Working Paper on possible terrorist threats and necessary nuclear security measures for NPPs and interim storages

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In the Joint Project, European NGOs and research institutions cooperate since 2003 on safe and sustainable energy issues with a focus on anti-nuclear activities in Central and Eastern Europe. For more information see www.joint-project.org/.

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In the past years, independent experts, NGOs and governments started to put a focus on terrorism and nuclear security – not always to the necessary extent and with the necessary knowledge. In Environmental Impact Assessment procedures of nuclear power plants (NPP) and interim storage facilities it is still not common to include information about security against terrorist attacks. But especially old NPPs and storages are not designed against possible terror attacks. Thus, in case of operation time extension, this topic is of special relevance. This working paper can be used for preparing the input for future environmental impact participation procedures as well as for media work.

Therefore, the Joint Project commissioned a working paper by the independent nuclear security expert Oda Becker.

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Summary

1 Introduction

Since September 11, 2001 the potential terror threat nuclear power plants are exposed to, received considerable public attention. For obvious reasons this attention is mainly focusing on the hazard of the deliberate crash of a large airliner. In reality however those threats are much more diverse and complex.

Terrorists can chose from a variety of potential targets for terrorist attacks. However, what makes an attack on a nuclear power plant very attractive for a terrorist group is the global attention this would generate. A successfully conducted attack on a nuclear power plant in one country would be understood as an attack on all NPPs around the world; countries highly dependent on nuclear power might have to face a serious dilemma.

In recent years, the rise of terrorist groups who have sufficient resources at their disposal and the wide spread use of civil nuclear power placed nuclear security[1] high on the political agenda.

Nuclear facilities are designed with safety provisions such as thick concrete walls, containment and independent and diverse systems providing multiple backups in case of an emergency. These provide some protection against terrorist attacks. However, 85% of nuclear reactors were built before the 9/11 attacks and were not designed to withstand potential acts of sabotage.

Old nuclear power plants have numerous known design flaws which make them vulnerable to terrorist attacks (as well as to earthquakes and to floods). At the same time, it is known that they lack measures to manage a severe accident. Also for new nuclear power plant, severe accidents with very high radioactive releases cannot be excluded.

New possible means to support attacks are emerging: Unmanned flying objects, drones, can – like in military application – be used for the preparation or support of terror attacks. In autumn 2014, drones had flown over French nuclear facilities over 30 times without their originators being identified, are an additional security threat to nuclear installations. Not only the drone overflights themselves but also the inability of security officials to explain and prevent such activity are issues for concern.

Furthermore, additional attack scenarios demanded attention: Experts voiced concerns that cyber security has not been fully anticipated in all European Union Member States as indicated by the nuclear security index of the Nuclear Threat Initiative (NTI). Recent attacks against banking and commerce systems, private companies, and national governments highlight the growing gap between the threat and the ability to respond to or manage it. (NTI 2017)

The main target of a terror attack is the reactor building. Storage facilities of spent fuel are vulnerable targets too and they will be possible targets for a very long time (up to 100 years). The identification of terrorist threats[2] against reactors and spent fuel pools is a necessary part of security planning at all nuclear facilities.

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[1]'Nuclear security' refers to the prevention of malicious acts involving nuclear or other radioactive materials and their associated facilities. Nuclear security is distinct from non-proliferation (preventing the spread of nuclear weapons to more countries).

[2]The terms *hazard*, *threat*, and *risk* are related but not interchangeable. Hazard is used in a safety context to denote conditions that can result in accidents, whereas threat is used in a security context to denote potential

Nuclear regulators use the **design-basis threat (DBT)** concept in its security-related regulations. DBTs describe a specified set of adversary attributes that must be considered in the design of plant security systems.[3]

The understanding of security risks at nuclear power plants and spent fuel storage facilities can be improved through risk assessment. There is also a pressing need to identify more systematically potential cyber, insider, and asymmetric security threats. More formalized processes for identifying and analyzing threats—for example the **probabilistic risk assessment** (PRA)—could help to improve security at nuclear plants. Event trees e.g. can be used to systematically explore terrorist attack scenarios, responses, and potential consequences. The identification of scenarios may be incomplete and can have large uncertainties. Nevertheless, risk assessment methods that focus on the risk triplet—scenarios, likelihoods, and consequences—can deliver useful security insights.

There have been several global initiatives to improve nuclear security, including the Nuclear Security Summit (NSS) process (2010-16). The Nuclear Threat Initiative (NTI), a US NGO, ranks measures taken by countries to reduce the risk of sabotage in its Nuclear Security Index. (NTI 2017)

2 Targets and their vulnerability

The area of a nuclear power plant (NPP) consists of several tens of thousands of square meters. The heart of the plant is the **reactor building**, which contains the reactor with the radioactive nuclear fuel (in the order of magnitude of 100 tones), as well as important cooling and safety systems. The reactor buildings of the reactor type VVER-440 at Dukovany NPP and Paks NPP are particularly vulnerable to external hazards. Their reactor cores are surrounded by a relatively thin-walled reactor building (less than 1 meter). This design no longer reflects current standards in science and technology. A thickness of about 2 meters is required for new construction projects.

The reactor buildings of the reactor type VVER-1000 used at Temelín NPP and Kozloduy NPP (wall thickness 1 to 1.2 meter) as well at the reactor type CANDU 6 at the Cernavoda NPP (wall thickness 1.1 meter) are better protected but still not protected enough against external hazards.

The **spent fuel storage pool** is another vulnerable component of nuclear power plants with considerable radioactive inventory. If a terror attack causes a breach of the concrete walls of a spent fuel pool, the cooling water will pour out. This causes the stored fuel to heat up due to the decay heat. Once the stored spent fuel reaches the temperatures of 900 °C, the zirconium cladding of the fuel starts to burn in air. High radioactive releases can be the result; a recently published document estimates a release of 75% of the cesium inventory. (NAS 2016)

The spent fuel is stored in the spent fuel pools of the reactor for at least two to three years. After that period, it would be transferred to an **interim storage facility**. Most interim storage facilities today are based on the dry storage concept, which means the fuel is stored in casks inside the interim storage facilities. In general, the possible release caused by a terror attack against a dry

malevolent acts. Risk assessment is a formalized thought process for answering the following triplet of questions: 1) What can go wrong? 2) How likely is that to happen? 3) What are the consequences if it does happen?

[3]The DBT is not designed to be the worst-case threat. It defines the upper bound within the total threat environment against which a nuclear plant licensee is required to guard against. The responsibility for protecting against beyond-DBT threats lies in the responsibility of federal, state, and local agencies. (NAS 2016)

storage facility would be smaller compared to an attack against a wet storage facility (spent fuel pools).

A loss of integrity of spent fuel casks during storage or **transport** due to a terror attack would lead to massive release of radioactive substances. Decentralized storages, which are located directly at the NPP site, are safer than central storages, because they minimize the necessary transport of radioactive material and the risk entailed.

3 Conceivable attack scenarios

The 9/11 attacks in 2001 led to speculation about the possibility that terrorists could cause a large release of radioactive material by sabotaging a civil nuclear facility. To assess the risk related to terrorist attacks, three possible attack scenarios are discussed in some more detail in chapter 3.[4]

Attacks using explosives by insiders: Insiders are at least as much of a threat to nuclear power plants as terrorist attacks from outside. "The insider threat is one of the most difficult to deal with, as this hinges on the ability to screen employees and figure out the nature of their intentions," according to Stoutland (NTI). (Reuters 2016) There are scenarios involving insiders of a varying “effectiveness”, but the most feasible appear to be attacks with explosives. Particularly dangerous are attacks which use explosives at critical points in the reactor building. Even small amounts of explosives (weighing just a few kilos) could trigger a core melt accident with a large-scale release of radioactive particles.

We must expect that a terror attack with the participation of insiders could be “successfully” concluded within just a few minutes. It is doubtful whether security personnel at a NPP would be able to prevent a well-prepared attack. It is conceivable that several drones could “deliver” the explosives. Overflights by drones have made it clear that existing security measures for (French) nuclear power plants cannot prevent such an attack. At the same time the possibility of supporting such an attack with drones is obviously realistic.

Terror attack by an anti-tank guided weapon: Improved armor technology and additional armor for armored vehicles have led to improved portable, shoulder-fired, anti-tank guided weapons (ATGW). Portable anti-tank weapons are available in great numbers on the black market. It is assumed that two groups of attackers would fire from a hidden position about 100 to 1,000 m away from the reactor with both shaped charge and thermo-baric warhead. It is highly probable that the cooling of the reactor core would completely fail and it would be very difficult or impossible to restore it within a short period of time. A core melt accident would then be practically inevitable. (Becker 2010)

Terror attacks by helicopter: A terrorist attack by helicopter is one of several conceivable aerial attack scenarios. For such an attack a terrorist group would have to obtain possession of a helicopter, load it with a large quantity of explosives, fly the loaded helicopter to the NPP and detonate a large quantity of explosives. Considering all the steps required, a terrorist attack using a helicopter is a relatively simple attack scenario to execute with a high probability of causing catastrophic consequences.

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[4] *In order to completely assess and weigh nuclear risks it is essential to view the entire spectrum of danger represented by terrorism. The public has a fundamental right to that. On the other hand an expert examination must avoid publishing critical details affecting the vulnerability of nuclear power plants that could be misused to provide immediately “useful” information or “how-to” instructions for executing such attacks. Likewise, “ideas” for new scenarios that were previously unknown and that could lead to imitation should be sketched only in broad outline. This working paper was drafted with appropriate consideration given to those concerns.*

A release of radioactive substances can likewise be feared if the explosion impacts the building used to store spent fuel elements. It is possible that explosives could cause considerable damage to the structure and thus the loss of its cooling water. Countermeasures being neither available nor possible, a large release of radioactive substances into the atmosphere would be unavoidable.

4 Consequences of an attack on a nuclear facility

A crash of a commercial airline or another terror attack – e.g. the scenarios described in chapter 3 - that causes a major damage of the reactor building would lead to an accident of the most severe category, core melt accident with open containment. Radioactive substances would thus be released especially early (within a few hours) and the release would be especially high. People in a big area must be evacuated in the short term. This is obviously not possible. If an evacuation should go wrong, then, depending upon the weather, hundreds of thousands of people could receive life-threatening doses of radiation.

Furthermore, in particular, the ground contamination of cesium-137 (Cs-137) forces a long-term relocation of the population. A possible release of 50 % of the Cs-137 inventory of the core corresponds to about 40 PBq[5] for a reactor at the Cernavoda NPP, to about 60 PBq for a reactor of type VVER 440 (Dukovany 1-4 or Paks 1-4) and to about 130 PBq for a reactor of type VVER-1000 (Kozloduy 5&6, Temelín 1&2).[6]

Accident scenarios involving spent fuel pools: A terrorist attack causing severe damage to the building could lead to the loss of the cooling fluid (water). In this case, the spent fuel would heat up and catch fire and release huge quantities of cesium-137 into the atmosphere. The possible release depends on the density of the stored fuel. The resulting spent fuel fire would release a significant fraction of the cesium-137 from the fuel into the atmosphere. A recent study calculates a faction of 75% (10-90%) of the cesium inventory.

Dry interim storages facilities and transport of spent fuel: Loss of integrity of one of the spent fuel casks during transport or storage due to a terror attack would lead to the release of radioactive substances and the contamination of the vicinity.

5 Countermeasures and their limitation

Several countermeasures against the terror threat were discussed in the aftermath of the 9/11 terror attacks. However, countermeasures for the existing nuclear facilities are limited. All conceivable protective preventive measures can be overcome by the imagination of an attacker and/or by the corresponding strengths and weaponry of the attacking group. This is also valid for attacks by land and in particular, to attacks from the air and by water; or combined attacks.

Short term shutdown of the reactor: A decisive problem for reactor safety lies in the fact that although a quick interruption of the nuclear chain reaction can be achieved by a fast shutdown that does nothing to stop heat developing through the radioactive decay of the fuel. Thus, if the cooling fails, a meltdown of the core can occur within a short period of time. Estimates indicate that the

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[5] Peta Becquerel=10^{15}Bq

[6]Compare for example the Chernobyl accident, where about 85 PBq of Cs-137 and at the Fukushima accident when about 10 PBq of Cs-137 were released.

shutdown must take place over weeks or months prior to the attack in order for there to be sufficient time to take intervention measures.

Strengthening protection of the facility: One option for defending against terrorist attacks is to strengthen the facility's protection. This includes measures such as increasing the number and armament of security personnel, extending fencing, erecting barriers on approaches, etc. However, these measures have only little effect to prevent sabotage by insiders or an asymmetric attack.

No-fly zones and anti-aircraft weapons: Although no-fly zones around nuclear power plants reduce the risk of accidental crashes, this measure has no effect against a targeted attack. Likewise, air force interceptors can contribute only marginally to the protection of nuclear power plants. Theoretically it would be possible for scrambled interceptors to shoot down a helicopter that had been recognized in time as having a terrorist intent. However, it is almost impossible to expect that the interceptors could get there in time. A high protection level offering a good opportunity to defend against attacks could be provided only by comprehensive military security however, appears to be untenable in an open democratic society. Furthermore, there are specific risks associated with such measures.

Design Protection for Nuclear Power Plant: The design of new nuclear power plants was improved to limit the vulnerability against the crash of a commercial airliner. The protective design of the reactor building of the **AES-2006** (VVER-1200/V491), which is the reactor type for the new nuclear power plant in Hungary (Paks II) appears to be well in line with the general standard of new nuclear power plants (Generation III). However, it must be noted that the safety buildings are not designed to withstand the impact of a large airplane.

Spent fuel storage: The possible release of radioactive substances and thus the consequences depend strongly on the density of the stored fuel. Thus, to reduce the possible release, spent fuel pools should return to low-density racking. Furthermore, a transport of the fuel to a dry interim storage facility as soon as possible would reduce the risk of the spent fuel pools. Decentralized storages, which are located directly on the NPP site, should be favored over central storages, because they minimize the necessary transport of radioactive material and the risk entailed.

6 Vulnerability of the nuclear facilities in specific countries

Old nuclear power plants suffer not only specific ageing related problems, they also show problems because of their **outdated design**. The safety design of nuclear power plants is very important to prevent as well as to deal with incidents or accidents. The concerns are growing due to the Fukushima accident, as the accident revealed that there could be basic safety problems with the old units, whose design was prepared back in the sixties or seventies. There are design weaknesses that cannot be remedied, e.g. the low protection against terror attacks.

Ageing of materials is a major safety issue in nuclear power plants. It must be expected, that the frequency of ageing related incidents will increase with the age of the NPP. In old plants, unexpected multiple failures of structures or components cannot be excluded in case of terror attack.

Almost all lifetime extension programs are carried out in combination with measures to increase the electricity generation, known as **'power uprating'**. An increase of reactor power reduces safety margins and at the same time accelerates ageing processes. Furthermore, power uprates accelerate the development of accidents thereby decreasing intervention time needed to take action to prevent a severe accident or to mitigate the consequences of an accident.

The **safety culture** in some of the nuclear power plants is poor. In this respect, we can assume that a lot of unidentified defects exist at the NPP that would lead to the functional failure of components or systems in case of an incident/accident cause d by a terror attack. Furthermore, a poor safety culture encourages carrying out a terrorist attack with the participation of insiders.

Bulgaria

The units Kozloduy 5 and 6 have been operating for over 20 years; therefore, ageing of materials becomes a safety issue. It must be expected that ageing induced effects will increase in the next years. This could be a danger for the units, in particular because of the lack of appropriate safety culture. Thus, to license a Plant Life Time Extension (PLEX) as intended, i.e. increasing the originally designed operation time of 30 years by 30 years more entails high nuclear risk.

