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**UNMANNED AERIAL VEHICLE AS A DEVICE SUPPORTING  
THE PHYSICAL PROTECTION SYSTEM OF CRITICAL  
INFRASTRUCTURE FACILITIES: NUCLEAR POWER PLANT AS  
A CASE IN POINT**

**Summary.** The purpose of this work is to demonstrate the advantages and disadvantages of unmanned aerial vehicles as devices supporting the system of physical protection of critical infrastructure facilities using the example of a nuclear power plant. This paper contains information on the reasons for the construction of a nuclear power plant in the era of economic development of the Polish state. The legal requirements consisting of the analysis of the risk of terrorist threats for the facility was indicated. One of the sources of danger is unmanned aircraft or flying models increasingly used in the airspace. Furthermore, this paper presents legal rules and principles according to which missions of unmanned aerial vehicles or flying models are performed. The current regulations allow the use of unmanned aerial vehicles as devices supporting physical security systems at facilities. This study showed that although the use of unmanned aircraft for the purpose of increasing the security level of critical infrastructure facilities has some limitations, however, the possibilities arising from their usefulness are the decisive advantage of the need to implement drone technology in security.

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## **1. PROGRAM FOR CONSTRUCTION OF A NUCLEAR POWER PLANT IN POLAND**

Systems and functionally related facilities are needed for the proper functioning of the state, allowing for efficient management and access to services crucial for the security of the state and its citizens [1]. These systems include, among others, energy supply systems, energy raw materials and fuels, as well as a system for the production, storage, storage and use of chemical and radioactive substances, including hazardous substances pipelines. Access to energy sources, is according to the United Nations Development Program [2] report, a condition for the development of each country. In Poland, the basic source of energy is the energy obtained from burning hard coal and lignite. These sources cause high air pollution, leading to an increase in the incidence of cancer and a decrease in the quality of life. In addition, literature data show that coal power plants are old and must be shut down successively in the coming years [3]. An alternative to traditional sources of energy may be renewable sources of renewable energy, which unfortunately depend on unstable weather conditions [4]. In Polish conditions, the only source of energy independent of the weather seems to be energy from the nuclear power plant. The use of fissile and radioactive materials to generate energy, which, if released into the environment, will contaminate the environment for many years, may be the cause of objection by the community of the country in which such nuclear power plant operates. Currently, 186 nuclear reactors are used in Europe, and a further 15 are being built [5]. Additionally, in Poland, since 2009, activities have been carried out to lead to the construction and use of a nuclear power plant [6]. Reliable and safe operation of a nuclear power plant is possible only if such an installation operates in conditions ensuring its physical security. This study analyses the advantages and disadvantages of using unmanned aerial vehicles in a physical protection system.

## **2. RULES FOR THE OPERATION OF UNMANNED AIRCRAFT USED FOR THE PURPOSES OF PHYSICAL PROTECTION OF FACILITIES, INCLUDING CRITICAL INFRASTRUCTURE BEING SUBJECT TO OBLIGATORY PROTECTION AND FACILITIES LOCALISED IN PROHIBITED AIRSPACE**

Unmanned aerial vehicles (UAV) perform missions based on regulations and in accordance with conditions set out in laws and ordinances. The basic act on the basis of which UAV flights are performed is the Aviation Law Act [7]. According to this Act, each aircraft operating in the Polish airspace should be signed with registration marks, should be equipped with a system for identification of its location and a two-way radio communication between the UAV operator and air traffic controller should be ensured. UAV available for sale do not meet the technical requirements required by the Act, and the operators of these aircraft usually do not have the authorisation to conduct radio communications. The minister for transport, by regulation, may exclude the application of certain provisions of the Aviation Act and the provisions issued on its basis to certain aircraft, including unmanned aircraft [8]. Based on this provision, a regulation was published, which specifies, among

other things, the requirements for UAV equipment and flight rules [9]. The flight rules are contained in Annex 6 and Annex 6a of the above- mentioned regulation. Based on these provisions, flights are made in the VLOS (Visual Line Of Sight) range, that is, at such a distance at which the operator controls the position of the aircraft, directly observing it with unaided eyes. The rules for flying over longer distances, out of sight BVLOS (Beyond Visual Line Of Sight) are carried out on the basis of Annex 6b to the regulation published in 2018 [10].

