REPÜLÉSTUDOMÁNYI KÖZLEMÉNYEK
33. évfolyam (2021) 2. szám 143–152. • DOI: 10.32560/rk.2021.2.10

Zsolt Jurás

The Role of Drones in Enhancing Production Efficiency of Nuclear Facilities

The huge challenge faced by nuclear power generating facilities at the beginning of the 21st century is to keep producing safe electricity that can compete with the energy produced by other electricity generating sectors. One of the means of overcoming this challenge is related to the increase of generation efficiency, which, naturally, shall not be to the detriment of nuclear safety. This paper describes how the application of drones can contribute to the achievement of competitive operation. To do so, it is necessary to highlight the operation specifics of nuclear power plants and to review special circumstances arising from the application of this technology. In this paper, the reader can get acquainted with another specialised area of drone applications, the appearance of which was, basically, brought to life by an economic aspect.

Keywords: *drone, maintenance, nuclear power plant, efficiency, inspection*

1. Introduction

Nuclear power plants spread world-wide in the second half of the 20th century as an efficient and long-term option for electricity generation aimed at meeting the growing energy demand resulting from industrial development. The need for the peaceful use of nuclear energy appeared in the 1950s, and later on in the 1970s and 1980s – as a result of continuous improvements – 287 reactors were connected to the grid and continue operation at present. According to the IAEA report prepared in 2019, 65% of the operating reactor fleet are more than 30 years old, which poses another huge challenge to the nuclear industry. Safe and cost-efficient operation of nuclear reactors heading towards the end of their lifetime is of key importance to keep market positions and stay in the market. The number and total installed capacity of operating reactors is depicted in Figure 1 in relation to their age [1]. As one can see from this figure, the number of reactors that have been in operation for 30 years or even longer is rather high; however, these reactors, despite their age, are able of ensuring stable electricity generation for another 10 or 20 years.

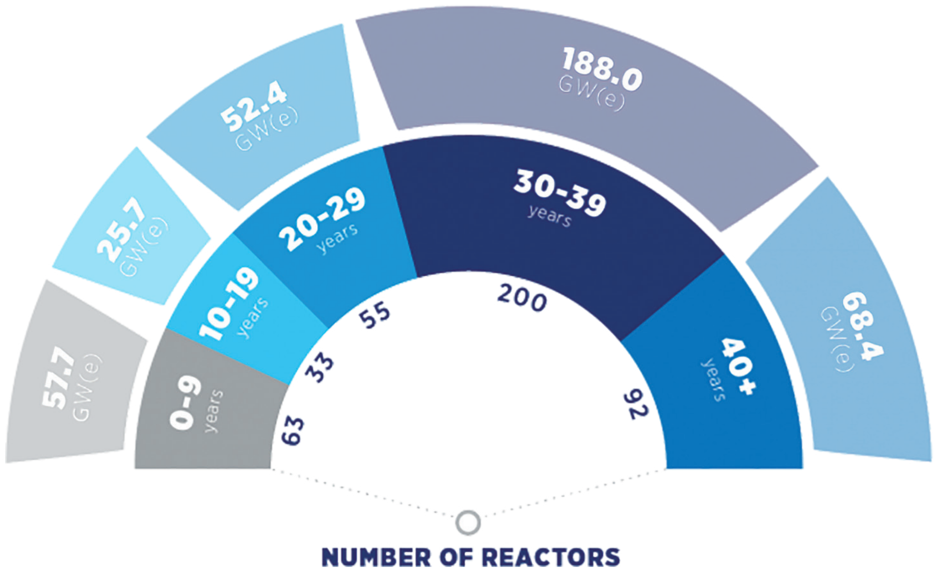

Figure 1.
Reactors in operation and capacity by age [1]

Nuclear reactors, based on their age and some other features like safety, economic efficiency and operability can be classified into so-called generations [2, p. 119]. The large majority of the currently operating power plant units belong to the 2nd generation; nuclear reactors of the 3rd generation are under construction now. It is not possible to draw a sharp line between generations, this differentiation is used rather to identify the eras in the development of nuclear energy and to specify the development level typical for that certain period. Based on the above said, it would seem to be evident that from all points of view it would be more reasonable to construct new units and nuclear power plants than to extend the lifetime of the old ones. However, one of the disadvantages of nuclear power plants in comparison with the low cost price is a very high historic cost and decades of return on investment. Needless to say, that lifetime extension is preceded by a lengthy licensing and review process; however, the cost of potential safety-enhancing actions defined based on the review results is negligible compared to the construction costs of a new power plant unit.