The protection against terror attacks (crash of commercial airplane) of reactor buildings (wall thickness 1 to 1.2 meter) of the Kozloduy NPP (reactor type VVER-1000/V320) is not sufficient. Furthermore, in case of a severe accident with core melt, the retention of the molten core inside the vessel is not possible. A very high release of radioactive substance would result (about 130 PBq of cesium-137). Thus, the risk of terror attacks is high for the Kozloduy NPP.

The Nuclear Security Index reveals the situation in Bulgaria (the risk environment) is a big issue of concern, because this situation enables the possibility of a terror attack. The lack of appropriate prevention of an insider threat is also an issue of concern. This is very important, because the poor safety culture encourages carrying out a terrorist attack with the participation of insiders.

Thus, it is unacceptable that Bulgaria is planning the construction of a new reactor. Until now there are not even concrete plans for the final disposal of spent fuel and high level waste. A very long-term storage of the spent fuel in interim storage facilities that are not sufficiently protected against terror attacks could be the consequence.

Czech Republic

A 10 year-lifetime extension program for all four units at the Dukovany NPP is ongoing. A lifetime extension to 60 years of operation is envisaged. This would require the operation time to double compared to the original operation time of 30 years. Ageing of material is an increasing issue at all units. Degradation effects of safety-related systems and components could significantly aggravate the development of an accident triggered by a terror-attack. At the same time, the Dukovany reactors increased their electric output (power uprate) because of economic reasons thereby increasing pressure on safety, reducing safety margins and accelerates ageing processes.

There are also indications that the safety culture is not sufficient. Thus, it must be assumed that a lot of unidentified faults exist. Furthermore, a poor safety culture encourages carrying out a terrorist attack with the participation of insiders.

To remedy all design weaknesses (in particular the thin walls of the reactor building and location of the spent fuel pool) of the outdated VVER 440/V213 reactor type is not possible. Considering the existing risk of terrorism, it is irresponsible to operate a nuclear power plant with such a high vulnerability to external attacks for 10 or even 30 more years.

The reactor building of the reactor type VVER-1000/V320 at the Temelín NPP are better protected against terror attacks but still not sufficient. Furthermore, in case of a severe accident with core melt, the retention of the molten core inside the vessel is not possible. A very high release of radioactive substance would result (about 130 PBq of Cesium-137). Thus, the risk of terror attacks is also high for the Temelín NPP.

The Nuclear Security Index reveals the situation in the Czech Republic (the risk environment) is an issue of concern regarding the possibility of a terror attack. The cybersecurity is also an issue of concern.

The problems connected to the search for the final disposal site for spent fuel from the existing reactors make it irresponsible to plan on producing an additional amount of the same size in new reactors before having solved this issue.

Hungary

All four units at the Paks NPP received the license to be in operation for additional 20 years. Because their design operation time has already been exceeded, ageing of material is an issue. In addition, the power uprates which were performed during the last years accelerated the ageing process. Degradation effects of safety-related systems and components could significantly aggravate the development of an accident triggered by a terror-attack.

To remedy all design weaknesses (wall thickness of the reactor building and location of the Spent Fuel Pool) of the outdated VVER 440/V213 reactor type is not possible. Taking into account the existing risk of terrorism, it is irresponsible to operate a nuclear power plant with such a high vulnerability to external attacks.

There are doubts about sufficient protection against terror attacks of the reactor type of the planned new NPP Paks II.

The Nuclear Security Index reveals that the situation Hungary (the risk environment) regarding the possibility of a terror attack is an issue of concern. The lack of sufficient protection against the insider threat is also an issue of concern.

Hungary does not have any concrete plans for the disposal of spent fuel; therefore, a key precondition of the construction of another NPP is lacking. Furthermore, the long-term safety of the existing interim storage facility at the Paks site cannot be ensured. Different terror scenarios can lead to massive radioactive releases.

Poland

The financing for the planned reactors in Poland is as difficult as it is for all other current new build projects. Therefore it will be very important to ensure that there will be no attempts made to save money on the interim storage facilities of spent fuel by cutting down on the design protection against terror attacks.

According to the Nuclear Security Index, the situation in Poland (risk environment) enables the possibility of terror attacks. Furthermore, the Nuclear Security Index reveals the prevention of insider threat as well as the cybersecurity must be improved to limit the possibility of terror attacks.

Romania

Units 1 and 2 at the Cernavoda NPP have been operating for only relatively short periods (since 1996 and 2007 respectively), but the reactors were designed in the 1970ies and thus the design is very outdated. Several design weaknesses of the reactor cannot be remedied – in particular the possibility of violent power excursion in case of loss of safety systems and the vulnerability against external hazards (e.g. terror attacks.) In case of a terror attack, a large amount of radioactivity can be released not only from the reactor core but also from the spent fuel pool that is located outside the containment.

Nevertheless, the operator stated in February 2012 that a lifetime extension of 20 years is planned. The operating time of Cernavoda 1 and 2 is 30 years, which will last until 2026 and 2037, respectively. Material degradation due to ageing effects of the pressure tubes, a persisting problem of existing CANDU, plants have already occurred at the Cernavoda-1. Degradation effects of safety-related systems and components could significantly aggravate the development of an accident triggered by a terror-attack.

The Nuclear Security Index reveals the situation in Romania (the risk environment) is a big issue of concern. This situation enables the possibility of a terror attack. Thus, the shortcomings of the security and control measures in regard of cybersecurity and the prevention of insider threat are worrying.

The envisaged completion of the reactor units Cernavoda 3 and 4 is irresponsible due to the increasing risks of terror attacks. Because the structures of the buildings already exist, it is not possible to enhance the thicknesses of the buildings to the necessary extent. Furthermore, it is irresponsible to generate additional radioactive waste and spent fuel, because Romania has no strategy for the disposal of spent fuel.

1 Introduction: Terror attacks on nuclear facilities

The terror threat to nuclear power plants has received considerable public attention during the last sixteen years. This attention has – for obvious reasons – focused on the hazard of the deliberate crash of a large airliner. But long before September 11, 2001, numerous acts of terrorism have taken place. However, the terrorist threat appears to be particularly great in the early 21st century. The overall situation, which is determined by economic, military, ideological and political factors, cannot be evaluated here. But is important to note: although general attention is focused on the threat from the direction of Islamic fundamentalism right now, there are, worldwide, many different ideological positions and organizations from which potential terrorists could be recruited.

There are numerous potential targets for terrorist attacks. Industrial plants, trains stations or filled sports stadiums can appear "attractive" if a terrorist group plans to kill as many human beings as possible in one attack. An attack on a nuclear power plant, on the other hand, could be attractive for a terrorist group because of its immediate effect on power generation, its symbolic character, its double civilian/military character and the global attention it would receive. A successful attack on a nuclear power plant in one country is at the same time an attack on all NPPs around the world. Countries that are highly dependent on nuclear power could face a real dilemma (e.g. Hungary with more than 50 percent).

In recent years, the rise of well-funded terrorist groups combined with the spread of civil nuclear power, has placed nuclear security[7] high on the political agenda. In March 2016, for example, it became known that two of the Brussels suicide bombers had secretly monitored a senior nuclear scientist working at one of Belgium nuclear facility.

Furthermore, concerns over the vulnerabilities of nuclear facilities in the context of conflicts are increasing. The continuing tension between Russia and Ukraine, and fighting in the Middle East, has again focused global attention on these security concerns.

Today, there are 449 nuclear reactors in operation in 30 countries. Nuclear facilities are designed with safety provisions such as thick concrete walls, containment and independent and diverse systems providing multiple backups in an emergency. These provide some protection against terrorist attack. However, 85% of nuclear reactors were built before the 9/11 attacks and were not designed with sabotage in mind.

Old nuclear power plants have numerous known design flaws which make them vulnerable to terrorist attacks (as well as to earthquakes and to floods). At the same time, it is known that they lack measures to manage a severe accident. Also for new nuclear power plant, severe accidents with very high radioactive releases cannot be excluded.

The main target of a terror attack is the reactor building. An additionally risk arises from the nuclear fuel cycle, which involves the enrichment of uranium, fuel production and reprocessing, transport and storage of radioactive material. Storage facilities of spent fuel are vulnerable and – they will be possible targets for a very long time (up to 100 years).

The probability of a terrorist attack cannot be determined using traditional methods for calculating probabilities. But experience has shown that once a terrorist group decides on an attack, it is highly

[7] 'Nuclear security' refers to the prevention of malicious acts involving nuclear or other radioactive materials and their associated facilities. It is typically used in the context of preventing terrorist groups from perpetrating hostile acts. Nuclear security is distinct from non-proliferation (preventing the spread of nuclear weapons to more countries).

likely to be successful. The hijackers of 9/11 were able to learn enough about piloting to reach their goal, and they were able to gain control of all aircraft as planned.

The public debate tends to concentrate on suicide attacks with a commercial airliner since 9 /11 2001. In fact, the threat is much more diverse and complex. It includes the idea of an attack from the air or a deliberate crash of a helicopter loaded with explosives, or dropping a bomb from helicopter. Terror attacks can also be performed by a terror group on the ground.[8]

New possible means to support attacks emerge: Unmanned flying objects, drones, can e.g. – like in military application – be used for the preparation or support of terror attacks. Drones, which have flown over French nuclear facilities in autumn 2014 more than 30 times without uncovering their originators, are also a security threat to nuclear installations. (see chapter 1.1)

Furthermore, additional attack scenarios take attention: In September 2015, a study by the think-tank Chatham House (London) showed the threat to nuclear power plants posed by **cyberattacks**, because the IT safety standards of the facilities are often flawed. (see chapter 1.2)

There have been several global initiatives to improve nuclear security, including the Nuclear Security Summit (NSS) process (2010-16). World leaders from 47 countries and three international organizations participated in the first Nuclear Security Summit, held in Washington April 12-13, 2010. Through the Summit, President Obama brought high-level attention to the global threat posed by nuclear terrorism and advanced a common approach to strengthening nuclear security. (NSS 2016). However, analysis by the Nuclear Threat Initiative (NTI) suggests that progress on nuclear security has slowed since 2014. (NTI 2017)

The identification of terrorist threats against reactors and spent fuel pools is a necessary part of security planning at all nuclear facilities. There is also a pressing need to more systematically identify potential cyber, insider, and asymmetric[9] security threats. More formalized processes for identifying and analyzing threats—for example probabilistic risk assessment (PRA)—could help to improve security at nuclear plants. (see chapter 1.4)

After the introduction in the issue of nuclear security in chapter 1, the possible targets of such an attack are explained in chapter 2. In chapter 3, three possible attack scenarios are described. Chapter 4 illustrates the possible consequences of a terror attack. Chapter 5 discussed countermeasures and their limitations. In chapter 6 country specific issue are presented briefly.

1.1 Drones

In October 2014, several still unidentified drones flying over French nuclear power plants have attracted the attention of the public and of authorities. These flights had taken place either late in the evening, during the night or early in the morning. On 19 October, for example, they had flown over four NPPs located far from each other, and on the next day over three other NPPs, indicating that this was a well-coordinated action. (NZZ 2014)

[8] There are two general possibilities: a large amount of explosive substances is placed outside buildings or a smaller amount is detonated at a sensitive spot in the reactor building.
[9] The term *asymmetry* refers to dissimilarities in the capabilities, strategies, and/or tactics between an adversary and a defending force, for example, a terrorist cell intent on attacking a nuclear plant and that plant's security forces.

According to the media, the drones were sometimes only 20 to 30 centimeters wide, but sometimes two meters wide and therefore could potentially carry smaller quantities of explosives. Even after France's minister of the interior declared that special units of the Gendarmerie, deployed for the surveillance of NPPs since 2007, had received orders to "neutralize" these flying objects, unidentified drones still flew over French NPPs several times. (BZ 2014)

A drone is an aircraft that flies without a human pilot on board and must be remotely controlled from a great distance or programmed before it leaves the ground to fly one or several routes. Basically, a drone is a reusable, unmanned carrier system that can be equipped with sensors as well as weapons.[10] (ALWARDT 2013)

In their military applications, drones have assumed increased importance as an instrument for reconnaissance and monitoring potential opponents. In that role, drone technology has made rapid progress in recent decades. To date, there has been no military application of smaller, easily transportable drones with "standard" armament or that are equipped with e. g. explosive munitions.

Civilian mini-drones are already available for purchase in greatly varying models. Civilian drones are usually called "multicopters". Although civilian drones that could transport several kilograms of explosives are rare, they are already commercially available. The Hexacopter, for example, a drone with 6 arms and altogether 12 motors, can transport loads weighing up to 8 kg. (GENERALVIEW 2014)

Drones also pose a threat if they are used, like the military, for reconnaissance. Drones can transmit detailed images of an NPP's grounds, its resources and the strategies used by its security personnel. This could substantially increase the probable success of an attack and make it more "attractive" for a terrorist group.

A 2014 study done on behalf of Greenpeace Germany investigated whether there are conceivable terror scenarios supported by the drones that make a core meltdown almost inevitable. The intention was not to speculate about who planned and carried out the drone flyovers in France, and for what reason. Rather, the question is whether these drone flyovers pose a threat if a terrorist group are responsible for them.

The result of a study is that, contrary to what officials and operators state, there has been a threat from drone flights over French nuclear power plants since the beginning of October 2014. Not only the drone overflights themselves but also the inability of security officials to explain and prevent such activity are issues for concern.

Most of the time the threat of terrorist attacks on nuclear power plants is deliberately played down. It is argued that nuclear power plants are sufficiently secured but for confidentiality reasons no details can be released. These arguments are contradicted by the drone overflights: For one thing, it appears that operators and officials are powerless to halt the overflights and for another, it must now be assumed - after potentially successful reconnaissance flights - that existing security measures are now known.

1.2 Cybersecurity of Civil Nuclear Facilities

Experts have concerns that cyber security has not been fully anticipated in all Member States of the European Union as indicated by the NTI index. (see chapter 1.3) The cyber threat has expanded exponentially in recent years, with a series of damaging, high-profile attacks that have made

[10] Other terms for drones are "unmanned aerial vehicle" (UAV) or "unmanned aerial system" (UAS).

headlines around the world. Recent attacks against banking and commerce systems, private companies, and national governments highlight the growing gap between the threat and the ability to respond to or manage it. (NTI 2017)

A new era of warfare began when the first attack was launched using a computer virus called Stuxnet against a nuclear installation. The result was a sabotage that altered the speed of the centrifuges with nothing more than a long string of computer code without operators ever noticing. Today, cybercriminals are highly professional and organized. More than 250,000 pieces of new malware are created daily, and they infect more than 30,000 websites every day.

Some nuclear facilities have been target of such an attack: Korea Hydro & Nuclear Power Co Ltd, which operates 23 nuclear reactors in South Korea, said in 2014 it was beefing up cyber security after non-critical data was stolen from its computer systems, although reactor operations were not at risk. In April 2016, German utility RWE increased its security after its Gundremmingen nuclear power plant was found to be infected with computer viruses. The company said they did not appear to have posed a threat to operations.

Concerns about cyber-attacks on nuclear sites have grown in recent years after the emergence of computer malware that can be used to attack industrial controls. A nuclear power plant became the target of a disruptive cyber-attack two to three years ago, and there is a serious threat of militant attacks on such plants. The Director of the International Atomic Energy Agency (IAEA) explained on October 10, 2016 "*This issue of cyber-attacks on nuclear-related facilities or activities should be taken very seriously. We never know if we know everything or if it's the tip of the iceberg*." (NS 2016)

In the opinion of the IAEA, nuclear facilities must priorities protection against cyber threats and determine the potential consequences. Digital systems must be characterized and routinely tested, just as safety features are tested, and a strong security culture must be implemented in the same manner that a safety culture is executed. A clear legal framework for protection of digital systems—preferably at an international level with stress tests and exercises, regulations and licensing requirements—is needed for all nuclear facilities and supporting infrastructure. (NEI 2017b)

1.3 International Physical Protection Advisory Service (IPPAS)

Raja Adnan, director of the IAEA's nuclear security division, said: "For any state that uses nuclear power, a strong commitment to security is a must."

