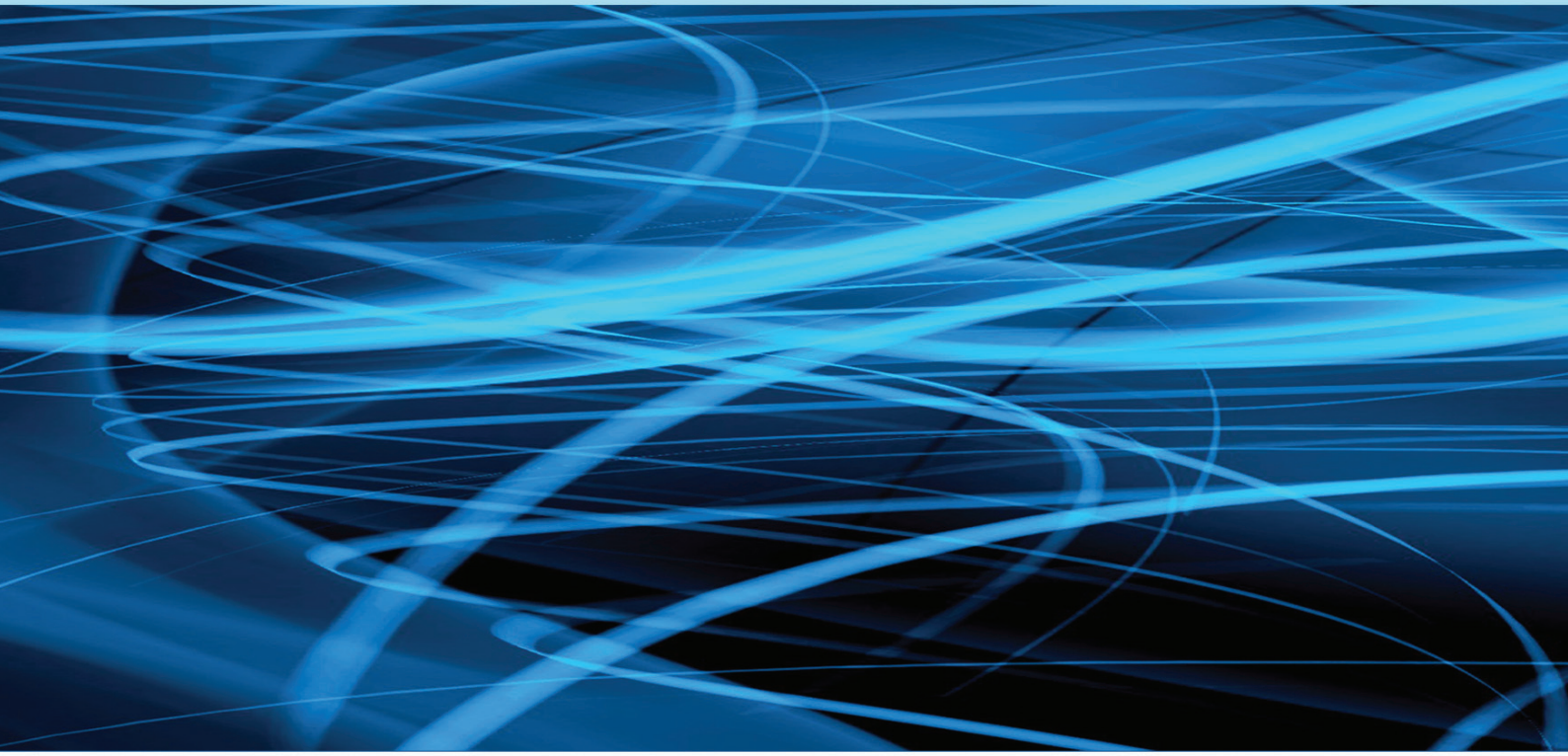

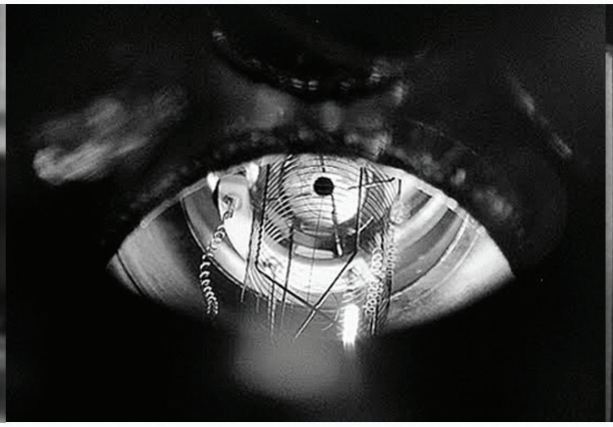

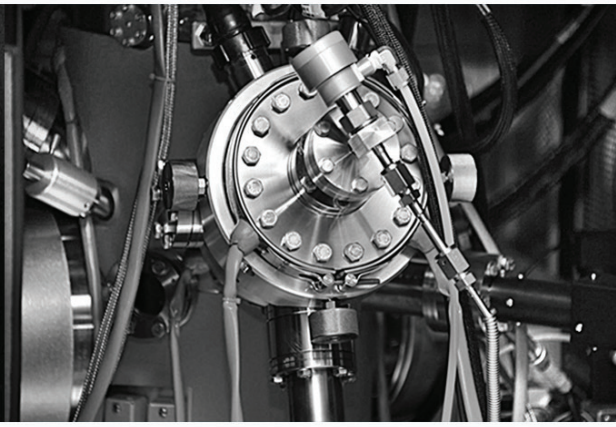

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