



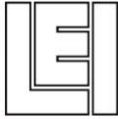
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Tel. +370 37 351403 • Fax +370 37 351271**LABORATORY OF NUCLEAR INSTALLATION SAFETY****IAEA COORDINATION RESEARCH PROGRAM
“Development of Small Reactors without On-Site Refueling”***Report of the First Working Year***Economic Benefits of Revising the Need for Relocation and
Evacuation Measures Unique to NPPs for Innovative
SMRs for Regions with Electricity Co-Generation**

IAEA Research Contract No. LIT13092

Dr. habil. J. Augutis

7 September, 2005



BRANDUOLINIŲ ĮRENGINIŲ SAUGOS LABORATORIJA

**TATENA KOORDINUOJAMA TYRIMŲ PROGRAMA
“Development of Small Reactors without On-Site Refueling”**

Pirmųjų metų ataskaita

**“Economic Benefits of Revising the Need for Relocation and
Evacuation Measures Unique to NPPs for Innovative
SMRs for Regions with Electricity Co-Generation”**

TATENA tyrimų sutartis Nr. LIT13092

Habil. Dr. J. Augutis

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| <i>Summary:</i> This report include the following: 1) Identification of changes which would be necessary if the emergency planning for the future power plants in Lithuania is to be eliminated or reduced; 2) A study of the economic impact of revised licensing requirements on district heating; 3) An overview of meteorological data necessary for dose evaluation, based on available databases. | | |
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LIST OF ABBREVIATIONS

| | |
|--------|--|
| ALWR | Advanced Light Water Reactor |
| CHP | Combined Heat and Power Plant |
| CRP | Co-ordinated Research Project |
| EPRI | Electric Power Research Institute |
| EPZ | Emergency Planning Zone |
| FP | Fission Product |
| FPZ | Flight Prohibition Zone |
| GIF | Generation IV International Forum |
| HPSPP | Hydro Pumped Storage Power Plant |
| IAEA | International Atomic Energy Agency |
| INPP | Ignalina Nuclear Power Plant |
| INPRO | International Project on Innovative Nuclear Reactors and Fuel Cycles |
| IRIS | International Reactor Innovative and Secure |
| LEI | Lithuanian Energy Institute |
| LPZ | Longer Term Protective Action Planning Zone |
| NEI | Nuclear Energy Institute |
| NPP | Nuclear Power Plant |
| NRC | U.S. Nuclear Regulatory Commission |
| PAZ | Precautionary Action Zone |
| PRA | Probabilistic Risk Analysis |
| PSA | Probabilistic Safety Analysis |
| SMR | Small and Medium Reactor |
| SPZ | Sanitary Protection Zone |
| TPP | Thermal Power Plant |
| UPZ | Urgent Protective Action Planning Zone |
| USA | United States of America |
| VATESI | Lithuanian State Atomic Energy Safety Inspection |

INTRODUCTION

Small and Medium Reactor in general are of interest to International Atomic Energy Agency member countries since they enable introducing new generating capacity at a rate matching the consumption increase rate and by its size limit financial risks. Moreover, they may be the only viable option for smaller and/or developing countries, due to limitation imposed by the grid size and available financial resources. Innovative SMRs with no on-site refueling (or, with refueling at infrequent intervals) are of special interest, since they enhance safety and proliferation resistance.

However, new approaches are needed to overcome the traditional economy of scale and make SMR economically attractive. These include:

- modularity, production in series, pre-fabrication;
- new features, e.g., passive safety systems leading to design and construction simplicity;
- no on-site (or infrequent) refueling, reducing operational and maintenance costs;
- enhanced licensing, with revised siting requirements, that improves operational and economic performance.

While relying on all these features, this work specifically focuses on the last one, addressing the objectives specified in the Agency's CRP on innovative SMRs with no on-site refueling, as well as the CRP on Identification of competitive technological options for SMRs.

Current regulations relevant for NPPs and their siting require "that adequate protective measures can and will be taken in the event of a radiological emergency." This requirement has been further interpreted in the USA (in 10CFR50.47) as a requirement for emergency planning in an area with a 10 miles radius, i.e., extending far beyond the site boundary. This prescribed 10 miles radius is the same for all NPPs. Historically, it was selected to very conservatively envelop all designs, but it does not include provisions to account for significant safety improvements achieved since.

The emergency planning requirement may pose a significant burden on plant owner (utility), both in the construction and in the operation phase. During construction, it may be necessary to build infrastructure (highways) to comply with the requirement. During operation, it is necessary to maintain an evacuation capability in a relatively wide area. Moreover, for all practical purposes it freezes any human development in a large area around the plant, a burden for small countries and/or areas with significant growth. Finally the fact that the off-site zone around NPP is treated in a special way sends an incorrect message to public regarding the safety of NPPs.

The advanced and safer reactor designs further reduce risk to public, and should therefore offer a possibility to reduce or eliminate some of the emergency plan and evacuation requirements. This need was identified by the Agency (INPRO [8], User Requirement "The innovative nuclear reactors and fuel cycle shall not need relocation or evacuation measures outside the plant site, apart from those generic emergency measures developed for any industrial facility") as well as by the Generation IV International Forum (GIF) [3]. It is deemed possible to reduce emergency-related site requirements for advanced plants, while at the same time providing a protection to general public equal or better than that provided by the current generation of NPPs and current regulations.

Achieving licensing with this new objective would offer significant societal and economic benefits to member countries, general public and plant owners/operators, including:

- increased public acceptance of nuclear power, since they will be treated as any other industrial facility;
- reduced need for infrastructure, thus reducing cost;
- reduced operational costs;
- enabling co-generation application, including district heating and desalination, where the plant cannot be located remotely from the intended user;
- enable siting that would reduce transmission costs;
- enable wider choice of siting locations in countries with relatively high population density.

In summary, achieving licensing with no need for emergency plan and evacuation measures will improve viability of deploying new NPPs, and is of particular importance for small and medium reactors, that cannot compete with larger plants if burdened by the same additional infrastructure and operational costs.

The aim of this report is to contribute toward the presented overall objective, using as a testbed the design of IRIS (International Reactor Innovative and Secure), as a representative innovative light-water SMR with option for infrequent on-site refueling, with the ultimate goal of developing a technology-independent approach.

BACKGROUND

During the past 30 years, the possibility of reducing or eliminating the EPZ has been subject of various efforts. In 1985 and 1986, the licensees for the Calvert Cliff and Seabrook power stations petitioned the NRC for a reduction of the EPZ requirement. These petitions were rejected for lack of technical detail. During the following 30 years the NRC issued various papers dealing with the definition of emergency planning procedures for evolutionary reactors. In recent years, studies from EPRI and NEI have directly addressed this issue. In TR-113509, EPRI documented [6] a set of probabilistic and deterministic studies to show that a significant reduction in the EPZ radius was possible for ALWR while maintaining the same level of safety of existing plants. In NEI-02-02 [16], NEI proposed a complete risk-informed revision to NRC 10CFR50 document, in which the need and extension of the EPZ would be based on purely probabilistic considerations. Outside the US, similar activities have been ongoing: just to make an example, a social and technical study on the possibility of reducing the EPZ for the APR-1400 was performed in Korea.

Presently, IAEA/INPRO [8] and GIF [3] have identified the need for licensing that would allow reducing emergency planning requirements, but we are not aware of any on-going work.

At the moment, no advanced SMR in either the design or deployment stage is actively considering elimination of the no emergency response requirement, with the lone exception of IRIS [14]. Thus, the approach that may be developed for IRIS under this program would become available to serve as a roadmap for similar initiatives by other advanced designs [13].

Lithuanian Energy Institute, as a member of an international team, is involved in developing IRIS, an innovative light-water Small/Medium size reactor. Among its innovative design features, of particular importance is the enhanced safety achieved through the IRIS safety-by design philosophy. Additionally, IRIS core design includes capability for a significantly extended reloading cycle, resulting in infrequent refueling. One of the IRIS project aims is to license the reactor with a revised (reduced or eliminated) need for relocation and evacuation measures. This would result in no off-site emergency planning requirements, or at least in a significantly reduced planning zone. Preliminary considerations of this objective have been initiated within the IRIS team, thus offering excellent synergy with the corresponding INPRO objective. Combined with its characteristics (innovative SMR with option for infrequent refueling), IRIS presents a very suitable testbed for examining means, methods and approaches to revise evacuation requirements and for evaluating impact (benefits) should such a change become possible.

LEI, as a member of the IRIS team, is involved in PRA analyses, including those related to external events. Additionally, LEI is actively participating in establishing design solutions for IRIS to enable effective implementation of co-generation for district heating.

1. THE EMERGENCY RESPONSE PLANNING IN LITHUANIA

The task of review the licensing regulations in Lithuania, and specifically the emergency response planning for the Lithuanian nuclear facilities (e.g. NPP) is identification of changes

which would be necessary if the emergency planning for the future power plants is to be eliminated or reduced. At present state the current practise is analysed in this report.