The IAEA promotes the safe, secure and peaceful use of nuclear energy. As part of this, it plays a key role in helping states protect their civilian nuclear materials and facilities. It uses safeguards to check that civil nuclear material is not being diverted into military programs and supports states by providing assistance such as:

- publishing recommendations and technical guidelines, such as the Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities, which helps states comply with the 2005 Amendment to the Convention on the Physical Protection of Nuclear Material;
- undertaking and organizing advisory security assessment and peer-review missions through its **International Physical Protection Advisory Service (IPPAS**) and International Nuclear Security Service.

An IPPAS mission is an assessment of the existing practices in a State, in the light of relevant international instruments and IAEA nuclear security publications, and an exchange of experience and accepted international practices aimed at strengthening the nuclear security organization, procedures and practices being followed by a State. This assessment includes a national level review of the legal and regulatory framework and security measures and procedures in place to execute this framework at facilities and during transport.

IPPAS is conducted by a team of international nuclear security experts. Conclusions are made by consensus based on combined expertise of the international team. The findings of IPPAS missions are reflected in mission reports, which are treated by the IAEA as highly confidential information. (IAEA 2014)

An IAEA IPPAS team completed recently a two-week follow-up mission to review the legislative and regulatory framework for nuclear security in Sweden. This was the 74th such mission conducted by the IAEA since the IPPAS program began in 1995. In addition to reviewing nuclear security practices, the team also discussed the country's implementation of the 2005 Amendment to the Convention on Physical Protection of Nuclear Material, which provides a strengthened framework for combatting nuclear terrorism and protecting nuclear material and nuclear facilities. (WNN 2016)

About IPPAS missions in the countries concerned in this working papier see chapter 6.

1.4 Nuclear Security Index

The Nuclear Threat Initiative (NTI), a US NGO, ranks measures taken by countries to reduce the risk of sabotage in its Nuclear Security Index. (NTI 2017) The index ranks countries based on a range of nuclear security measures by analyzing factors such as government policy and regulation. It does not conduct direct observations of security measures at individual sites.

For the first time, the 2016 NTI Index assesses nuclear security conditions related to the protection of nuclear facilities against acts of sabotage. This new ranking includes 45 countries where an act of sabotage against a nuclear facility could result in a significant radiological release similar in scale to the release in Japan in 2011 when a tsunami hit the Fukushima Daiichi Nuclear Power Plant. The sabotage ranking also found that although some states have been taking steps to protect their nuclear facilities from cyber-attacks, many are still unprepared to deal with cyber-attacks that might lead to sabotage. (NTI 2017)

Table 1 lists the scores and ranks of the NTI Nuclear Security Index for the European countries. In the NTI Index scores of 0 and 100 represent the lowest or highest possible score, respectively; as measured by the NTI Index criteria. More details about the scores of the specific countries are given in chapter 6.

Table 1: 2016 NTI Nuclear Security Index (Sabotage) for the European countries

Rank / 45 countries with nuclear facilities		score
1	Finland	95
=3	United Kingdom	90
=6	**Hungary**	88
9	Sweden	87
=10	France	86
=10	Netherlands	86
=10	**Romania**	86
13	**Czech Republic**	84
=14	**Bulgaria**	83
=14	Germany	83
=14	**Poland**	83
=14	Slovenia	83
19	Belgium	82
21	Slovakia	77
=25	Spain	68

1.5 Design Basis Threat (DBT)

The US regulator NRC as well as the regulators of other countries uses the *design-basis threat* (DBT) concept in its security-related regulations. DBTs describe a specified set of adversary attributes that must be considered in the design of plant security systems. The detailed characteristics of the DBT—for example the number of attackers, their training, and weaponry—are determined by USNRC commissioners based on NRC staff analyses of terrorist motivations, capabilities, and technical means. Generic characteristics of the DBT in the US for radiological sabotage are described as follows:

<u>Radiological sabotage</u>

(i) A determined violent external assault, attack by stealth, or deceptive actions, including diversionary actions, by an adversary force capable of operating in each of the following modes: A single group attacking through one entry point, multiple groups attacking through multiple entry points, a combination of one or more groups and one or more individuals attacking through multiple entry points, or individuals attacking through separate entry points, with the following attributes, assistance and equipment:

(A) Well-trained (including military training and skills) and dedicated individuals, willing to kill or be killed, with sufficient knowledge to identify specific equipment or locations necessary for a successful attack;

(B) Active (e.g., facilitate entrance and exit, disable alarms and communications, participate in violent attack) or passive (e.g., provide information), or both, knowledgeable inside assistance;

(C) Suitable weapons, including handheld automatic weapons, equipped with silencers and having effective long range accuracy;

(D) Hand-carried equipment, including incapacitating agents and explosives for use as tools of entry or for otherwise destroying reactor, facility, transporter, or container integrity or features of the safeguards system; and

(E) Land and water vehicles, which could be used for transporting personnel and their hand-carried equipment to the proximity of vital areas; and

(ii) An internal threat; and

(iii) A land vehicle bomb assault, which may be coordinated with an external assault; and

(iv) A waterborne vehicle bomb assault, which may be coordinated with an external assault; and

(v) A cyber-attack.

The DBT is not designed to be the worst-case threat. It defines the upper bound within the total threat environment against which a nuclear plant licensee is required to protect. The responsibility for protecting against beyond-DBT threats is the responsibility of federal, state, and local agencies. (NAS 2016)

It can be important to know what is the DBT in a specific country. This could be relevant for discussions with the authority, the public and the media about this issue.

1.6 Security Risk Assessment Methodologies

The identification of terrorist threats[11] against reactors and spent fuel pools is a necessary part of security planning at all nuclear facilities. (NAS 2016)

There is also a pressing need to more systematically identify potential cyber, insider, and asymmetric security threats. More formalized processes for identifying and analyzing threats—for example Probabilistic risk assessment (PRA)—could help to improve security at nuclear plants. Probabilistic risk assessment (PRA) or probabilistic safety assessment (PSA) is a highly-developed methodology for performing a risk assessment that is widely applied by the nuclear industry and its regulator.[12] PRA describes the application of risk assessment to accidents at nuclear power plants.

Analyses or exercises can be undertaken for each identified threat to explore whether the terrorist is likely to succeed in causing significant damage, and defenses can be adjusted accordingly. But whether the identified set of threats is complete is generally unknown.

The use of risk assessment can help to

- Broaden scenario identification for both physical and cyber terrorist attacks, including insider and asymmetric attacks;

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[11] The terms *hazard*, *threat*, and *risk* are related but not interchangeable. Hazard is used in a safety context to denote conditions that can result in accidents, whereas threat is used in a security context to denote potential malevolent acts. Risk assessment is a formalized thought process for answering the following triplet of questions: 1) What can go wrong? 2) How likely is that to happen? 3) What are the consequences if it does happen?

[12] The adjective “probabilistic” is included in this terminology to emphasize that the likelihood of an event is expressed in the assessment.

- Account for the performance of plant security personnel in responding to the identified scenarios;
- Identify potential onsite and offsite consequences of such scenarios, ranging from radioactive releases to psychological impacts; and
- Characterize uncertainties in the scenarios, likelihoods, and consequences.

In fact, risk assessment can provide useful security insights that are analogous to the insights derived from safety risk assessments. For either type of risk assessment, explicit treatments of uncertainty are essential, because the components of the assessment (e.g., scenarios, likelihoods, and consequences) can have substantial uncertainties.

The current state of development of risk analysis for nuclear plant security is similar to that for safety risk analysis in the early 1970s. At that time, it was argued that characterizing the likelihoods of physical accidents was infeasible or at least impractical because they had such low probabilities of occurrence and large uncertainties. There has been considerable technical progress in the use of risk assessment for nuclear plant safety over the past four decades. According to NAS (2016), it is not unreasonable to expect that similar progress can be achieved with security risk assessment. In fact, efforts are already under way to further develop this methodology.

Progress is currently being made in adapting and extending risk analysis to security applications. Procedures for conducting security risk assessments do not yet have consensus-level agreement from professional standards organizations as do safety risk assessments, but there do exist methods for performing security risk assessments, for example, HIRSCHBERG (2016).

Hirschberg (2016) proposed an analytic approach that leverages intelligence community knowledge to derive quantitative risk estimates for terrorist threats with potential for catastrophic consequences. Their estimates are based on three elements:

- Probability that an attack is conducted. This estimate is derived based on historical evidence of attractiveness of the target and evidence of terrorist activity in the country of interest.
- Probability that a given terrorist scenario can be successfully implemented. This estimate is based on assessments of the required resources, time, know-how, and countermeasures in place.
- The consequences of an attack in terms of fatalities, injuries, and land contamination.

The experts concluded in NAS (2016): The understanding of security risks at nuclear power plants and spent fuel storage facilities can be improved through risk assessment. Event trees e.g. can be used to systematically explore terrorist attack scenarios, responses, and potential consequences. Expert elicitation can be used to rank scenarios; develop likelihood estimates; and characterize adaptive adversary responses to various preventive, protective, or deterrence actions. The identification of scenarios may be incomplete, and the estimates developed through expert elicitation are subjective and can have large uncertainties. Nevertheless, risk assessment methods that focus on the risk triplet—scenarios, likelihoods, and consequences—can contribute useful security insights.

2 Targets and their vulnerability

The area of a nuclear power plant (NPP) consists of several tens of thousands of square meters. The heart of the plant is the reactor building, which contains the reactor with the radioactive nuclear fuel (in the order of magnitude of 100 t), as well as important cooling and safety systems. Further targets for a terror attack are spent fuel buildings, because these facilities also contain a large amount of nuclear fuel.

2.1 Reactor Building

It is likely that the reactor building will be the primary target in case of an attack. If the reactor is operating as the attack occurs, and if the cooling is interrupted, a core melt can result within a very short time (about a few hours). Such an accident can also occur when the reactor is shut down, although somewhat slower in this case (HIRSCH 2005).

The reactor buildings of the reactor type VVER-440 at Dukovany NPP and Paks NPP are particularly vulnerable to external hazards. Their reactor cores are surrounded by a relatively thin-walled reactor building (less than 1 meter). This design no longer reflects current standards in science and technology. A thickness of about 2 meters is required for new construction projects.

The reactor buildings of the reactor type VVER-1000 at Temelín NPP and Kozloduy NPP are better protected but still not protected enough against external hazards (wall thickness 1 to 1.2 meter).

Regarding the potential effects of a crash by an airliner against a nuclear power plant or another terror attack, a distinction should be made between two cases (HIRSCH 2001):

1) **The impact causes a major damage of the reactor building**: If the reactor building is destroyed terror attack, it has to be assumed that the reactor's cooling circuit will be damaged and that safety and control systems because of debris and fire will also suffer major damage. If the pipelines of the cooling system or the reactor pressure vessel itself are damaged, it would be irrelevant if the emergency cooling system still functioned, since it would no longer be able to be effectively fed in.
   Such a case would thus in a short time – within a few hours – lead to the meltdown of the reactor core. Radioactive substances will be released from the melted fuel and, since the containment will have been destroyed, they can get into the atmosphere with practically no delay or retention inside the building.[13]

2) **The reactor building remains intact or is only slightly damaged**; other buildings on the site are destroyed, with possible damage to the interior of the reactor building as a result of shocks and vibrations caused by the accident. If the reactor building remains intact, there is nevertheless a considerable probability that destruction on the site and vibrations caused by the crash inside the reactor building itself could lead to a core meltdown. If damage were confined to one of the installations of safety relevance, a situation with an enhanced risk would be created, but one which could probably be controlled. While it might seem plausible that only limited damage would occur in the event of a small (military) plane crashing, this cannot be assumed if a commercial airliner crashes. More widespread destruction must be feared from the impacts of debris and fires. It can no longer be guaranteed that the cooling of the reactor would function, even if the integrity of the cooling system had not been

[13] In all studies on risks such a scenario – a core meltdown with open containment – is regarded as the worst conceivable scenario. It leads to particularly large and – even worse – to particularly early releases of radioactivity. The time available for taking protective measures against the disaster is very short.

impaired. In these cases, a core meltdown will occur. Compared to the scenario with reactor building destruction, the consequences are somewhat less severe.

2.2 Spent fuel pools

Spent nuclear fuel, which is removed from the reactor core, is normally stored in pools of water in the reactor building or in the spent fuel building. The spent fuel storage pool is another vulnerable component with considerable radioactive inventory. In some plants, it can contain several times the amount of fuel than the reactor itself. In some nuclear power plants, this pool is located inside the containment and is protected against external impacts by concrete walls. In many cases, however, the pool is installed in a separate building with less protection. Information about the spent fuel pools at the NPPs in countries discussed in this working paper see chapter 6.

As the storage pools of all U.S. reactors are located outside the reactor containment structure, concern has been raised after the 11/9 terror attacks about the vulnerability of spent fuel by terror attacks. A report released in April 2005 by the U.S. National Research Council of the National Academy of Sciences (NAS) found that “successful terrorist attacks on spent fuel pools, though difficult, are possible.” Terrorists could breach the concrete walls of a spent fuel pool and drain the cooling water and “if an attack leads to a zirconium cladding fire, it could result in the release of large amounts of radioactive material.” (NAS 2006)

During a certain period, intervention could be possible to provide cooling of the fuel. If the pool cooling system fails because of the attack and water gradually boils off, it will take about days or weeks (depending on amount and cooling times of the spent fuel in the pool) until the tops of the fuel elements are exposed. But, if the pool is damaged and the water drains off, this point, of course, can be reached much faster.

If a terror attack causes a breach of the concrete walls of a spent fuel pool, the cooling water will pour out. This causes the stored fuel to heat up due to the decay heat. Once the discharged fuel reaches the temperatures of 900 °C, the zirconium cladding of the fuel starts to burn in air. Freshly discharged fuel would reach the point where it burns in air (900 °C) and very severe radioactive releases begin within hours. The resulting fire is very hot and cannot be extinguished with water. In the spent fuel pool the fire could spread to older fuel assemblies, which would not have heated up so quickly by themselves. This could result in the complete melting of the inventory of the spent fuel pool. High radioactive releases can be the result; the cesium release rate would be 10 to 100%. (ALVAREZ 2003) A recently published document estimates a release of 75% of the cesium inventory in spent-fuel pools (NAS 2016)

The ignition of zirconium in air is boosted when during a terror attack the fuel assemblies in the pool is destroyed by crashing debris. Small zirconium pieces can ignite already at a temperature of 200°C.

The spent fuel is kept under several meters of water that constitute an effective radiation barrier. Without water, dose rates in the range of 1 Sv/h are possible up to 10 m. Unshielded, radiation of spent fuel at short distance would be lethal within a few minutes. Therefore, it is very difficult to perform interventions during accidents.

2.3 Dry interim storages facilities and transport of spent fuel

The spent fuel is stored in the spent fuel pools of the reactor for at least two to three years. After that period, it would be transferred to an interim storage facility.[14] Most interim storage facilities today are based on the dry storage concept, which means the fuel is stored in a cask. The casks themselves are stored in a building. Other interim storage facilities are based on the wet storage concept: storage in spent fuel pools. The spent fuel pools are accompanied with the risk explained in chapter 2.2.

In general, the possible release of a terror attack against a dry storage facility would be smaller compared to an attack against a wet storage facility. However, a loss of integrity of one of the spent fuel casks during transport due to a terror attack would lead to massive release of radioactive substances. An attack with man-portable armor piercing weapon, for example, is a relatively "simple" terror attack.

Additional steps can be taken to make dry casks less vulnerable to terrorist attacks. The regulators should upgrade the requirements of its spent fuel storage regulations to improve the resistance of dry casks and the storage building to terrorist attacks.

Decentralized storages, which are located directly on the NPP site, should be preferred to central storages, because they minimize the necessary transport of radioactive material and the risk entailed.

