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Dnevi Posavske Energetike 2010

Fakulteta za energetiko Univerze v Mariboru je s partnerji iz gospodarstva uspešno izvedla projekt "Dnevi posavske energetike 2010", ki se je odvijal od 10. do 12. novembra 2010, in je večinoma potekal na Fakulteti za energetiko v Krškem. Projekt je letos potekal drugič.

V sklopu aktivnosti so bili izvedeni naslednji dogodki:

1. dan - Konferenca »Pomen jedrske energetike za Slovenijo«,

2. dan - Seminar »Učinkovita raba energije v lokalnih skupnostih«,

3. dan - Srednješolski kviz »Energetika v Posavju«,

- Brucovanje študentov Fakultete za energetiko.

V okviru projekta smo se odločili, da v posebni izdaji revije - Journal of Energy Technology, objavimo prispevke s konference in seminarja, ter objavimo rezultate srednješolskega Energetskega kviza.

Prispevki na konferenci pričajo, da ima Slovenija bogate izkušnje na področju jedrske tehnologije, ki jih kaže še naprej razvijati in te izkušnje izkoristiti pri novogradnji druge enote jedrske elektrarne NEK-2. Z izgradnjo odlagališča srednje- in nizko-radioaktivnih odpadkov, v Vrbini pri Krškem, bo ustrezno rešen tudi ta slovenski problem.

Prispevki s seminarja poudarjajo znano dejstvo, da je učinkovita rabe energije naša najbolj učinkovita elektrarna, ki jo je potrebno izkoristiti tudi na nivoju lokalnih skupnostih.

Dijaki so se na kvizu izkazali, saj jih je večina dosegla dobre rezultate, prvi trije skoraj vse možne točke, pravzaprav smo imeli dva prva mesta po številu točk. Prvega je komisija določila na osnovi rešitev več zahtevnejših vprašanj.

Naši mladi študentje Fakultete za energetiko – bruci, so se izkazali tako pri organizaciji in izvedbi brucovanja, na katerem so uspešno odgovarjali na energetska vprašanja.

Dneve posavske energetike bo Fakulteta za energetiko pripravila tudi naslednje leto, pri tem bo sledila cilju, da projekt postane eden najpomembnejših stičišč izmenjave mnenj, idej in znanja s področja energetike, tako med univerzitetnimi strokovnjaki, gospodarstvom, javnim sektorjem, kot tudi med študenti in zainteresirano javnostjo v Posavju ter širše v Sloveniji.

Posavje Energy Technology Days 2010

The Faculty of Energy Technology, University of Maribor with partners from industry successfully implemented the project *Posavje Energy Technology Days 2010*, which took place from 10th to 12th November 2010, at the Faculty of Energy Technology, in Krško. This was the second time the event was held. As part of the activities, following events were carried out:

1st Day - Conference "*The importance of nuclear energy in Slovenia*"

2nd Day - Seminar on "*Efficient use of energy in local communities*"

3rd Day - High School Quiz "*Energy technology in Posavje*"
- Freshmen's student party at the Faculty of Energy Technology.

Within the project, we decided to have a special issue of the Journal of Energy Technology, to publish conference papers and seminars, and to announce the results of High School Energy Technology quiz.

The contributions to the conference show that Slovenia has a great amount of experience in the field of nuclear technology, and suggest that we further develop and exploit this experience with the construction of another nuclear power plant unit (NEK-2). The construction of the landfill for medium-and low-radioactive waste in Vrbina in Krško will resolve the problem of nuclear waste.

Contributions to the seminar highlight the well-known fact that the efficient use of energy is our most efficient power plant, which should be exploited at the level of local communities.

High school students showed quite good knowledge; while most of them achieved very good results (the top three almost every possible point), we actually had two first places based on the number of collected points. The winner was announced by the commission, determined on the basis of which candidate correctly answered the more complex questions.

The freshmen at the Faculty of Energy proved their skills in preparation work by organizing the freshmen party. Representatives of the faculty freshman successfully answered questions from the field of energy technology, allowing them to successfully progress from freshman to student.

The Posavje Energy Technology Days will once more be organized by Faculty of Energy Technology next year. We will keep the goal of the project to be one of the major hubs of exchange of views, ideas and knowledge in the field of energy, both among academic experts, business, the public sector, as well as between students and the interested Posavje public and beyond.

Krško, November, 2010

Andrej PREDIN

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HYDROGEN TECHNOLOGIES IN CONNECTION WITH NUCLEAR POWER PLANT

VODIKOVE TEHNOLOGIJE V POVEZAVI Z JEDRSKO ELEKTRARNO

Jurij Avsec[ℜ]

Keywords: Hydrogen production, hydrogen consumption, Cu-Cl cycle, S-I cycle, thermochemical cycles, steam methane reforming

Abstract

Efficient and sustainable methods of clean fuel production are needed in all countries of the world in the face of depleting oil reserves and the need to reduce carbon dioxide emissions. With commitments for a hydrogen village, a hydrogen airport and a hydrogen corridor, the Canadian province of Ontario has already begun to move toward a hydrogen-fuelled economy. However, a key missing element is a large-scale method of hydrogen production. As a carbon-based technology, the predominant existing process (steam-methane reforming (SMR)) is unsuitable.

This paper focuses on a production of hydrogen in connection with a nuclear power plant. We will show the technologies which allow the coupling between a nuclear power plant and hydrogen technologies.

Povzetek

Toplogredni plini, ki nastajajo pri zgorevanju fosilnih goriv, predstavljajo eno izmed velikih potencialnih nevarnosti za prihodnost obstoja človeka. Zaradi zmanjševanja emisije ogljikovega dioksida v ozračju in zaradi zmanjševanja zalog fosilnih goriv v svetu je potrebno preiti v prihodnosti na nove tehnologije pridobivanja goriv. Kanada in mnogo druge visoko razvite in

ℜ Corresponding author: Assoc. Prof. Jurij Avsec, Tel.: +386-7-620-2217, Fax: +386-2-620-2222, Mailing address: University of Maribor, Faculty of Energy Technology, Hočevarjev trg 1, 8270 Krško, SLOVENIA
E-mail address: jurij.avsec@uni-mb.si

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ekološko zavedne države so z razvojem vodikovih avtomobilov, vlakov, vodikovih vasi, vodikovih letališč… že pričeli z aplikacijo vodikovih tehnologij. V principu manjka za primer širokomasovne proizvodnje le cenovno ugodna in ekološko ustrezna metoda za pridobivanje vodika v velikih količinah.

Ta članek opisuje tehnike pridobivanja vodika, ki lahko delujejo v povezavi z jedrsko elektrarno. Še posebej je v članku poudarjena povezava med vodikovimi tehnologijami in jedrsko elektrarno v Krškem.

1 INTRODUCTION

Currently, the world consumes about 85 million barrels of oil and 104 trillion cubic feet of natural gas per day [1-3], releasing greenhouse gases that lead to global warming. In contrast, hydrogen is a clean energy carrier. Some have questioned whether the “hydrogen economy” is feasible in the near future or remains a distant ideal. However, the global hydrogen market is already valued at over $282 billion/year, growing at 10%/year, rising to 40%/year by 2020, and reaching several trillions of dollars by 2020. In Alberta, Canada, the oil sands need large amounts of hydrogen to convert bitumen to synthetic crude and remove impurities. A key challenge facing the hydrogen economy is a more efficient, sustainable and lower cost method of hydrogen production. As a carbon-based technology, the predominant existing process (steam-methane reforming (SMR)) is unsustainable.

Due to ecological and demographic impacts, there is a high probability of a series of changes occurring on our planet over the next fifty to seventy years. There is no longer any doubt about that. The only thing scientists still disagree about is the extent and the level of these changes. Ecological changes will be drastic, but it will depend on the people as to how extensive they will be.

Transport is one of the major ecological pollutants. In the field of transport, the existing internal combustion engines use a large amount of air and contaminate it with exhaust gases. One of the most important factors in improving the ecology will therefore undoubtedly be the introduction of environmentally friendly technologies, which certainly include fuel cells. Japan, being one of the most advanced countries, has already started the process of introducing the fuel cells in the railway sector, for slower trains. Also Germany will start with production of submarines and ships with fuel cell technology. Apart from critical ecological problems, the automotive groups are being forced to develop new technologies also by the fact that the scientists predict a decrease in the extraction of fossil fuels after 2020. This will cause a great difference between demand and supply, which is likely to result in a very high price of petroleum fuels.

Economic reasons and a number of unknown effects are forcing large automotive groups, such as Ford, General Motors, Honda, Toyota into developing several development solutions in the field of drive units. For this purpose, the laboratories of automotive groups are developing and optimising new generations of diesel engines, motor-electric motor or fuel cell-electric motor hybrid systems, hydrogen internal combustion engines etc.

There has been a lot of talk about how the diesel and the petrol engines will be forced to withdraw because of better drive units. Some scientific analyses actually support the fact that a fuel cell enables a higher useful efficiency than for example a diesel engine. However, in practice it shows that, up until now, the mentioned engines have still been presenting the

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dominant share on the market due to their flawlessness and sophistication, relatively low price and great popularity. But the high prices of fuel, as well as increasingly advanced solutions, indicate that it is now time for new forms of energy conversion.

One of the possible solutions to the future transport are fuel cells. Fuel cells represent a promising alternative to internal combustion engines. In principle, there are several types of fuel cells. Currently, in the field of road transport, a proton exchange membrane fuel cell (PEMFC) and a solid oxide fuel cell (SOFC) are the most promising.

Rather than deriving hydrogen from fossil fuels, a promising alternative is the thermochemical decomposition of water. Electrolysis is a proven, commercial technology that separates water into hydrogen and oxygen using electricity. Net electrolysis efficiencies (including both electricity and hydrogen generation) are typically about 32%. In contrast, thermochemical cycles to produce hydrogen promise heat-to-hydrogen efficiencies up to approximately 50%.

Essentially, the technique of hydrogen use has been solved, it would only be necessary to provide sufficient amounts of hydrogen. For this reason, it is sensible to consider the use of large energy facilities, such as nuclear power plants or thermal power plants, for hydrogen production. Apart from using the electric power during night-time, there are large amounts of waste heat available as well. For this purpose, new methods of hydrogen production are being developed in the most developed countries. The most recent results show that the hybrid thermochemical cycles are the cheapest method of hydrogen production.

The Krško-Brežice municipality has strong potentials to be the first municipality to turn into a carbonless society by introducing hydrogen and sustainable technologies. This could replace all fossil sources with sustainable sources and an energy-generating product. Table 1 shows the average annual consumption of fossil fuels in the factories NEK, VIPAP and KOSTAK.

Table 1: *Annual consumption of fossil fuels in the factories KOSTAK, NEK and VIPAP*

FUEL		KOSTAK+NEK+VIPAP
Diesel fuel	(L)	450.000
Natural gas	(m^3)	185.533
Petrols	(L)	1.300.000
Coal	(t)	100.000
Hydrogen	(m^3)	40

2 HYDROGEN AS AN ENERGY VECTOR

Studies show that the developed world will need even more energy in the future. At the same time, the reserves of fossil fuel are rapidly running out. Because of ecological problems, the developed world will have to drastically reduce the release of CO2 into the environment. One possible solution is switching to hydrogen technologies in combination with a very low cost production of electrical energy. In this case, we can say that hydrogen, much like the electrical

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energy, is an energy conductor or vector. Throughout the centuries, the human kind has first used wood as an energy product, then coal, oil, gas.

Figure 1 suggests that the next most logical step in using increasingly advanced and energy-efficient fuels is hydrogen. Many experts predict that before the end of this century, hydrogen will have taken the leading role as the next logical step in use. The only real competition which hydrogen technologies face is the use of electrical energy through batteries. However, modern batteries at this moment are not of sufficiently high quality. It is especially necessary to point out the significant decrease in capacity of batteries when they are subject to extreme weather conditions.

Figure 1: *Schematic of a planned hydrogen village in Canada near Toronto*
http://www.hydrogenvillage.ca/About_hydrogen_village.htm

Figure 2: *Prince Edward scheme of hydrogen-wind village*
http://www.treehugger.com/files/2005/04/prince_edward_i.php

3 NUCLEAR REACTORS

Considering their way of operating, nuclear power plants are very similar to thermal power plants, except, for heating of water, they use heat which is released from the uranium nuclear fission chain reaction in a *reactor*. There are different types of nuclear power plants and they vary according to the coolant which removes the heat from the reactor. The coolant can be ordinary water, heavy water, gas or melted metal.

There are two basic types of reactors, which differ according to their energy spectrum or the speed of neutrons (http://sl.wikipedia.org/wiki/Jedrski_reaktor)

- Thermal (slow) reactors
- Fast reactors

In a thermal reactor the neutrons have to be slowed down from fast to thermal area, using a moderator. There are two types of thermal reactors, namely a homogeneous type, where uranium salt is dissolved in water as the moderator, and a heterogeneous type, where uranium rods are inserted in water or graphite.