1.1. Current National Practice in Lithuania

The general objectives of emergency planning are to: prevent serious deterministic health effects and reduce the likely stochastic health effects of ionising radiation (cancer and other radiation-induced cases). In case of a radiological accident (due to internal or external events) in a nuclear power plant, in enterprises and facilities using nuclear sources, transporting radiological materials, the territory may be contaminated by radioactive substances. In order to evaluate the extent and consequences of radiological contamination in detail, the National emergency response plan is currently usually singled out from the rest of emergency response action plans. It gives a comprehensive description of possible consequences and actions of civil protection institutions and the population during the general accident. However, for the future licensing we need to promote enhanced licensing that should treat risk due to NPPs in the same way it is treated for other industrial facility.

As an example of the current regulation and planning, in the National emergency response plan of Lithuania, in the event of a radiological accident at a NPP, provided measures become operational as soon as the accident happens and when radioactive substances are spread or may be spread beyond the boundary of the NPP sanitary protection zone.

This Lithuanian plan provides means of protecting the population, their scope, terms, assignment of responsibilities, and implementation procedure. The plan is needed for organisation and co-ordination of actions taken over by ministries, other State Administration institutions, county and local municipal authorities for taking protective measures for arrangement of immediate response actions, for the operative notification of neighbouring countries of a nuclear accident or radiological emergency.

For the accident types, emergency response takes place over two distinct areas: sanitary protection zone and the area beyond the sanitary protection zone. Sanitary protection zone (SPZ) means the area surrounding the facility, which is under the immediate control of NPP in Lithuania.

The area beyond the sanitary protection zone is divided into three main zones: Precautionary action zone (PAZ), Urgent protective action planning zone (UPZ), and Longer-term protective action planning zone (LPZ). Precautionary action zone (PAZ) goal is to substantially reduce the risk of deterministic health effects of ionising radiation before radionuclides emission into the environment. Urgent protective action planning zone (UPZ) means a predesignated area around the facility where a plan for urgent protective measures is made in advance. Longer term protective action planning zone (LPZ) means a predesignated area around the facility farthest from the facility and including the urgent protective action planning zone. It is the area for the actions to reduce the long-term doses from deposition and ingestion should be developed in advance.

These zones are roughly circular areas with NPP in the centre. The size of the zones (see Table 1) in Lithuania has been determined by an analysis of international practice.

Table 1. The Size of Controlled Zones

| Name of the Zone | Sanitary protection zone (SPZ) | Precautionary action zone (PAZ) | Flight prohibition zone (FPZ) | Urgent protective action planning zone (UPZ) | Longer term protective action planning zone (LPZ) |
|-------------------|--------------------------------|---------------------------------|-------------------------------|--|---|
| Distance from NPP | 3 km | 5 km | 10 km | 30 km | 50 km |

In IAEA-TECDOC-955 [9] and IAEA-TECDOC-953 [10] there is recommendation regarding the size of PAZ, UPZ and LPZ. The basis that leads to selecting these limits is mainly deterministic; however some risk related considerations are involved too.

The size of the *PAZ* is based primarily on the following considerations:

- Urgent protective actions taken before or shortly after release within this zone will *significantly reduce the risk of dose and prevent doses above the deadly threshold* for the most severe accidents at the NPP;
- For atmospheric release under average meteorological conditions this zone covers the distances where about *90% of the off-site risk of serious deterministic health effects could occur*.

The size of the *UPZ* represents a judgment on the extent of detailed planning which must be performed in order to ensure effective response. The zone should cover the distance where about *99% of the off-site risk of serious deterministic health effects could occur*. In particular emergency, protective actions, measures might well be restricted to a small part of UPZ. On the other hand, for the worst possible accidents, protective measures might need to be taken beyond the UPZ. The UPZ is the area where preparations are made to promptly perform *radiation monitoring* and implement urgent protective measures based on the monitoring results. Such as plans and capabilities *to implement sheltering, evacuation and distribute thyroid blocking iodine*; they reflected the fact that evacuation could be required up to the boundary of the UPZ (reception centers for evacuation are sited outside the zone).

The size of the *LPZ* represents an area where preparation for effective implementation of protective actions *to reduce the risk of deterministic and stochastic health effects from long term exposure* to deposition and ingestion of locally grown food should be developed in advance. The LPZ area covers distances where about *99% of the off-site risk of dose above generic intervention levels could occur*. More time will be available to take effective action within this zone; in general, protective actions such as *relocation, food restrictions and agriculture countermeasures* will be based on the radiation monitoring and food sampling.

As the zones can be defined only for national territory (in spite that the NPP can be located near the border of country), in Lithuania UPZ and LPZ are evenly divided into 16 sectors, with the starting point from the geographical co-ordinates of the NPP. The angle of every sector is equal to 22,5 degrees. Each sector in its turn is further sub-divided into 6 segments: 3-5 km, 5-10 km, 10-15 km, 15-20 km, 20-30 km, 30-50 km from NPP.

The international co-operation of the Republic of Lithuania in the sphere of civil protection is based on universally recognised international principles of civil protection, human rights protection, environmental protection and common welfare following international treaties and other legislative acts. In case of a radiation accident in NPP, the Civil Protection Department shall immediately notify neighbouring countries on the incident and its expected consequences.

Information on the occurrence of the radiological accident or the exceedance of radiation in the Republic of Lithuania is passed to foreign countries and international organisations in the manner and size as required by the 1986 IAEA Convention On Early Notification of a Nuclear Accident in accordance with Governmental Regulation No 972 “On the Accession to the 1986 Convention On Early Notification of a Nuclear Accident” dated on 13 October 1994. To enforce the requirements of this resolution, in the event of a nuclear accident in the NPP, the Ministry of Environment shall present to the regulatory body (VATESI) current and forecasted hydro meteorological information, results of environmental gamma monitoring, on-going and planned radiation protection measures beyond the area of the sanitary protection zone, the expected time of the release of radioactive substances into the environment. The Radiation Protection Centre presents to VATESI the information on ongoing or planned population protection measures.

In case of a nuclear accident due to internal or external events, in its turn VATESI shall provide the IAEA and, directly or through the IAEA, the neighbouring countries, with which bilateral or multilateral co-operation agreements or treaties are signed, in accordance with the established format by the 1986 Vienna Convention the information on:

- time, exact geographical co-ordinates of the NPP and nature of the accident;
- possible or determined cause of the accident as well as the forecasted development of the accident, related to possible transboundary radioactive contamination;
- characteristic features of radioactive contaminants, including their nature, possible physical-chemical form, quantity, composition and effective emission height;
- current and forecasted hydrometeorological conditions in order to predict transboundary radioactive contamination;
- results of gamma environmental monitoring, in relation to transboundary radioactive contamination;
- on-going and planned radiation protection measures beyond the area of the sanitary protection zone;
- expected changes in emissions of radioactive substances over time.

In case of any change of the emergency situation, these data are updated, corrected and also provided to the IAEA and neighbouring states directly or through the IAEA and to the countries, with which bilateral or multilateral co-operation agreements or treaties are signed.

As Lithuania has joined the Europe Union, currently national regulations are taking into account the EU system on urgent exchange of information on radiation (ECURIE).

1.2. Discussions on Future Siting and Risk Zoning

In fact, in the context of some severe external events, the assumption of continued availability of NPP infrastructure required to administer emergency measures (for example roads and bridges) may not be valid. Under such situation, it is more effective to enhance the quality of the other levels of defence in depth. There is therefore, a need to define the scope of off-site emergency planning activities for advanced reactors, consistent with the ability of these reactor designs to meet enhanced safety objectives.

In some cases, such as the presence of a nearby airport, consideration of the hazards may change risk zoning or eliminate a site from further consideration for an NPP, but most external

hazards are either screened out from the necessity of being considered further or are taken account of in plant design and siting. Siting and risk zoning is a matter for:

- The uncertainties of risk measures and influence to the public perception;
- Economic consideration (where power is needed, the availability of existing grid);
- Social and political factors;
- Topography affecting the dispersion of radio-nuclides through the atmosphere, rivers and ground-water;
- Political and safety consideration;
- Demographic characteristics;
- Hazards (natural and man made).

Some IAEA member states only address the risk to an individual member of the public, others have requirements to consider the potential aggregated effects to the population as a whole – societal risk.