2. Specific features of nuclear power plants

Nuclear power plants generate thermal energy from the energy released in the process of nuclear fission during the controlled chain reaction. Due to its nature, the operation of nuclear power plants is a hazardous activity, as the process of energy generation is accompanied by continuous release of ionising radiation [2] [3]. As a result of the reduction of physiological effects of ionising radiation, implementation of nuclear safety as well as the applicability of the complete technology, it has become necessary to separate the sub-processes of energy generation. During the development of nuclear reactor technologies, the primary circuit, i.e. heat circuit containing active coolant and secondary circuit transforming the generated thermal energy into electricity by means of its equipment, were designed. Boiling water reactors (BWR) and pressurised water reactors (PWR) belong to liquid-moderated, liquid-cooled reactor types. In order to provide a detailed description of the ways for enhancing operational efficiency at nuclear power plants, it is necessary to give an overview of their operation, placing a particular focus on several reactor types. To do so, I have selected two reactor types among nuclear power plants belonging to the second and third generation, which – taken together – account for 89.2% of the total electricity production by the nuclear power reactors being in operation as of today [1]. Figure 2 illustrates the distribution of electricity generation in 2019 with reference to nuclear reactor types.

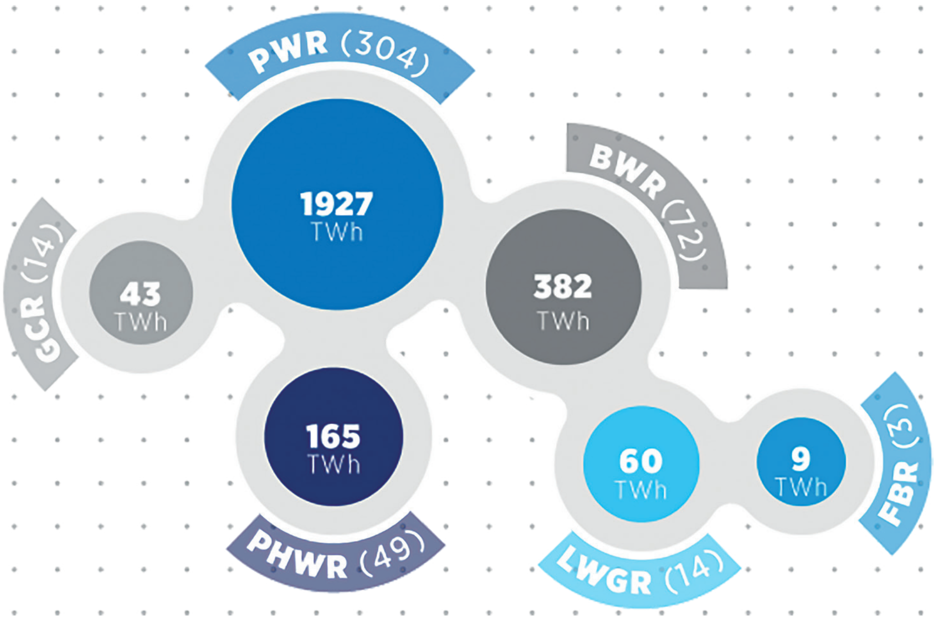

Figure 2.
Electricity supplied by type of reactors [1]

These two types are nothing else than the boiling water (BWR) and pressurised water (PWR) reactors. Despite the fact that in case of both reactor types light water plays the role of moderator and coolant, the principal difference between these types consists in the design of the primary and secondary circuits. While in case of pressurised water reactor types, the two closed thermal circuits are well separated and the primary coolant remains in the liquid state throughout the entire process, the boiling water reactors, in fact, comprise only one single circuit: the coolant passing through the reactor undergoes a state change and steam originating during this process drives the turbines. The process of operation described above is shown schematically in Figure 3.