In the case of VLOS flights by unmanned aircraft used for the protection of areas, facilities and equipment referred to in the Act on the Protection of Persons and Property [11], or nuclear facilities, flights shall only be carried out with the consent or for the needs of the manager of a given area, facility, area or device. The list of facilities being subject of mandatory protection is confidential, and only persons with the appropriate credentials may have access to it. In the case of using UAV to protect fuel pipelines, power lines, telecommunications lines, dams and water locks or other devices located in an open area, the destruction or damage of which could pose a threat to human life, health, environment, or cause serious material damage, flights are carried out with extreme caution.

In the case of conducting VLOS flights by UAV over the facilities around which the prohibited area (P) is established, the flights shall be conducted only with the consent or for the needs of the facility manager within the zone and on the conditions specified by him. The list of facilities protected by the P area is an open list [12] and contains 31 items including the EP P10 Świerk zone protecting the National Center for Nuclear Research [13]. Such a zone should be established around newly-built nuclear power plant in the future.

In the case of BVLOS flights performed for the purpose of physical protection of the facility, specialised flights are carried out as part of or for the purpose of supervision, monitoring, control or protection of personnel or property. Flights over areas, objects and devices referred to in the Act on the Protection of Persons and Property [11], or nuclear facilities, may be performed only with the consent or for the needs of the manager of a given site, site, area or device. Flights over fuel pipelines, power lines, telecommunication lines, dams and water locks or other devices located in an open area, the destruction or damage of which could pose a threat to human life, health, environment or cause serious material losses shall be carried out with extreme caution. In the case of BVLOS flights over P zone established around protected facilities, the flights shall be carried out with the consent or for the needs of the manager of the given object.

### **3. UNMANNED AIRCRAFT AS A SOURCE OF THREATS TO PROTECTED NUCLEAR FACILITY**

Unmanned aerial vehicles may pose a threat to critical infrastructure facilities. Sources of danger may include aircraft equipped with a camera, aircraft as a platform allowing the transport of unauthorised materials to and from the area of the facility, aircraft carrying explosives and aircraft carrying devices used for listening to telephone communication and WiFi communication. Nuclear power plant facilities require, in all countries with nuclear technology, special involvement of physical protection forces, due to the extraordinary sensitivity of their citizens to threats arising from the use of fissile materials. Public opinion with high distrust for the operator, and serious doubts on whether a nuclear facility is properly protected, may lead to the suspension of construction of the nuclear power plant [14] or to stop its activities [15].

UAV as a platform equipped with a camera: In UAV, cameras recording electromagnetic radiation from the visible and infrared spectrum are usually used. Both of these wavelengths allow observation regardless of the time of day or night. The camera recording a visible image can be used for espionage purposes. One can use it to learn about the layout of buildings, installations and equipment of the protected facility. Moreover, it can recognise the type of technical devices used in the physical protection system, and be used to learn about the daily activities of staff, customs and procedures of the physical security personnel. A certain threat is its ability to recognise the identity of power plant employees. Infrared cameras can be used for similar purposes at night. Flights to nuclear power plants have already taken place in France [16], which is the European leader in the use of nuclear energy, despite the ban on flights within a radius of up to 5 km from the plant.