Off-site emergency measures are still seen as part of the Defence in Depth approach, which is mainly understood in deterministic sense, but to take full advantage of new reactor designs it should be moved towards a more probabilistic approach performing risk, sensitivity and uncertainty analysis. The full benefit of innovative and evolutionary NPP requires the ability to licence without the need of an off-site Emergency Planning Zone. In general, the desirability or possibility of reducing or eliminating emergency response plans for accidents depends not only on the reactor type but also on a number of complex and intertwined factors including technical, societal, economical and cultural. The subject cannot be coupled directly and solely to the requirements for the external events but requires a separate consideration. Under the same subject also the risk-informed decision making related to the design basis accidents and severe accidents are considered with the intent of moving away from postulated risk zones and towards mechanistically calculated risk zones. Without such a change, related procedures and criteria, the issue of the emergency response plans cannot be resolved. In particular, in order to deal with external events and apply the risk-informed approach for plant design and siting, it is desirable to couple the PRA with techniques of civil engineering.

1.3. Further Work for Enhanced Licensing

The ultimate objective for advanced NPPs is to establish an enhanced approach to licensing, reflecting improved safety characteristics of advanced reactors, that is expected to justify and enable revised (reduced or eliminated) emergency planning requirements, while providing at least the same level to protection to the public as the current regulations. Ideally, the emergency planning zone would coincide with (or be contained within) the site boundary, thus, there would be no need for off-site evacuation planning, and the NPP would become, relative to the general population, the same type of facility as any other industrial enterprise.

In order to contribute toward achieving this ultimate objective by addressing some of the relevant issues there is a need to consider the following research tasks:

- Critically evaluate current regulations to identify what changes are necessary to enable advanced licensing.

-
- Identify criteria based on technical, quantifiable parameters that may be used in support of the objective.
 - Identify approach, based on a combination of deterministic, probabilistic, and risk management, that will enable assessment of advanced plants based on their key design operational and safety characteristics with respect to adequate emergency planning requirements.
 - Prepare site-specific representative data (e.g., meteorological).
 - Perform probabilistic analyses needed to support this approach.
 - Perform deterministic / dose evaluation analyses needed to support this approach.
 - Perform a detailed evaluation of the representative reactor utilizing the combined approach.
 - Identify, discuss and quantify the benefits attainable through the implementation of this objective, i.e., licensing with reduced emergency planning requirements.

In order to perform these tasks with the ultimate goal of developing a technology-independent approach, the design of IRIS is used as a testbed. IRIS is representative of innovative reactors, but because it is a LWR, its possible sequences and its behaviour under accident conditions is much better understood and predicted than that of some more distant new technologies. Moreover, it has the necessary prerequisite, excellent safety, due to its Safety-by-Design™ approach.

The further work is within the scope of activities defined within the IAEA CRP on Small Reactors with no or infrequent on-site refueling. Specifically, it is relevant to “Definition of the scope of requirements and broader specifications” with respect to its ultimate objective (revised evacuation requirements), and to “Identification of requirements and broader specifications for NPPs for selected representative regions” considering specific impact on countries with colder climate and increased interest for district heating co-generation.

Within this framework the information gathered from the PRA (both internal and external events) will be used to provide a basis for the redefinition of the EPZ defining criteria. This approach consists of coupling the PRA results with deterministic dose evaluations associated to each relevant PRA sequence considered, and thus achieving a technically sound bases for the definition of a plant specific EPZ. In this approach the two basic components of risk (i.e. probability of occurrence and consequences of a given accident) are therefore explicitly combined. The EPZ radius can then be defined as the distance from the plant such that the probability of exceeding the dose limit triggering the actuation of emergency procedure is equal to a specified threshold value. To identify this threshold value, detailed analysis of existing installations should be performed to infer the risk associated with the current EPZ definition.

It must be noticed that the use of existing regulations and installations as the basis for this redefinition will not in any way impact the high degree of conservatism inherent in current regulations. Moreover, the remapping process makes this methodology partially independent from the uncertainties still affecting probabilistic techniques. Notwithstanding these considerations, it is still expected that applying this methodology to advanced plant designs with improved safety features will allow significant reductions in the emergency planning requirements, and specifically the size of the EPZ. In particular, in the case of IRIS it is expected that taking full credit of the Safety-by-Design™ approach of the IRIS reactor will allow a dramatic reduction in the EPZ requirement, while still maintaining a level of protection to the public fully consistent with existing regulations.

2. ECONOMIC IMPACT OF NPP-BASED DISTRICT HEATING

A performed study of the economic impact of revised licensing requirements on district heating is based on economic evaluation of the nuclear district heating cogeneration option.

Due to climate, district heating presents a notable fraction of energy consumption in winter months, and infrastructure for its use is already in place in some population centers in Lithuania. This work will continue into the second and third project year, to ultimately determine potential economic benefits of revising the evacuation requirements and enabling NPP-based district heating.

In this report the focus is set on the primary data collection and preparation of mathematical model.

2.1. Primary Data and Modelling Tool

2.1.1 Energy Generation Technologies

Total installed capacity of the Lithuanian power plants is about 4900 MW, including one unit of Ignalina Nuclear Power Plant (NPP) with 1500 MW installed capacity and the Lithuanian Thermal Power Plants (Lithuanian TPP) with 1800 MW. Installed capacity in Combined Heat and Power plants (CHP) accounts for about 780 MW, Kruonis Hydro Pumped Storage Power Plant (HPSPP) for 800 MW, hydro power plants for 120 MW, etc. Maximal domestic electricity demand in 2003 was 2015 MW. There are three large CHP plants in Lithuania (Vilnius, Kaunas and Mazeikiai). There are also several small public CHPs and industrial cogeneration plants. Mazeikiai CHP is oil-fired and all other plants are dual fuel (oil or gas). Lithuania also has a large district heating system. Lithuania has a well-developed electricity network and strong connections with Latvia and Belarus. However, it has no direct connection with its southern neighbour – Poland.

Until 2005 Ignalina NPP was generating up to 85% of total electricity in Lithuania. However, the first unit of the Ignalina NPP was closed at the end of 2004 and the second one will be closed before 2010. This will lead to very significant changes in the Lithuanian power system as well as in the whole energy sector. The results of various studies concerning the future structure of power plants in Lithuanian energy system have showed that looking from the economical point of view Ignalina NPP should be replaced by a modernised Lithuanian power plant or new combined cycle condensing units together with the existing and new CHP units [4, 5, 17]. In the future new CHP is likely to be the best alternative for electricity and heat generation in Lithuania if energy demand grows. The construction of new nuclear power plant at Ignalina site is also one of the options.

IRIS could be a rather attractive option of nuclear technology for Lithuania because of its medium size (335 MWe) units compatible with predicted Lithuanian needs on new nuclear power deployment by 2015. Nuclear power units smaller than currently available reactors and flexible arrangement (multiples of single or twin-units) are much more compatible with Lithuanian needs for slow increase in generating capacity, enabling economic base-load use of nuclear power plant. Its predicted total overnight cost of 1100-1240 US\$/kW [11] is in the range of investment cost at which new nuclear power plant may become competitive in Lithuanian power system. The levelized cost of electricity production is in the range of 2.0 - 3.1 c/kWh and competitive with other possible alternatives, which means that IRIS is a plausible electricity generation option after decommissioning of the second unit of the Ignalina NPP [7]. The comparatively small size of each module reduces the investment needed for a

new unit and improves cash flow. Continued operation of nuclear technology will also diversify Lithuanian energy sources, reduce dependency on natural gas and price fluctuation. In addition it will help to benefit from emission trading or even to solve future problems related to environmental obligations [7].

The IRIS offers a significant reduction and simplification of the passive safety systems, which not only improves safety but simultaneously reduces the overall cost. Moreover, it supports licensing the power plant without the need for off-site emergency response planning. This would allow IRIS to be treated as any other industrial facility, located closer to population centres. The excellent safety characteristics of IRIS allow a larger choice of sites and avoiding the expenses of physically preparing the site and conducting planning for emergency response. This allows better implementation of cogeneration option and reduction of transmission costs.

Seeking to have consistent modelling of the energy sector development in this work, final electricity and heat demand was used as input information for the model. The future projections of net electricity production by scenarios are presented in Figure 1. The growth rate of heat demand for different counties is presented in Table 2. Fuel prices used in calculations are shown in Table 3.