2.4 Other Buildings of the Nuclear Power Plant

Apart from the reactor building and, if applicable, the building with the spent fuel pools, there are further buildings and installation of varying safety significance, for example:

- Switchgear building with plant control room and central electric and electronic installations
- Building for cooling water intake and discharge

So far, not all nuclear power plants have been specially designed against external, human-made impacts (for example aircraft crash). In the case of those that have been, an impact in one spot only has been assumed (corresponding, for example, to the crash of a small military aircraft). Spatial separation of safety-relevant installations was the most important counter-measure. This should guarantee that only one installation vital for safety can be destroyed by an impact – a situation where compensation is possible. If, for example, the plant's electricity supply failed, an emergency supply from the diesel generators would be made via an appropriate transformer. If the control room with the important controlling facilities were destroyed the facilities in the emergency standby building should be able to guarantee the safety functions which are necessary (i.e. the conduction of heat from the reactor).

Even if the reactor building remains intact in case of an attack, it is still likely for the situation to get out of control, if more than one safety relevant installation of the plant is destroyed. This can happen even in case of spatial separation of important components, if the attack has effects which are spread out on the site. For example, in case of the simultaneous failure of power supply from the grid and emergency power supply, there are no more coolant pumps operable. In case of simultaneous

[14] Spent fuel is highly radioactive when it is removed from the reactor. All radioactive materials decay in time, however it takes many thousands of years. The high level of radioactivity concentrated within spent fuel results in a significant level of heat being produced. This characteristic makes a period of interim storage necessary during which the level of heat production decreases.

destruction of control room and emergency feed building, a situation could arise where the safety systems required are still operable, but could not be regulated and controlled any more. Far-reaching destruction on the plant area can furthermore have the effect that access by personnel, and thus emergency measures and repairs are rendered impossible – or are at least not possible within the required time span of a few hours.

Destruction of the cooling water intake building alone already has the effect that all cooling chains of the power plant are interrupted. However, a critical situation is slow to develop in this case, since there are various water reservoirs available at the plant area. Thus, there is time for improvised measures – unless those are hindered by further destructions at the site (HIRSCH 2005).

3 Conceivable attack scenarios

The 9/11 attacks in 2001 led to speculation about the possibility that terrorists could cause a large release of radioactive material by sabotaging a civil nuclear facility. The public debate tends to concentrate on suicide attacks with a commercial airliner; however, the threat is much more diverse and complex. In the following, some possibilities for terror attacks on nuclear power plants (NPPs) are listed as illustrative examples – without claiming completeness. (HIRSCH 2005)

Attack from the air:

- Deliberate crash of a commercial airliner, of a cargo plane or of one or several business jets (possibly loaded with explosives)
- Deliberate crash of a helicopter loaded with explosives or dropping a bomb from helicopter
- Attack by a military plane (with bombs or other weapons)

Firing on plant from a distance:

- Firing with anti-tank guided weapon (ATGW) with shaped charge and thermobaric warheads from ground, water or air

Intrusion of attackers onto plant area:

- Use of one or more car bomb(s)
- Intrusion of armed attackers, carrying explosives, from land, water and/or air

Not all nuclear power plants are vulnerable to the same extent. Generally, older ones are more vulnerable. Most attack options listed here can lead, in the worst case, to very severe releases. Some will have rather limited effects. However, all these aspects will not be discussed in detail here. It is not the intention of this working paper to provide "useful" information to terrorists, which could be used for the planning of attacks.

To assess the risk related to terrorist attacks, however, we need to describe some scenarios in greater detail. The public also has a right to this information. Thus, three possible attack scenarios are discussed in some more detail in this chapter.

Please note: During the discussion on the risk of terrorist attacks, no indications will be made or thoughts expressed that could have instructional character and be "helpful" in planning or carrying out an attack. For this reason, the scenarios and discussions in the working paper are consciously *formulated with great caution and have avoided describing sensitive details. Terrorists with the skills, knowledge and resources to carry out effective attacks will find no information here that they do not already have or can gain access to. However, in presenting the scenarios and outcomes, the author also made sure that restrained wording would not seriously compromise the validity of the working paper or the reader's understanding of its content.*

3.1 Terror attack by insiders

Insiders are at least as much of a threat to nuclear power plants as terrorist attacks from outside. The threat posed by insiders is therefore given a lot of attention in international discussion. One expert pointed out at the international NUSEC conference that the most dangerous thing about insiders is their knowledge – which they always carry with them and over which there is no control. (HONELLIO 2005)

So-called reliability tests are supposed to prevent the hiring of people who could become internal perpetrators in nuclear power plants. Although these tests complicate the infiltration of perpetrators into NPPs, they cannot completely prevent it. In 2014, it became known that a Belgian jihadist worked for three years as a technician for Vincotte Wilrijk before he left for Syria in November 2012. His job gave him access to the control area of the Doel nuclear power plant. (BRUSSELS 2014)

The current shortage in trained personnel and the increased use of outside companies opens up more opportunities for terrorists to work in a NPP, if only for a short time. If a potential attacker once succeeds in securing a job at a nuclear power plant, then he can recruit more insiders – either through ideological persuasion, bribery or blackmail.

Industry experts explain that deliberately triggering a disastrous meltdown of a nuclear reactor would be difficult as nobody is ever alone in its control room, which typically has four to six operators there always. Deliberate acts of sabotage cannot be ruled out, though. (REUTERS 2016)

One of the most important protective measures against attacks by insiders is the four-eyes principle. However, this is ineffective if there are several insiders in the plant. It can also be undermined by carelessness, sloppiness or a generally poor safety culture.

Opportunities for insiders might include acts of sabotage on safety-relevant valves during repair or maintenance work. Such an incident apparently occurred early in August 2016 at the Doel NPP in Belgium when Block 4 had to be shut down at an unscheduled time because 90,000 liters of oil leaked out in the steam turbine area. The Belgian anti-terror agency OCAD is investigating the case. (FLANDERS 2014) Vandoren, the director of OCAD**,** estimates that it was a criminal act that had been prepared for a long time. According to him, investigators are focusing on an act of terrorism. (FLANDERSNEWS 2014)

Islamist militants are turning their attention to the atomic industry's weak spots, security experts say. "The insider threat is one of the most difficult to deal with, as this hinges on the ability to screen employees and figure out the nature of their intentions," said Page Stoutland at the U.S.-based Nuclear Threat Initiative (NTI), citing recent reported incidents in Belgium. His assessment reflects growing anxiety among Western governments and regulators, including the IAEA, about the risk of radicalized individuals gaining access to sensitive energy infrastructure, including nuclear sites. (REUTERS 2016)

Examples for attacks involving insiders:

- Armed members of the security personnel or other insiders perform an attack from the inside or support an attack from outside (through creation of confusion, obstructions of counter-measures or simultaneous attack from the inside)
- Explosives are smuggled on the site or delivered by drones and are detonated in safety-relevant sectors of buildings
- A group of insiders directly intervenes in the operation of the plant, triggering a severe accident
- Insiders perform sabotage during repair and maintenance (for example: sabotaging safety-relevant valves of the cooling circuit to achieve unplanned opening during operation, while blocking re-closure).

There are diverse "effective" scenarios involving insider, but the most feasible appear to be attacks with explosives. Particularly dangerous are attacks which use explosives at critical points in the reactor building. Even small amounts of explosives (weighing just a few kilos) could trigger a core melt accident with the large-scale release of radioactive particles.

We must expect that a terror attack with the participation of insiders could be "successfully" concluded within just a few minutes. It is doubtful whether security personnel at a NPP would be able to prevent a well-prepared attack. Members of the security staff might even be involved as insiders. It is conceivable they could smuggle weapons or explosives into buildings or help others to smuggle them in.

It is conceivable that drones would be used to support an explosives attack. It is also conceivable that several drones could "deliver" the explosives. Estimations show that knowledgeable insiders would need less than 10 kilos of explosives to trigger a core melt accident. Several drone types could deliver this amount without any difficulty since they have load capacities of several kilos and are apparently able to fly over NPPs without interference (see chapter 1.1).

3.2 Terror attack by an anti-tank guided weapon (ATGW)

Improved armor technology and additional armor for armored vehicles have led to improved portable, shoulder-fired, anti-tank guided weapons (ATGW). Above all, in recent decades the effectiveness of the warheads has increased. Modern armor piercing weapons could also be aimed at nuclear power plants – the more effective the weapon, the more consequential such an attack. The technical possibility of rapid fire and easy reloading simplifies an attack. The lighter weight and ease of use also simplify maneuver and thus an attack. Portable anti-tank weapons are available in great numbers on the black market because they are easy to transport and conceal. (BECKER 2010)

The **AT-14** (Kornet E)[15] is a third-generation portable anti-tank guided weapon – a weapon system developed by the Russian company KBP. It is designed to destroy tanks, fortifications, entrenched troops as well as small-scale targets (range: 100 to 5,500 meters). The launcher fires missiles with

[15] Nato name: AT -4; Russian name: Kornet, for export Kornet E

tandem shaped charge[16] HEAT that can pierce 1.2 m of homogenized steel armor plate or about 3 m of steel reinforced concrete. The missiles can also fire high explosive / incendiary (thermobaric effect) warheads, for use against bunkers, fortifications and fire emplacement. The explosive power of this warhead is equivalent to the explosive power of 10 kg of explosives (TNT).

The guided rocket is launched directly from its transport and firing container. This allows for very rapid firing readiness and a relatively fast rate of fire (loading time: 30 seconds). In addition to the daylight optics, the tripod firing equipment is equipped with a thermal imaging device that allows targeting at night. It is possible to use one targeting device to simultaneously control two firing platforms and thus engage a single target with two rockets simultaneously (ARMY 2017).

It must be generally assumed that it would be possible for potential attackers to illegally obtain and AT-14 including components. The AT-14 is sold worldwide. In 1994, the first deployable systems were delivered to the Russian armed forces. In the meantime, the weapon system has been exported to Syria, Jordan, the UAE, Kuwait, Saudi Arabia, Turkey, India, Morocco, Algeria and Greece (ARMY 2017). The more such weapons systems are in worldwide circulation the easier it will be for terrorist organizations to get their hands on them.

The effect of the thermobaric weapon or aerosol bombs (FAE = fuel air explosive) is based on the ignition of a flammable substance dispersed in the air.[17] The primary effect of thermobaric warheads is achieved through the shock wave created by the deflagration that destroys buildings and equipment. The overpressure of the detonation can reach three mega pascals (30 bar). In addition, aerosol bombs have a considerably stronger heat effect than conventional explosives. The temperature could reach 2,500 to 3,000 degrees Celsius. Other damage is done by the vacuum effect: The explosion sucks oxygen out of the air creating a strong under pressure that attracts movable objects and thus lead to further destruction.

Attack scenario

A few years ago, firing tests using a model construction were conducted in Russia to test the vulnerability to modern weapons systems of a new (Generation IV) type of reactor. The AT-14 was used as one of the weapon systems. Conclusion: under the attack scenario of the firing tests a core meltdown accident could be caused. (BECKER 2010)

The following presents an analysis of a possible attack scenario involving the firing of a AT-14 weapon system (without sensitive details): Analogous to the Russian firing test, it is assumed that two groups of attackers each with at least two persons would perform the attack. At the beginning of the attack the terrorists would be in a hidden position about 100 to 1,000 m away from the reactor with a clear view of a small area of the building. Both groups would simultaneously fire shaped charge munitions in several double salvos. This would be followed by the firing of several thermobaric warheads. They would use an aiming device to hit the same target area.

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[16] A shaped charge warhead consists of a hollow metal cone encased with explosives. Upon impact with the target the explosive is ignited. The stream of metal (shaped charge spike) created strikes the target with very high velocity (several thousand meters per second).

[17] A thermobaric warhead consists of a container containing a flammable substance and two explosive charges: the first charge finely disperses the fuel in the air creating a fuel-air mixture, or aerosol. A few tenths of a second later the second charge ignites the aerosol cloud.

The shaped charge munitions could penetrate the steel reinforced concrete of the external containment shell without difficulty since the thickness of the wall is less than 1 m.[18] Every shaped charge munition would create only a very small penetration hole on the exterior of the containment. On the interior side, however, the concrete would be loosened in a circular pattern around the entrance hole. It can be assumed that several shots at the same target area would create a small opening as well as cracks in this small area of the wall. Through that opening the aerosol of the thermobaric warhead would be forced into the interior of the reactor building. The effect of the first thermobaric warhead would be to increase the size of the opening in the previously damaged wall area. The destructive force of the following thermobaric warheads could then develop far into the reactor building. The shock wave would destroy several safety relevant components. The heat would cause sensors and controls to malfunction. In any case the effect of thermobaric explosions would be spread over a wide area so that several redundancy systems might be impacted simultaneously.

It is highly probable that the cooling of the reactor core would completely fail and would be very difficult or impossible to restore within a short period of time. A core melt accident would then be practically inevitable. Since the containment would have a leak the most dangerous accident would result: a core meltdown with an open containment.

3.3 Terror attack by helicopter

There are several conceivable attack scenarios besides using a commercial airliner for a terror attack from the air. The danger of a terror attack from the air is particularly high for reactors - since these are protected from external effects by relatively thin walls.

A terrorist attack by helicopter is one of several conceivable aerial attack scenarios. For such an attack a terrorist group would have to a) obtain possession of a helicopter, b) load it with a large quantity of explosives, c) fly the loaded helicopter to the NPP and d) detonate a large quantity of explosives.

a) It is relatively simple for terrorists to get possession of a helicopter: Flying helicopters even for private purposes is a growing trend. A helicopter, e. g. for sightseeing flights, can be booked in many places. As the following example shows it would also be possible to hijack a helicopter with its pilot: using a helicopter three prisoners escaped a prison in Bruges (Belgium). Two persons had previously taken the pilot of the helicopter hostage; they both pretended to be tourists who had booked a sightseeing flight. (WELT 2009)

b) Loading a large quantity of explosives is simple: a helicopter can land and take off at many places relatively easily. It needs only a relatively small area. For example, a helicopter could land at a hidden site and there be loaded with explosives. The possible loaded weight of a helicopter is roughly about 1 ton. Even smaller helicopters could be loaded with several hundred kilograms.

c) Getting to the target with a helicopter is obviously possible: With a speed over 200 km per hour a helicopter has a relatively high speed. It can therefore fly to a nuclear power plant very quickly so that the intention of the terrorists would not be evident prior to the attack.

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[18] The shaped charge spike would lose about a third of its energy on impact so that it could have enough left, at least in certain areas, to destroy safety-relevant technical components. However, since such damage would be relatively localized, these events could be mastered by the safety systems of the nuclear power plant.

With a fuel capacity of several hundred liters a helicopter has a large range (several hundred kilometers).

d) Due to its easy to use and precise steering as well as the ease of landing even in small areas (e.g. on roofs of hospitals), a helicopter was predestined for rescue use. Precisely these characteristics enable terrorists to use a helicopter as a weapon against a nuclear power plant. A helicopter loaded with a large quantity of explosives can be easily flown by terrorists into a reactor building or the spent fuel building. Overflights of French NPPs by drones in autumn 2014 have revealed point of weakness in the aerial monitoring of (French) nuclear power plants and above all in the defense against such potential attacks from the air.

   It is possible to trigger an explosion on buildings: With the help of a helicopter quantities of explosives of more than 100 kg could be used. In addition, they could also be attached to the building. The effect of explosives is largest when they are brought into direct and close as possible contact with the structure to be blown up. A few minutes would be sufficient to attach the charge and detonate the explosives. That is not enough time for alerted security forces or police to prevent the action. That being the case, a “successful” action must be assumed.[19]

   Alternatively, a suicide attacker could crash a helicopter loaded with explosives into the building. In such case a large quantity of fuel would increase the extent of the potential damage. Al in all, it must be assumed that terrorists could detonate a large quantity of explosives at a suitable point.

Effects of the attack

Nuclear power plants are not designed against detonations of explosives. Protection from explosives is supposed to be achieved by not allowing explosives to be stored near the power plant.