UAV as a platform for carrying explosives: The widespread availability of these devices in stores at very low prices means that they are easily accessible devices which, due to the lack of registration of aircraft, can be used to attack any critical infrastructure facility including a nuclear power plant, in an anonymous, unexpected and effective way. The possibilities of transferring an explosive charge to an object can be assessed based on cases described in the press. In 2012, an attempt to smuggle explosives was detected at the largest Swedish nuclear power plant in Ringhals near Goteborg [17]. This discovery was made during a routine inspection of a car entering a nuclear power plant. Security personnel made the discovery. The investigation did not confirm that the person driving the truck was aware of smuggling. No other person involved in the smuggling was discovered. No one was charged. To date, no new information on this event has been published. If such smuggling were carried out by means of UAV, it could remain unnoticed by security personnel and the explosive would be delivered to the required location by the attacker. The effects of an explosion of smuggled material near the reactor, the reactor's control room or other safety systems in the case of loss of control over the chain reaction would be enormous. Violations of the airspace surrounding the nuclear power plant were reported in France in 2018 [18]. Members of the Greenpeace environmental organisation intentionally hit a UAV on the reactor concrete building at the Bugey nuclear power plant located near Lyon city. Greenpeace activists made this act to demonstrate the weakness of the physical protection system of nuclear power plants in France. The impact did not affect the concrete building or equipment operating at the power plant, but the manner of conducting the attack clearly indicated that nuclear power plants are not resistant to UAV attacks and the physical protection system is not adapted to respond to attacks carried out with the use of new technologies. Therefore, the effects of this particular attack can only be considered in terms of a loss of public trust that the power plant is well protected. The trust is necessary for the operation of such energy sources as a nuclear power plant. The effects of an attack using UAV-transported explosives can be assessed in the example of attacks on humans or oil processing installations carried out in recent years. The use of UAV as devices to attack people occurred in 2018 in Venezuela [19]. Two UAVs brought explosives near the addressing President of the state. The explosions caused panic with several people injured. Furthermore, UAVs was used in 2019 to attack oil processing installations [20]. As a result of the explosion, the facility equipment caught fire, which subsequently resulted in the refinery being shut down. The day after the attack, oil prices on the stock exchange rose by 15% [21].

UAV as a platform used for the theft of fissile materials from a nuclear power plant: All incidents related to smuggling, theft, illegal transport or use of radioactive materials in criminal or terrorist activities are reported by members of the International Atomic Energy

Agency (IAEA) to the Incident and Trafficking Database (ITDB). Currently, IAEA associates

171 countries [22]. In 2018 alone, members reported 253 incidents involving radioactive material [23]. It should be assumed that part of the above materials come from theft at nuclear power plants. Procedures for the protection of nuclear power plants require that every vehicle and every person leaving the area of a nuclear facility be subjected to an inspection aimed at detecting attempts to illegally export radioactive materials. All persons leaving the power plant area are subject to this procedure, regardless of their position. UAV taking off from the facility could be an excellent means of transport, enabling the transfer of radioactive materials outside the facility without control by the physical security personnel.

UAV can also be used in espionage missions to scan telephone or WiFi communications at the area of an observed facility [24]. Eavesdropping on telephone communication or WiFi communication may lead to obtaining information of great importance for the physical security of the facility or to disclosing information about the technologies used, or the financial condition of the facility operator. Eavesdropping communication by unmanned aircraft can be a problem due to the fact that operators do not include this type of aerial attack in their protection plans.

#### **4. UNMANNED AIRCRAFT AS EQUIPMENT USED IN THE PHYSICAL PROTECTION SYSTEM OF A FACILITY**

UAV due to their exceptional utility properties can be used as devices supporting the physical protection system of a protected facility. Both the equipment of the aircraft with cameras and other devices that may disturb the flight of another enemy aircraft has made such an equipped aircraft a universal tool, significantly increasing the security level of the object. The miniaturisation and low weight of on-board equipment and the development of lithium-polymer battery construction technology allow the aircraft to fly for a long time. The rapid development of algorithms to identify potential threats allows UAV to quickly inform security personnel about the threat.

UAV as devices enabling remote assessment of the technical condition of the physical protection system of a facility: Cameras operating in the infrared and visible band of electromagnetic radiation can be used to assess technical conditions. Currently produced cameras allow recording of both photos and videos [25]. The recording format can also be different: from the RAW format that allows advance professional processing to formats containing compressed images that has lost some of its information. Using appropriate lenses, one can record the image of objects located at a distance of 0.5 metres from the camera. The camera is usually mounted on a gimbal, which allows the lens to be pointed in any direction, regardless of the direction and speed of the flying aircraft. Variable exposure time allows recording an image in various lighting conditions. The UAV camera can, for example, be used to check the technical condition of the security fencing, which can be several dozen kilometres long. Also, the technical condition of other, hard to reach elements of the physical protection system can be assessed with the help of an aircraft. Such elements include, for example, detectors mounted on high walls. Control of such elements from ground level is usually very difficult. Infrared cameras are used to control the technical condition of electrical devices that are part of the physical protection system [26]. Such a camera allows to locate places where an electrical device emits heat. In the case of wires, this is usually associated with an increase of electrical resistance at the joints of two

elements.