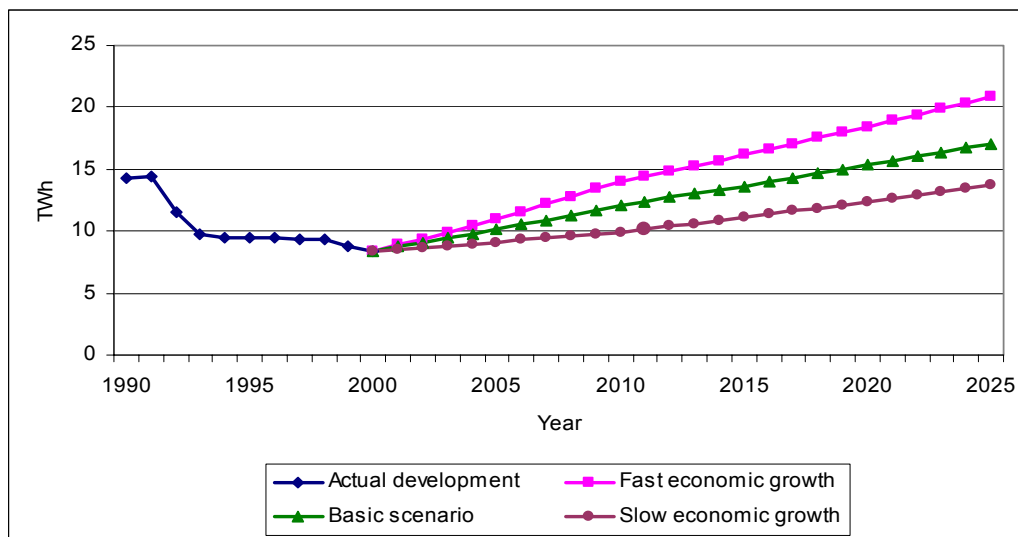


Figure 1. Electricity Demand by Scenarios [5]

Table 2. The growth rate of heat demand, % [17]

| Scenario | County | 2005 | 2010 | 2015 | 2020 | 2025 |
|----------------------|---------|------|------|------|------|------|
| Basic scenario | Kaunas. | 2.5 | 2.5 | 1.5 | 1.5 | 1.5 |
| | Vilnius | 2.5 | 2.5 | 1.6 | 1.6 | 1.5 |
| | Other | 2.1 | 2.1 | 1.3 | 1.3 | 1.3 |
| Slow economic growth | Kaunas. | 2 | 1.8 | 0.62 | 0.62 | 0.6 |
| | Vilnius | 2.1 | 1.9 | 0.62 | 0.62 | 0.6 |
| | Other | 1.4 | 1.3 | 0.62 | 0.62 | 0.6 |
| Fast economic growth | Kaunas. | 3.8 | 3.2 | 1.7 | 1.5 | 1.4 |
| | Vilnius | 3.7 | 3.1 | 1.5 | 1.4 | 1.3 |
| | Other | 3.5 | 3 | 1.3 | 1.2 | 1.1 |

Table 3. Fuel prices and its forecast, US\$./toe [5]

| Fuel | Price of fuel transportation and distribution US\$/toe | Fuel price, US\$./toe | | | | | |
|--------------------|--|-----------------------|-------|-------|-------|-------|-------|
| | | 2001 | 2005 | 2010 | 2015 | 2020 | 2025 |
| Coal | 25.0 | 78.4 | 73.4 | 70.1 | 68.0 | 66.7 | 66.7 |
| Heavy fuel oil HSC | 10.4 | 94.1 | 109.7 | 112.1 | 114.4 | 116.8 | 119.2 |
| Heavy fuel oil LSC | 10.4 | 119.8 | 157.5 | 158.1 | 158.8 | 159.5 | 160.2 |
| Natural gas | - | 136.5 | 161.6 | 162.9 | 164.1 | 165.4 | 166.6 |
| Wood | 20.3 | 57.9 | 60.4 | 66.5 | 72.6 | 78.7 | 84.8 |
| Wood waste | 20.6 | 7.4 | 7.7 | 8.5 | 9.2 | 10.0 | 10.8 |
| Straw | 25.5 | 18.7 | 19.5 | 21.5 | 23.5 | 25.4 | 27.4 |
| Orimulsion | - | 91.4 | 92.2 | 92.2 | 92.2 | 92.2 | 92.2 |
| Nuclear | - | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 | 23.9 |

2.1.2 Choice of the Modelling Tool

In order to reach the study objective the MESSAGE modelling tool was chosen for modelling of the future energy system development in Lithuania. MESSAGE is designed to formulate and evaluate the alternative energy supply strategies consonant with user-defined constraints on new investment limits, market penetration rates for new technologies, fuel availability and trade, environmental emissions, etc. The underlying principle of the tool is the optimisation of an objective function under a set of constraints [15]. It was originally developed at the International Institute for Applied Systems Analysis. The International Atomic Energy Agency acquired the latest version of the MESSAGE and added a user-interface to facilitate its applications.

The most powerful feature of MESSAGE is that it provides the opportunity to define constraints between all types of technology-related variables. The user could, among others, limit one technology in relation to some other technologies (e.g., a maximum share of wind energy that can be handled in an electricity network), give exogenous limits on sets of technologies (e.g., a common limit on all technologies emitting SO₂, that would be defined in millions tons of SO₂), or define additional constraints between production and installed capacity. This modelling tool is extremely flexible and can also be used to analyse energy/electricity markets and climate change issues.

The representation of the energy system used in MESSAGE is based on a network concept. The activities and relationships of an energy system are described as an oriented graph, depicting the energy chain starting from extraction or supply of primary energy, passing through several energy conversion processes (e.g. electricity generation, transmission and distribution) in order to satisfy the demand for final energy. Using the notation of oriented graph, links of the graph represent technologies or transportation and allocation process of energy, whilst the nodes represent energy forms (like electricity, oil and gas, etc.). The decision variables in the model formulation are the energy flows and the equipment capacities of the several technologies in different time periods. They are linked by capacity-flow constraints. The model variables are subject to a system of constraints, representing the structural and technological properties of the energy system, the existing stock of equipment, the projected energy demand, energy policy, restrictions, and the impact of the energy technologies on air pollution, emission control technologies and emission control policy restrictions.

Each sub-system of the created model contains a set of existing and new technologies. The objective of model application is determination of an optimal allocation of these technologies and the associated energy resources to satisfy the projected final energy demand. The mathematical method used in the MESSAGE model is linear programming, which means that all technical and economic relations describing the energy system are expressed in terms of linear functions. The optimisation criterion or objective function of the programme is the minimization of the present value of the cumulated energy system costs in the planning period. However, the definition of other objective functions, such as the minimization of air pollution or of energy imports is possible, either separately or by using a multicriteria approach.

The decision variables in the model formulation are the energy flows and the equipment capacities of the several technologies in the different time periods. They are linked by capacity-flow constraints. The planning period of the model is user-defined. The model variables are subject to a system of constraints, representing the structural and technological properties of the energy system, the existing stock of equipment, the projected energy demand, energy policy, restrictions, and the impact of the energy technologies on air pollution, emission control technologies and emission control policy restrictions.

The technologies are represented and aggregated in the model in such a way that the real technological energy supply structure of a country or region is represented in a reasonable way. The technologies are represented by a set of parameters in the model database, which is transformed into the model's system of equations by a matrix generator programme. Such parameters are e.g. prices of primary energy carriers, investment, fixed and variable costs, of various technologies, energy conversion efficiencies, existing capacities, availability factors, emission factors and others.

The application of the model based on MESSAGE tool results in a least-cost inter-temporal mix of primary energy, energy conversion and emission control technologies for each scenario. Scenarios may represent different hypotheses on important parameters, like the future fuel price, the market penetration of new technologies, political decision on development of one or another type of technology, etc., in order to take into account uncertainties in the future. By analysing the results, "what if?" statements on the future energy supply structure can be made, and different strategies of utilization of various primary energy sources can be compared with respect to their emission reduction efficiencies and their impact on structure and economy of the energy system.

2.2. Preparation of mathematical model

2.2.1 Model for the Analysis of Energy Sector

This model was created on the basis of the above-described MESSAGE modelling tool. The mathematical model prepared for the analysis of development of the Lithuanian energy system represents the whole energy system of the country, including all processes from the primary energy extraction or import to the supply of final energy. However, the main attention was paid to heat and electricity supply sectors while other sectors were represented in a simplified way. Power and heat supply systems are very interdependent. Both systems are being connected by CHP plants. Therefore, the future development of these sectors cannot be analysed separately. The model is adjusted to specific country conditions in order to represent correctly peculiarities of Lithuanian energy system.

Shortly the created model can be characterized by the following properties:

- It is an energy supply model, representing the energy conversion and utilization processes of the energy system;
- It is an optimisation model which from the set of existing and possible new technologies selects the optimal, in terms of selected criterion, mix of technologies able to cover given country demand for various energy forms during the whole study period;
- A techno-economic or engineering approach is applied, i.e. the model represents the energy systems by its technological structure, aiming at the optimisation of this structure, generally with respect to energy system costs;
- It is used for the development of medium-term strategies;
- It takes into account demand variations of various final energy forms during day, week and seasons, as well as different technological and political constraints of energy supply;
- It is an energy and environmental model, enabling the user to carry out the integrated analysis of the energy sector development and its environmental impacts;

The created model consists of 12 different modules, which are connected by technologies representing energy transmission or distribution (Figure 2). The following modules (“Vilnius”, “Kaunas”, “Alytus”, “Taurage”, “Utena”, “Panevezys”, “Siauliai”, “Klaipeda”, “Telsiai” ir “Marijampole”) represent heat supply systems in 10 counties of Lithuania together with modules “Fuel” and “Electricity”.