In fast reactors, ^{235}U is used as fuel, and is mostly split already by neutrons in fast and middle area of speed. ^{238}U can be used as well. Two advantages of this type of reactor are its small size, which facilitates transferring to areas that are difficult to access, and a large number of available neutrons (as they do not disappear in other components of the reactor), while the two disadvantages are expensive fuel (because of the process of separating or separation of ^{235}U from the uranium mixture during its production) and an increased risk of explosion.

The existing families of nuclear reactors

- Pressurized water reactor (PWR), pressurized water reactor is a type of nuclear reactor which uses ordinary light water as a coolant, as well as a neutron moderator.
- Boiling water reactor (BWR)
- Heavy water reactor (PHWR or CANDU)
- High power channel reactor (RBMK)
- Gas cooled reactor (HTGR, AGR, GCR (Magnox), early production reactors, cooled by air (Hanford), the moderator is graphite, experimentally also heavy water)
- Fast breeder reactor (FBR or SNR)

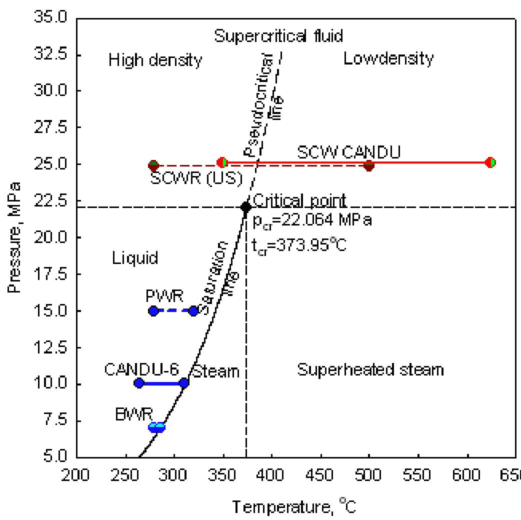

Figure 3: *Types of current and future reactors [8]*

Nuclear power plants cooled by ordinary water are known as *light water* reactors. These can be *pressurized water* (*PWR* – Pressurized Water Reactor) and *boiling* (*BWR* – Boiling Water Reactor) reactors, according to whether the water in the reactor boils or not. There are 439 nuclear power plants operating in the world today, 60% of which are pressurized water and around 21% are boiling. Other types of power plants are represented by a significantly smaller percentage. The Krško Nuclear Power Plant has a pressurized water reactor PWR. When considering the possibility of a second nuclear power plant, it would be sensible to stay within the limits of the technology which is well known in Slovenia and is also the most established technology on a global scale. According to information from GEN, the new nuclear power plant will essentially be of the same type as the existing one.

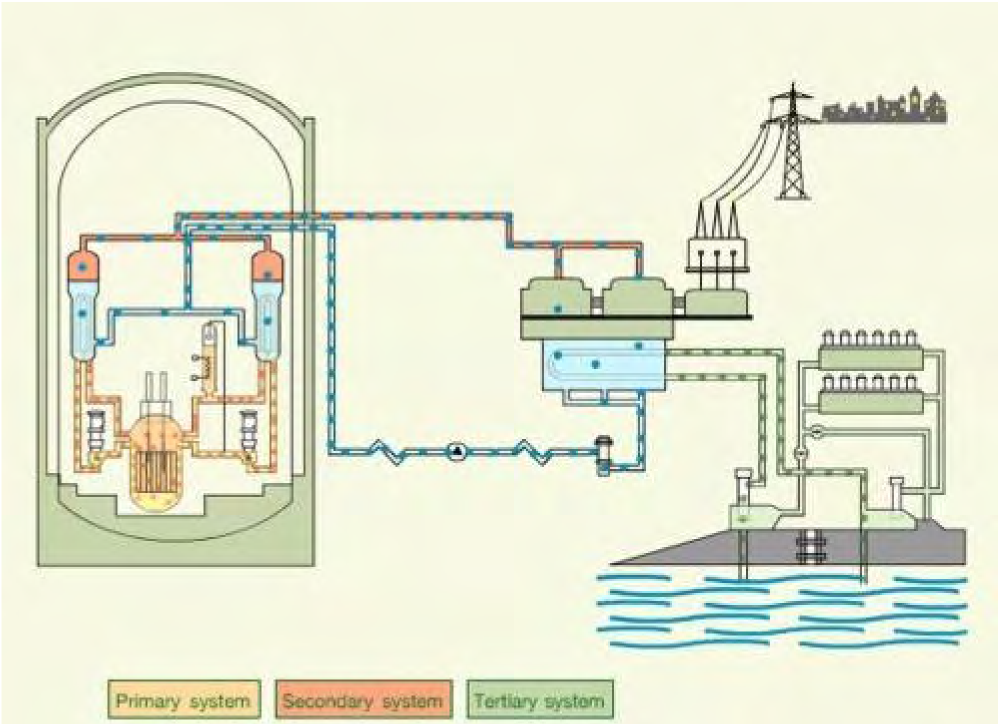

Figure 4: *Operating principle of the Krško Nuclear Power Plant (NEK)*

http://www.nek.si/en/about_nuclear_technology/the_operation_of_nek/

Table 2: *Table: basic information about NEK1*

Reactor type:	Pressurized Light Water Reactor (PWR)
Reactor thermal power:	1994 MW
Gross electrical output:	727 MW
Net electrical output:	696 MW
Thermal efficiency factor:	35%

4 HYDROGEN PRODUCTION BY NEK

A nuclear power plant which would use the electrical energy surplus to produce hydrogen could use the hydrogen on two levels:

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1. Sale of hydrogen on the market.
2. Using hydrogen as an energy vector and a subsequent conversion of hydrogen back to electrical energy.

Each of the variants has its advantages and disadvantages.

In principle, it is possible to produce hydrogen in two ways: from fossil fuels and from water. When using fossil fuels, the following processes can be used:

- -production from fossil fuels, biomass, coal using processes;
- -steam reforming;
- -partial oxidation;
- -steam reforming process using NEK electrical energy.

Figure 5: *Steam reforming process in Canada*

Processes of the traditional steam reforming or partial oxidation are very cost-effective, however, a construction of such a facility in the environment would be an issue from several points of view:

- enormous emissions of CO2
- factories pollute the environment with other waste as well. This is why the next part of this article focuses mainly on obtaining hydrogen from water. Water offers several possible ways to produce electrolysis.

4.1. Traditional electrolysis using nuclear electricity

Classical electrolysis is a promising and expensive electrochemical method, which helps to obtain hydrogen from water. Hydrogen produced with electrolysis is very pure. Electrolysis enables the production of about 4% of hydrogen in the world [3-7]. The produced hydrogen is very pure. Electrolysis is an electrochemical process which, by supplying direct electric current, leads to a chemical reaction. For the electrolysis of water, the following reactions apply:

reaction on the cathode: $2H_2O + 2e^- = H_2 + 2OH^-$

reaction on the anode: $2OH^-$ g=$^1/_2\ O_2 + H_2O + 2e^-$

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total reaction: $H_2O = H_2 + {}^1/_2\, O_2$

energy change: $\Delta H = \Delta G + T\Delta S$

Figure 6: *An example of an electrolysis plant with tanks and water pipes in the Šoštanj thermal power plant TEŠ*

The electrolysis of water process does not convert 100% of electrical energy into chemical energy. Useful efficiency basically ranges between 50–80%. These values are related only to the conversion of electrical energy to chemical energy of hydrogen, if we considered for example the conversion of nuclear reactions to hydrogen using electrolysis, the useful efficiency would amount to 20–37%. At the present stage of development, the electrolysis process is the most expensive process of hydrogen production [3]. Electrolysis processes are usually divided according to the electrolyte used by the process [2].

Alkaline electrolysis processes use a 25% potassium hydroxide solution. The pressures reach up to 25 bar [3].

Electrolysis processes with proton exchange membrane. In this case the electrolyte is an organic polymer membrane, where the protons are generated at the anode. Theoretical calculations indicate that the useful efficiency of this type can reach up to 94%, while in practice electrolysis processes with proton exchange membrane demonstrate a slightly lower useful efficiency than alkaline electrolysis processes. Practical testing has shown that the electrolysis processes with proton exchange membrane are more suitable for small appliances, while the alkaline processes are more suitable for larger systems. Their advantage is that they are suitable for stationary as well as mobile use, and the pressures can reach several hundred bars.

The laboratories have also been developing new electrolysis processes. Two promising processes are the high pressure electrolysis and the high temperature electrolysis, where the useful efficiency measured in laboratories is supposed to go beyond 90%.

4.2 Thermochemical cycles for decomposition of water

Rather than deriving hydrogen from fossil fuels, a promising alternative is thermochemical decomposition of water. Electrolysis is a proven, commercial technology that separates water into hydrogen and oxygen using electricity. Net electrolysis efficiencies (including both electricity and hydrogen generation) are typically about 32%. In contrast, thermochemical cycles to produce hydrogen promise heat-to-hydrogen efficiencies up to about 50%.

Through thermochemical cycles hydrogen is produced by chemical processes and heat supply at significantly lower temperatures then a natural decomposition into hydrogen and oxygen. In the case of a natural decomposition, temperatures of more than 2500^{0}C are necessary. Usually, the temperatures necessary for the thermochemical decomposition range between 750^{0}C and 1000^{0}C (Table 2). The mentioned requirement of a relatively high temperature prevents the application of thermochemical cycles to conventional, water-cooled nuclear reactors. However, a use of high temperature gas-cooled reactors or 4th Generation reactors would be possible. For the purpose of thermochemical cycles, the methods of solar energy use are being developed as well (maximum temperatures of approximately 1500^{0}C) or in combination with wind turbines. The beginnings of researching the thermochemical cycles of hydrogen production from water date back to around 1960. The key advantage of thermochemical cycles over others is the high useful efficiency, which, in some cycles, goes beyond 50%. The next great advantage over other cycles is the circular process, where the environmental strain caused by CO_2 is no longer a problem. In scientific literature, there are more than 200 thermochemical cycles [8], majority of which was never tested as pilot projects. Most of them are being developed in the USA, Japan, Canada, France. The following table displays the most well known thermochemical cycles:

Table 3: *A short description of the most tested thermochemical cycles [9]*

Name of the cycle	Maximum temperature (^{0}C)	Useful efficiency (%)	Advantages
Sulphur-iodine	823-900	42-51	Useful efficiency beyond 60% is also planned
UT-3 Calcium-bromine	750	40-50	Lower maximum temperature
Vanadium-chlorine	925	40.5-42.5	
Steel-chlorine	650	47-49	Lower maximum temperature
Calcium-Bromine	750	44	Not yet tested
Hybrid sulphur cycle Westinghouse		41-53	Over 60% useful efficiency designed
Hybrid Copper-chlorine cycle	550	46	Low maximum temperature
Hybrid copper-sulphur	827	68-73	High useful efficiency
Hybrid sulphur-bromine cycle	Data not available	39	

One of the most optimistic procedures is sulphur-iodine cycle. The sulfur-iodine cycle (S-I cycle) is a three-step thermochemical cycle used to produce hydrogen. The S-I cycle consists of three

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chemical reactions whose net reactant is water and whose net products are hydrogen and oxygen. All other chemicals are recycled. The S-I process requires an efficient source of heat at 900^0C. The high temperature of process is one of the biggest problems to start with the production of hydrogen with S-I process.

Especially interesting are the thermochemical hybrid cycles, which, apart from waste heat, require electrical energy to operate.

This article examines the thermophysical properties of a specific cycle called the copper-chlorine (Cu-Cl) cycle, with particular relevance to nuclear-produced hydrogen. A conceptual schematic of the Cu-Cl cycle is shown in Fig. 8.

In the Cu-Cl cycle, water is decomposed into hydrogen and oxygen through intermediate Cu-Cl compounds. Nuclear-based "water splitting" requires an intermediate heat exchanger between the nuclear reactor and hydrogen plant, which transfers heat from the reactor coolant to the thermochemical cycle. An intermediate loop prevents exposure to radiation from the reactor coolant in the hydrogen plant, as well as corrosive fluids in the thermochemical cycle entering the nuclear plant.