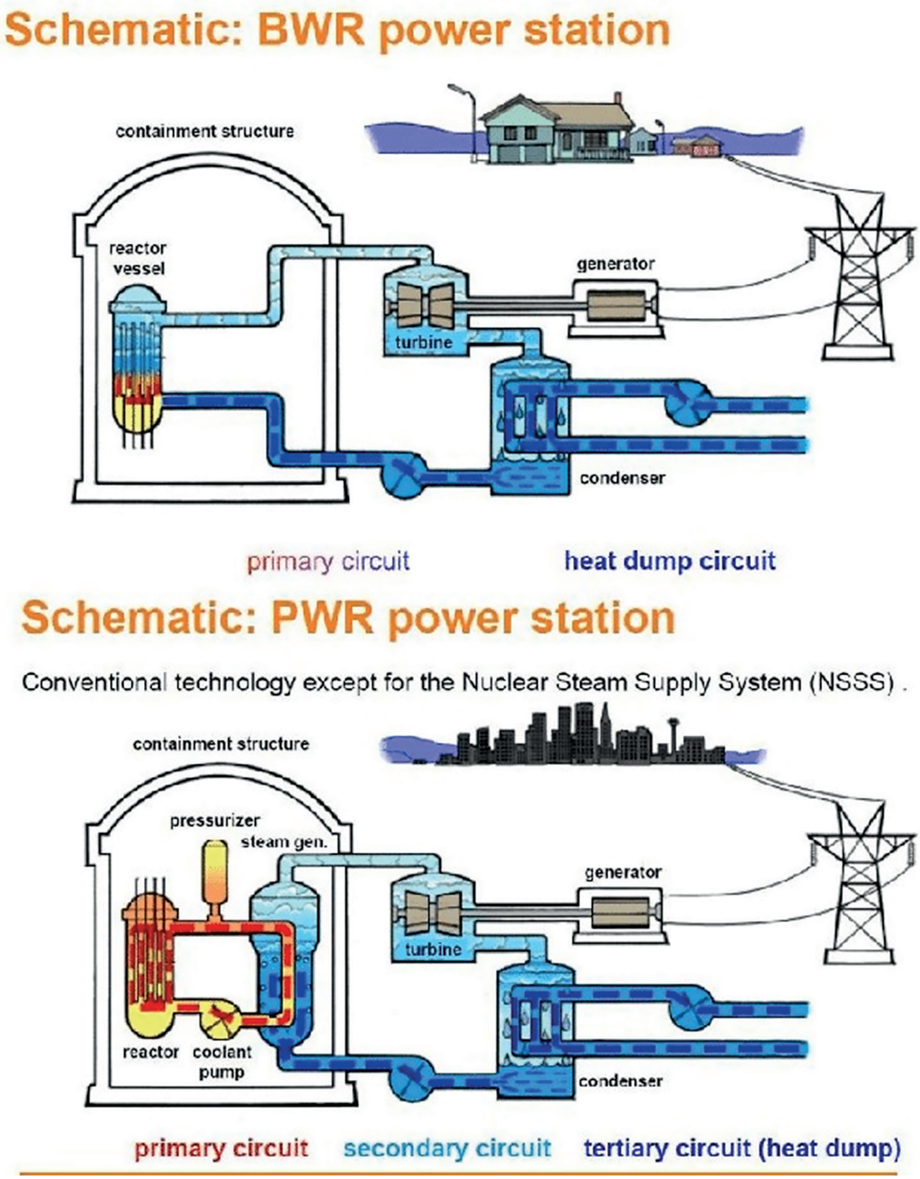

Figure 3.
Difference of principle between BWR and PWR [4, p. 4]