A widely-used explosive is trinitrotoluol (TNT) that, among other things, is also used in the military for weapons and explosives. Estimation about the quantity of TNT that would be required to achieve the complete penetration of the reactor building. A multiple of that quantity can be easily transported by a helicopter.

Falling concrete rubble weighing tons, shock waves and shaking from the detonation of that quantity of explosives or effectively placed explosive charges could cause heavy damage within the reactor building and interrupt the cooling of the reactor and due to that destruction sufficient cooling could not be restored. There is a high probability that it would result in a core meltdown accident with release of considerable amounts of radioactivity.

A release of radioactive substances can likewise be feared if the explosion impacts the building used to store spent fuel elements. It is therefore possible that explosives could cause considerable damage to the structure and thus the loss of its cooling water. Countermeasures being neither available nor possible, a large release of radioactive substances into the atmosphere would be unavoidable.

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[19] This is all the more true if the attack is supported with drones to investigate the current situation (location and activity of security personnel, etc.) or to attack those personnel. Drones could support such an attack both in its preparation and during its execution. For example, detailed imagery from the drone could be used to select a suitable landing site for the helicopter and the point for attaching explosives and to observe security personnel.

Considering all the steps required, a terrorist attack using a helicopter is a relatively simple attack scenario to execute with a high probability of causing catastrophic consequences.

4 Consequences of an attack on a nuclear facility

4.1 Reactor core

A crash of a commercial airline or another terror attack that causes a **major damage of the reactor building** would lead to an accident of the most severe category, core melt with open containment. For the terror scenarios discussed in chapter 3 there is also a high probability that the result of an attack would be a core meltdown with an open containment. Radioactive substances would thus be released especially early (within a few hours) since none of the restraints of the containment would be available even for a brief period.[20] In addition, the release would be especially high. The quantity of volatile radioisotopes (e. g. cesium-137) released would be between 50 and 90 % of the core inventory, plus a few percent of further nuclides like strontium-90 (HAHN 1999).

In the event of a core meltdown with an open containment there would be only an extremely short time to evacuate the populace. People in a big area must be evacuated in the short term (about a few hours). This is obviously not possible. If an evacuation should go wrong, then, depending upon the weather, hundreds of thousands of people could receive life-threatening doses of radiation. The level of protection for the inhalation of radioactive substances of buildings is rather low. Often, buildings only halve the inhalation dose. As a result, a lethal radiation dose is likely to occur at a distance of several kilometers, even inside buildings. At greater distances, considerable long-term consequences for the health are to be expected (above all cancer and genetic damage to subsequent generations).

Cesium-137 is the main radioactive contaminant that has forced the long-term relocation of populations from large areas around the Chernobyl and Fukushima Daiichi nuclear power plants.[21] A portrayal of the possible consequences of an accident due to exceeding design limits is available from the results of the FlexRisk Project (FLEXRISK 2017). The cesium-137 depositions computed were graphically depicted since they provide an idea of the long-term contaminations. For the reactors considered in this working paper it was assumed that 10 to 30 % of the core inventory of cesium-137 would be released under a severe accident scenarios at each of the reactors. The release under the terrorist attack scenarios discussed here could be even greater.

A possible release of 50 % of the Cs-137 inventory of the core corresponds to about 40 PBq[22] for a reactor at the Cernavoda NPP, to about 60 PBq for a reactor of type VVER 440 (Dukovany 1-4 or Paks 1-4) and to about 130 PBq for a reactor of type VVER-1000 (Kozloduy 5&6, Temelín 1&2). Note: At the Chernobyl accident, about 85 PBq of caesium-137, at the Fukushima accident about 10 PBq of caesium-137 were released.

The consequences of accident scenarios **without a major damage of the reactor building** compared to the scenario with reactor building destruction are somewhat less severe. The radioactive

[20] After a longer delay a portion of the radioactive isotopes that would be released from the molten fuel rods would precipitate down to colder surfaces within the building. This factor that reduces exterior release of radioactivity is lost when the containment is breached.
[21] Cesium-137 is a fission product with a 30-year half-life that emits a high-energy gamma ray when it decays.
[22] Peta Bequerel=10^{15}Bq

substances released are to some extent reduced because radio-nuclides condense inside the building and there is more time for intervention measures especially for evacuation the population. In this scenario, however, there are also long-term disastrous consequences for a large area.

4.2 Spent fuel pools

It has long been known that the loss of water from a nuclear power plant's spent fuel pool could have catastrophic results. The dense-packing of pools in the United States also has been a long-term concern because such pools contain several times as much spent fuel as they were originally designed to hold. This makes it more likely that, if there were a loss of coolant, the spent fuel would heat up and catch fire and release huge quantities of cesium-137 into the atmosphere. The possible release depends on the density of the stored fuel. The spent fuel pool in Unit 4 at the Fukushima Daiichi was of particular concern because it had a high decay-heat load.

A terrorist attack that led to severe damage to the building could cause loss of the cooling fluid (water). This would lead to the heating of the fuel stored inside. In 2003, following the terrorist attacks of 11 September 2001, a group of researchers argued that, given the risk of terrorist attacks and the huge potential consequences of a spent fuel pool fire, the NRC should require that U.S. spent fuel pools be returned to low-density racking. To make that possible, they proposed that spent fuel should be moved into dry-cask storage after five years of pool cooling. (ALVAREZ 2003)

In a situation with leakage in the pool, draining it faster than the water could be replenished, it was found that, if the top half of the spent fuel were uncovered and the drainage of the pool were not too fast, a steam-zircaloy reaction would produce substantial amounts of hydrogen. In the case of a dense-packed pool, enough hydrogen could be generated to produce an explosive concentration in the large space over the pool. A hydrogen explosion would blow out the upper walls and roof of the reactor building, as happened at Fukushima, and allow the ingress of air carrying unlimited quantities of oxygen. The resulting spent fuel fire would release a significant fraction of the cesium-137 from the fuel into the atmosphere. Base-case estimates of cesium-137 releases and the associated uncertainty ranges for fires in dense-packed spent-fuel pools of U.S. PWRs[23] are 75% (10-90%) of the cesium inventory. (HIPPEL 2016)

According to NRC estimates, a fire in a dense packed U.S. spent-fuel pool could release 100 times as much cesium-137 into the atmosphere as was released by the three reactor meltdowns that occurred in Fukushima; on average, such an accident would cause the relocation of 3.5 million people. Comparison of the average consequences of releases of about 7 PBq of cesium-137 from a low-density pool and 330 PBq from a high-density pool, it found that the smaller release would cause the displacement for a year or so of about 120,000 people from an area of about 600 km^2, on the same order as the area made uninhabitable by the Fukushima accident. The larger release would displace an average of 4.1 million individuals from an area of 24,000 km^2. The calculated population radiation doses would result in an estimated 3,000 and 20,000 cancer deaths respectively. (HIPPEL 2016)

[23] for operating PWR but also for the new reactor AP-1000

4.3 Dry interim storages facilities and transport of spent fuel

Loss of integrity of one of the spent fuel casks during transport or storage due to a terror attack would lead to a release of radioactive substances and a contamination of the vicinity. An attack with man-portable armor piercing weapons, for example, is a relatively “simple” terror attack.

For firing at transport and storage cask of the CASTOR type with an armor piercing weapon, a study by the GRS (Gesellschaft fur Anlagen- und Reaktorsicherheit) a radiation exposure of 300 mSv in a distance of 500 m was calculated. (GRS 2003) For a similar scenario, with additional possible zircaloy fire in a cask, another study concluded, that the evacuation of the population in the area up to 5 km distance would be necessary. (GRUPPE ÖKOLOGIE 2004)

Decentralized storages, which are located directly on the NPP site, should be preferred to central storages, because they minimize the necessary transport of radioactive material and the risk entailed.

5 Countermeasures and their limitation

Several countermeasures against the terror threat are discussed in the aftermath of the 9/11 terror attacks. However, countermeasures for the existing nuclear facilities are limited. For new nuclear power plants the design is improved to limit the vulnerability against terror attack, in particular against the crash of a commercial airliner.

5.1 Short term shutdown of the reactor

A decisive problem for reactor safety lies in the fact that although a quick interruption of the nuclear chain reaction can be achieved by a fast shutdown, that does nothing to stop heat developing through the radioactive decay of the fuel (so called decay heat). Thus, if the cooling fails, a meltdown of the core can occur within a short period of time. After shutdown heat development initially drops rather quickly. A timely shutdown can reduce this decay heat and thus slow the process of core meltdown. However, estimates indicate that the shutdown must take place over weeks or months prior to the attack to be sufficient time to take intervention measures.

The chances of successful countermeasures are better for a reactor that has been shut down for long time. The amount of radioactive substances released is also less since some of the short half-life radioisotopes (e.g. iodine-131) has already mostly decayed.

A shutdown done as a short-term measure in case of a direct threat, however, does not accomplish very much.

5.2 Strengthening protection of the facility

One option for defending against terrorist attacks is to strengthen the facility’s protection. This includes measures such as increasing the number and armament of security personnel, extending fencing, erecting barriers on approaches, etc. Details concerning such measures are not published.

New license conditions for Sweden’s NPPs, for example, came into force on 4 February 2017. The conditions mandate the use of armed security guards at nuclear stations and say perimeters should be guarded and controlled 24/7 with the help of guard dogs. The Swedish Radiation Safety Authority (SSM) said the new license conditions improve the physical protection regime for NPPs, noting: “The need for broader conditions has evolved over time due to aspects such as the changed state of international security.” (NEI 2017a)

Protection against attacks by land are doubtless improved by such measures. As the drone overflights in France, show they are of less help against attacks from the air.[24] Furthermore, drones can be used, like the military, for “reconnaissance”. Drones can transmit detailed images of an NPP’s area and the security personnel. This could substantially increase the success of an attack and make it more “attractive” for a terrorist group.

Strengthening the facilities protection by increasing the number and armament of the security personnel has only little effect to prevent sabotage by insiders or an asymmetric attack.

5.3 No-fly zones and anti-aircraft weapons

In European countries flying over nuclear power plants within a radius of 5 km and at a height below 1000 m is prohibited. Although no-fly zones around nuclear power plants reduce the risk of accidental crashes, this measure has no effect against a targeted attack, e. g. with a helicopter. The drone overflights in France have made the low value of no-fly zones obvious.

Likewise, air force interceptors can contribute only marginally to the protection of (French) nuclear power plants. Theoretically it would be possible for scrambled interceptors to shoot down a helicopter that had been recognized in time as having a terrorist intent. However, it is hardly to be expected that the interceptors could get there in time. After being alerted they require at least 15 minutes to takeoff and a few minutes more to arrive at the nuclear power plant. During that time, however, a helicopter could cover 70 km. It is therefore even more improbable that at that distance the terrorist intention of the helicopter could be recognized.

Following the 9/11 attacks on the United States, French authorities deployed ground-to-air missiles in La Hague, though these were removed a few months later after the threat level was deemed to have receded.

A high protection level offering a good opportunity to defend against attacks could be provided only by comprehensive military security - i.e. the stationing of ground troops with protective positions, antiaircraft batteries, fast patrol boats and combat divers on the water etc. such militarization of the energy business, however, appears to be untenable in an open democratic society.

Besides that, there are specific risks associated with such measures. Weapons can be triggered accidentally or through technical defects. Civilians could be the victims of defensive measures triggered through a supposed or actual threat.

In addition, weapons can also cause damage to the nuclear power facility. They could even intentionally be used against the facility if military personnel were bribed by terror organizations or otherwise recruited. Even the capture and takeover of defensive positions by terrorists cannot be excluded.

[24] According to media reports, on 30 October 2014 gendarmes received permission to fire on drones flying over the sites of nuclear power plants [LU. –WORT 2014]. The question also appears to be what weapons are suitable for that purpose. In any case, after the authority to fire was issued there have been other drone flights over nuclear power facilities.

5.4 Training and exercises

One measure to increase the protection of a nuclear facility is to perform exercise and trainings. One example is the exercise at the Temelín NPP in April 2017.

Military equipment has been installed around the Czech nuclear power plant in Temelín at the start of the Safeguard Temelín 2017 exercise to train the defense of the facility from both a possible ground and air terrorist attack. The soldiers and police trained an action against a lorry that tried to break through the barriers. They formed two checkpoints. The lorry attack in Berlin (December 2016) was the topic of the exercise. The action against a small L-410 transport plane was tried by the soldiers from an anti-aircraft regiment. They used the equipment for the firing of missiles and a radar that intercepts air targets. Some 200 police, soldiers and specialists from the CEZ national power company took part in the four-day exercise. Fighter planes from Caslav[25], east Bohemia, are permanently on alert for the defense of Temelín. Temelín repeats the exercise once in two years. (PRAGUEMONITOR 2017a, b)

Exercises are an essential tool for assessing the capability of nuclear power plant security officers to protect their facilities from terrorist attacks, and they need to be preserved and strengthened. However, in case of an unexpected attack neither the soldiers nor the equipment will be available as fast as necessary.

5.5 Design Protection for Nuclear Power Plant

The wall of reactor buildings generally consists of reinforced concrete. The thickness of this hull and hence its resistance to attacks varies following the revisions of the criterion, regarding airplane crash, applied to the design of the buildings. In Germany, for example, the walls of the oldest plants, being permanently shut down, consist of reinforced concrete about 0.60 meters. This is only enough to withstand a crash of a sporting plane. Other old NPPs, also permanently shut down since summer 2011, have walls which are about one meter. They should be able to withstand the crash of a small military plane (Starfighter). The "newest" nuclear power plants in Germany are designed to withstand the crash of a bigger military plane (Phantom, 20 t and speed of about 770 km/h). The reactor buildings of these plants have a wall thickness between 1.60 and 2 meter. (BMU 2010; Hirsch 2001).

Protection concerns the accidental crash of a military aircraft onto safety-relevant plant areas were taken against the background of a high crash rate of military aircrafts in the 1970s.[26] Similar requirements were found only in Switzerland. Reactor buildings of NPPs in other countries tend to be less protected than plants in Germany.

Even the best protected German plants may in the event of a plane crash face stresses and strains beyond those they have been designed to cope with. The impact of an aircraft crash can be even greater than that of a Phantom jet. The impact of a crash depends on the mass and speed of the plane causing the impact, and on the area impacted and the extent to which concrete structures are broken down (the smaller the area, the more concentrated and so greater the effect). The greater

[25] More than 100 km away from both Temelín NPP und Dukovany NPP.

[26] The general basis was the analysis of the crash frequency (the exceedance probability for impacts on safety-relevant buildings is about 10^{-6}/year and plant). The German Federal Republic was for a long time a country in the front line in the Cold War. Its airspace had a high density of military planes. Since the end of the 1980s, the crash rate of military aircraft has decreased considerably. This has the effect that the crash frequency today can be assumed to be smaller by about one order of magnitude.

mass of a commercial airliner spreads the effect of its impact over a larger area. At the same time, the engines are compact "missiles", which can have a mass of several tones. It is obvious that the effects of flying debris and fires with fuel would be far greater in the crash of a commercial airliner than those assumed for a military jet (HIRSCH 2001).

Accidental crashes of airplanes have been considered in the design of reactors for several decades. However, according to the estimated frequencies of crashes, only crashes of small airplanes and/or military airplanes were generally taken into account. After the 9/11 attack, the consequences of an intentional crash of a commercial airplane were then considered.

All new reactor designs aim for protecting against a deliberate crash of a commercial airliner. An example is the European pressurized reactor (EPR): The outer walls of the reactor building, the fuel building and two of the four safeguard buildings are designed against penetration. For these buildings, the internal structures are decoupled from the outer walls in order to reduce induced vibrations, and the fixing of sensitive or safety relevant systems onto the outer walls is avoided.