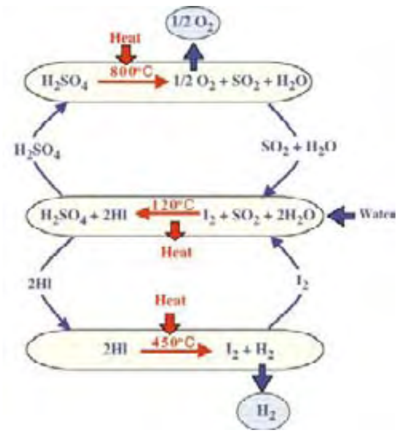

***Figure 7**: Principle of S-I process*
http://asyncbrain.baf.cz/sanatorium/1/h2fuel/index.htm

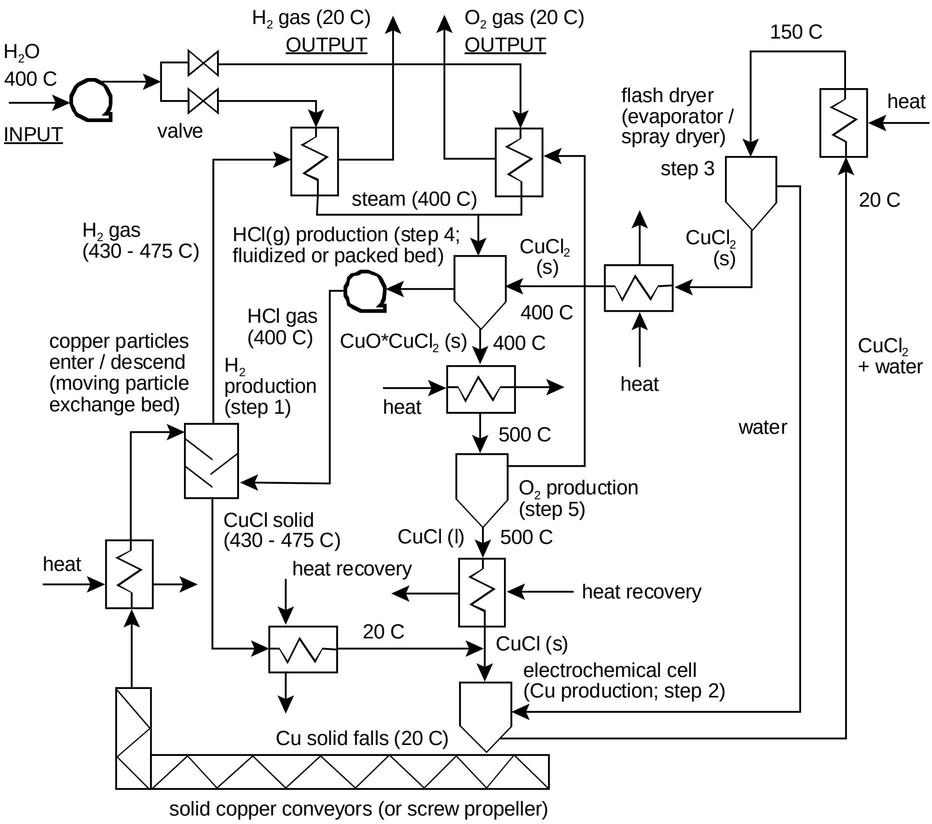

Figure 8: *Schematic of the copper-chlorine cycle for thermochemical hydrogen production [3]*

Table 4: *Hydrogen production price*

Steam reforming	• $1.40/kg hydrogen production costs • add 20¢/kg H2, for carbon storage, $30/tonne of CO2 • Add 67¢/kg H2, carbon tax ($100/tonne, i.e., Sweden) • Increasing prices for hydrocarbons, ever smaller reserves
Cu-Cl thermochemical hybrid cycle	• $US1.53/kg, including production costs, maintenance, decomposition • Minus 21 ¢/kg H2 due to oxygen sale
Electrolysis	3–5 $/kg
High temperature electrolysis	
S-I cycle	• 1.5–1.8 $/kg
Westinghouse cycle	• 1.8 $/kg

Hydrogen can then be used in several machines, where it is possible to convert chemically bound energy back to electrical energy or to useful work. One of the most promising

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possibilities is the use of fuel cells. At this time is the most interesting and economically using the combined steam-vapour cycles or combination between fuel cells and steam-vapour cycles.

For transport will be fuel cells in the future of vital importance. Normally, fuel cells are divided into groups according to the type of the electrolyte they use. Alkaline fuel cells (AFC) operate optimally within the temperature area of 120^0C–250^0C, with concentrated KOH utilized as the electrolyte. A proton exchange membrane fuel cell (PEMFC) uses a very thin polymer membrane as the electrolyte. Its working temperature ranges approximately from 60^0C–80^0C and it currently represents the most promising fuel cell for installation in cars, trains etc. A solid oxide fuel cell (SOFC) uses non-porous metal oxide as the electrolyte. These cells operate at higher temperatures, 600^0C–1000^0C. Also known are phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC), but they are not used very often. Figure 1 shows a comparison between fuel cells according to the optimum operating temperature. At present, all of the important automotive factories have their own system of powering vehicles with fuel cells. Due to significant overpopulation and being highly export-oriented, two Japanese factories have become highly developed in this field, Honda and Toyota. However, other factories and automotive groups are not far behind. Table 1 shows some of the basic types of vehicles already powered by fuel cells.

A 35% efficiency (electricity) with Slovenian's PWR generation reactor leads to a 25% net efficiency by electrolysis for hydrogen production. In contrast, a 43% heat-to-hydrogen efficiency has been demonstrated from Aspen Plus simulations for the Cu–Cl cycle [3]. This implies a significant margin of superior overall conversion efficiency, with more than one-third improvement over electrolysis, excluding even larger gains if ''waste heat'' is utilized in the thermochemical cycle [3,4,7]. If we compare systems for production of electricity with reversible pump turbine, has reversible pump turbine better efficiency. On the other hand reversible pump turbine needs a lot of costs for construction and building which are not included in efficiency. Figures 10,11, and 12 show that thermochemical Cu-Cl cycle has much batter efficiency than electrolysis, the result is that production of hydrogen with Cu-Cl cycle is much cheaper than with electrolysis (Table 3).

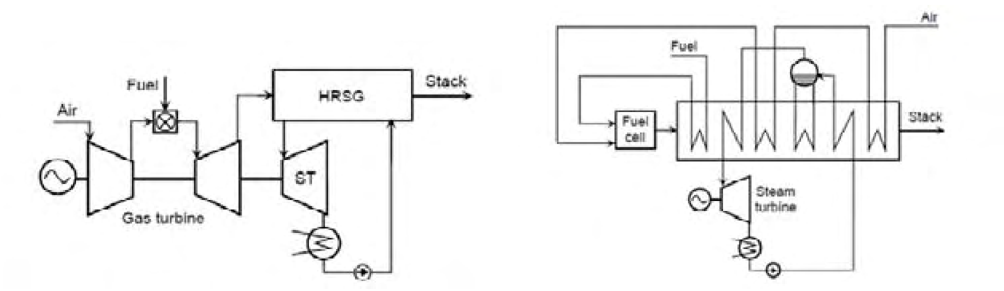

Figure 9: *Some combined processes for electricity production from hydrogen [5]*

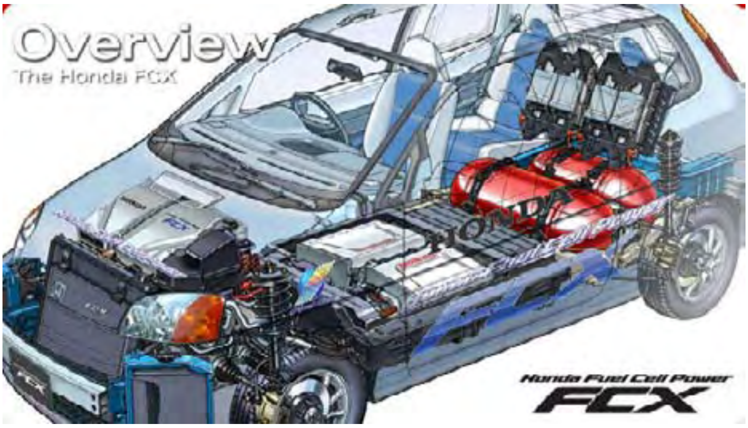

Figure 10: *Schematic of the tank and fuel cell installation in one of the HONDA FCX vehicle versions*
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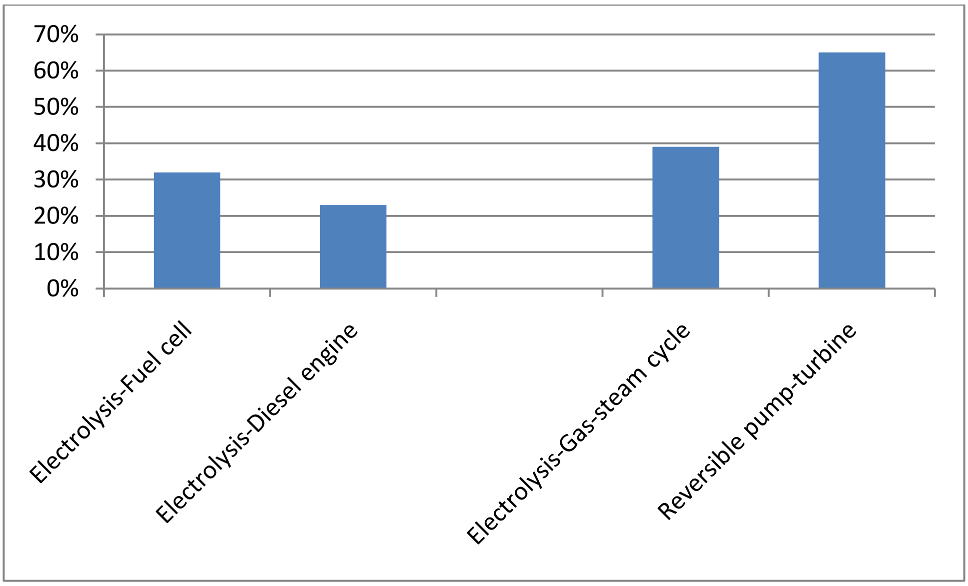

Figure 11: *Efficiency for production of electricity with hydrogen with different procedures*

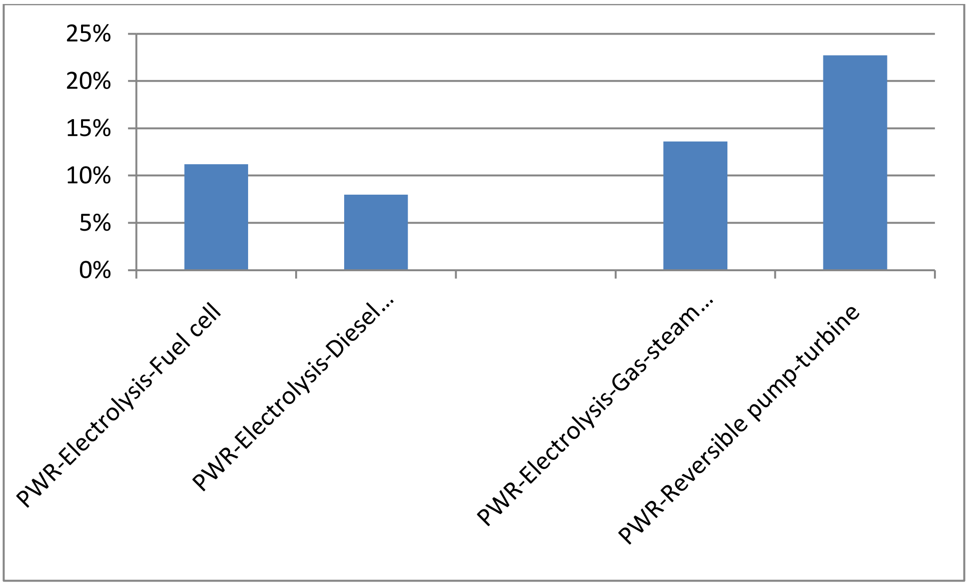

Figure 12: *Efficiency for production of electricity with hydrogen with different procedures including 35 % of thermal efficiency of nuclear power plant*

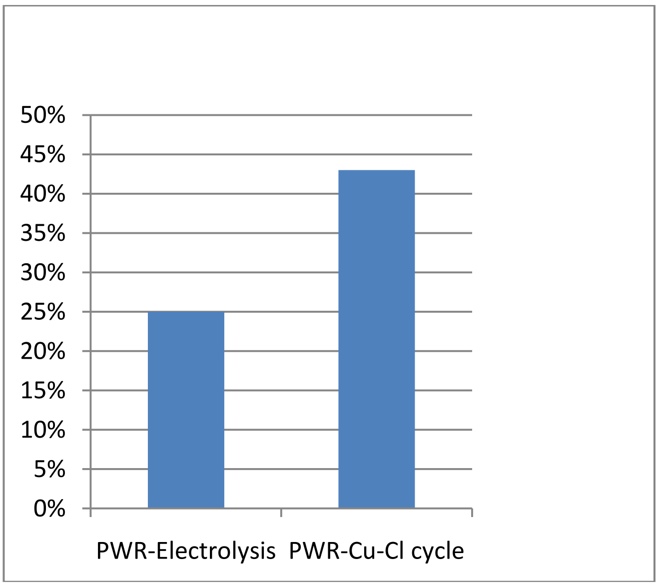

Figure 13: *Total net efficiency for production of of hydrogen in comparison with electrolysis and Cu-Cl cycle*

5 CONCLUSIONS

This paper has examined the hydrogen production in combination with the nuclear power plant located near city Krško. The results show that hydrogen production is a very interesting and economic issue, especially if we use thermochemical equipment for production of hydrogen.