Fuel assemblies are able to provide an adequate amount of thermal energy throughout several fuel campaigns, as a result of the so-called continuous burn-up. To compensate for the fuel burn-up, operation campaigns should be interrupted from time to time to perform partial reloading of the reactor core and to load fresh fuel. During the refuelling there is a possibility of carrying out maintenance activities on the equipment directly involved in energy generation, this period is called outage. The lengths of operating periods between the planned outages, as well as the outage durations differ depending on the reactor type and manufacturer: as a rule, the operation campaign lasts 1–2 years and the outage durations vary between 22 and 55 days. The planned outage durations depend on the scope of scheduled maintenance activities. There are some types of large equipment that require full-scope preventive maintenance (PM) only once every eight years. To summarise the above, it can be stated that:

- a large amount of energy can be generated by nuclear power plants in the continuous operation mode, thus they can be operated as a base power plant
- due to the physiological effects of ionising radiation, a part of the primary circuit, for example, its equipment located in the containment or protective building, cannot be approached during the entire campaign or can be accessible only for a very short period of time
- high-quality, precise and professional maintenance have to be performed within a short period of time

3. Efficiency-enhancing solutions

Several different options for enhancing efficiency can be considered in the operation of nuclear power plants. It should be emphasised that all reconstructions performed in the nuclear industry can be implemented only through the application of justified technical solutions and proven technologies. Reconstructions are preceded by the performance of impact assessments, technical justifications, planning, safety analysis and, finally, by licensing procedures.

3.1 Efficiency enhancement manifesting in operation

One of the most obvious solutions consists in the improvement of performance characteristics of the operated technology. Basically, there are two ways for increasing the amount of electricity generated, one of them is the reduction of technology-related losses, the other one is the increase of heat input on the primary side. In case of the Paks Nuclear Power Plant, this process has been carried out in 2 phases. The first step included the reduction of losses on the secondary side and implementation of several efficiency-enhancing investments, in the result of which the total installed capacity of two turbines was increased from the original 440 MW(e) to 470 Mw(e). The second step included an 8% thermal power rate of the plant reactors. Upon the project completion, the total power uprate at Units 1–4 of Paks NPP achieved 240 MW(e). Practically, one could say that it looks as if a ninth turbine would have been put into operation. At the second phase, the specific cost price of 31.3 MHUF/MW of 136 MW(e) capacity increase was implemented, which is orders of magnitude less than the investment expenditures of any other electricity generation capacity [5].

3.2 Efficiency enhancement connected with maintenance activities

The goal of nuclear power plant operators is to maximise the economic efficiency of production along with emphasising the priority of safe electricity generation. The contribution to the achievement of this goal can be made by means of a certain increase in the length of operation campaigns. In case of many nuclear reactors worldwide, the transfer from the 15-month to the 18-month and from the 12-month to the 15-month fuel campaign was implemented in parallel with the lifetime extension program. Longer fuel campaigns can be achieved with the use of fuel assemblies with higher enrichments. This has been done in case of the Paks Nuclear Power Plant as well, the enrichment of certain fuel assemblies has been increased from 4.2% to 4.7%. As a result of the extended fuel campaigns, only 3 outages are required per year and 4 outages once per five years. Having completed the transfer to the 15-month fuel cycle at all the units, the number of outages was reduced by 26 reactor days on the average per annum, resulting in the annual efficiency increase of 2%. Another indirect economic result is connected with the fact that 3% less fuel is needed annually than before. Another possibility for efficiency enhancement is the development and optimisation of maintenance cycles. The on-line maintenance of safety systems allows to reduce the safety risk of the units without reducing their operational safety. Outage durations can be reduced, the availability factor of the nuclear power plant and, thus, the amount of electricity that can potentially be generated can increase. Typically, this can also mean reactor days that already reflects the cost-increasing potential in terms of which it is expedient to re-organise work processes.