An airplane crash into an NPP has the potential to damage the roofs and walls of the building, as well as other systems and components such as pipelines, electric motors, power supplies and power cables for electricity transmission that are important for safety. A lot of studies investigate special issues of these effects in order to protect the next generation of nuclear power plants. It can be concluded that roughly a wall thickness of two meters is sufficient to prevent the perforation even in the case of the Boeing-747. But the problem which remains is the strong shaking of the structures and of components. (PETRANGELI 2010).

The **Western European Nuclear Regulators' Association** (WENRA) defined and expressed a common position on the safety objectives for new nuclear power plants in November 2010.

Selected key safety issues are discussed in a safety report of the Reactor Harmonization Working Group (RHWG) of the WENRA, among other, the intentional crash of a commercial airliner. The WENRA RHWG (2013) stated: Despite measures taken to prevent the intentional crash of a commercial airplane, this event should be considered in the design of new reactors.

According to WENRA, buildings or appropriate part of the buildings containing nuclear fuel and housing key safety functions should be designed to prevent airplane fuel from entering them. Fires caused by airplane fuel shall be assessed as different kinds of fire ball and pool fire combinations. Other consequential fires due to the airplane crash shall be addressed.

The general expectation is that such a crash should not lead to core melt and therefore not cause more than a minor radiological impact as stated in Objective O2. (=O2: ensuring that accidents without core melt induce no off-site radiological impact or only minor radiological impact (in particular, no necessity of iodine prophylaxis, sheltering nor evacuation))

Safety functions required to bring and maintain the plant in a safe state after such a crash shall be designed and protected adequately.

According to WENRA RHWG (2013), direct and indirect effects of the airplane crash shall be considered, in particular:

- effects of direct and secondary impacts on mechanical resistance of safety structures and systems required to bring and maintain the plant in a safe state after airplane crash;
- effects of vibrations on safety structures and systems required to bring and maintain the plant in a safe state after airplane crash;

- effects of combustion and/or explosion of airplane fuel on the integrity of the necessary structures and on the systems required to bring and maintain the plant in a safe state after airplane crash.

According to the developer of the **AES-2006 (VVER-1200/V491)**, which is the reactor type for the new nuclear power plant in Hungary (Paks II), the design basis aircraft crash corresponds to the following load: Crash of an airplane with a mass of 5.7 t, at a speed of 100 m/s. (ASE 2015) According to the design institute Atomenergoproject, there is protection against the impact of an (unspecified) large commercial. (AEP 2011)

The protective design of the reactor building (double ferro-concrete cover) appears to be well in line with the general standard of new nuclear power plants (Generation III). It is plausible that it provides good protection against the mechanical impact of the crash of a commercial airplane, and against the effects of vibrations.

However, it should be noted that the safety buildings are not designed to withstand the impact of a large airplane. The building sections of the four redundant trains of the safety systems are located side-by-side; they are separated, but directly adjacent, without any physical distance, and hence several or all of them could be impaired by mechanical impacts. The same applies to the four diesel generators. (AEP 2011)

According to the STUK´s assessment in 2009, not all parts of the design objectives and principles of the AES-2006 plant alternative are consistent with Finnish safety requirements. (STUK 2009) Of particular concern is the structural protection against airplane crashes.

It must be considered that the Paks II NPP will be also vulnerable against other attacks.

5.6 Mitigation measures for Spent fuel storage

The safe storage of spent fuel in pools depends critically on the ability of nuclear plant operators to keep the stored fuel covered with water. This fact was understood more than 40 years ago and was powerfully reinforced by the Fukushima Daiichi accident. If pool water is lost through an accident or terrorist attack, then the stored fuel can become uncovered, possibly leading to fuel damage including runaway oxidation of the fuel cladding (a zirconium cladding fire) and the release of radioactive materials to the environment.

As mentioned in chapter 4, the possible release of radioactive substances and thus the consequences depend strongly on the density of the stored fuel. Thus, to reduce the possible release, spent fuel pools should be returned to low-density racking. Furthermore, a transport of the fuel to a dry interim storage facility as soon as possible would reduce the risk of the spent fuel pools.

6 Vulnerability of the nuclear facilities in specific countries

Old nuclear power plants suffer not only specific ageing related problems, they also show problems because of their outdated design. The ageing of nuclear power plants leads to two kinds of dangerous changes:

- Physical degradation, i.e. gradual deterioration in the physical characteristics,
- Obsolescence, i.e. becoming out of date in comparison with current standards and technology (design weaknesses).

Ageing of materials is a major safety issue in nuclear power plants. It must be expected, that the frequency of ageing related incidents will increase with the age of the NPP. These incidents have the potential to trigger, but particularly to aggravate accidents sequences. **In old plants, unexpected multiple failures of structures or components cannot be excluded for example in case of external event (earthquake or terror attack**); in particular, common cause failures of safety relevant systems cause concern.

To limit ageing related failure at least to a certain degree, a comprehensive ageing management program (AMP) is necessary. AMPs include in-service inspections, monitoring of thermal and mechanical loads, safety reviews and also the precautionary maintenance. These measures rely on the optimistic assumption that cracks and degradation will be detected before they lead to failure. However, this is not realistic. This means that once the reactors have passed the design lifetime, the number of failures could start to grow.

There is another issue regarding ageing effects, which has occurred very often. Incidents or accidents can also be caused or aggravated indirectly by ageing: When original or old components are replaced, (new) faults because of defective mounting or of forgotten scrap etc. are possible. These faults have the potential to aggravate an accident situation. It cannot be taken for granted that all the structures, systems and components (SSC) after modernization's programs (back-fitting measures) are in place and without faults.

Almost all LTO programs are carried out together with measures to increase the efficiency of electricity generation, known as **'power uprating'**.[27] An increase of reactor power reduces safety margins and at the same time accelerates ageing processes. Power uprates cause several different unexpected failures in safety systems. Power uprates accelerate the development of accidents thereby decreasing intervention time needed to take action to prevent a severe accident or to mitigate the consequences of an accident. Furthermore, in case of a severe accident, the potential radioactive release is higher.

The **safety culture** in some of the nuclear power plants is poor. In this respect, we can assume that a lot of unidentified defects exist at the NPP that would lead to the functional failure of components or systems in case of an incident/accident. **Furthermore, a poor safety culture encourages carrying out a terrorist attack with the participation of insiders**.

The safety design of nuclear power plants is very important to prevent as well as to deal with incidents or accidents. The concerns are growing due to the Fukushima accident, as it revealed that there could be basic safety problems with the old units, whose design was prepared back in the

[27] To uprate the electrical power of NPP, there are two different possibilities, which are often combined:
The thermal efficiency of the plant is increased (mostly achieved by optimising the turbines). The safety level of the plant remains nearly unaffected. An increase of thermal power implies more nuclear fissions (and so more fission products). Also, higher loads to the reactor materials are unavoidable.

sixties or seventies. The safety design of all operating plants is outdated and showing deficiencies. There are design weaknesses that cannot be remedied, e.g. the low protection against terror attacks.

The following chapter describes **design weaknesses**, particularly those which cannot be resolved by performing back-fitting measures. There are three reactor types operating in four of the five country which this study considers: the CANDU 6 reactor (Cernavoda 5/6, Romania), the VVER-440/V213 reactor (Dukovany 1-4, Czech Republic; Paks 1-4, Hungary) and the VVER-1000/V320 reactors (Kozloduy 5/6, Bulgaria; Temelín 1/2, Czech Republic).

6.1 Bulgaria

Kozloduy 5 and 6 (**VVER-1000/V-320** reactors with a net capacity of 963 MW each), put into operation in 1988 and 1993 respectively, are the only reactors still operating in Bulgaria; Kozloduy NPP-Plc. is operating these units[28]. The Kozloduy NPP is located in the north-west of Bulgaria on the Danube River, 5 km to the east of the town of Kozloduy and 200 km to the north of Sofia. In 2016, the Kozloduy NPP provided about 35 percent of the Bulgaria's electricity (PRIS 2017).

The units 5 and 6 of Kozloduy NPP are originally licensed to operate until October 2016 and 2019 respectively (30 years design life time). In October 2014, an agreement for refurbishment and life extension of unit 5 was signed with Rosenergoatom, Rusatom Service and EDF. Work to upgrade unit 5 of the Kozloduy NPP has been completed, extending its operations by 30 years to 2047. A contract with a consortium of Rusatom Services and Bulgaria's Risk Engineering Ltd was signed in January 2016 to extend also the operating license of unit 6 to 60 years. The government is strongly committed to the life extension and uprate to 104% of original capacity for both units. (WNA 2017b)

Material degradation of the old units can significantly aggravate the development of an accident caused by a terror attack. A serious incident in 2006 caused by the control rods of unit 5 proved that back-fitting measures can result in new safety problems (PG 2012). Furthermore, this incident showed that the safety culture at Kozloduy NPP was not strong enough. Both factors are important issues regarding the need of comprehensive back-fitting and upgrading measures in the framework of lifetime extension.

In December 2012, the two-week IAEA safety review at Kozloduy (OSART Mission) pointed out further negative aspects the lack of safety culture is causing, when it summarized that "Analyses of the cause of events are not always performed in a thorough and timely manner to prevent the recurrence of events related to human performance". According to the OSART Follow-up mission in June 2014, this issue was not resolved. (IAEA 2012a, 2014a)

Design weaknesses of VVER-1000 reactors

Two reactors VVER-1000 model V-320 are in operation in Kozloduy and at Temelín (Czech Republic). The primary equipment is installed in a dry, full-pressure type containment. It is a pre-stressed concrete shell structure which consists of a cylindrical part and a hemispherical dome. The inside diameter of the cylinder is 44 m and its height is 41.2 m up to the spring-line. The inside radius of the dome is 22 m. The wall thickness in the cylinder part is 1.2 m and in the dome 1.0 m.

The VVER-1000/V320 has a basic shortcoming not encountered in western PWRs. The lower containment boundary (containment basement) is not in contact with the ground, but is located at a higher level inside the reactor building. In case of a severe accident, melt-through can occur within

[28] Originally, six reactors were in operation at the Kozloduy NPP site. Under commitments made by Bulgaria as part of its accession to the European Union, units 1 and 2 were shut down in 2002; units 3 and 4 followed in 2006.

approx. 48 hours. The containment atmosphere will then blow down into parts of the reactor building that are not leak-tight resulting in high radioactive releases. The reactor building – including the Main and Emergency Control Rooms (MCR/ECR) – will have to be abandoned (HIRSCH 2005).

In case of a severe accident with core melt, the retention of the molten core inside the vessel is not possible. The design of the VVER-1000/V320 containment and the reactor cavity are such that any water supplied to the containment through the spray system or other means would not reach the reactor cavity. Thus, there is no possibility to directly flood the melt pool in the cavity. (BECKER 2013).

Currently, the molten core handling for the VVER-1000 reactors is being analyzed as an international effort and the solution for the problem can only be decided after the completion of these analyses (ENSREG 2013). If appropriate measures will be developed it will take all in all at least ten years to implement the provisions, in this time span the specific hazard persist.

(The spent fuel pool is located in the reactor building inside the containment.)

New NPP Projects

In 2012, the Council of Ministers approved in principle the construction of **Kozloduy 7**.[29] A transboundary EIA was started, considering several options for the reactor type. Currently however the government is negotiating exclusively with Westinghouse about the construction of an AP1000. In 2015, progress of the project was delayed by lack of finance and low electricity demand. In April 2015, Westinghouse announced that while the shareholder agreement for Kozloduy 7 had expired, discussions were continuing a new structure and timeline. (WNN 2015a)

Interim storage and final disposal of spent fuel

A new dry storage facility for spent fuel has been built at Kozloduy, with finance from the Kozloduy International Decommissioning Support Fund administered by the European Bank for Reconstruction and Development (EBRD). This Dry Spent Fuel Storage Facility (DSFSF) was being constructed by a joint venture partnership between Nukem Technologies and GNS. The facility, was officially opened in May 2011. It will store used fuel of the four closed VVER-440 units at the Kozloduy NPP, currently in pool storage, and will be subsequently enlarged to receive casks with fuel from VVER-1000 units 5 and 6. (WNA 2017b)

A part of the spent nuclear fuel of the existing reactors was transported to Russia for reprocessing. Vitrified HLW will be returned to Bulgaria.

For the new NPP a new spent fuel storage facility will be constructed. (DICON 2013) According to the National Strategy for spent nuclear fuel and radioactive waste management, it is recommended to use an open cycle (direct disposal) with priority to the use of dry spent fuel storage method. (DICON 2014) No information is known about any serious efforts to construct a final disposal for high active waste and spent fuel in Bulgaria.

Nuclear Security

Bulgaria is among the countries like Russia that take not part in the Nuclear Security Summit. This indicates the lack of importance for nuclear security issues.

Table 2 shows some details about the Nuclear Security Index for Bulgaria (see chapter 1.4). It must point out that the score for section “Risk Environment” is very low, in particular because of the

[29] The Minister for Finance announced that it will without government money or state guarantees, an investor is being sought for the project.

shortcomings in “Pervasiveness of Corruption” and “Effective Governance”. Furthermore, the score for “Insider Threat Prevention” indicates deficiencies in this issue.

Table 2: The 2016 Nuclear Security Index for Bulgaria

	Weight	Weight	2016 score	
1) NUMBER OF SITES	5%		100	
1.1) Number of Sites		100%		100
2) SECURITY AND CONTROL MEASURES	33%		91	
2.1) On-site Physical Protection		22%		100
2.2) Control and Accounting Procedures		17%		86
2.3) Insider Threat Prevention		21%		67
2.4) Response Capabilities		20%		100
2.5) Cybersecurity		20%		100
3) GLOBAL NORMS	19%	100%	75	
3.1) International Legal Commitments		42%		86
3.2) Voluntary Commitments		27%		60
3.3) International Assurances		31%		75
4) DOMESTIC COMMITMENTS AND CAPACITY	23%	100%	95	
4.1) UNSCR 1540 Implementation		27%		80
4.2) Domestic Nuclear Security Legislation		38%		100
4.3) Independent Regulatory Agency		35%		100
5) RISK ENVIRONMENT	20%	100%	59	
5.1) Political Stability		26%		65
5.2) Effective Governance		25%		38
5.3) Pervasiveness of Corruption		22%		25
5.4) Group(s) Interested in Committing Acts of Nuclear Terrorism		27%		100
Overall score			**83**	

Conclusion

The units Kozloduy 5 and 6 have been operating for over 20 years; therefore, ageing of materials becomes a safety issue. It must be expected that ageing induced effects will increase in the next years. This could be a danger for the units, in particular because of the lack of appropriate safety culture. Thus, to license a Plant Life Time Extension (PLEX) as intended, i.e. increasing the originally designed operation time of 30 years by 30 years more entails high nuclear risk.

The protection against terror attacks of reactor buildings (wall thickness 1 to 1.2 meter) of the Kozloduy NPP (reactor type VVER-1000/V320) is not sufficient. Furthermore, in case of a severe accident with core melt, the retention of the molten core inside the vessel is not possible. A very high release of radioactive substance would result (about 130 PBq of caesium-137) Thus, the risk of terror attacks is high for the Kozloduy NPP.

The Nuclear Security Index reveals the situation in Bulgaria (the risk environment) is a big issue of concern, because this situation enables the possibility of a terror attack. The lack of appropriate prevention of insider threat is also an issue of concern. This is very important, because the poor safety culture encourages carrying out a terrorist attack with the participation of insiders.

Thus, it is unacceptable that Bulgaria is planning the construction of a new reactor. Until now there are not even concrete plans for the final disposal of spent fuel and high level waste. A very long-term storage of the spent fuel in interim storage facilities that are not sufficient protected against terror attacks must be feared.

6.2 Czech Republic

In the Czech Republic two nuclear power plants are operation, the **Dukovany NPP and the Temelín NPP**. The license holder and operator is ČEZ, a.s. which is 70% owned by the government. In 2016, the nuclear power plants in the Czech Republic provided about 29 percent of electricity (PRIS 2017).