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NUCLEAR ENERGY AS A FUTURE DIRECTION IN SLOVENIA

JEDRSKA ENERGIJA KOT PRIHODNJA USMERITEV V SLOVENIJI

Jože Špiler, Robert Bergant[ℜ], Tomaž Žagar

Keywords: nuclear power plant, electricity production, electricity consumption, technology, economy, environment, licensing

Abstract

Based on a recently completed energy/electricity forecast, Slovenia will need new electricity generation capacities.

In order to ensure sustainable development for the national economy, bearing in mind environmental constraints (Kyoto Protocol), the EU energy and climate package, and the reliable and safe supply of electricity, the nuclear option seems to be the most plausible one to match all mentioned requirements.

Furthermore, the Slovenian Ministry of the Economy is preparing the National Energy Program (NEP) in which the nuclear energy is recognized as one of the possible options for future development.

In recent years, the supply of electricity in Slovenia has been under high demand, due to two main factors. The first is the lack of investment initiatives in new electricity generation capacity. The second is the growth of the gross domestic product (GDP) in Slovenia and consequent increase of the domestic electricity consumption. This situation changed slightly in 2008 with the onset of the current economic crisis, which led to less demand for the electricity. However, this situation must not be used as an excuse to do nothing. It is obvious that the lack of electricity will be only postponed for some years.

GEN energija started with the project of new nuclear power plant in the beginning of 2006 and has completed the pre-preparation phase. Many studies and analysis were performed during

[ℜ] Corresponding author: dr. Robert Bergant, Tel.: +386 7 491 0137, Fax: +386 7 490 1118.
E-mail address: robert.bergant@gen-energija.si

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this initial phase, and all results confirm good harmony with the philosophy of sustainable development, in which ecological, economical and social effects of the project have to be balanced. The studies covered four main areas: analysis of development possibilities in the field of electricity supply in Slovenia, environmental impacts of different technologies, technology itself as well as economic and financial effects of the new nuclear power plant (NPP). All studies were performed by well-regarded foreign and Slovenian institutions, research organisations and companies. The main conclusions based on these studies confirm the justification and technical feasibility of the project.

The planning of such major projects is of the greatest significance, especially for a new NPP. Therefore, the licensing process with main players is also described and depicted.

Povzetek

Glede na napovedi porabe električne energije, bomo v Sloveniji v prihodnosti nedvomno potrebovali nove vire električne energije.

Med večimi možnimi projekti, se projekt nove jedrske elektrarne zdi zelo primeren. Nova jedrska elektrarna bi omogočila trajnosten razvoj za celotno slovensko gospodarstvo. Pri tem bi upoštevala vse okoljske omejitve (kjotski protokol, okoljski in podnebni paket EU) ob hkrati zanesljivi in varni dobavi električne energije.

V trenutku nastajanja članka pripravlja Ministrstvo za gospodarstvo nov Nacionalni Energetski Program (NEP), kjer bo jedrska opcija predvidoma ena izmed možnih opcij za prihodnji razvoj slovenske elektroenergetike.

V preteklih letih je bila dobava električne energije zaradi velikega povpraševanja pod velikim pritiskom. Ta pritisk gre pripisati dvema glavnima dejavnikoma. Prvi je pomanjkanje investicij na tem področju, drugi pa rast slovenskega bruto domačega proizvoda (BDP) in temu posledično tudi rast porabe električne energije. Položaj se je spremenil v letu 2008, ko je prišla gospodarska kriza, ki je pomenila manj povpraševanja po električni energiji. Vendar pa nas ta olajševalna okoliščina ne sme pustiti ravnodušne, saj je očitno, da bo nadalnja rast pomanjkanja samo preložena za nekaj let v prihodnost.

GEN energija je leta 2006 začela s projektom nove jedrske elektrarne in v tem času zaključila s pred-pripravljalno fazo projekta. V tem času je bilo izvedenih precej študij, ki so pokazale skladnost s filozofijo trajnostnega razvoja, kjer morajo biti ekološki, ekonomski in družbeni učinki medsebojno uravnoteženi. Študije so pokrile štiri večja področja: razvojne možnosti na področju električne energije v Sloveniji, okoljske vplive različnih možnih tehnologij, tehnologijo ter ekonomske in finančne učinke nove jedrske elektrarne. Študije so izvedli priznani slovenski in mednarodni raziskovalni inštituti in podjetja. Glavni zaključki teh študij so, da je projekt upravičljiv in izvedljiv.

Načrtovanje takšnih velikih projektov je zelo pomembno, še posebej kadar govorimo o jedrski elektrarni. Zato je na koncu članka predstavljen in opisan tudi proces licenciranja z vsemi najpomembnejšimi akterji, ki bodo sodelovali v tem procesu.

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1 INTRODUCTION

A strong debate about new electricity production units is presently underway in Slovenia. What technologies will be the future direction of Slovenia strongly depends on the new National Energy Plan (NEP), which is expected to be published in 2011 by the Ministry of the Economy? The currently valid NEP [1] was prepared in 2000 and approved in 2004. According to the Energy Act, the NEP has to be revised every five years. In May 2009, the Ministry of the Economy issued the Green Book for the National Energy Plan [2] as a consultation document for the new NEP. The Green Book represented first public discussion on forthcoming new NEP.

An application towards an Energy License for second reactor at the Krško NPP was submitted to the Ministry of Economy, Directorate for Energy by GEN Energija in January 2010. The application was for an Energy License for a new NPP with installed power up to 1600 MW.

This paper will highlight the status of the project of a new NPP in Slovenia. Since the status of the project has already been presented in the Journal of Energy Technology in 2008 [3], this paper will mainly focus on upgrade of the project.

2 DEVELOPMENT POSSIBILITIES OF ELECTRICITY PRODUCTION SECTOR

Despite the economic crisis, which has not yet finished, long-term electricity generation and consumption trends have not changed. Figure 1 shows electricity generation and consumption projected until 2100 [4]. Generation, as shown, considers only the renovation of existing hydro power plants and the life extension of the existing nuclear power plant. No potential new generation units are considered in this scenario. There are two major reasons for the increasing gap between generation and consumption. The first one is the shutdown of old production units in Slovenia. According to their originally design lifespan, practically all coal- and gas-fired power plants as well as the nuclear power plant will shut down by 2030. In contrast, as Slovenia's economy approaches that of the most developed European countries, electricity consumption will unavoidably rise. The most important factors that influence long-term electricity consumptions are:

- extent, size and structure of the gross domestic product (GDP) and its future projection,
- demographic development,
- future expectations in the field of technology,
- development of society,
- social consciousness and presence of sustainable development directives,
- price of energy sources and their parities,
- others.

The growth of GDP was the strongest factor influencing electricity consumption in Slovenia in recent decades. The correlation between GDP and the electricity consumption was very high, regardless of the economic crisis. We are expecting further strong correlation, which will diverge over a longer time period. Electricity consumption will presumably also grow in the future due to the technology redirection (e.g. air conditioning, heat pumps, electric cars etc.) despite the measures of intensive implementing savings and effective use of energy. Thus, we

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considered three different increase rates depending on the time period: 2% up to 2020, 1% up to 2050 and less than 1% beyond 2050.

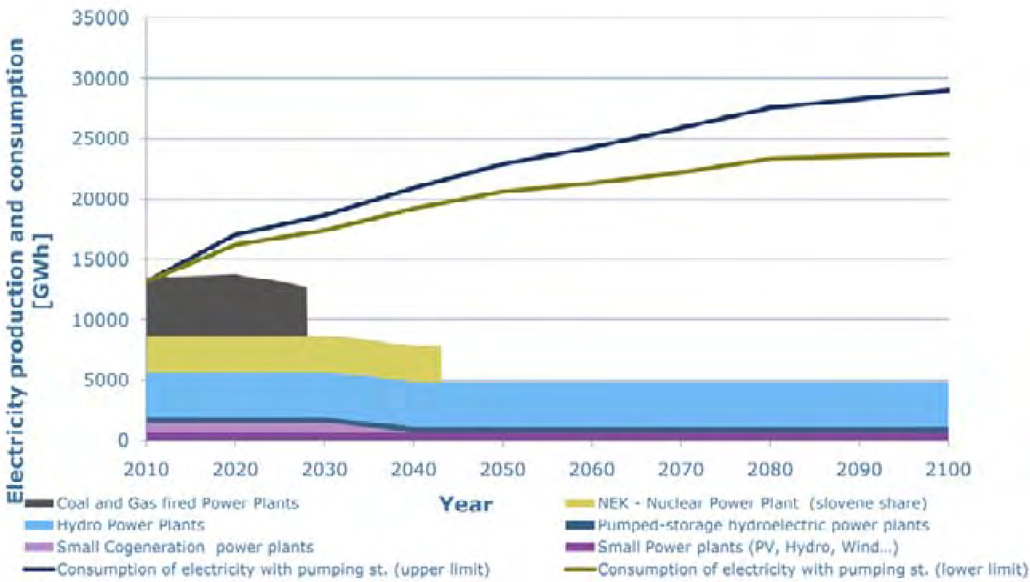

***Figure 1:** Projections of future electricity generation and consumption in Slovenia [4].*

In order to find the best possible solution, an analysis of development possibilities [5] was performed. Three distinct scenarios were determined, based on the technology used: a) business as usual scenario with no new investments, old coal-fired power plants shut down and increased import; b) scenario based on imported coal and gas, with refurbishment of old coal-fired plants and the construction of new coal and gas-fired plants; and c) scenario with new NPP and with refurbishment of old coal-fired plants.

All three scenarios have in common economic development scenarios of the Republic of Slovenia, reference actions of energy efficiency, intensive strategy of renewable energy sources and combined heat and power up to 10 MW (photovoltaics, wind, small hydro power plants, and biomass), and the development of renewable energy sources over 10 MW and the life extension of NEK up to 2043.

Scenarios were assessed based on four points of view:

- Reliable and quality supply of electricity
- Strategic point of view (ratio of renewable energy resources, ratio of domestic energy resources)
- Economic-financial criteria (net positive value, average production costs and other economic indicators)
- Environmental criteria (emissions of CO_2, SO_2, NO_x, PM)

Scenario 3a showed the highest score; it is the enhanced construction of renewable energy resources, refurbishment of existing coal-fired plants with modern technology and the construction of a new nuclear power plant with a capacity of 1,000 MWe. All other scenarios

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received fewer points; the closest one is Scenario 3b, based on a larger nuclear power plant (1,600 MWe). Scenario 2 is based on fossil fuel technology and is, according to the above viewpoints, much less desirable; Scenario 3, based on the import of electricity, is completely undesirable. Both nuclear scenarios are persuasively better than the others, in the following point:

- Ratio of domestic sources,
- Economic-financial indicators and
- Environmental viewpoints.