Heat energy cannot be transported in a long distance so heat supply sector consists of many district-heating systems. Therefore, district heating systems have to be aggregated taking into account technical and economical aspects and other selected criterions. So heat supply systems were aggregated according to its dependence to a particular county of Lithuania. Structure of all modules, representing heat supply systems, is almost the same, only technical and economical parameters of modelled technologies differ. The existing CHP power plants and boiler-houses, networks of district heating, as well as other present infrastructure of heat and electricity supply systems, are modelled in every module. The option of modernization of existing CHP power plants and boiler-houses is foreseen in the model. Also there is a big list of new heat energy generation technologies, which can replace the existing ones in the future. These future energy generation technologies are: new renewable boiler houses, new gas boiler houses, new gas or renewable CHP plants, new small CHP plants, new decentralized heating systems based on individual gas fired boilers, construction of new IRIS nuclear power plant(s) with cogeneration option in some of the counties (at least Vilnius, Kaunas and Klaipeda counties). Electricity produced by cogeneration plants is supplied to national transmission or distribution networks, which are modelled in “Electricity” module. In parallel to energy generation technologies, emission abatement technologies are modelled. Limitation of SO₂ emissions in the model is performed using the allowed concentrations in flue gases. According to the existing regulations in Lithuania permissible SO₂ concentration from 2004 to the end of 2007 is 1700 mg/Nm³, while since 2008 permissible concentration of SO₂ for large combustion plants using liquid fuel will be 400 mg/Nm³.

Module “Electricity” represents the electricity supply system. In order to find a future structure of Lithuanian energy system, together with existing power plants a set of new possible technological options was analysed: modernization of Lithuanian TPP, including flue gas desulphurisation measures; construction of new CCGT units at different sites (of the Lithuanian TPP, the Ignalina NPP, as well as at new site); construction of new gas turbines and wind power plants.

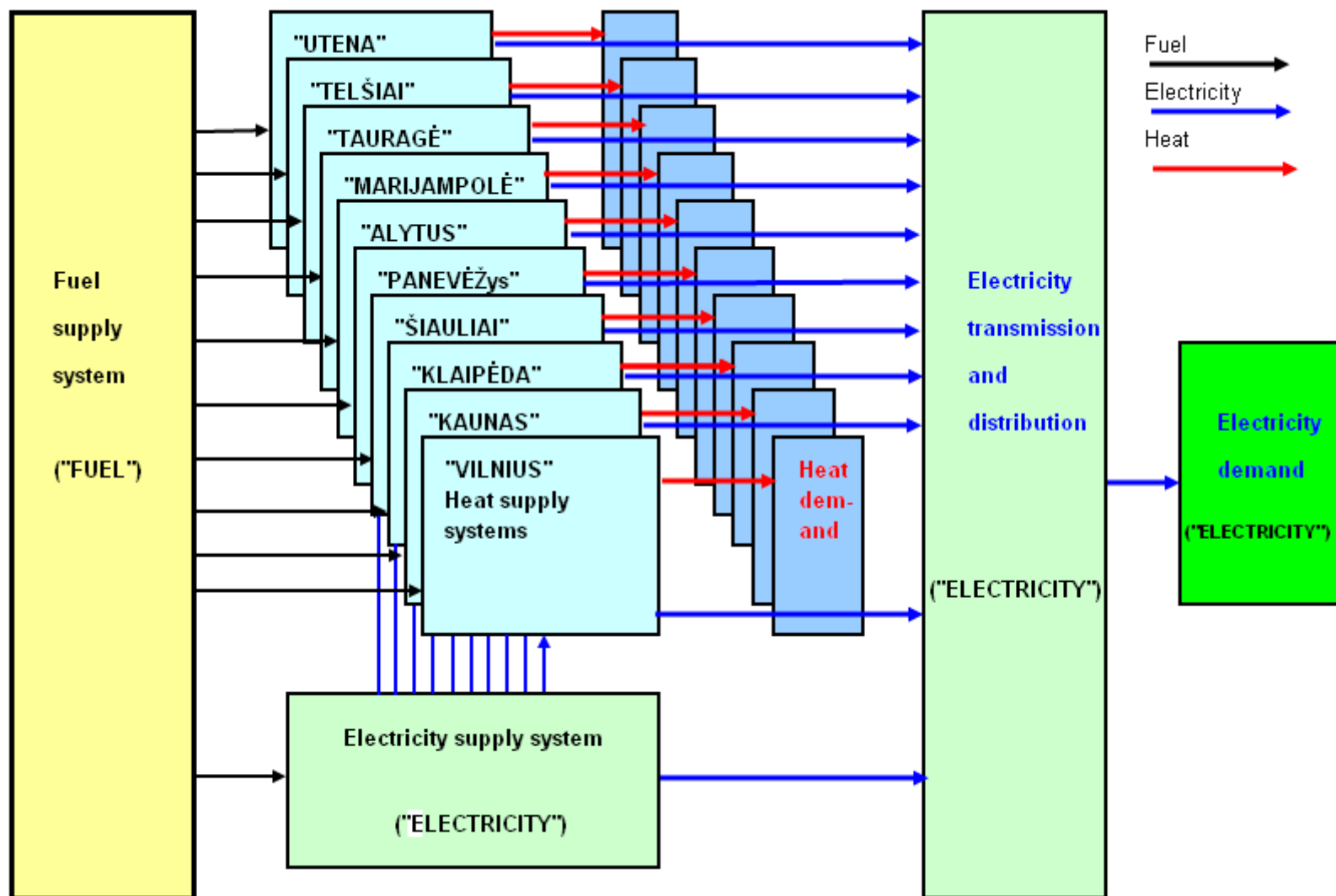


Figure 2. Structure of the model

System of fuel supply is represented in “Fuel” module. It models import, preparation, transportation and distribution of gas, oil, orimulsion and other fuels. Variable cost of technologies representing the import of various fuels includes fuel prices in the world market and transportation cost till Lithuanian border.

2.2.2 Options for Future Energy Supply System

Lithuanian TPP consists of four 150 MW and four 300 MW units. The oldest units No 1 and No 2 operating in combined heat and power production mode had been refurbished before 1990, which extended their lifetime to 2035. The remaining units may be operated at full load until 2025-2030. Utilization of those units at full load would likely start only after shut down of the second unit of the Ignalina NPP. However, in order to prepare this power plant for reliable operation after 2010 units should undergo minor modernization (replacement of control devices and instrumentation, as well as control room equipments, refurbishment of steam turbines, etc.). Such kind of modernization requires all together about 54 million Euro (Overnight investment cost). Investments for environmental protection measures will require additionally 249 million Euro.

Vilnius CHP-3 total installed electric capacity is 384 MW, it has two turbines with thermal capacity 2x302.3 MW. This power plant can fire both natural gas and heavy fuel oil. The fuel type is chosen depending on the fuel prices. In order to comply with environmental standards on emissions installation of low NO_x burners will be required. In addition to the above mentioned, modification of air pre-heaters, control and instrumentation system and reconstruction of electrical system to meet UCPT requirements will require additionally investments.

Kaunas CHP total installed electric capacity is 170 MW, thermal capacity of Kaunas CHP turbines is 186 MW and 203 MW. In addition, Kaunas CHP has 4x116 MW and 209 MW of water heating boilers and 255 MW of heat exchangers that can convert high potential (pressure and temperature) heat from steam boilers into low potential heat that can be delivered to residential consumers. Similarly to Vilnius CHP-3, Kaunas CHP will require some modernization.

Mazeikiai CHP total installed electric capacity is 194 MW, thermal capacity of Mazeikiai CHP turbines is 2x215 MW. This power plant can fire only heavy fuel oil.

Kaunas hydro power plant and Kruonis hydro pumped storage plant. Kaunas Hydro power plant was built on the bank of Nemunas River and has been in operation since 1960. Total capacity of 4 units of the power plant is 100 MW. Annual electricity production fluctuates between 280 and 440 GWh depending on water flow in river Nemunas. Some parts of generation and control systems are obsolete and have to be renovated in order to prolong lifetime of the plant and increase reliability of operation. The Kruonis HPSPP was built in 1992-1998 and comprises four units of 200 MW each. The plant serves peak and semi-peak loads of the Lithuanian power sector and previously also of the North-Western region of the Former Soviet Union. This plant takes up peak loads and compensates for the night drops in connected load, serving as a frequency and short-term emergency reserve. Further, it allows Ignalina NPP to operate at a higher power load factor.

IRIS. New medium sized advanced light water cooled modular reactor (IRIS) could be constructed at the different sites of Lithuania, for example Vilnius, Kaunas, Klaipeda cities or other places there is a demand for heat. The modular IRIS—with each module rated at ~335 MWe—is an ideal size for small countries like Lithuania, as it allows to easily introduce single modules in regions only requiring a few hundred MWs, or a moderate amount of power on limited electric grids. IRIS can be also deployed in multiple modules successively at time

intervals in areas requiring a larger amount of power increasing with time. It is assumed that IRIS could start its operation at 2015.