The Dukovany NPP with four **VVER-440/V213** (EDU 1-4) is situated in the southwest of the city of Brno. The reactors were put into operation between 1985 and 1987. Thus, the original operation time of 30 years ends between 2015 and 2017.

At the beginning of 2009, CEZ commenced its Long-Term Operation (LTO) project, the immediate focus of which is to extend the planned operating lifetime of the Dukovany reactors by 10 years. CEZ aims to extend the plant lifetime eventually to 60 years. In March 2016 unit 1 was licensed for continued operation subject to ongoing reporting. The SUJB has just received the Application for operating license of Dukovany NPP Unit 2. Applications for Unit 3 and 4 will probably be received in June 2017.

In September 2016, problems at Dukovany started, when an inspection revealed that x-ray pictures of welds were of poor quality. Faults in pipe welding and poor quality of inspection were detected by the State Nuclear Safety Office (SUJB). This led to the shutdowns of units 2 and 3 and the extension of a planned outage at unit 1. Two criminal complaints have been lodged about the problematic x-ray pictures - one by CEZ and the other by SUJB. (NEI 2017c)

The originally designed reactor power of 1375 MWth (440 MWe) was increased to 1444 MWth (500 MWe), which corresponds to a power uprate of 105%. (WNA 2017c)

Design weaknesses of VVER-440 reactors

The VVER-440/V213 is a second-generation WWER of Russian design. This reactor type is not equipped with full-pressure containment. The confinement system consists of a system of rooms, containing the primary circuit, as well as the bubble condenser tower with large trays filled with water and air traps and an active spray system. The behavior of the confinement system is of crucial importance for all severe accidents.

However, the confinement itself does not guarantee to hold back the radioactive steam from large leaks, but needs to condense the steam in the special pressure relief system (Bubbler Condenser). A failure of the relief system can cause the confinement to burst and result in a major emission of radioactive material. Safety analyses showed that the confinement and in particular the Bubbler Condenser have very low or even no safety margins under certain conditions (WENISCH 2012).

One of the most important modifications concerning the prevention of major radioactive releases during accidents is envisaged to implement the **external cooling of the reactor pressure vessel** (RPV). This so-called in-vessel retention (IVR) concept aims to ensure the integrity of the RPV during a severe accident. Proof that this concept fulfils all the functions intended was until now delivered only with limited experimental analyses (UBA 2012).

The vulnerability of a VVER 440/V-213 against external hazards is relatively high: The reactor building does not provide sufficient protection against external impacts like airplane crashes or explosions. The buildings are vulnerable against an **aircraft crash** (accidental or intentional) that can seriously damage the external concrete structure, with the possibility of projectiles penetrating the reactor building. The highly probable failure of the cooling system would result in a severe accident of the most hazardous category: core melt with an open containment. The radioactive releases would be very high and occur particularly early. (see chapter 4)

Furthermore, the Spent Fuel Pool (SFP) is located in the reactor building outside the hermetic zone. In case of a severe accident, there is no barrier to the environment. In case of a damage of its structures and the loss of cooling water, a severe accident with a major radioactive release would occur. Taking into account the existing risk of terrorism, it is irresponsible to operate a nuclear power plant with such a high vulnerability to external attacks.

The construction of the **Temelín NPP** (ETE) started in 1987 but was put to a halt, construction resumed later; **Temelín 1& 2** (**VVER-1000/V320**) was put into operation in 2000 and 2002 resp.

Design weaknesses of the WWER-1000/V320 see chapter 6.1.

New NPP Projects

In June 2015, the Czech cabinet has approved an action plan on nuclear energy, providing for future construction of 1 or 2 reactors at both the Temelín and Dukovany nuclear sites. Dukovany 5 has priority over Temelín. (WNN 2015b) Start-up for Dukovany 5 and Temelín 3 are scheduled for 2035 and for Temelín 4 in 2040. Though the government had not yet resolved the financing question, early in 2017 CEZ held talks with six companies and consortia which had expressed interest in building reactors at Temelín and Dukovany: Westinghouse, Rusatom, EDF, Areva-Mitsubishi Heavy Industries joint venture Atmea; China General Nuclear Power Corp (CGN); and Korea Hydro and Nuclear Power (KHNP). (WNA 2017c)

Interim storage and final disposal of spent fuel

At the Dukovany NPP, two dry interim storage facility are in operation. The storage capacity is sufficient to cover all spent fuel production of the Dukovany NPP with the anticipated operation of the units at least until 2035. The storage capacity of the dry spent fuel storage facility at Temelín (in operation since 2010) is sufficient to cover all spent fuel of the two Temelín units for 30 years of its operation and it may be expanded on as needed basis by building of additional storage halls.

The program of a deep geological repository (DGR) development started back in 1992. The works were suspended in 2005 due to public resistance. During 2015, seven potential sites obtained an approval for the first phase of geological works using surface techniques. However, at all sites the people and the communities organized a strong resistance to those investigations and the final disposal. However, the government expects selection of a candidate and a reserve site by 2025, with construction start after 2050, and operation beginning in 2065.

Nuclear Security

During 2014, a permanent working group composed of representatives of central governmental authorities focused its efforts on developing and maintenance of the Design Basis Threat. As a result, the new DBT for Czech nuclear facilities and nuclear material led to re-evaluating of nuclear material transports in February 2015, now covering also airborne threats as well as cyber threats to computer based systems used for nuclear safety, nuclear security and nuclear material accountancy and control.

In 2014, a complex research by the operator of both Czech NPPs - Dukovany and Temelín has been carried out. It covers intentional use of three types of aircrafts (business jet, fighter and transport plane) to perform air crash to object located at nuclear power plant site. Results of the study shows the vulnerability of the different objects towards the attack and what can be done to protect the object and to minimize the consequences of such attack.

In 2014, there was a security exercise carried out at the Dukovany NPP. This exercise was aimed at verification of protocols and mechanisms for guarding of the outside perimeter of the NPP. It included cooperation and coordination of the Operator with the Czech Army and response units of the Police. The same exercise was conducted in 2015 at the NPP Temelín.

The regulatory body of the Czech Republic in 2014 and 2015 has been involved in preparation of the new Atomic Act and also in a Regulation on physical protection of nuclear material and nuclear facilities. The new regulation will be covering in greater detail especially the new aspects of nuclear security, such as: vital area identification, trustworthiness check by National Security Agency, computer security at NPPs and air-born threat. (NSS 2016)

There were no International Physical Protection Advisory Service (IPPAS) in the last years.

The following table shows the scores of the Nuclear Security Index in Poland (see chapter 1.4). Of particular concern is the very low score for the “Cybersecurity”. Furthermore, the score for the section “Risk Environment” is low, in particular because of shortcomings in “Pervasiveness of Corruption” and “Effective Governance”.

Table 3: 2016 Nuclear Security Index for the Czech Republic

	Weight	Weight	2016 score	
1) NUMBER OF SITES	5%		80	
1.1) Number of Sites		100%		80
2) SECURITY AND CONTROL MEASURES	33%		85	
2.1) On-site Physical Protection		22%		100
2.2) Control and Accounting Procedures		17%		100
2.3) Insider Threat Prevention		21%		100
2.4) Response Capabilities		20%		100
2.5) Cybersecurity		20%		25
3) GLOBAL NORMS	19%	100%	79	
3.1) International Legal Commitments		42%		100
3.2) Voluntary Commitments		27%		80
3.3) International Assurances		31%		50
4) DOMESTIC COMMITMENTS AND CAPACITY	23%	100%	100	
4.1) UNSCR 1540 Implementation		27%		100
4.2) Domestic Nuclear Security Legislation		38%		100
4.3) Independent Regulatory Agency		35%		100

	Weight	Weight	2016 score	
5) RISK ENVIRONMENT	20%	100%	70	
5.1) Political Stability		26%		75
5.2) Effective Governance		25%		50
5.3) Pervasiveness of Corruption		22%		50
5.4) Group(s) Interested in Committing Acts of Nuclear Terrorism		27%		100
Overall score			84	

Conclusion

A 10 year-lifetime extension program for all four units at the Dukovany NPP is ongoing. A lifetime extension to 60 years is envisaged. This would require the operation time to double compared to the original operation time of 30 years. Ageing of material is an increasing issue at all units. Degradation effects of safety-related systems and components could significantly aggravate the development of an accident triggered by a terror-attack. At the same time, the Dukovany reactors increased their electric output (power uprate) because of economic reasons thereby increasing pressure on safety, reducing safety margins and accelerates ageing processes.

There are also indications that the safety culture is not sufficient. Thus, it must be assumed that a lot of unidentified faults exist. Furthermore, a poor safety culture encourages carrying out a terrorist attack with the participation of insiders.

To remedy all design weaknesses (in particular the thin walls of the reactor building and location of the spent fuel pool) of the outdated VVER 440/V213 reactor type is not possible. Taking into account the existing risk of terrorism, it is irresponsible to operate a nuclear power plant with such a high vulnerability to external attacks for 10 or even 30 more years.

The reactor building of the reactor type VVER-1000/V320 at the Temelín NPP are better protected against terror attacks but still not sufficient. Furthermore, in case of a severe accident with core melt, the retention of the molten core inside the vessel is not possible. A very high release of radioactive substance would result (about 130 PBq of Caesium-137) Thus, the risk of terror attacks is also high for the Temelín NPP.

The Nuclear Security Index reveals the situation in the Czech Republic (the risks environment) is an issue of concern regarding the possibility of a terror attack. The Cybersecurity is also an issue of concern.

The problems surrounding the searching for the final disposal site for spent fuel from the existing reactors make it irresponsible to intend producing the same additional amount in new reactors before solving this issue strongly.

6.3 Hungary

In Hungary, currently four **VVER-440/V-213** reactors are operating at the **Paks NPP**, which is located 5 km south of the city center of Paks, 114 km south of Budapest. Paks NPP is owned and operated by Paks Nuclear Power Plant Ltd, which is a subsidiary company of state-owned Hungarian Power Companies Ltd (Magyar VillamosMűvek, MVM). In 2016, Paks NPP provided about 52 percent of Hungary´s electricity (PRIS 2017).

The four units are placed in two building structures in a twin arrangement. The first grid connection of unit 1 was in 1982, unit 2, 3 and 4 followed in 1984 and 1986 and 1987, respectively. The original design lifetime was 30 years, so the four units would have reached the end of their operation times between 2012 and 2017.

A 20-year license extension (2032 – 2037) has been approved by the Hungarian Atomic Energy Authority (HAEA). Between 2002 and 2009, the thermal capacity of the units was up-rated to reach 108% (1485 MWth), compared to the original value (1375 MWth), resulting in increased electric gross capacity to 500-510 MWe each unit. (WNA 2017a).

Hungary was the first case where an environmental impact assessment (EIA) was required for a plant lifetime extension. According to the Austrian Expert Statement on the EIA Report, several issues remain open, despite the comprehensive lifetime extension program. Several important topics are concerned: Seismic hazards and design, ageing management program, reactor pressure vessel integrity, negative effects of power uprate, confinement integrity, terror attacks and severe accident management (UBA 2012).

Design weaknesses of the VVER-440/V-213 see chapter 6.2.

New Build Project

The Paks NPP is **planning** to add **two new units (Paks 5 and 6)**. In 2009, the Hungarian Parliament gave preliminary approval to build **Paks II**, though some foreign investment would be needed. Out of five reactor types considered in the first phase of the EIA procedure (the scoping phase), only the VVER-1200 technology has been selected for environmental assessment. In January 2014, the Hungarian Government and the company Rosatom already signed an agreement with the Russian company Rosatom about delivery of the NPP. This decision was taken without conducting a transparent tender process before. Paks II with two VVER-1200 reactors should cost around € 12.5 billion, out of which ten billion will be provided by the Russian partners and the missing € 2.5 billion will be taken out of the Hungarian state budget. In February 2017, the Russian President said that Russia was prepared to finance 100% of the plant if necessary.

An environmental permit was issued in September 2016, a construction permit was expected in 2017 and construction start in 2018 remains the target. The operation of the new units is scheduled for 2024 and 2025, respectively. An operation time of 60 years is envisaged.

In November 2015, the EC announced it had started legal action against Hungary over the Rosatom contract for the Paks II project, expressing concerns about its compatibility with EU public procurement rules but clearing the matter in November 2016. The EC also opened a state aid investigation into the project financing for Paks II, but in March 2017 the EC approved it, as being in line with state aid rules. (WNA 2017a)

Interim storage and final disposal of spent fuel

Since 1997 the spent fuel interim storage KKÁT is in operation at the Paks site. When the interim storage KKÁT was build, a maximum operational time of 50 years was assumed. Meanwhile an operational time of 75 years is considered necessary. During an EPRI (Electric Power Research Institute) research undertaking significant research need was identified for the extended interim storage period for Hungary. Therefore, it seems that long term safety for the interim storage cannot be ensured. Different terror scenarios can lead to massive releases from interim storages at the Paks site. (UBA 2016)

It is not clear yet, whether the spent fuel of Paks II after unloading from the reactor pool will be stored at the site (most likely in a dry interim storage) or transported to Russia. For final disposal of a deep geological repository will have to be established in Hungary. It is stated, for choosing the location, studies were conducted in the area of the Western Mecsek hills; a deep geological laboratory is planned in the clay soil to be built until 2030.

However, no decision has yet been taken on the back-end of the fuel cycle. The EIA report explains three option for the management for spent fuel of Paks II. The first one is the direct disposal of spent fuel into a deep geological repository. The second approach is reprocessing. The third scenario is the so-called approach *"Do and See" (previously "Wait and See")*. This means that the program could consist of several consecutive phases and switching between these phases is possible. At certain points the next steps will be decided made concerning the program according to the appropriate deliberations. (UBA 2013)

Nuclear Security

The Hungarian nuclear security regulatory framework was revised between 2008 and 2011, in full compliance with the IAEA recommendations and guidance. The conduct of the National Threat Assessment and the determination of Design Basis Threats (DBTs), and the subsequent regulatory procedures of licensing and inspection of the newly established physical protection plans of nuclear facilities, nuclear and other radioactive material license holders were completed by the end of 2012. The DBTs are updated on an annual basis. The design basis threat (DBT) includes cyber threats.

At the request of the Government of Hungary, a full scope International Physical Protection Advisory Service (IPPAS) mission started on the 27th of May 2013 to review the physical protection systems of nuclear and radioactive materials and associated activities and facilities in Hungary. In order to implement the suggestions and recommendations of the IPPAS mission team, a national Action Plan has been launched for the period up until 2017. A follow-up IAEA IPPAS mission has already been requested by the government of Hungary for the year of 2017. (NSS 2016)

The following table shows some details about the Nuclear Security Index for Hungary (see chapter 1.4). It must point out that the score for section "Risk Environment" is low, in particular because of the shortcomings in "Pervasiveness of Corruption" and "Effective Governance". Furthermore, the score for "Insider Threat Prevention" indicates some deficiencies in this issue.

Table 4: 2016 Nuclear Security Index for Hungary

	Weight	Weight	2016 score	
1) NUMBER OF SITES	5%		80	
1.1) Number of Sites		100%		80
2) SECURITY AND CONTROL MEASURES	33%		98	
2.1) On-site Physical Protection		22%		100
2.2) Control and Accounting Procedures		17%		100
2.3) Insider Threat Prevention		21%		89
2.4) Response Capabilities		20%		100
2.5) Cybersecurity		20%		100
3) GLOBAL NORMS	19%	100%	87	
3.1) International Legal Commitments		42%		100
3.2) Voluntary Commitments		27%		80
3.3) International Assurances		31%		75
4) DOMESTIC COMMITMENTS AND CAPACITY	23%	100%	95	
4.1) UNSCR 1540 Implementation		27%		80
4.2) Domestic Nuclear Security Legislation		38%		100
4.3) Independent Regulatory Agency		35%		100
5) RISK ENVIRONMENT	20%	100%	70	
5.1) Political Stability		26%		75
5.2) Effective Governance		25%		50
5.3) Pervasiveness of Corruption		22%		50
5.4) Group(s) Interested in Committing Acts of Nuclear Terrorism		27%		100
Overall score			88	

Conclusion

All four units at the Paks NPP are approved to be in operation for additional 20 years. Because their design operation time is exceeded, ageing of material is an issue. In addition, the power uprates which were performed during the last years accelerated the ageing process. Degradation effects of safety-related systems and components could significantly aggravate the development of an accident triggered by a terror-attack.