UAV used for physical interception of enemy unmanned ships breaching the airspace in the vicinity of a protected facility: There is currently no unequivocally effective solution to the problem of UAV flying into the airspace of a protected facility. Most commercially available solutions work by interfering with the communication between the aircraft and the operator [27], the impact and knock-down of an enemy aircraft by aircraft belonging to the physical security personnel or the capture of an enemy aircraft in a fishing net fired from aircraft belonging to the physical security personnel [28]. Disturbance of communication between the operator and the aircraft is carried out by means of an emitter of electromagnetic radiation, used by the security personnel. The advantage of this type of device is its mobility. A member of the security staff can go anywhere in the protected area and disrupt communication between the aircraft and the operator. Such devices emit a signal interfering with the standard frequency at which communication takes place, that is, 2.4 GHz. However, the disadvantage of using interfering devices is the inability to fly UAV operated by the security personnel. Their flight may be disturbed by devices whose operation is directed against enemy aircraft. According to the law, UAV can be used in automatic flights, thus, eliminating man in routine operations. Such a flight must take place in such a way that the operator can take control of the flying aircraft at any time. Interference-disturbing devices may prevent such use of aircraft by the security personnel [29]. Another way to intercept an enemy aircraft is to strike it and bring it down to the ground by an aircraft operated by the security personnel. This task is accomplished by hitting an enemy aircraft from the side or bottom. The disadvantage of this solution is the high probability of damage to the rammed aircraft at the moment of collision or crash. This may mean that it would be impossible to read data from the on-board computer, and thus, it would not be possible to detect the start place or identify the enemy aircraft owner. Falling unmanned aircraft drops uncontrollably which means the possibility of damage to devices working at the area of the protected facility or falling on employees of the facility. The kinetic energy of a drone falling from a height of 10 metres with a mass of 2 kg is at the moment of impact 196 J (self calculated). Striking with such energy, a falling aircraft will certainly cause serious injury or even death of the victim. Another option is to intercept an unmanned enemy by firing a net connected to the parachute towards it. Such a shot can be fired from an unmanned aircraft operated by the security personnel. The UAV violating the airspace is entangled in the mesh and brought slowly to the ground using a parachute [30]. The advantage of this solution is the ability to read from the on-board computer any data that can identify the owner and place of start. Such data can be used as evidence in court. Unfortunately, most of the protection systems currently commercially available require additional devices to detect an incoming unmanned enemy. These devices detect enemy drone in various ways: they can detect a drone-based on frequency analysis of the sound emitted by an unmanned drone, analysis of the visible image and detection of the shape of the aircraft, detection of heat emitted by a drone or lithium polymer battery, using radar or by detecting electromagnetic radiation emitted between operator and aircraft during their communication.

UAV as a platform used for observation of the terrain and foreground of the protected facility: The observation may take place outside the operator's range of sight based on an automatic flight or a flight implemented within the operator's range of sight. The cameras can operate in the visible or infrared range of the electromagnetic radiation spectrum. In the event that security system detectors identify an unauthorised intrusion attempt into the protected facility, the procedures provide that the system operator using the stationary

cameras should specify the source of the alarm. A UAV is a perfect complement characterised by mobility and speed of arrival at the place of alarm. The flying aircraft gives the opportunity to observe the situation from a bird's eye perspective.