New CHP plants. In addition to the above mentioned existing power plants it will be possible to install new CHP plants for supply of electricity and heat in existing district heating systems in Lithuania.

New Combined cycle gas turbine (CCGT) power plants. New CCGT plant can be built at the site of Ignalina NPP, after its decommissioning to utilize existing site, infrastructure and qualified personal. Investment cost in this case is lower in comparison with the cost of construction of a completely new plant at new site. In order to avoid concentration of big capacities in one place, total capacity of new installations at the site of Ignalina NPP should not exceed 600 MW. In addition, new gas fired power plant will require construction of new gas pipeline. Similarly, existing space on the site of the Lithuanian TPP can be used for construction of new CCGT units. This can be done in addition to the existing capacities or instead of rehabilitation of existing units. Advantage of this site in comparison with the site of the Ignalina NPP is that gas network extension will be not required. The same capacity constrain of 600 MW was also applied. New CCGT plants also can be constructed at new sites in Lithuania. This, however, will require higher investment costs and extension of gas network.

New wind power plants. Because Lithuania does not have sufficient primary energy resources, electricity production based on renewable energy sources could be very attractive. One of possible ways to utilize renewable energy is construction of wind power plants. Taking into account the big decrease in investment cost per kW of installed capacity of wind power plants in recent years, an assumption was made that investment cost will be further decreasing. However, total installed capacity was constrained by 180 MW taking into account limited number of available sites with comparatively high wind speed.

Conversion of existing boiler-houses into CHP. Existing boiler-houses can be converted into CHP. For this purpose additional gas turbine with generator can be installed in front of existing boilers. Flue gas from turbine in this case will be used as a hot air in steam or water heating boiler in addition to fuel being used before modernization. According to experts' opinion, capacity of gas turbine in this case would be small (about 25%) in comparison with boiler capacity. Another way of boiler conversion into CHP is installation of steam turbine with corresponding generator. Installation of steam turbine can be also combined with construction of additional gas turbine in front of the boiler. In addition, possibility to construct new CHP based on biomass was also taken into consideration.

Reserve capacity. 10% of installed capacity from each power plant was assumed to be used for reserve capacity in order to satisfy necessary requirements in electricity system. Major part of capacity of Kruonis hydro pumped storage power plant was also allocated for reserve, as well as reserve capacity from neighbouring countries, calculated assuming current principles, was taken into account too.

Main parameters of technologies producing electricity and heat are summarized in Table 4.

Table 4. Technologies Representing System of Electricity and Heat Generation

| Plant name | First year of operation | Plant factor | Operation time | Plant life | Construction time* | Investment cost** |
|-----------------------------|-------------------------|--------------|----------------|------------|--------------------|-------------------|
| | Year | Fraction | Fraction | Year | Year | US\$/kW |
| IRIS (single module) | 2015 | 0.98 | 0.98 | 60 | 3 | 1200 |
| New CCGT at Ignalina | 2007 | 0.9 | 0.9 | 25 | 2 | 400 |
| New CCGT at Elektrenai | 2007 | 0.9 | 0.9 | 25 | 2 | 400 |
| New CCGT | 2007 | 0.9 | 0.9 | 25 | 3 | 500 |
| New CHP | 2006 | 0.9 | 0.9 | 30 | 3 | 800 |
| New small CHP | 2006 | 0.9 | 0.9 | 15 | 1 | 500 |
| New CHP on renewables | 2006 | 0.9 | 0.9 | 30 | 2 | 1000 |
| New Gas boilers | 2006 | 0.9 | 0.9 | 20 | 1 | 100 |
| New Wind PP | 2005 | 0.3 | 1 | 30 | 1 | 1050 |
| Existing hydro power plants | | 0.9 | 0.9 | 30 | 1 | 123 |
| Ignalina NPP | | 0.9 | 0.76 | | | |
| Lithuanian 300MW units | | 0.9 | 0.9 | 20 | 1 | 36 |
| Lithuanian 150MW units | | 0.9 | 0.75 | 20 | | 0 |
| Vilnius CHP | | 0.9 | 0.82 | 20 | 1 | 40 |
| Kaunas CHP | | 0.9 | 0.82 | 20 | 1 | 86 |
| Mazeikiai CHP | | 0.9 | 0.82 | 20 | 1 | 71 |
| Klaipeda CHP | | 0.9 | 0.72 | 5 | | 0 |
| Oil/gas boilers in cities | | 0.9 | 0.8 | 30 | 1 | 25 |
| Biomass boilers in cities | | 0.9 | 0.8 | 30 | 1 | 30 |

*Construction time for existing power plants represents time necessary for their modernization.

**Investment cost for existing plants represent investment cost for their modernisation.

2.3. Preliminary Results of Economic Study

This section shows some preliminary results of the Lithuanian energy system development analysis. In order to test model as well as to pre-evaluate possibilities of IRIS construction in Lithuania two scenarios were calculated:

- Base scenario: construction of IRIS NPP is not allowed;
- IRIS scenario: construction of IRIS NPP is allowed (construction of single module IRIS reactor in Vilnius city).

Optimisation of the Lithuanian energy sector among alternatives described above has shown that base scenario has caused higher total discounted cost of the Lithuanian energy system operation and development in the time period analysed if compared to the IRIS scenario. So it means that construction of IRIS nuclear power plant in Vilnius city would be an economically attractive option.

Electricity production in Lithuania in the case of IRIS scenario is presented in Figure 3. Electricity generation after closure of the Ignalina NPP becomes rather diversified. Modernised Lithuanian TPP in this case will take dominant position after 2010, and together with existing and new CHP will cover biggest part of Lithuanian electricity demand. Modernisation and operation of the Lithuanian TPP in the middle term time period will also not prevent from deployment of smaller NPPs (335 MWe each), the first one in 2015 and subsequent ones as demand arises. The preliminary results of energy system optimization have showed that building of single module IRIS reactor in capital of Lithuania Vilnius is attractive option. If operation of IRIS will start in 2015 it could supply up to 20% from total electricity production in Lithuania.

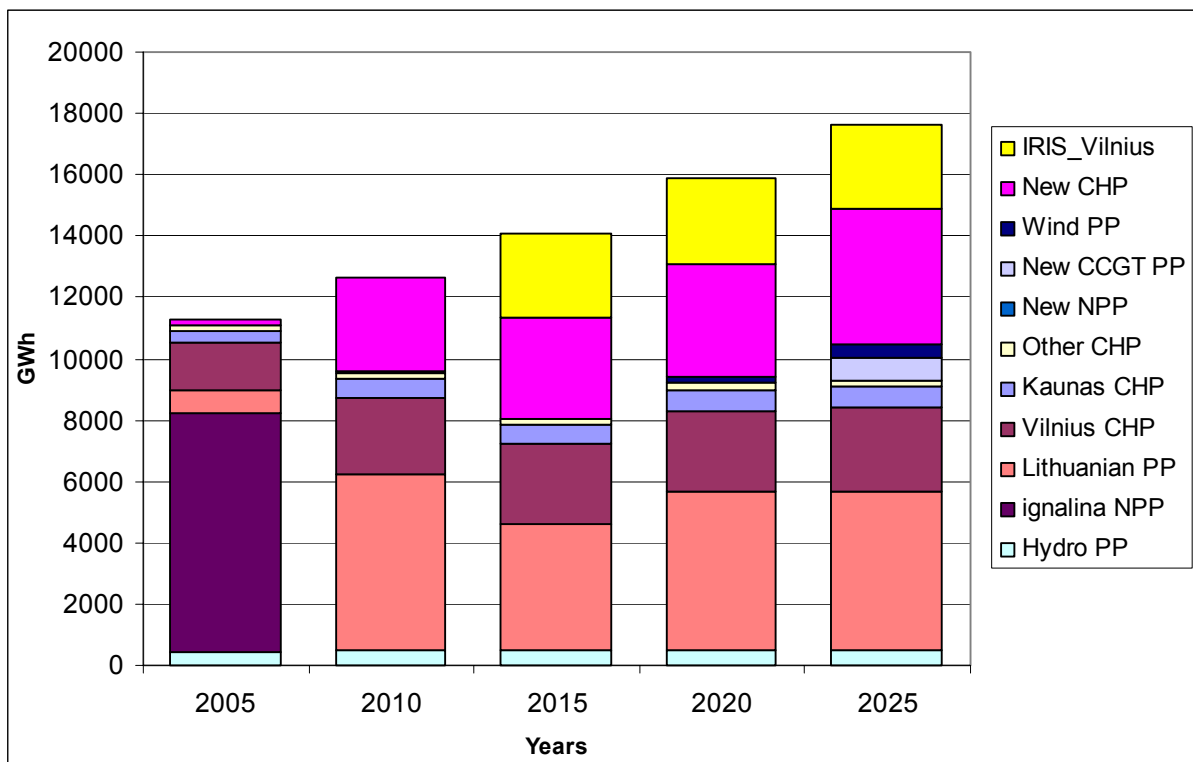


Figure 3. Dynamics of Electricity Production in the Case of IRIS Scenario

Dynamics of heat production in Vilnius county for both scenarios is presented in Figure 4 and Figure 5. The main supplier of heat in Vilnius County is Vilnius CHP. In the base scenario after

closure of the Ignalina NPP utilization of CHP increases because they become competitive in the electricity market in the case they operate in combined heat and electricity production mode. Also it is possible to see fast penetration of new CHP that replace existing boilers. In the case when new IRIS nuclear power plant will be constructed until 2015, it will be the most attractive option for heat generation in Vilnius County. The Vilnius CHP in this case will not be modernized and will be replaced by IRIS nuclear power plant. After the start-up of the new nuclear plant energy production at the Vilnius CHP will go down. IRIS could generate up to 50% of the total heat production in county. The share of heat production in new CHP power plants will remain almost the same as in the base scenario. New small CHP power plant will replace existing and old heat only boilers and mainly will supply heat to rural districts of Vilnius County.