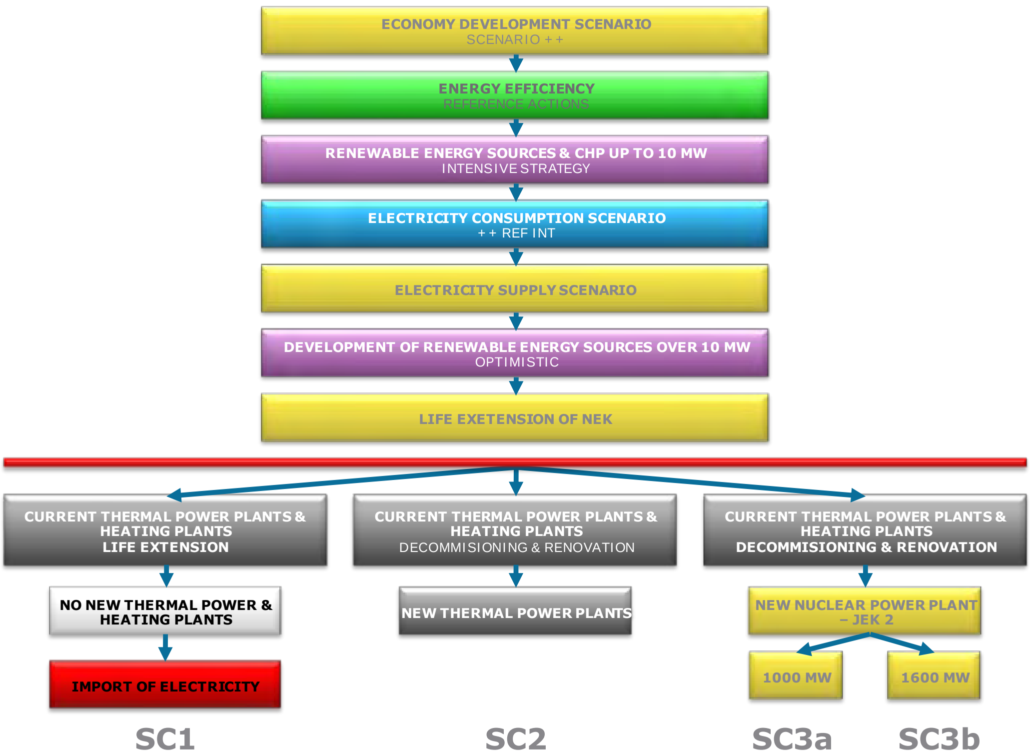

Figure 2: *Scenarios of development possibilities in the field of future electricity production [5].*

3 TECHNOLOGY

All major European electrical utilities are focusing on the construction of light water reactors (LWRs), which enables selection between pressurized water reactors (PWRs) and boiling water reactors (BWRs). Other technologies are considered inappropriate due to the lack of operational experience, which is the basis for licensing and construction. The choice between PWR and BWR for a new NPP in Slovenia relies on current experience in the world as well as in Slovenia. PWR technology represents more than 60% of all NPPs in the world; the majority of NPPs presently under construction are also PWR. Since the only existing NPP in Slovenia uses PWR technology, it is the logical selection. We have approximately 30 years of very good operational experience as well as the knowledge needed for regulator surveillance and technical support organizations.

The very likely life extension of the existing NPP is for an additional 20 years (to 2043), which means maintaining as well as upgrading of current level of knowledge and additional experience in the field of PWR technology.

There are not many qualified vendors in the world who can offer PWR reactors of the third generation. If we limit ourselves to European, American and Japanese technology, we can choose between AREVA, Westinghouse, Mitsubishi and ATMEA (a consortium of AREVA in Mitsubishi). All these vendors are already certified by European Utility Requirements organisation (EUR) or will be shortly in certification process either by EUR or some other European organization. Figure 3 shows four potential reactors:

- EPR provided by AREVA,
- EU-APWR by Mitsubishi,
- Atmea1 by ATMEA and
- AP1000 by Westinghouse

where the first two have an electrical output between 1,600 and 1,700 MWe, and the second two between 1,100 and 1,200 MWe.

Figure 3: *Nuclear power plants taken into consideration (EPR, EU-APWR, AP1000, Atmea1).*

A conceptual design of Krško 2 NPP [6] was performed in order to obtain a high quality technical basis for the spatial planning process, which will take place in the preparation phase. In addition to the conceptual drawings, the reference plant (or the plant parameter envelope (PPE)) was developed; this is the set of plant design parameter values that are expected to define the characteristics of an individual reactor type that may later be deployed at the corresponding site. Also, the parameters are expected to define a set of values on the plant's impact on the environment and the existing systems in the form of specific values for individual quantities. The design parameters specified in the Reference Plant are dependent primarily on input from

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the reactor vendors. The parameters are based on certified design information and the best available information for as-yet uncertified designs. Most parameters are independent of any site characteristics and permit an initial site assessment to be performed in advance of the selection of the technology vendor. However, some design parameters are also dependent on site characteristics. One example is the design of the circulating water system, which is based on site-specific water supplies and temperature. Additionally, site-specific environmental data is used to design the condenser and circulating water heat removal systems. Parameters such as cooling tower drift depend on site meteorological information (temperatures and humidity), as well as the rejected heat from the reactor. There are more than 200 parameters in the reference plant.

As a result of the conceptual design, two reference plants were prepared for the purpose of the spatial planning process; the first is downstream from the existing NPP and the second is upstream.

The design parameters are the postulated features of a reactor that could be built at the proposed site. Design parameters are usually addressed in Preliminary Safety Analyses before the Construction Permit Acquisition stage. They refer primarily to site suitability issues, environmental protection issues, and plans for coping with emergencies, independent of the review of a specific nuclear plant design.

A nuclear power plant is very large building and thus it has to be also evaluated under what conditions it can be connected to the electrical grid and cooled, as well as how the heaviest components can be transported to the site.

The existing NPP uses the Sava River as ultimate heat sink of heated cooling water. It is a fact that cooling capacities of Sava River are already completely used; it cannot be used anymore for the cooling of the heated circulating water (CW). The only option for new NPP would be cooling towers which discharge heat into the air. A Feasibility Study and Optimization of Cooling Towers for the New NPP at the Krško Site [7] was performed. Three cooling tower designs were examined: natural draught, cell-type and a round forced-draught hybrid as shown in Figure 4. There are many factors to consider in selecting a wet cooling tower. These include technical factors (cooling tower performance over a range of ambient conditions, flexibility of operation and maintenance of desired water temperatures), economic factors (capital cost, operating costs, lifetime cost and reliability), foot print (space requirement including provision for air inlets and shape) and environmental factors (noise, plume generation, visual impact).

Figure 4: *Cooling towers for circulating water system (CWS) and essential service water system (ESWS).*

The natural draught cooling towers have been selected as a single unit where possible, with an alternative where appropriate for two smaller units.

The heat loads for the essential service water system (ESWS) applications are too low for the use of natural draught or round forced draught hybrid cooling towers. For these applications, only cell-type coolers are considered.

Combined heat and power production is highly encouraged in order to increase the total efficiency of the plant. Therefore, a feasibility study of the district heating of nearby cities [8] was performed. Two scenarios were examined. The first one was the district heating for Krško and Brežice (radius within 10 km), and the second one was the district heating of Krško, Brežice and Novo Mesto (radius within 30 km). There are financial benefits as well as environmental ones: the emissions of CO_2, SO_2 and NO_x can be significantly reduced. The contract capacity in the case of Krško, Brežice and Novo Mesto would be approximately 200 MW, which means 33 MWe less electricity production (for larger unit) and more than 80,000 tons of CO_2 savings per year. From a technical point of view, district heating to Ljubljana is also feasible. However, the economic viewpoint depends on potential state-subsidized funds.

Conditions for the connection to the national electrical grid are important for all generating units and even more important for units as large as the new NNP will be. Two studies were performed, separately for smaller and larger units [9, 10]. The studies showed that connection is feasible if the following conditions are fulfilled:

- Erection of 2 x 400 kV overhead transmission lines Krško-Beričevo,
- Upgrade of existing 220 kV to 400 kV,

- Phase shift transformer in Divača and
- 400 kV transmission lines to Italy and Hungary.

New connections to Italy and Hungary are needed only in the case of larger unit. However, it has to be mentioned that all above conditions are already in the long term plans of our national transmission operator (ELES) and are scheduled before the new NPP will start to operate. ELES is planning to implement these projects independently of what will happen with the project of new NPP.

One very important issue that has to be elaborated in the pre-preparation phase is whether the transport of various new pieces of equipment for the NPP to the Krško site is feasible or not. The feasibility study [11] showed that transport of the modules and components to the foreseen location of the new NPP can be performed in a safe manner once the transportation routes are prepared and correct interpretation of the law and/or legislative amendment is achieved.

4 ENVIRONMENTAL IMPACT ASSESSMENT

A Preliminary Report on Environmental Impacts of Different Energy Technology Options for Slovenia [12] was performed to investigate the environmental consequences of different electrical power-producing energy technologies for Slovenia. Electrical power production from four potential nuclear reactor designs, imported coal-fired power generation, combined-cycle gas-fired generation, and renewable power generation sources are considered. The four nuclear designs evaluated are the 1) Westinghouse AP1000 with a nominal electrical output of 1000 MWe, 2) Mitsubishi Heavy Industries (MHI) EU-APWR with a nominal 1700 MWe output, 3) AREVA EPR with a 1600 MWe power output, and 4) the ATMEA-1 with an assumed nominal power output in the range between 1000 and 1150 MWe. The imported coal power plant and combined-cycle natural gas power options assumed an output of 1100 MWe for both technologies. The nuclear, imported coal and natural gas options are assumed to have 90% availability (Baseload Capacity Factor). Renewable options considered are 1) hydroelectric generation, 2) solar photovoltaic generation, 3) wind generation, 4) biomass cogeneration, and 5) geothermal electric generation. The combined renewable options are assumed to have 34% Baseload Capacity Factor. Additionally, a no-action option (electricity import) was evaluated.

The electrical energy generation technologies were evaluated for environmental impacts to 1) climate, 2) air quality, 3) surface water and groundwater, 4) noise, 5) land and agriculture, 6) the landscape, 7) nature and natural areas, 8) waste management, 9) human and environmental health, 10) impacts from ionizing radiation, 11) impacts to inhabitants and their environment, 12) cumulative impacts with other projects, 13) impacts to cultural heritage, and 14) impacts to protected areas and zones.

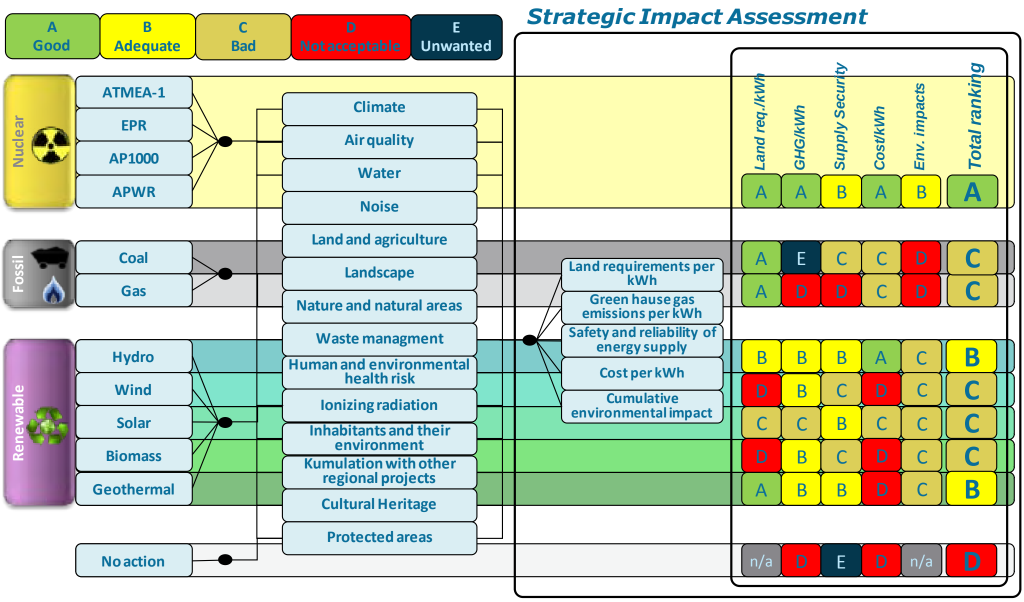

Figure 5: *Strategic impact assessment of different technologies.*

5 LICENSING PROCESS

The licensing process of a new NPP can be divided into four phases: political decision, spatial planning, construction and operation. The NPP Krško 2 project is currently in the first phase, waiting on a strategic national decision as prerequisite for starting the spatial planning process. There are more conditions for the strategic national decision. A new revision of the National Energy plan (NEP), presently under development, is the most important one. The draft of a new NEP will also involve a nuclear option as one of the possible future energy development programs in Slovenia. This would be a great improvement compared to the still valid NEP, in which nuclear power is not even mentioned. If so, the new NEP will be the first strategic document based on which Ministry of the Environment will be able to initiate the spatial planning process for NPP Krško 2. Another prerequisite for a strategic decision is an energy license. GEN energija submitted an application for the energy license to the Ministry of Economy at the beginning of 2010.

The governmental coalition also announced in its coalition contract that the decision for new NPP will have to be supported with national referendum. However, the referendum itself is neither required nor prescribed by Slovenian legislation. After obtaining the energy licence, the spatial planning can start. It starts with the preparation of all needed expert bases (e.g. layouts of the plant, cooling of the plant, flood protection, connection to the national electrical grid and other nearby infrastructures). The comprehensive environmental impact assessment process involves an environmental report and, in the case of nuclear plants, an additional special site safety report that has to be confirmed by the Slovenian Nuclear Safety Administration (SNSA). The environmental report has to examine the impacts of NPP as well as other possible alternatives on the environment. The proposal of spatial planning has to be continuously revised until all involved parties agree with the proposed plan. Afterwards, there is the first

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hearing to which the public is invited to comment on the proposed spatial plan. Since the NPP might have cross-border influences, Slovenia has to inform neighbouring countries, which have the right to comment the environmental report. The Ministry of the Environment and Spatial Planning has to take a position on all comments and make new proposal, which goes to the government for confirmation. Once the spatial plan is confirmed, the environmental protection consent has to be issued. During the licensing process, the environmental impact report has to be prepared again, this time only for the object which was confirmed in the previous spatial planning process. A preliminary approval of radiation and nuclear safety as a very comprehensive document has to be issued by SNSA. After radiation and nuclear safety approval, the second public hearing takes place before environmental protection consent is issued.