## **5. FAULTS OF USE OF UNMANNED AIRCRAFT IN THE PHYSICAL PROTECTION OF FACILITIES**

UAVs are devices that can work only in certain weather conditions. Unsuitable weather eliminates UAV from use. Aircraft are devices that are extremely sensitive to the presence of moisture in the air. Atmospheric precipitation may damage the drone or shorten the flight time. Moisture in the air can damage the on-board computer, engine control systems or electric motors. snowfall, hail, etc. can lead to mechanical damage of the propellers, loss of lift and the fall of an unmanned aerial vehicle. The fog limiting the range of visibility eliminates such an aircraft from VLOS flights. Water molecules in the air absorb electromagnetic radiation that is used to control the aircraft. Another problem is the low air temperature during the flight. Moisture that builds up on the leading edge, when the temperature is too low, can lead to icing on the propeller surfaces, loss of lift, and the aircraft falling. Very strong wind is also a big problem. When flying in built-up areas, you can expect turbulence that can cause the aircraft to hit an obstacle, for example, the wall of the building. Solar activity is also important for flight safety; too high activity can lead to disruption of aircraft electronic systems, including disruption of GPS system operation. Under normal conditions, GPS devices are very accurate. In the event of disturbances, aircraft position reading errors can increase dramatically and reach up to several metres [31].

Another problem with UAVs is their sensitivity to electromagnetic radiation at frequencies that interfere with the aircraft's communication with the operator. Such radiation is emitted by devices used to defend against enemy aircraft by the security personnel. When attempting to use an aircraft to intercept an enemy aircraft, security personnel may not simultaneously use electromagnetic radiation emitters to neutralise an enemy aircraft.

The use of UAV in the security of facilities requires that the operators of these aircraft have appropriate operating skills. Statistical data show that 80% of all accidents in aviation are caused by human factor [32]. The maintaining of competences requires training flights and systematic improvement of knowledge. The rapid development of unmanned technology requires constant adaptation of aviation law. Changes in the Polish aviation law in the field of unmanned aircraft operating [33] are also forced by unifying regulations in the European Union [34].

The last disadvantage of UAV is the high cost of cameras operating in the infrared band [35]. Such cameras have been miniaturised for the needs of UAV flights and equipped with image transmission systems [36]. In addition, the hardware manufacturer usually provides the software that allows image analysis. The prices of cameras operating in the visible band of electromagnetic radiation are significantly lower despite being miniaturised. Furthermore, it is common practice to use cameras that send monochrome images. The reason for using this solution is the ability to send an image without interference (transmission problems) resulting from sending fewer data in time.

## 6. ADVANTAGES OF USING UNMANNED AIRCRAFT IN PROVIDING THE PHYSICAL SECURITY OF FACILITIES

The use of UAV allows security personnel to increase the level of security of a protected facility. The use of unmanned platforms allows the replacement of security personnel in routine operations. Systematic performance of the same activities over a long period of time means that the person performing the activity begins to perform it automatically, without the required attention. This can lead to a weakening of the security status of a protected facility. Eliminating a man in routine activities and replacing him with robots allows to maintain the current level of security or to increase it. UAVs can automatically fly around a protected area along a predefined route. Man's tasks in such a flight include only the interpretation of the alarm signal emitted by an aircraft in the event of a threat being detected.

Another benefit of using a UAV is the ability to observe the environment from a different perspective than from the perspective of stationary cameras. Installing infrared and visible electromagnetic radiation cameras on aircraft allows observation at any time of the day or night. Image analysis algorithms allow immediate detection of a threat. If the camera is integrated with a database containing biometric data, it is possible to recognise the identity of a person approaching a protected facility and know whether it is a worker of the facility or an uninvited person [37].

UAV can also be used to quickly assess the reason for an alarm. A large problem for the physical security personnel is the large number of false alarms caused by animals. The standard procedure, in this case, is for the security personnel to check the area where the alarm occurred. Access by security personnel to the place of alarm is time-consuming and makes room for an effective attack. Faster identification of the causes of the alarm is possible by means of an unmanned aerial vehicle flying in the operator's sight or beyond it.

## 7. CONCLUSIONS

The rapid development of unmanned platform technology is a threat to critical infrastructure facilities, and similarly, an opportunity to increase the level of security. The advantages of flying aircraft mean that despite their disadvantages, they will be increasingly used in physical protection. In accordance with the principle that each facility must be protected by at least two systems operating on different principles, unmanned aerial vehicles will be supported by devices using different detection methods. Such a security organisation guarantees that the likelihood of an enemy's intrusion into the protected infrastructure will be quite minimal.

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