3.3 Efficiency enhancement as a result of the drone application

On first reading, it may seem strange and difficult to imagine how a drone can contribute to the safety of a nuclear facility, more specifically of a nuclear power plant, and even increase its efficiency. Nowadays, the pace of technological development and progress is so high that "toys" appearing to be an ordinary, everyday thing in just a few moments can enter such important and hazardous operational areas that we have never ever dared to imagine. After the development of information technology, management and production technology has made it possible to produce and create computers in as small a size as possible, programming of small-sized aerial robotics is no longer an obstacle [6, p. 279]. Unmanned aerial vehicles collect information necessary for their operation from their everyday environment and use their sensors for position detection leading to the decision-making process; thereby, they are able to correct their operation, position and movement in a three-dimensional space. In addition to the autonomous operation mode, they can also fly with the use of human remote control, or possibly using the combination of these two depending on the circumstances [7, p. 197]. By further study of the professional literature and in-depth examination of the topic, one can come across the specific use of drones in connection with nuclear power plants; however, the application area reported in September last year by the International Security Journal had not been described in the earlier literature. The emergence of unmanned aerial vehicles opened up the opportunity for solving tasks that cannot be solved or are difficult to be solved by humans. While further reflecting on the possibilities of using drones, one can observe that these aerial vehicles are capable of performing various work processes, in order to increase productivity, efficiency, or even safety [8, pp. 107–109]. At the Barakah Nuclear Power Plant, drones will be used to support the power plant safety and reliability [9]. Two out of four units in the project have already been granted the operating license. By its nature, due to the nuclear environment, only a special radiation-immune drone can be used for this purpose. One of such collision-resilient and radiation-immune drone types is Flyability Elios 2. Successful test flights have already been conducted at some of the U.S. nuclear power plants and their use has already been approved at several power plants.

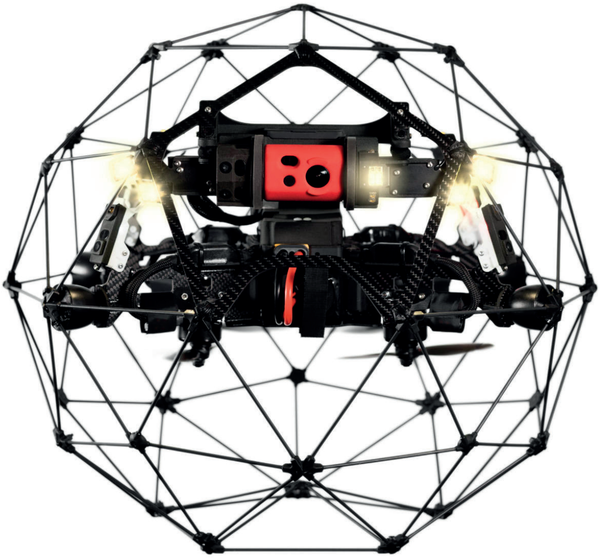

Figure 5.
Elios2 Indoor drone [10]

Such aerial vehicles were not yet available to nuclear power plant operators in December 2014. On 19 December 2014, an unidentified leak was detected at one of the units of one of the U.S. plants. In the course of the first walk-downs in the containment, the potential location of this leak was narrowed to one of the primary loops. Due to the high radiation exposure rate in the concerned area, performance of a more detailed search was not possible. When the initial leak rate of 0.11–0.15 litres/minute increased to 0.19 litres/minute, the decision was made on cutting back the reactor power to 30% in order to lower the radiation exposure rate for the performance of a more detailed examination. On 22 December 2014, the personnel managed to identify the leak location at the discharge flange of the primary loop, on a non-isolated pipeline section. To eliminate the problem, the plant personnel had to shut down the unit, which led to a significant loss of production due to an 11-day long unplanned outage. The detection and elimination of the leak in the above-mentioned case could have been performed much more efficiently with the deployment of Elios 2. The time elapsed between the leak detection and precise identification of its location could have been reduced from 72 hours to 20–30 minutes during the first walk-down and by conducting visual inspection with the use of a drone equipped with a normal and thermal camera, even though the primary circuit piping is thermally insulated. Based on the image cut from a video made on the basis of the 2018 study report published on the manufacturer's website, one can clearly see the leak in a thermally insulated pipeline.