In the application for the issue of the concordance for the construction permit, different documents to different involved parties have to be delivered. In addition to the design documentation, the following documents have to be prepared: a preliminary safety analysis report, a decommissioning plan, a plan for the management of radioactive waste and spent fuel, a security plan, etc. When all delivered documentation is in accordance with legislation and agreed by all involved ministries, the construction permit can be issued. During the construction phase, the safety analysis report has to be regularly updated. Once the construction is completed, the commissioning phase follows with the issue of the Final Safety Analysis Report (FSAR) at the end of successfully performed tests. In addition, many other documents have to be approved, e.g. Quality Management System, Operational Experience Program performance indicator program, as-built design, ageing program etc. Finally, an operation license can be issued for commercial operation.

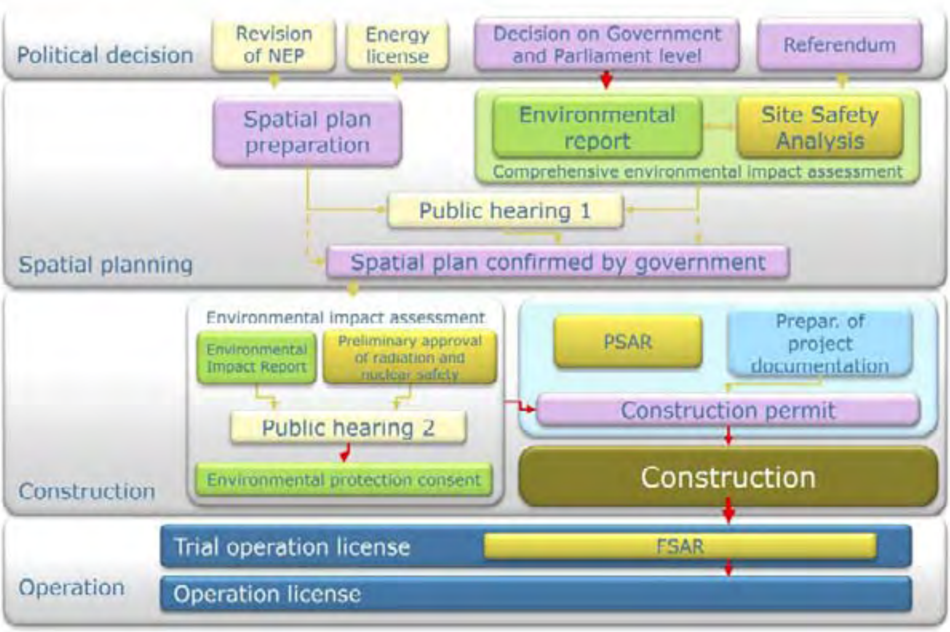

Figure 6: *Licensing process of NPP in Slovenia (different options for the political initiation of the project are still possible, referendum is one of the options and is not mandatory).*

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6 ECONOMIC AND FINANCIAL EFFECTS OF THE NEW NPP

The economic and financial effects are usually of primary interest to investors. GEN energija, as the only investor in the project of new NPP so far, has ordered different economic analyses.

The macro-economic effects of the construction and operation of NPP Krško 2 [13] showed an influence on the economic development of the local community as well as on Slovenia. The Krško 2 project would involve 20,000 to 27,000 employees during construction and 3,000 to 5,000 employees during operation. The gross domestic product would be higher by about 500 to 700 million EUR per year during construction and between 100 to 150 million EUR per year during the operation. This means up to 2.2% of GDP during construction and up to 0.5% of GDP during operation, so the effect on the relatively small Slovenian economy is very high.

According to the "Decree on the uniform methodology for the preparation and treatment of investment documentation in the field of public finance" [14], the Pre-Investment Study of New NPP [15, 16] is the second out of the three documents that have to be completed by investors before the final decision on investment is taken. The Pre-Investment Study is the expert basis for the examination of the investment and its expected effects. A confirmation of the desired effects means continuation of the project. There are many expected benefits in the case of the new NPP:

- Higher domestic electricity production,
- The use of the existing site for electricity production,
- Reducing of greenhouse gas emissions,
- Stable and quality jobs,
- Positive political economy in the field of macro economy,
- Positive effects on local region,
- Positive economic and financial results of the project and consequently long-term economic of investor(s).

Three variants were analyzed:

1. Variant: NPP with approximately 1,100 MWe and anticipated electricity production of 8,800 GWh per year (reactors: AP1000 and Atmea1).
2. Variant: NPP with approximately 1,600 MWe and anticipated electricity production 12,800 GWh per year (reactors: EPR and EU-APWR).
3. Variant: NPP with dual units with approximately 2 x 1,100 MWe and anticipated electricity production of 17,600 GWh per year (reactors: AP1000 and Atmea1).

The average cost price per kWh is between 28 and 30 EUR, while the internal rates of return (IRR) are around 10%. A larger unit means slightly lower cost price and slightly higher IRR. Economic indicators show that the new NPP project has no competitive projects in the field of electricity production units and is thus very advantageous. Investment studies are not only a matter of the economic aspects but also of many other aspects. All variants were evaluated according to five groups of criteria:

- Technology aspect,
- System network aspect,
- Spatial and environmental aspect,
- Safety and radiologic aspect and
- Economic aspect.

Since the differences between all variants are smaller than the uncertainties of the data, all three variants are remaining by the next phase of the project (Investment Program). A mandatory part of the pre-investment study is a sensitivity analysis of inputs on economic indicators. The biggest impacts are changes of investment price, selling price and reducing of electricity production. However, significantly changed input data (up to 30%) still bear positive economic effects. As part of the sensitivity analysis, load follow operation and cooperation in secondary regulation were also analyzed. The results showed only minor differences to the base load operation.

7 CONCLUSION

There are many different future predictions about electricity consumption in Slovenia, but most of them do not go beyond 2030. However, new power plants are long-term projects, and the preparing and licensing phases are usually exacting processes which take years, followed by several decades of operation with possible refurbishment, which can prolong operation for a substantial period of time. From this perspective, the year 2100 does not seem to be far away. In fact, long-term planning becomes even more important when sustainable development is taken into consideration. Slovenia certainly needs very good strategic planning of future electricity needs, which will simultaneously consider economy, ecology and society.

Despite numerous different studies and, consequently, many different scenarios with differing figures, the common thing to all of them is the gap between production and consumption, which will increase in the future. One should also know that increasing electricity consumption also continues in spite of the savings in total energy consumption (e.g. heat pumps etc.).

This paper has shown that there is already a need for new power units and that this need will soon increase in line with increases in consumption. One of the most suitable solutions to close the gap is new nuclear power plant. Therefore, GEN energija initiated the NPP Krško 2 project in 2006. Since then, we have completed many feasibility studies, which all confirm that new NPP will guarantee sustainable, low-carbon, reliable and economical supply of electricity for the country. One of the most important milestones in the decision making process is the approval of the new National Energy Program (NEP) based on which Ministry of the Environment and Spatial Planning could the start spatial planning process. The new NEP will be issued in 2011.

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SPECIFIC TRAINING FOR NUCLEAR SERVICE PROVIDERS

SPECIALISTIČNO USPOSABLJANJE KADROV ZA DELO V JEDRSKI ENERGETIKI

Rebeka Srebotnik[ℜ], Andrej Lešnjak

Keywords: nuclear services, training, certification, qualification, non-destructive testing

Abstract

The aim of the specific training courses for nuclear service providers is to ensure that capable personnel as a paramount objective not only for nuclear power plants, research facilities, institutes and regulatory bodies, but also for industries that provide products and services in support of the maintenance and operation of existing plants, as well as for the whole supply chain for new builds.

Q Techna has been systematically developing an education and training program in support of their services to nuclear power plants and facilities. Apart from locally available education and training, opportunities are taken, in cooperation with foreign companies and institutions, to gain and maintain knowledge and skills. Experience from jobs at foreign nuclear power plants complements that.

For service providers, it is of crucial importance to assure a balanced mix of well-trained and educated personnel.

Apart from external and internal training courses of its own personnel, Q Techna delivers training courses to other interested parties in the nuclear industry. More specifically, this paper focuses on training and certification of non-destructive testing (NDT) personnel.

[ℜ] Corresponding author: Rebeka Srebotnik, Tel.: +386 7 49 12 484, Fax: +386 7 49 12 482, Mailing address: Q Techna d.o.o., Podružnica Krško, CKŽ 135e, 8270 Krško, Slovenija
E-mail address: rebeka.srebotnik@qtechna.si

Povzetek

Cilj usposabljanja je bil zagotoviti usposobljenost osebja ne le za jedrske objekte, raziskovalne ustanove, inštitute in regulatorne organe, temveč tudi za industrijo, ki ponuja izdelke in storitve v podporo vzdrževanja in delovanja obstoječih naprav, kot tudi za novogradnje.

Q Techna je sistematično razvijala program izobraževanja in usposabljanja za podporo svojih storitev na jedrskih objektih.

Za pridobivanje in ohranjanje znanja in usposobljenosti, poleg lokalno razpoložljivih izobraževanj in usposabljanj, v veliki meri sodelujemo s tujimi podjetji in ustanovami. Izkušnje pri delu na jedrskih objektih dopolnjujejo tovrstna pridobljena znanja.

Za ponudnike storitev je bistvenega pomena, da se zagotovi uravnoteženo mešanico dobro usposobljenih in izobraženih kadrov.

Poleg zunanjih in notranjih usposabljanj osebja, Q Techna omogoča treninge tudi drugim zainteresiranim podjetjem v jedrski industriji. Ta prispevek se osredotoča na usposabljanje in certifikacijo na področju neporušnih preiskav (NDT) osebja.

1 INTRODUCTION

In the nuclear industry, well-educated and trained personnel are one of the vital prerequisites for safe and reliable operation. Our education system has a long tradition; many good engineers, technicians, skilled workers and other key personnel have graduated from various local schools within the public education system. Such education is necessary, yet not sufficient to assist in the development of individuals who need to be qualified for highly demanding work in the nuclear environment. Additional training courses for different types of highly specialised expertise are required, with certification, in many cases. Finally, after education, training, and certification, appropriate experience is expected, which is essential for an individual to be assigned to a specific task within a company.

Non-destructive testing is one of the many highly demanding activities in the nuclear industry. It plays an important role in the production of different components and also during maintenance and in-service inspection. Since different NDT certification schemes have been used for an extensive period of time, they may serve as an example of personnel qualification and certification.

2 Q TECHNA IN BRIEF

Q Techna is one of the leading Slovenian companies, competitive in Europe and the USA, providing quality assurance and quality control, education and certification in areas of electric power generation, pharmacy, infrastructure and other demanding facilities. Many references, especially in the nuclear sector, attest to this, as do many approvals, authorizations, accreditations and notices based on our integral management system.

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3 SPECIFIC EDUCATION AND TRAINING FOR PERSONNEL WORKING IN THE NUCLEAR INDUSTRY

As mentioned earlier, individuals working in the nuclear industry must have a variety of specific skills and qualifications. We could say that this is a process similar to making a mosaic; there is no specific formula and it depends on many factors. There is a major difference whether an individual works within a company producing equipment or provides maintenance within a utility. However, it is important that every workplace is governed by clear requirements. Senior management must determine the competence requirements for individuals at all levels and must provide training or take other actions to achieve the required level of competence. Many requirements have to be defined, including: minimal education, general employee training, radiological protection, specific training, necessary certificates, experiences etc. Individuals need to receive appropriate education and training, and acquire suitable skills, knowledge and experience to assist their competence. Training should ensure that individuals are aware of the relevance and importance of their activities and of how their activities contribute to safety in the achievement of the organization's objectives [1]. When all prescribed requirements are met, an individual is ready to be qualified for a specific job. Senior management needs to ensure that individuals are competent to perform their assigned work and that they understand the consequences for the safety of their activities.
For its field of expertise, Q Techna utilizes different ways of education and training for its employees, as follows:

3.1 Local education and training

Apart from education at Slovenian schools and universities, its personnel receive additional locally available training, e.g.:

- Hands-on training for on-line maintenance, as well as preparatory training for outages at Krško NPP, which are extremely valuable;
- NPP Technology courses, delivered by the Nuclear Training Centre of the Jožef Stefan Institute, dealing with: nuclear and reactor physics, thermal-hydraulics and heat transfer, radiation protection, electrical engineering, materials, nuclear safety and technological systems of NPP [2, 3].
- Radiation protection courses;
- Courses on different nuclear topics, delivered by IAEA;
- Training and certification of NDT personnel, etc.