These are only preliminary results and in the next project year the more detailed analysis will be done. For example in order to evaluate the benefits of eliminating EPZ and therefore being able to have district heating, two separate IRIS options has to be included in the model: first option that IRIS is generating only electricity (assuming current EPZ), and second one with district heating option (assuming no EPZ), etc.

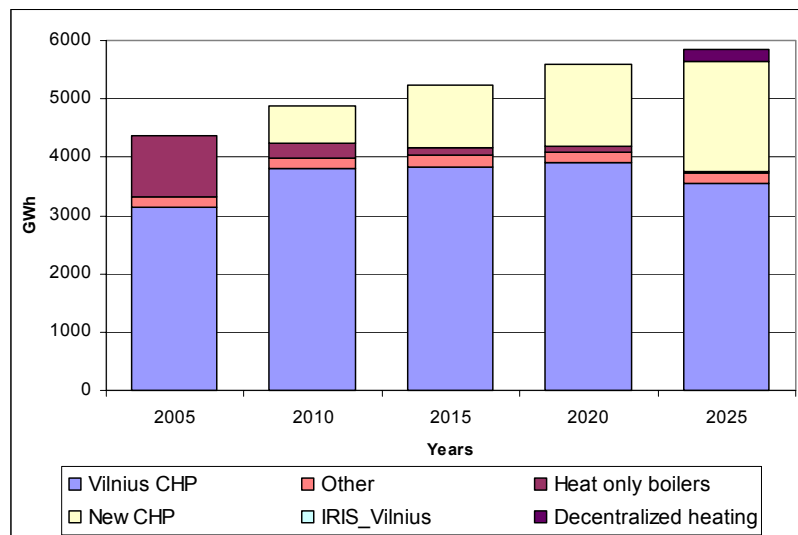


Figure 4. Dynamics of heat production for base scenario

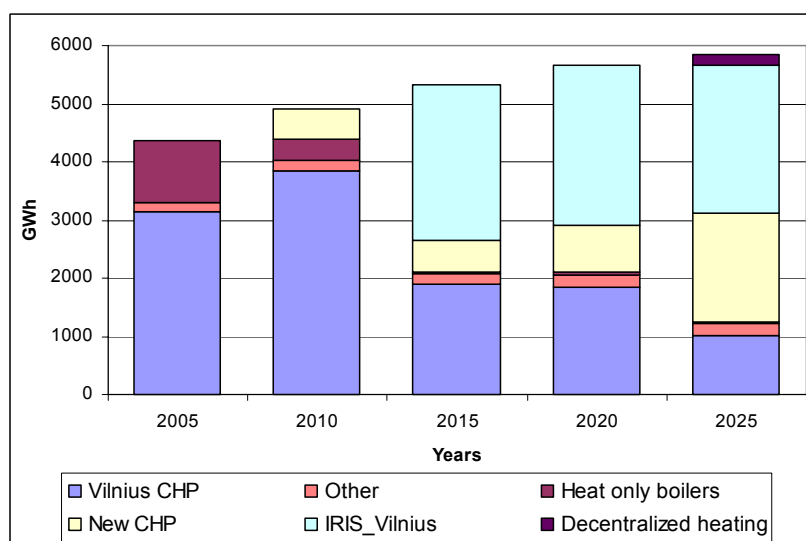


Figure 5. Dynamics of heat production for IRIS scenario

3. APPROACH FOR EVALUATION OF THE RADIATION DOSE

3.1. Permissible Radiation Doses to the Public

The main acceptance criteria for radiological accidents is to comply with the permissible doses to the public, that are defined in the basic standards for radiation protection [18]. According to these standards the permissible dose to a human body is defined as 1 mSv of the annual effective dose and for special circumstances 5 mSv of the annual effective dose.

Effective dose is defined as a summation of the tissue equivalent doses, each multiplied by the appropriate tissue weighting factor:

$$E = \sum_T w_T H_T,$$

where H_T is the equivalent dose in tissue T and w_T is the tissue weighting factor for tissue T.

The radiation doses used in this report are the doses accumulated during the first year after the accident at the exclusion zone border (i.e. at 3 km from NPP). In the performed analysis the doses are calculated and compared with the permissible limits considering the following conservative assumptions:

- FP from the NPP compartments are released as a single puff at the height, which corresponds to the FP source to the environment;
- the worst meteorological conditions are assumed;
- the individual remains at the border of the exclusion zone infinitely (i.e. unprotected and without evacuation).

3.2. Emergency FP Release to the Environment

The first material barrier preventing the radioactive materials release is the fuel pellet. The radioactive FPs are accumulated in the fuel pellet and in the fuel-cladding gap increasing with burn-up. The main part of FP remains in the fuel pellet but some part of gaseous and volatile FP enters the fuel-cladding gap.

The release of these FPs to the environment depends on the pressure differences between the compartments and environment. The transport of the volatile FP depends not only on pressure differences but on such processes as gravitational settling or pool scrubbing as well. While entering compartments the isotopes of iodine and caesium may be in different chemical forms. Entering the compartment the most probable form of iodine is caesium iodide (CsI) and of caesium – caesium hydroxide CsOH [1, 2]. These are hygroscopic aerosols, i.e. they are soluble. The hygroscopicity of aerosols has a significant influence of the FP transport [12]. The isotopes of elemental iodine I_2 are reactive, i.e. they react with various materials of constructions and equipment that located are in compartments [1].

In case of radioactive material release to the environment in the form of aerosols and gases the human body is irradiated via the direct and indirect impact pathways. Direct impact pathways are the external irradiation by the photons and β^\pm -particles that are present in the atmosphere and deposited on the ground. In the first case the dose is formed by the irradiation with the photons and β^\pm -particles from the radioactive cloud, in the second case – the dose is formed by the irradiation with the photons from the isotopes deposited on the ground. The internal irradiation from the

isotopes that enter human body with the inhaled air forms the so called inhalation dose and may also be attributed to the direct irradiation pathways. In these cases the individual doses are formed in the place of FP source location. The breathing rate of the human is assumed $2.67 \cdot 10^{-4} \text{ m}^3/\text{h}$.

The indirect impact pathway is the internal irradiation from the isotopes that enter human body due to nuclides migration via the food and biological chains and forms the internal irradiation via the ingestion pathway.

The above-mentioned impact ways to human body by the ionizing radiation from the radioactive FP release to the atmosphere are presented in Figure 6.

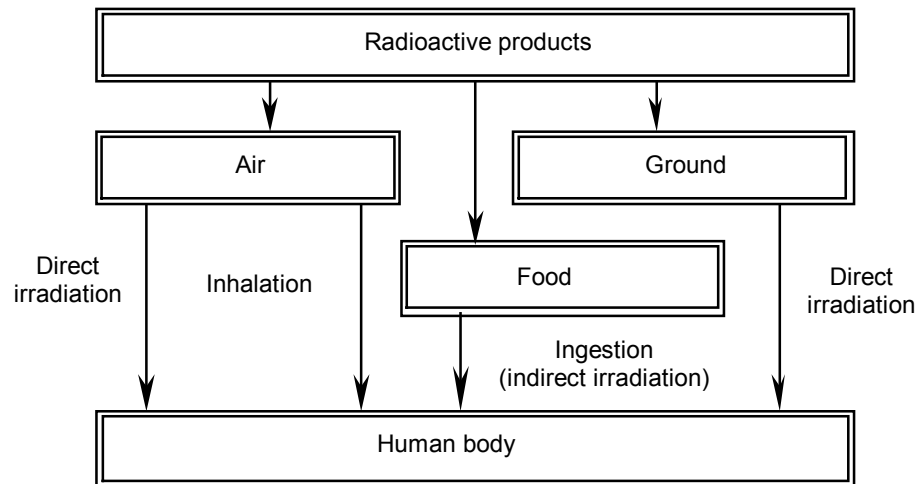


Figure 6. Impact ways to human body from the radioactive FP released to the environment

3.3. Meteorological Data for Dose Evaluation

A study to prepare meteorological data necessary for dose evaluation for one selected NPP site is based on available databases. This activity started in first year and will continue during the second and third year, when correspondent data may be updated or added.