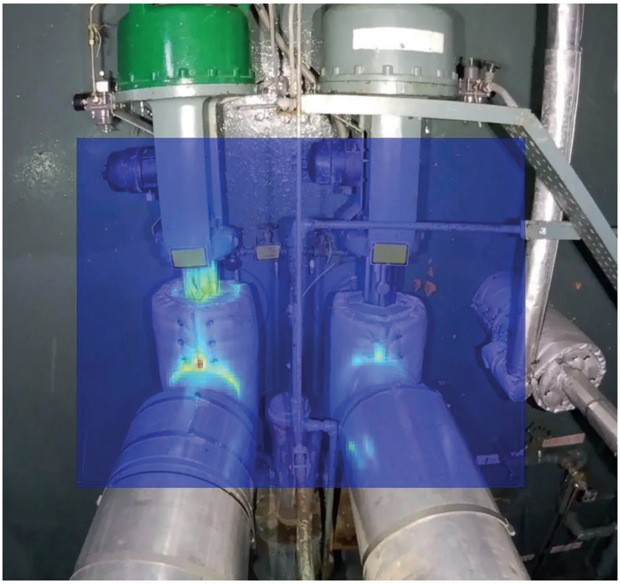

Figure 6.
Thermal camera image showing a pipeline leak [11]

Referring to the similarity of these two failures and taking into account the applied inspection method (visual examination), it can be stated that the failure in question can be identified with high probability and high repeatability by using a drone. In view of the above, the economic loss resulting from the time spent on the identification of failure location can be quantified and calculated as follows. One thing is for certain: the unit operated at 30% of its rated power during 3 days that elapsed between the problem detection and identification of the leak location. The rated power of the considered power plant unit is 1,000 MW(e); therefore, the resulting production loss for this time accounted for 50,400 MWh. Correspondingly, in terms of money, the loss accounted for at least $ 6 million at the production cost of 0.12 cents per kWh applicable at that time. The extent of failure occurred in the technology would not have required reactor power cutback or shutdown of the reactor if the leak could have been monitored on a continuous basis. In practice, it means that – while maintaining the production – it would have been possible to get properly prepared for the failure repair and to carry out in parallel all necessary licensing procedures at the nuclear regulator. Even in case of assuming the worst sequence of events, an additional 72-hour loss of production could have been avoided. Referring to the aggregated amount of financial loss, it can be stated that the profit deficit originating from the 12 million USD production loss can be avoided in case of utilising a special drone. This technology was not yet available at the time of the above-mentioned event; however, due to the accelerated development in special areas of application occurred during the recent years, some nuclear power plants are already using a part of radiation-immune and collision-resilient drone technologies.

4. Summary

This paper describes several options aimed at addressing challenges faced by the nuclear power plants in the 21st century. In my opinion, nuclear-based electricity generation will continue to play a key role for at least another 50 years. Rapidly growing energy demand – taking into consideration the expected boost in electric auto industry – can be met only by the energy system capable of producing large quantities of electricity in a carbon-free way and on a continuous basis. Electricity generated by nuclear power plays a key role in this energy mix. In this paper, possible solutions for enhancing efficiency are outlined through the presentation of the specifics of nuclear power plants. To sum up, it can be stated that the cost of investments required for efficiency enhancement of the facility is negligible compared to the construction costs of a new nuclear power plant. In addition to the improvement of operation and maintenance processes, it is demonstrated by means of a case study that several million-dollar losses can be prevented by utilising the drone technology. Along with the economic advantages, the application of this technology offers additional positive benefits in terms of radiation protection and waste management. From my point of view, it will not take much time for the developers to start considering the development of drones applicable for online primary circuit monitoring. In the current era of technical and technological revolution, these aerial vehicles play an important role in the military, civilian and energy sectors. This multi-purpose, cutting edge aerial vehicle can be used for various types of surveillance, detection and even intervention tasks, as nowadays there are numerous specific needs for aerial robots to perform tasks that are considered dangerous [12, p. 115–119]. Upon the development of an automatically re-charged drone that is capable to depart from and return to the charging station, this device would be able to fly along the service route and perform a visual inspection without human control. This would result in a further enhancement of the nuclear power plant efficiency.