3.2 Internal training

Internal training has been increasingly used for specific topics, especially for project management practices, materials, quality management, occupational health and safety, fire protection and, recently, the preparation of personnel for work in foreign NPPs in accordance with internally developed procedures. The latter includes lectures on: Fitness for Duty, Station Organization & Administration, Nuclear Power Plant Overview, Nuclear Security, Industrial Safety, Fire Protection, Quality Programs, Site Specifics, Radiological Orientation, Nuclear English etc. Internal assessments are provided after the training course to verify the knowledge gained and the readiness of personnel for engagements in foreign nuclear power plants.

3.3 On-the-job training

On-the-job training is becoming increasingly important as groups of workers are gaining new skills and experience through work in foreign NPPs. Strong cooperation with major players at the domestic plant also provides opportunities to gain new knowledge and skills. On-the-job training, especially through work in foreign NPPs, is considered to be an important prerequisite for future participation in the construction of new plant [4].

4 Q TECHNA TRAINING AND CERTIFICATION SERVICES

More than 10 years ago, it was quite difficult to get specific training courses in the field of Q Techna's expertise. Therefore, the company was forced to attend lectures abroad. That situation led to the initiation of in-house courses, first for its own staff. These courses have grown into a commercial activity offered to external parties. Many programs have been introduced in the field of pressure equipment, non-destructive testing, welding, materials etc.

Q Techna's key activities are inspections and non-destructive examinations. When preparing for accreditation according to SIST EN ISO/IEC 17025, properly certified level III personnel were needed for all accredited NDE methods. For that reason, the first group of experienced inspectors went to Germany for additional training and certification. Later, Q Techna became the first accredited institution for NDT in Slovenia. At the same time, it became obvious that our country lacked an appropriate personnel training and certification system, even though the demand was increasing. Consequently, Q Techna decided to establish its own training and certification centre providing personnel training and examination in accordance with European [5] and American [6, 7] standards.

Accordingly, the focus of its training centre activities remains in the field of training and certification of NDT personnel. Its experts, together with those from different industrial environments who actively participate in NDT services on a daily basis, transfer their knowledge and experiences to junior candidates.

4.1 NDT training courses

There are programs established to train and certify personnel for visual (VT), penetrant (PT), magnetic particle (MT), radiographic (RT), ultrasonic (UT) and leak testing (LT). NDT training and certification programs are delivered in Slovenian and Croatian and lay great emphasis on nuclear specifics, which in Slovenia mostly refer to the ASME B&PV Code. For certification purposes, Q Techna continues its cooperation with its German partner. In the last nine years, over 1,000 individuals have passed training and certification in its centre.

4.2 Levels of qualifications

There are different levels of NDT personnel qualifications. Standards define tasks and responsibilities as follows:

NDT Level I. An NDT Level I individual must have the skills and knowledge to properly perform specific calibrations, specific test, and with prior written approval of the NDT Level III, perform specific interpretations and evaluations for acceptance or rejection, and document the results in accordance with specific approved procedures. NDT Level I individuals must be able to follow

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approved non-destructive testing procedures and must receive the necessary guidance or supervision from a certified NDT Level II or NDT Level III individual.

NDT Level II. An NDT Level II individual must have the skills and knowledge to set up and calibrate equipment, to conduct tests, and to interpret, evaluate, and document results in accordance with procedures approved by an NDT Level III individual. NDT Level II personnel must be thoroughly familiar with the scope and limitations of the method in compliance with certification and should be capable of directing the work of trainees and NDT Level I personnel. The NDT Level II individual must be able to organize and report non-destructive test results.

NDT Level III. An NDT Level III individual must have the skills and knowledge to establish techniques to be used; and to verify the adequacy of procedures. The individual must also have general familiarity with the NDT methods. NDT Level III personnel must be capable of conducting or directing the training and examination of NDT personnel in the methods for which the NDT Level III individual is qualified.

4.3 Qualification requirements

Candidates for certification must be properly qualified, which includes appropriate:

- formal education,
- training in the method required in the amount of hours required for specific method,
- experience.

Good training is key to the entire qualification and certification procedure. It must cover a theoretical part, a practical part and codes and standards with an aim that candidates become familiar with the applicable test technique.

In its training centre, Q Techna uses a systematic approach to fulfil all formal requirements for a defined scope; however, it is also necessary to emphasise facts that directly influence quality training. First, it is important to mention NDT instructors. Apart from any theoretical background they might have, it is equally important that they possess some hands-on experience, which enables them to balance theoretical elements with practice. Another issue is training material, which is systematically prepared in Slovene or Croatian; standards are also translated. Experience shows that less than 50% of engineers are capable of using standards in English without difficulties. Normally problems arise with specific wording.

At the end of every training course, there is a practical part that requires a number of different specimens with flaws to be examined. Candidates must practice a lot for a method to become a routine. There are more than 400 training specimens in Q Techna’s laboratory, from all major areas, including base material, forgings, castings, welds, vessels and some special products.

After the training course, the participants take an examination. There are approximately 60 questions to an examination, both from general and specific areas. At the end, typically two specimens have to be examined. The pissing score for either part of the examination is 70% and normally, an average grade of 80% in all three parts is mandatory to pass.

A candidate for certification must acquire practical experience to assure they are capable of performing the duties at the level in which certification is being sought. The minimum number of hours of experience required for candidates is defined with standards. This number can vary and in some cases may reach up to 18 months net. Due to the fact that individuals normally have different assignments, rather than practicing only one specific method all the time, this

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period could be much longer. This is one of the reasons the formation of an experienced individual may take as long as 5 to 10 years.

In the table below, there is a summary of requirements for training and experience for most frequently used NDT techniques.

Table 1: *Minimum requirements for training and experience of NDT personnel*

Method	SIST EN 473						ANSI/ASNT CP-189			
	Hours of training (hours)			**Experience** (hours)			**Hours of training** (hours)		**Experience in method/in NDT** (hours)	
	Level I	**Level II**	**Level III**	**Level I**	**Level II**	**Level III**	**Level I**	**Level II**	**Level I**	**Level II**
MT	16	24	32	1	3	12	12	8	70/130	210/400
PT	16	24	24	1	3	12	4	8	70/130	140/270
RT	72	80	72	3	9	18	40	40	210/400	630/1200
UT	64	80	72	3	9	18	40	40	210/400	630/1200
VT	16	24	24	1	3	12	8	16	70/130	140/270

4.4 Certification

After a candidate is qualified (has appropriate education, records for training/experience and examination passed), certification can take place. According to the European approach, the certification is done by a third-party organization. All requirements are defined in the applicable standard and they have to be fulfilled. In the case of Q Techna, candidates receive certificates from an accredited certification body. Certificates are also acceptable for work on pressure equipment.

In the USA, certification is performed by the employer, which must develop and maintain a procedure detailing the program that will be used for the qualification and certification of NDT personnel. The procedure must describe the minimum requirements for certifying personnel in each NDT method and the levels of qualification desired. The procedure must also include personnel duties and responsibilities, training and examination requirements, records and documentation etc.

4.5 Recertification

Certificates have limited validity, ranging from three to five years. According to European standards, recertification after five years is based on certain conditions, and after 10 years the requirements are the same as those for the initial qualification and certification, except the requirements for training. In the US, every recertification requires a written examination.

In all cases, every recertification requires documented experience, which must be defined in detail, explaining the scope of examination, hours needed for examination and date of examination. A level III individual in charge in the company has to approve such a performance record.

4.6 Synergy

It is a great advantage that Q Techna can request certified experts from other companies, for support in the execution of large plant outage projects. This is a guarantee that contracted personnel are also knowledgeable of nuclear specifics. Such a scheme had practically been impossible before the centre was formed. Q Techna continually follows new requirements of codes and standards. In the future, it plans to put more emphasis on specifics related to the maintenance of different plant components and to the construction of new NPPs. The latter inevitably introduces new inspection requirements. Furthermore, new training programs are planned to be developed for inspection of mechanical components. One of the main obstacles to the faster development of these is a lack of certification schemes, which may also change in the future.

5 NU-WELD LINCOLN WELDING SCHOOL

In addition to the example above, other specific training courses can be organized for the nuclear industry. Another good example is the NU-WELD LINCOLN welding school, which was established in 2008 by Q Techna's mother company, NUMIP, in response to the market's increasing needs for qualified welders. Its mission has been two-fold; first, to train welders for NUMIP and its daughter company NU-WELD; second, to do so for welders for other service providers on the market. The training program had been developed in accordance with the company’s own experience and knowledge, good practices and IIW/EWF guidelines, and was adapted to the needs of nuclear industry. The training consists of a theoretical, practical and examination part. A special emphasis is put on safety and technical culture; basic welding terms in foreign languages are also taught. State-of-the-art equipment is used for the training in the welding booths, accompanied by a welding simulator that is a unique and powerful aid, especially for the newcomers to welding.

The welders qualified through the NU-WELD LINCOLN welding school are ready to work at home and abroad.

Within the welder training process, Q Techna provides NDT and certification services.

The welding school is expected to have an important role in the future, especially within the context of the construction of the new unit of the Krško NPP.

6 CONCLUSION

The intention of this paper was to present the importance of specific training courses for the nuclear industry. Together with day-to-day activities and corresponding experience, this is a prerequisite for the safe operation of existing nuclear facilities as well as an important factor for the construction of new power plants.

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RENOVATION OF PUBLIC LIGHTING IN THE MUNICIPALITY OF KRŠKO: EXPERIENCES AND PLANS

IZKUŠNJE IN NAČRTI PRI PRENOVI JAVNE RAZSVETLJAVE V OBČINI KRŠKO

Darko Hrženjak, Slavko Pirc, Vanja Somrak

Keywords: public lighting, energysavings, lightpollution, energyreview.

Abstract

Public lighting is one of the areas in which it is possible to achieve significant energy savings, as well as reducing light pollution and CO_2 emissions. The company Kostak d.d. has, as a concessionary for public lighting maintenance in the municipality of Krško, prepared a project for the renovation of public lighting in accordance with the new regulation on maximum light pollution. To this end, a detailed review and inventory of all the public lighting in Krško was made. This was the basis for a later energy review of public lighting. Energy accounting was implemented to control energy consumption. In the framework of these preparations, a few new projects were started to analyse both the market of classic lamp and lumenaire producers and the market of lamp and lumenaire producers that comply with parameters defined in the new regulation. The main focus was on a market analysis of LED technologies and LED lamps for street lighting. To this end, we set up a test street to test the LED lamps and lumenaires. The result of the energy review has shown that by only replacing traditional lamps with LED technology we will not achieve the level of energy consumption required by new regulations. Therefore, we started research in the field of systems for luminous flux control and remote control of public lighting.

Povzetek

Javna razsvetljava je eno od področij, na katerem je možno doseči pomembne prihranke energije, zmanjšati svetlobno onesnaževanje in izpuste CO_2. Podjetje Kostak d.d. se je kot koncesinar na področju vzdrževanja javne razsvetljave v Občini Krško lotil priprave projekta za prenovo javne razsvetljave v skladu z novo uredbo o mejnih vrednostih svetlobnega onesnaževanja okolja. V ta namen je bil opravljen podroben pregled in popis celotne javne

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razsvetljave v Občini Krško, ki je predstavljal osnovo za kasnejšo izdelavo energetskega pregleda. Za nadzor porabe električne energije se izvaja energetsko knjigovodstvo. V okviru teh priprav je bilo odprtih nekaj projektov, s katerimi smo opravili raziskavo na področju ponudb proizvajalcev klasičnih svetilk in sijalk za namen javne razsvetljave, ki zadovoljujejo predpisane parametre zakonodaje. Veliko pozornost smo namenili raziskavi trga na področju razvoja LED tehnologije in LED svetilk za javno razsvetljavo. V ta namen smo postavili tudi testne proge za testiranje LED svetilk. Rezultat energetskega pregleda je pokazal, da samo z zamenjavo klasičnih svetilk in svetilk z LED tehnologijo ne bomo dosegli nivoja porabe električne energije predpisane v zakonodaji. Zato smo se lotili še raziskav na področju sistemov za regulacijo svetlobnega toka in daljinski nadzor nad javno razsvetljavo.

1 INTRODUCTION

Public lighting is one of the most important segments for providing safety for transport in low visibility conditions. It is usually also a large consumer of electricity. In Slovenia, until recently, we were neither concerned with the consumption of electricity used for public lighting nor with the control, management and coordination of public lighting.