To remedy all design weaknesses (wall thickness of the reactor building and location of the Spent Fuel Pool) of the outdated VVER 440/V213 reactor type is not possible. Taking into account the existing risk of terrorism, it is irresponsible to operate a nuclear power plant with such a high vulnerability to external attacks.

There are doubts about sufficient protection against terror attacks of the reactor type of the planned new NPP Paks II.

The Nuclear Security Index reveals the situation Hungary the (risk environment) is an issue of concern regarding the possibility of a terror attack. The lack of sufficient protection against the insider threat is also an issue of concern.

Hungary does not have any concrete plans for the disposal of spent fuel; therefore, a key precondition of the construction of another NPP is lacking. Furthermore, the long-term safety of the existing interim storage facility at the Paks site cannot be ensured. Different terror scenarios can lead to massive radioactive releases.

6.4 Poland

In Poland, no nuclear power plant is in operation yet.[30] Poland is generating over 90% of electricity from coal. To decrease the dependency on coal, in 2005 the Polish cabinet changed the energy policy and decided to build nuclear power plants. PGE (Polska Grupa Energetyczna), as Poland's largest power group by generating capacity, announced in January 2009 plans to build two nuclear power plants, each with a capacity of 3,000 MWe.

The entity PGE EJ1 is set up to build the first plant and it will be future operator and licensee. PGE expected to make a final investment decision on the two plants early in 2017, including site and technology. Final design and permits for the first NPP were expected to be ready in 2018, allowing construction start in 2020. The first unit was then expected to be operational in 2024, the second in 2029.[31] The second power plant is scheduled for operation in 2035.[32]

In April 2017, PGE EJ1 announced the start of "localization and environmental studies" to be carried out by ELBIS at Choczewo, Krokowa and Gniewino, all in Pomerania, to be completed in 2020.

Interim storage and final disposal of spent fuel

Until now Poland has produced only small amounts of spent fuel in research reactors, which are currently in interim storages. In year 2014 studies on possible sites for deep geological repository (DGR) have begun. It is intended to continue research and development on DGR undertaken in Poland in the late 1990s. Poland also decided to participate in international project connected with final spent nuclear fuel disposal (ERDO[33]). By this time, spent nuclear fuel will be stored on-site the NPP or in an interim storage facility located in a different place. (PAA 2014)

Nuclear Security

Poland received a mission of the International Physical Protection Advisory Service (IPPAS) of the IAEA in 2016. To assure better compliance with the IAEA guidelines and recommendations, a national workshop on Design Basis Threat (DBT) implementation was held in Warsaw in September 2013. As a result of discussion conducted during the workshop, the series of high-level and working-level meetings of all interested Polish institutions were held and led to draft an amendment to the national security legal framework. It is foreseen that updated regulation related to the DBT will enter

[30] In 1990, the construction of the Zarnowiec NPP was stopped after protests in reaction to the Chernobyl accident.

[31] However, in mid-2015 the transmission operator said that PGE projected 2029 for the first unit. The second power plant is scheduled for operation in 2035.

[32] It is not clear whether Poland will be able to find the necessary funds for the NPP programme. Early in 2015 PGE said that "having described and justified a catalogue of potential support mechanisms, it had singled out contracts for difference (CfD) as the mechanism that should be dedicated to nuclear energy. However, in June 2016 the new government rejected the use of CfDs as being too costly, but in favor of some other, not yet defined, financial model, on which they are working and which is expected by mid-2017.

[33] European Repository Development Organisation

into force in 2017. Among the options suggested by the IAEA, approach of a single DBT covering all threats and potential targets in country has been chosen.

A special task-force group for developing proposals to strengthen the anti-terrorist security of the nuclear research reactor “Maria” in Świerk was established. The group formulated a number of recommendations aimed at improving the nuclear security of the reactor. Moreover, the National Anti-Terrorist Program has been adopted by the Government of Poland on 9 December 2014. (NSS 2016)

The following table shows the specific scores and their weight of the Nuclear Security Index for Poland. (see chapter 1.4) The score for the section “Security and Controls Measures” is low, especially because of missing of sufficient “Insider threat protection” and “Cybersecurity”. It must point out that the score for section “Risk Environment” is low, especially because of the shortcomings in “Pervasiveness of Corruption” and “Effective Governance”.

Table 5: 2016 Nuclear Security Index for Poland

	Weight	Weight	2016 score	
1) NUMBER OF SITES	5%		100	
1.1) Number of Sites		100%		100
2) SECURITY AND CONTROL MEASURES	33%		76	
2.1) On-site Physical Protection		22%		80
2.2) Control and Accounting Procedures		17%		86
2.3) Insider Threat Prevention		21%		67
2.4) Response Capabilities		20%		100
2.5) Cybersecurity		20%		50
3) GLOBAL NORMS	19%	100%	87	
3.1) International Legal Commitments		42%		100
3.2) Voluntary Commitments		27%		80
3.3) International Assurances		31%		75
4) DOMESTIC COMMITMENTS AND CAPACITY	23%	100%	95	
4.1) UNSCR 1540 Implementation		27%		80
4.2) Domestic Nuclear Security Legislation		38%		100
4.3) Independent Regulatory Agency		35%		100
5) RISK ENVIRONMENT	20%	100%	74	
5.1) Political Stability		26%		80
5.2) Effective Governance		25%		63
5.3) Pervasiveness of Corruption		22%		50
5.4) Group(s) Interested in Committing Acts of Nuclear Terrorism		27%		100
Overall score			**83**	

Conclusion

The financing for the planned reactors in Poland is as difficult as it is for all other current new build projects. Therefore it will be very important to ensure that there will be no attempts made to save money on the interim storage facilities of spent fuel by cutting down on the design protection against terror attacks.

According to the Nuclear Security Index, the situation in Poland (risk environment) enables the possibility of terror attacks. Furthermore, the prevention of insider threat as well as the cybersecurity must be improved to limit the possibility of terror attacks.

6.5 Romania

In 1980, the construction of five units at the Cernavoda site began. But the project was scaled back in the early 1990s to focus on unit 1, which was completed in 1996. The second unit was connected to the grid in August 2007. Romania´s two reactors (Cernavoda 1 and 2) at the country´s only NPP Cernavoda are located in Constanta County, about 2 km southeast of the Cernavoda town boundary, at 4 km southeast of Danube River. Cernavoda NPP comprises two Pressurized Heavy Water reactors (PHWR) of CANDU 6 design, which are the only units in Europe based on the CANDU (**CAN**adian**D**euterium **U**ranium) technology.

Cernavoda NPP is owned and operated by the National Company Nuclearelectrica (**S**ocietatea **N**ationala **N**uclearelectrica, SNN). In 2016, unit 1 and 2 (650 MWe net capacity each) generated about 17 percent of Romania's electricity (PRIS 2017).

The operating time of 30 years for unit 1 and 2 will end in 2026 and 2037, respectively. Therefore, the operator (SNN) intends to start a PLEX procedure for an extension of 20 years. This announcement causes concerns, because already today the design of CANDU 6 reactors is very outdated, for example external threats as airplane crash and other human impacts as terrorism are not considered in the design. Also, ageing of the pressure tubes is an issue.

Because major problems were encountered in the refurbishment projects at CANDU 6 reactors the owner of the Canadian CANDU 6 reactor Gentilly-2 in 2012 decided to close its reactor after the planned operation time of 30 years. Hydro-Quebec explained that the decision was made for financial reasons, additionally the Fukushima accident in March 2011 contributed to concerns about lifetime extension (NW 11/10/2012).

Design weaknesses of CANDU 6 reactors

CANDU 6 reactors pose risks that arise from basic features of the design, especially the use of natural uranium (fuel) and heavy water (moderator). As a result, a CANDU reactor has a **positive void coefficient** of reactivity. Thus, if the flow of cooling water is interrupted and shutdown systems were ineffective, the reactor would experience a violent power excursion, challenging the integrity of the containment structure. Such an event occurred at Chernobyl-4 in 1986, with a large release of radioactive material to the atmosphere. Chernobyl-4 was another reactor type (RBMK), but it also had a positive void coefficient (THOMPSON 2008).

In 2000, the IAEA established international standards for the design of new nuclear power plants.[34] The IAEA recommends that plants have "inherently safe" behavior. The CANDU 6 design does not meet that standard, because it has a positive void coefficient of reactivity.[35]

The core of CANDU 6 reactor consists of many pressure tubes instead of being confined in a pressure vessel, this design precludes the possibility of massive pressure vessel failure, but the accompanying greater length, surface area and complexity of the primary system piping results in a greater risk of loss-of-coolant accidents (LOCAs). Additionally, the possibility for on-load refueling introduces means by which loss-of-coolant can be initiated. The refueling machine is also the major pathway for releases of radioactive particles that have broken off the fuel.

Material degradation of the pressure tubes is a persisting problem of existing CANDU plants. The pressure tubes are exposed to the neutron flux, with consequent weakening effects. Problems occurred with delayed hydride cracking as a result of deuterium-zirconium alloy reactions. Also, pressure tube fretting corrosion appears to be a generic flaw of the CANDU design. This degradation mechanism has been traced back to vibrations of the pressure tubes and could lead to a loss-of-coolant accident. Both ageing effects of the pressure tubes have already been observed at the Cernavoda-1 (JPG 2012)

Another design issue of the CANDU 6 design exist in the context of the use of natural-uranium fuel and on-line refueling. Thus, spent fuel discharged from a CANDU 6 plant could be diverted and used to produce plutonium for nuclear weapons (THOMPSON 2008).

The reactor building show design weaknesses: The CANDU 6 reactor has a containment consisting of a concrete dome (diameter 41.46 m with a cylindrical perimeter wall of only 1.07 m thickness), which is not designed to withstand worst case accidents, for example hydrogen detonations.[36] The containment is seismically qualified, but external threats as airplane crash and other human impacts as terrorism and sabotage are not considered in the design. Furthermore, the Spent Fuel Pool (SFP) is located outside the containment, which could result in a major release of radioactive substances in case of an accident (JPG 2012).

The construction of **Cernavoda 3 and 4** are to be completed; an environmental mental assessment (EIA) was conducted in 2007. In October 2014 Nuclearelectrica (SNN) designated China General Nuclear Power Group (CGN) as the "selected investor" for the project. The units will be updated versions of the CANDU 6 (reactor type of Cernavoda 1&2), but not the full EC6 version, since the concrete structures are already built. Unit 3 is reported to be 53% complete and unit 4 is 30%. They will have an operating time of 30 years with the possibility of 25-year extension. Start of operation is scheduled for 2019 and 2020 resp. (WNA 2016)

Interim storage and final disposal of spent fuel

Spent fuel of Cernavoda 1 and 2 is transferred to a dry storage facility at Cernavoda based on the Macstor (Modular Air-Cooled Storage) system designed by AECL. The storage capacity will be

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[34] Those standards are, in many respects, the "lowest common denominator" of standards set by national regulators.

[35] AECL is currently offering a new version of the CANDU design concept. As a result of design changes (including the use of light water as primary coolant, and low-enriched uranium fuel), AECL expects that the void coefficient of reactivity for the ACR-1000 would be slightly negative.

[36] The large zirconium inventory of the CANDU could react exothermically with steam during a severe accident. This reaction produces hydrogen, which is a threat for the containment stability, because it reacts explosively with air in the containment.

expanded gradually, assuring storage of spent fuel resulted from operation of two reactors for the 30 years each one. The first module was commissioned in 2003.

In the EIA report concerning the construction of Cernavoda 3&4 it is stated that existing storage facilities for spent fuel will be extended to handle the radioactive waste and spent fuel from the new units. It is also stated that a national final disposal facility for spent fuel are planned. Further information is not presented. (UBA 2007)

Until now no dedicated efforts to find a site and to construct a final disposal for spent fuel and high and medium level waste are noticeable. According to the fifth report of *Joint convention on the safety of spent fuel management and on the safety of radioactive waste management (2014),* ANDR (*Nuclear Agency for Radioactive Waste)* is setting up a knowledge database for siting, by gathering existing information on geological, hydrogeological and seismic characteristics of the preferred investigation areas. Also, studies are planned to assess the possibility of reprocessing the spent fuel generated by the CANDU Units of Cernavoda NPP. (CNCAN 2014)

Nuclear Security

In 2016, Romania has invited an IAEA IPPAS (*International Physical Protection Advisory Service*) follow-up mission to assess the stage of implementation of the recommendations presented on the previous IPPAS mission, in 2012. (NSS 2016)

The following table show the detail scores and their weight for Romania. The score for “Security and Controls Measures” are low, especially because of missing of sufficient insider threat protection and cybersecurity. Furthermore, the score for the section “Risk Environment” is low, in particular because of the shortcomings in “Pervasiveness of Corruption” and “Effective Governance”.

Table 6: 2016 Nuclear Security Index for Romania

	Weight	Weight	2016 score	
1) NUMBER OF SITES	5%		80	
1.1) Number of Sites		100%		80
2) SECURITY AND CONTROL MEASURES	33%		90	
2.1) On-site Physical Protection		22%		100
2.2) Control and Accounting Procedures		17%		100
2.3) Insider Threat Prevention		21%		78
2.4) Response Capabilities		20%		100
2.5) Cybersecurity		20%		75
3) GLOBAL NORMS	19%	100%	95	
3.1) International Legal Commitments		42%		100
3.2) Voluntary Commitments		27%		80
3.3) International Assurances		31%		100
4) DOMESTIC COMMITMENTS AND CAPACITY	23%	100%	100	
4.1) UNSCR 1540 Implementation		27%		100
4.2) Domestic Nuclear Security Legislation		38%		100
4.3) Independent Regulatory Agency		35%		100

	Weight	Weight	2016 score	
5) RISK ENVIRONMENT	20%	100%	57	
5.1) Political Stability		26%		70
5.2) Effective Governance		25%		25
5.3) Pervasiveness of Corruption		22%		25
5.4) Group(s) Interested in Committing Acts of Nuclear Terrorism		27%		100
Overall score			86	

Conclusion

Units 1 and 2 at the Cernavoda NPP have been operating for only relatively short periods (since 1996 and 2007 respectively), but the reactors were designed in the 1970ies and thus the design is very outdated. Several design weaknesses of the reactor cannot be remedied – in particular the possibility of violent power excursion in case of loss of safety systems and the vulnerability against external hazards (e.g. terror attacks.) In case of a terror attack, a large amount of radioactivity can be released not only from the reactor core but also from the spent fuel pool that is located outside the containment.

Nevertheless, the operator stated in February 2012 that a lifetime extension of 20 years is planned. The operating time of Cernavoda 1 and 2 is 30 years, which will last until 2026 and 2037, respectively. Material degradation due to ageing effects of the pressure tubes, a persisting problem of existing CANDU, plants have already occurred at the Cernavoda-1. Degradation effects of safety-related systems and components could significantly aggravate the development of an accident triggered by a terror-attack.

The Nuclear Security Index reveals the situation in Romania (the risk environment) is a big issue of concern. This situation enables the possibility of a terror attack. Thus, the shortcomings of the security and control measures in regard of cybersecurity and the prevention of insider threat are worrying.

The envisaged completion of the reactor units Cernavoda 3 and 4 is irresponsible due to the increasing risks of terror attacks. Because the structures of the buildings already exist, it is not possible to enhance the thicknesses of the buildings to the necessary extent. Furthermore, it is irresponsible to generate additional radioactive waste and spent fuel, because Romania has no strategy for the disposal of spent fuel.

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