References

[1] M. M. Gospodarczyk and M. Nari Fisher, 'IAEA Releases 2019 Data on Nuclear Power Plants Operating Experience', 25 June 2020. Online: www.iaea.org/newscenter/news/iaea-releases-2019-data-on-nuclear-power-plants-operating-experience

[2] I. Vidovszky, 'A jövő atomerőművei'. *Fizikai Szemle,* Vol. 55, no 4. pp. 118–122. 2005. Online: http://fizikaiszemle.hu/archivum/fsz0504/VidovszkyI.pdf

[3] K. Radnóti and M. Király, 'Az atomenergiáról egyszerűen: az atomerőművek működése, típusaik és jövőjük'. *Nukleon,* Vol. 8, no 177. pp. 1–13. 2015. Online: https://nuklearis.hu/sites/default/files/nukleon/8_1_177_Radnoti_0.pdf

[4] R. Mouginot and H. Hannu, 'Microstructures of nickel-base alloy dissimilar metal welds'. *Aalto University publication series Science + Technology,* no 5. p. 178. 2013.

[5] L. Szőke and L. Hadnagy, 'A teljesítménynövelés megvalósítása a paksi atomerőműben'. *Nukleon,* Vol. 4, no 3. pp. 1–4. 2011.
[6] G. Major, 'Does an Autonomous Drone Return Home at all Time?' *Repüléstudományi Közlemények,* Vol. 30, no 2. pp. 275–284. 2018.
[7] M. Palik, G. Major and B. Kiss, 'Migration from Bird's Eye View'. *Repüléstudományi Közlemények,* Vol. 29, no 3. pp. 189–202. 2017.
[8] L. Gajdács and G. Major, 'Az UAV alkalmazásának kockázatai a biztonságtechnika területén' [Risks of UAV Application in the Field of Security]. *Repüléstudományi Közlemények,* Vol. 30, no 2. pp. 101–112. 2018.
[9] International Security Journal, 'Falcon Eye drones utilised to protect Abu Dhabi Nuclear Power Plant', s. a. Online: https://internationalsecurityjournal.com/drones-utilised-to-protect-abu-dhabi-nuclear-power-plant/
[10] Flyability Elios2 Indoor drone. Online: www.flyability.com/hs-fs/hubfs/drone-newsletter-transp-1.png?width=461&name=drone-newsletter-transp-1.png
[11] Drones in Power Generation: How Exelon Uses Drones to Improve Safety, Save Downtimes, and Save Money screenshot by 15 min. 00 sec. Online: www.youtube.com/watch?v=7S4fKtcLFLw&t=740s
[12] G. Major, 'A pilóta nélküli légijármű rendszerek nemzetbiztonságicélú felhasználásával kapcsolatos kutatások'. *Repüléstudományi Közlemények,* Vol. 27, no 1. pp. 115–119. 2015.

A drónok szerepe a nukleáris létesítmények termelési hatékonyságának növelésében

A 21. század elején a nukleárisenergia-termelő létesítmények óriási kihívása, hogy továbbra is biztonságosan és az egyéb villamosenergia-termelő szektorokkal szemben versenyképes energiát állítsanak elő. A kihívás leküzdésének egyik eszköze a termelési hatékonyság növelésében rejlik, amely természetesen nem mehet a nukleáris biztonság rovására. Az alábbi publikációban bemutatom, hogy a drónok alkalmazása hogyan járulhat hozzá a versenyképes üzemeltetés megvalósításához. Ehhez szükséges rávilágítani az atomerőművek üzemeltetésének sajátosságaira és a technológia alkalmazásából származó speciális körülményeire. A cikken keresztül az olvasó egy újabb speciális drónalkalmazási területet ismerhet meg, amelyet egy gazdasági szempont hívott életre.

Kulcsszavak: *drón, karbantartás, atomerőmű, hatékonyság, ellenőrzés*

Jurás Zsolt, MSc doktori hallgató Óbudai Egyetem Biztonságtudományi Doktori Iskola zsoltjuras@gmail.com orcid.org/0000-0003-4670-9325	Zsolt Jurás, MSc PhD student Óbuda University Doctoral School on Safety and Security Sciences zsoltjuras@gmail.com orcid.org/0000-0003-4670-9325