Light pollution has recently become an increasing problem of the developed world and also developing countries, since it is known that artificial light in the night has great impact on both people and animals. However, inadequate lighting also has a negative effect on overall human health and it can increase the number of traffic accidents. Last but not least, we should not overlook the financial aspect of wasteful lighting, since the difference in electricity consumed between outdated and modern lighting with the same light parameters can reach a factor of two or more.

In 2007, Slovenia was among the first members of the European Union to adopt a Regulation on the Maximum Levels of Light Pollution (Official Gazette of RS, no. 81/2007).

This regulation provides for the protection of nature against the adverse effects of light pollution, and the protection of living areas from distracting lighting of open areas; it enables protection of people from light glare and the protection of astronomical observations from the glowing sky. The regulation determines the reduction of power consumption of light sources that are causing light pollution. The regulation defines the following target and limited values:

- target value of annual electricity consumption of lamps installed for the lighting of roads and other uncovered public areas;
- limit values of electricity for lamps used for lighting of uncovered public areas;
- limit values of electricity for lamps used for the illumination of facades, cultural monuments and facilities for advertising;
- limit values for illumination of areas around cultural monuments and conditions for directed illumination of cultural monuments;
- limit values for the illumination caused by lighting lamps in uncovered areas of protected spaces in buildings.

The regulation also:

- provides a way for determining the fulfillment of the requirements;

- prohibits the use of lamps that radiates the light into the sky in the form of light beams, or the use of lamps that radiates the light towards areas where the light reflects into the sky and
- provides measures to reduce emission of light in the environment.

Among other points, the regulation sets a maximum limit on the annual use of electricity for local communities. The annual maximum limit should not exceed 44.5 kWh per capita. The regulation allows only the use of such lamps in which 0% of the luminous flux radiates upward; this means that all lights must be completely dimmed and properly installed.

2 PUBLIC LIGHTING RENOVATION IN KRŠKO

There are 25,500 inhabitants in the municipality of Krško, which has one of the largest areas of Slovenian communities. More than half the population lives in the towns and villages of Krško, Videm, Leskovec, Senovo, Podbočje and Raka. In a large part of the municipality, scattered settlements dominate, which means a considerably higher cost per capita in terms of providing adequate public infrastructure, whether it be roads, water supply, sewers, communications, waste disposal or street lighting. This results not only in significantly higher levels of investments, but also in higher maintenance costs and electricity consumption, and consequently higher costs per capita for electricity.

In Slovenia, the average annual consumption of electricity for public lighting is 90 kWh per capita; in the municipality of Krško, it is 106 kWh per capita.

Public lighting in the municipality of Krško is divided among local communities, which are very different in size. Public lighting in the town Krško alone represents almost 32.7% of all electrical energy consumed in the entire municipality of Krško. Some individual connection points in larger settlements may have higher energy consumption than entire small local communities.

There are several factors that need to be considered when public lighting is being renovated. The main objectives are:

- to define the exact number of street lamps and produce a quality register of public lighting;
- to raise the quality of street lighting in terms of designing the landscape;
- to increase safety on the roads as well as in the city;
- to reduce the consumption of electricity;
- to reduce light pollution in accordance with the Regulation on the Maximum Levels of Light Pollution;
- to build an open system for public lighting, with the ability to use equipment from different manufacturers;
- to establish remote control and management of public lighting.

The initial step of the project was the production of a snapshot of the register of public lighting in the municipality of Krško. To this end, in 2009 a complete inventory of all connection points and lamps with similar description and status was made. Key information in this inventory was the location of individual lamps and information about the purpose of lighting for every lamp.

A further step in the project was the introduction of accounting of electricity consumption for street lighting. A significant amount of the work was done in the initial stage, as it was

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necessary to collect all the data on electricity consumption over the last five years and the costs for all demand sites, which are linked to the street lighting. The data of the overall consumption and cost for electricity for public lighting in municipality Krško are presented in Table 1.

***Table 1**: Consumption and cost for electricity for public lighting in municipality Krško (2009)*

Electricity consumption	2,703,803.00	kWh/year
Electricity costs	287,899.80	€/year

Based on the data from the inventory and energy accounting, an energy review was made, which gave an overview of the current situation, the possibility of savings in energy costs and the fulfillment of the terms of the new Regulation on the Maximum Levels of Light Pollution (Official Gazette of RS, no. 81/2007).

Based on the energy review from 2009, there are 4,531 lamps in the public lighting system in the municipality of Krško. The total power of the lamps is 656,756 W. The lamps are connected to 153 connection points, which are equipped with account electricity meters. Because of the afore-mentioned specific population (scattered settlements), the powers on individual connection points vary. Figure 1 shows the number of lamps and lumenaire lighting in public lighting in the municipality of Krško.

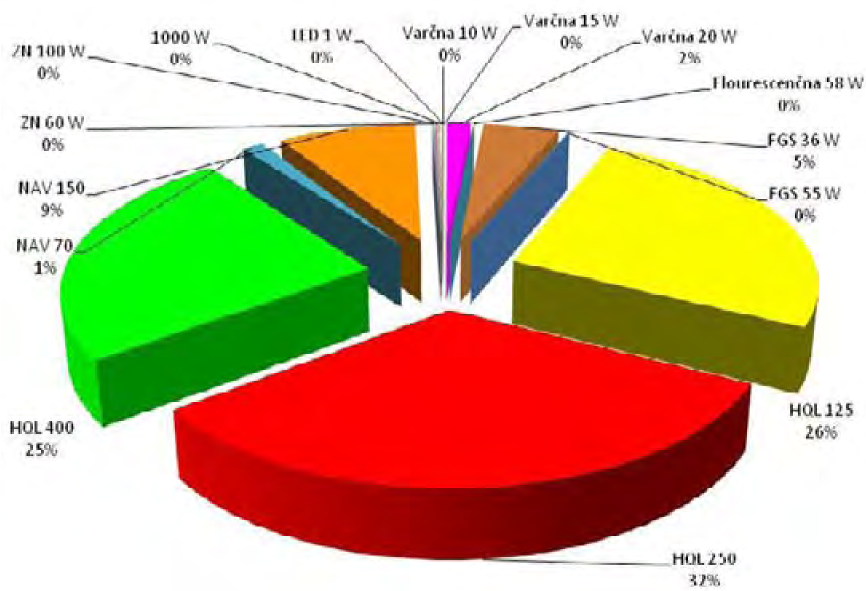

***Figure 1:** Number of lamps and lumenaire lighting in public lighting in the municipality of Krško*

The energy review determined that the majority of lamps used for street lighting do not comply with the Regulation on the Maximum Levels of Light Pollution. Public lighting in the municipality of Krško is composed of a wide range of lambs and lumenaires, which is a result of the gradual construction and expansion of the public lighting network in recent years. In the past, the expansion of public lighting took place without prior technical studies. The lighting time of the lamps/lumenaires is longer than the optimal and most of the lamps or lumenaires are constantly working at full intensity, regardless of actual needs.

Recently, there has been some replacement of the defective or damaged lamps during scheduled maintenance. The replaced lamps comply with the new regulations.

The proposed measures in the energy review are primarily serving the legal restrictions. The first proposed measure is the replacement of lamps and lumenaires with:

- lumenaires with a higher luminous flux and efficiency;
- lumenaires with longer life expectancy;
- lamps with optimal system leak;
- lamps with simpler assembly methods;
- lamps with the appropriate lighting diagram.

With the above-mentioned measures, it is possible to achieve the following objectives:

- reducing the energy consumption for public lighting to 50 kWh per capita per year, which means 47% energy savings;
- reducing the level of light pollution to the level required by regulations.

The energy review proposes the imposition of a lighting regulation by time and luminance for achieving an additional savings of 5.5 kWh per capita per year.

The use of new LED technologies in lamps for street lighting has shown some very promising results in achieving electricity savings.

We have come to interesting findings: LED lamps have high energy efficiency, low consumption, long life expectancy and a wide spectrum of colours. Another advantage is the possibility of controlling the luminous flux in steps of 1% throughout the entire range (1%–100%).

Measurements and calculations show that the replacement of mercury lumenaires with LED lumenaires can reduce power by up to 80%. Technical and visual characteristics of the LED lamps vary significantly among different manufacturers. It is of great importance how the lamp is constructed. The lifetime of LED lamps depends on the technology of heat removal on the surface of the diode, and luminance depends on raster/grating performance and the quality of lenses for light dispersion.

Although LED technology still developing, present LED versions of lamps and lumenaires enable high-quality lighting with low energy consumption.

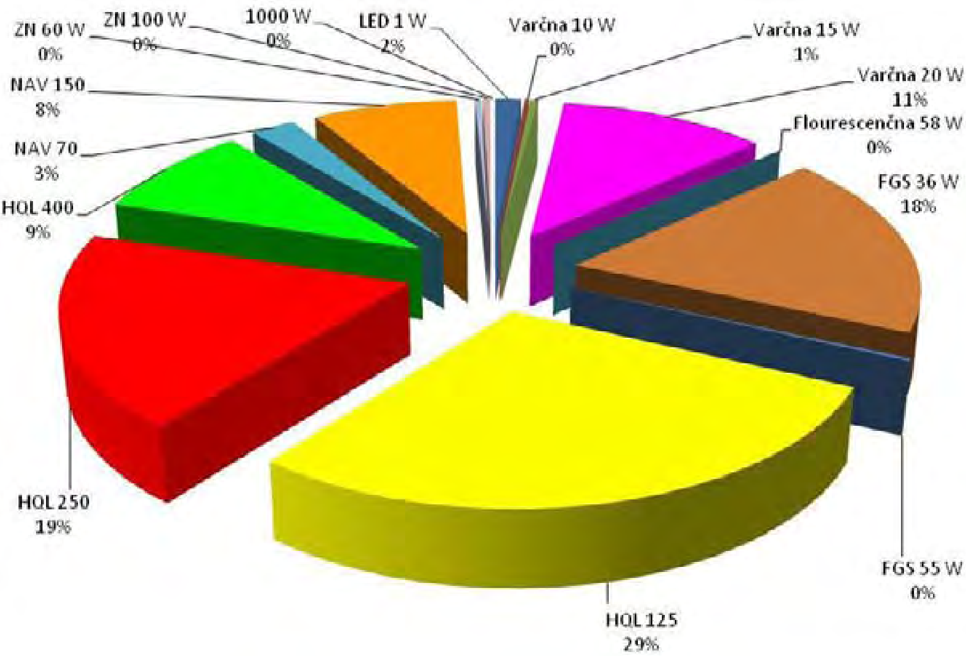

Figure 2: *Electricity consumption by individual lumenaires*

Calculations in the energy review showed that, given the current budget and available technology indicators, with only the replacement of lamps we will not achieve the required levels of electricity consumption. Therefore, we launched a research sub-project on a market analysis of supply systems for the regulation and remote control of public lighting.

Current technology enables basic regulation with the hardware on the level of connection points. However, such regulation does not allow noteworthy energy savings and the reliability of such regulation is not satisfactory. That is the main reason why we have searched for new possibilities.

Another possibility, which we are testing now, is the ZigBee wireless protocol. In the beginning, it was used mainly for simple communications with devices for water meter temperature reading. Today, the use of the ZigBee protocol is increasing and spreading rapidly.

We are using the ZigBee protocol primarily because of the advantages offered by its implementation; we are using wireless communication with no interference. The data are encrypted with 128-bit key that guarantees security. A special feature of the ZigBee network is "self-healing" technology that ensures that the failure of one of the modules does not cause the failure of the whole system, because the modules are connecting and searching for each other.

Another advantage of this system is the remote control of street lighting, which enables better oversight of the entire system, faster response to failures of the system, the possibility of planning maintenance work and upgrading of public lighting, and faster correction of errors and anomalies, which usually cause increases of energy consumption.

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3 CONCLUSION

Street lighting is a highly complex system that requires a high degree of professionalism. During the preparation of the project of public lighting renovation, we have come to the conclusion that good knowledge of the existing street lighting is crucial. The basis of this knowledge is a well-ordered register of public lighting with a detailed description of all the lamps, connection points and power lines, with a well-organized and conducted energy and financial accounting. This is the basis for a quality energy review, which prompts suggestions for designing and implementing an effective renovation project.

The first step that we took in the municipality of Krško was the renewal and completion of a public lighting register and the establishment of energy accounting, which gave us the basis for a complete energy review of public lighting. The energy review revealed that the greatest part of savings and rationalization of public lighting should be feasible by replacing the existing lamps with more economical and efficient lamps. However, the exchange itself would not be sufficient to achieve the regulatory limits. It also requires a rationalization of lighting and remote control of public lighting.

Although legal restrictions can be strict and sometimes not very reasonable, they can be achieved and even exceeded. However, this requires good knowledge of modern lighting technologies as well as control and communication technologies, especially when aspiring to always finding the most suitable configuration for each segment of street lighting. Greater economic and technical impact could be achieved with the cooperation of municipalities or even the whole region.

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