The meteorological parameters presented in Figure 7 can be applied for the dose evaluation. It should be noted, that the standard values of FP deposition and dispersion included in the calculation codes can be applied, e.g. dry deposition velocity for iodine (I_2) 0.01 m/s.

Figure 7. Meteorological parameters for the analysis of FP dispersion in the environment

| Atmosphere stability class | Wind speed, m/s | Inversion layer, m |
|----------------------------|-----------------|--------------------|
| A | 3 | 1600 |
| B | 3,5 | 1200 |
| C | 4 | 800 |
| D | 5 | 560 |
| E | 3 | 320 |
| F | 2 | 200 |

The Lithuanian Republic is situated in the temperate climate zone. The possible new NPP site, i.e. the concerned territory near capital Vilnius, as well as whole Lithuanian territory, is located along

the path dominated by western wind currents. Therefore in the global sense whole Lithuanian territory climates can be considered as homogeneous. However, on the regional scale it is rather variable, because of the prevalent intrusion of air flows from the adjacent geographical zones.

On the whole the local climate depends on the circulation of air mass from the Atlantic, but the influence of air mass from the continents of Europe and Asia continent are perceptible as well.

About 60 cyclones and 50 anticyclones are expected yearly due to the weather conditions of the territory concerned. Cyclones are influenced by the weather about 170 days and anticyclones about 130 days a year, because they are moving faster. During the rest of the time baric formation are observed.

The entire territory of Lithuania has practically no influence on the formation of new air masses or their considerable transformation. During the year about 170 atmospheric fronts pass over the concerned territory.

During the cold season the warm fronts predominate over the cold ones, while during the warm seasons they are distributed equally. Colds fronts move faster than the warm ones. Western and southern winds predominate. The strongest winds have western and south - east directions. The average annual wind speed is 3.5 m/s, and maximal (gust) speeds can reach 28 m/s. No-wind conditions are observed on the average of 6 % of the time and last no more than one day (24 hours) in the summer, and no more than two days in the winter.

The predominant wind direction changes depending on the distance above the ground. Beginning from the 200 m distance above ground the predominate direction is as follows: in January from south to south-west, in April from south-south-east to south-east, in October from west-north-west to north. Only during July is the predominate direction west at elevated altitudes.

In general, the wind velocity changes depending on the distance from the ground surface. At a distance of 100 m from the ground the average wind velocity doubles in comparison with wind velocities at the height of the wind vane. They continue to grow within the half km layer. Then the increase of the wind velocity as a function of height decrease.

The atmospheric conditions are formed by circulation of air mass on the whole. Average annual amount of precipitation with correction for the moistening of the draught gauge is 638 mm. During the warm period of the year (April-October) about 70 % of all precipitation takes place, and during the cold period (November-March) - about 30 %. The coefficient of variation of multi-year annual precipitation is 0.15. Minimum of precipitation occurs in March, and the maximum - in July-August. There are about 170-180 days with precipitation (0.1 m and more) per year. The snow cover in the region is about 100-110 days per year. Average height of snow cover is 30-40 cm.

Multi-year amount of annual evaporation from the dry land is about 500 mm, evaporation from the water surface during the warm period (April-November) is about 600 mm with the coefficient of variation 0.15.

Average relative humidity of air reached 80 %, and about 90 % in winter. A minimum relative humidity (53-63 %) is observed in June, and a maximum - in January.

The season of spouts begins at the end of April and ends in the first half of September. The directions of spout motion is from south-west to north-east in 73 % of the cases. The average length of spout shift trajectory is 20 km and the length varies from 1 to 50 km. Average width of the spouts is 50 m, and it varies mostly from 10 to 300 m. Calculated maximal spout velocity with frequency one time per 10000 years is about 39 m/s.

Data about the most destructive spouts are incomplete. However, the following data practicaly can be used for calculations:

- maximal rotation speed of the spout wall is 105 m/s,
- pressure differential between center of the funnel and the fringe region of the spout is 135 kPa.

Collection and evaluation of the necessary meteorological data will continue through the following project years. In spite of assumption that whole Lithuanian territory climates can be considered as homogeneous a detailed study of meteorological data necessary for dose evaluation related to new NPP is site specific.

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1 Appendix. Executive Summary

**LITHUANIAN ENERGY INSTITUTE
LABORATORY OF NUCLEAR INSTALLATION SAFETY**

**IAEA COORDINATION RESEARCH PROGRAM
“Development of Small Reactors without On-Site Refueling”**

Summary of Report of the First Working Year

**Economic Benefits of Revising the Need for Relocation and
Evacuation Measures Unique to NPPs for Innovative
SMRs for Regions with Electricity Co-Generation**

IAEA Research Contract No. LIT13092

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This work is within the scope of activities defined within the Agency's CRP on Small Reactors with no on-site refueling. Specifically, it is relevant for Activity 2 "Definition of the scope of requirements and broader specifications to be identified for small reactors without on-site refueling" with respect to its ultimate objective (revised evacuation requirements), and to Activity 3 "Identification of requirements and broader specifications for NPPs with small reactors without on-site refueling for selected representative regions" with respect to considering specific impact on countries with colder climate and increased interest for district heating co-generation.

The ultimate objective is to establish an approach to licensing with a revised (reduced or eliminated) emergency planning requirements. Ideally, the emergency planning zone would coincide with (or be contained within) the site boundary, thus, there would be no need for off-site evacuation planning, and the NPP would become, relative to the general population, the same type of facility as any other industrial enterprise. This research will contribute toward achieving this ultimate objective, by addressing some of the relevant issues.

The aim of this work is to contribute toward the presented overall objective, using as a testbed the design of IRIS (International Reactor Innovative and Secure), as a representative innovative light-water SMR with option for infrequent on-site refueling, with the ultimate goal of developing a technology-independent approach.

For the purpose of presenting this approach, the main objectives/tasks deemed necessary to reach this final objective are listed below, however, this does not imply that all the tasks will be addressed and resolved by Lithuanian Energy Institute (LEI) alone within correspondent project.

1. Critically evaluate current regulations to identify what changes are necessary to enable advanced licensing
2. Identify criteria based on technical, quantifiable parameters that may be used in support of the objective
3. Identify approach, based on a combination of deterministic, probabilistic, and risk management, that will enable assessment of advanced plants based on their key design operational and safety characteristics with respect to adequate emergency planning requirements
4. Prepare site-specific representative data (e.g., meteorological)
5. Perform probabilistic analyses needed to support this approach.
6. Perform deterministic / dose evaluation analyses needed to support this approach.
7. Perform a detailed evaluation of the representative reactor utilizing the combined approach.
8. Identify, discuss and quantify the benefits attainable through the implementation of this objective, i.e., licensing with reduced emergency planning requirements

LEI will contribute to the overall objective by performing research related to a subset of the above listed tasks. It is expected that other tasks may be addressed by other participants within the IAEA CRP.

Over the foreseen 3-year period, the research scope for LEI is expected to include the following objectives:

1. In Task 1, LEI will review the current licensing regulations in Lithuania and identify necessary changes. It is expected that these results, supplemented by similar results obtained within this CRP by other member countries, would contribute to ultimately defining a generic, country-independent approach.
2. Perform economic study to evaluate positive economic effect on the nuclear district heating co-generation option, due to revised siting requirements with reduced emergency planning, that would allow placement of NPPs closer to population centers.

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3. Support development of justification for reduced emergency planning through PRA analyses of external events to support activities performed by POLIMI and FER, primarily to PRA analyses.
 4. Prepare meteorological data for a selected site, or several sites, that may be used within this same CRP for dose calculations, in support of the development of reduced emergency planning requirements.

During the first year LEI performed the following tasks:

1. Review the licensing regulations in Lithuania, and specifically the emergency response planning for the NPP Ignalina.
2. Identify changes which would be necessary if the emergency planning for the future power plants in Lithuania is to be eliminated or reduced
3. Initiate a study of the economic impact of revised licensing requirements on district heating. Due to climate, district heating presents a notable fraction of energy consumption in winter months, and infrastructure for its use is already in place in some population centers in Lithuania. This work will continue into the second and third project year, to ultimately determine potential economic benefits of revising the evacuation requirements and enabling NPP-based district heating.
4. Initiate a study to prepare meteorological data necessary for dose evaluation based on available databases.