STORAGE OF RADIOACTIVE MATERIAL AT THE KRŠKO NUCLEAR POWER PLANT

Seminar

Author: Andraž Konc
Slovenia, 2023

Table of contents

1. WHAT IS A NUCLEAR POWER PLANT? 4
1.1 NEK - HISTORY AND DEVELOPMENT 4
1.2 NEC - BASIC UP-TO-DATE INFORMATION 5
1.3 CORPORATE SOCIAL RESPONSIBILITY 6
2. STORAGE OF RADIOACTIVE MATERIAL IN A FACILITY 7
2.1 STORAGE OF LOW- AND INTERMEDIATE-LEVEL RADIOACTIVE MATERIAL IN A NON-RADIOLOGICAL FACILITY 8
2.2 HIGH-LEVEL RADIOACTIVE WASTE AND SPENT FUEL IN NON-NUCLEAR WASTE 9
3. LEGISLATION AND PERFORMANCE STANDARDS 10
4. NUCLEAR SAFETY 11
5. SOURCES AND LITERATURE 12

Index of images

Figure 1: From uranium to nuclear fuel (NEK, 2021) 4
Figure 2: Current plant data (NEK, 2021) 6
Figure 3: Spent Nuclear Fuel Pool (NEK, 2021) 10

SUMMARY

In this seminar paper I will present in more detail the storage of hazardous waste used and produced at Slovenia's only nuclear power plant, Krško. The first part describes NEK, its history and its social responsibility, which is very important for today. Then comes a section on the operation of the nuclear power plant, and I have focused the thesis on the division and specifics of NEK's hazardous waste storage. Finally, I have presented the legislation and environmental standards that apply in this area.

Keywords: nuclear power plant, energy, NEK, storage, waste, uranium, radioactive materials

1. WHAT IS A NUCLEAR POWER PLANT?

A nuclear power plant is an installation that generates electricity. A nuclear power plant uses a nuclear reactor - a fission reactor of uranium nuclei - as the primary heat source instead of fossil fuels or coal.
In the nuclear part, the energy released from the fission of atomic nuclei generates heat which vaporises water [1. The vaporised water or steam transfers the heat to the conventional or thermoelectric part of the plant, where the steam then drives a turbine. The turbine's job is to produce mechanical energy from this steam, which is converted into electrical energy by an electrical generator. This completes the process of converting nuclear energy into electricity. The initial investment in building a nuclear power plant is high - we are talking billions of euros - and the cost of storing the spent nuclear fuel is also high, but the fuel itself and other operating costs are relatively low. Because of the stability of production, nuclear power plants are used primarily to provide a steady supply of basic electricity needs and, barring extremely rare catastrophic accidents, are a very safe form of electricity generation.

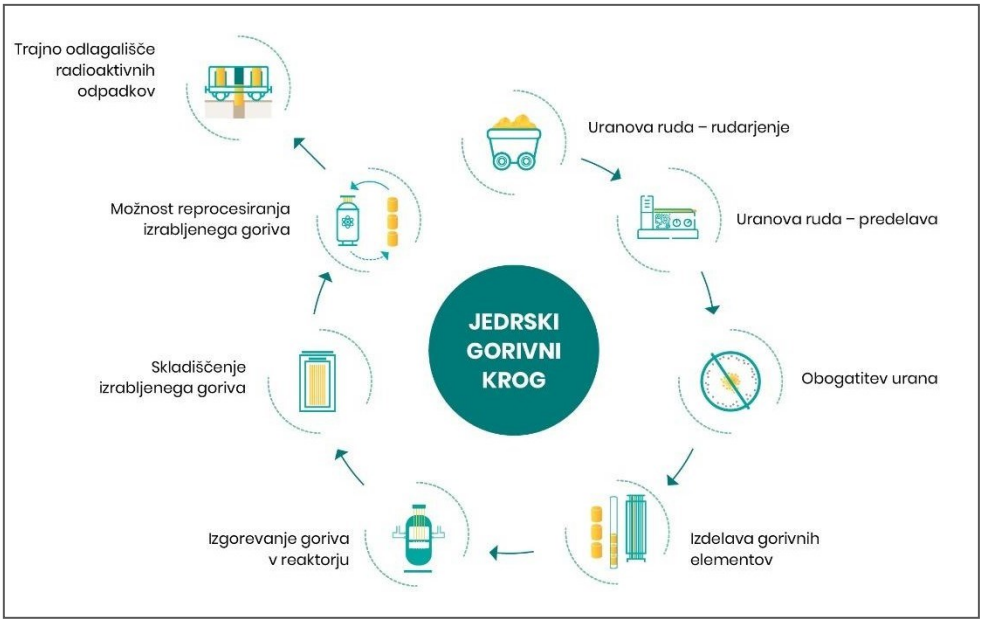


Image 1From uranium to nuclear fuel (NEK, 2021)

1.1 NEK - HISTORY AND DEVELOPMENT

Research begins on the Krško field, making it a possible site for a nuclear power plant (1964). Stane Kavčič, President of the IS of the Assembly of the Republic of Slovenia, and Dragutin Haramija, President of the IS of the Sabor of the Republic of Croatia, sign an agreement on the construction of a nuclear power plant (1970). The founders sign an agreement on the preparation for the construction of the NPP (1971). The first tender for the construction of the NPP is published. On the basis of a technical, commercial and financial evaluation of the bids, the US company Westinghouse is selected as the supplier of the equipment (1971). The Republican Secretariat for Urban Planning issues a site permit for the construction of the facilities needed for the NPP. The foundation stone

for the first nuclear power plant in Yugoslavia is laid (1974). Excavation and construction work on the site begins (1975). The two evaporators and the reactor vessel are installed (1978). Fuel is delivered (1980). The first phase of experimental operation begins - fuel is loaded into the reactor vessel and the plant becomes a nuclear facility. Synchronisation of the generator with the grid is completed and NEK delivers the first kW h of electricity to the power system (1981). 100% power output of the plant is achieved for the first time (1982). Commercial operation begins. First annual overhaul and first fuel change start (1983). NEK receives authorisation to start regular operation (1984). Stane Rožman takes over the management of NEK (1988). Shutdown of the plant due to the war in Slovenia (1991). Introduction of the IDDS system - drying of NSRAO in a drum to reduce the amount of this waste in the temporary storage at the plant (1998). Modernisation completed with the construction and replacement of the evaporators, the increase of the plant's power to 707 MW and the delivery of a complete simulator for the training of the operating staff (2000). First 10-year comprehensive safety review of the plant completed (2003). Switch to 18-month fuel cycle (2004). New digital turbine control and monitoring system (2009). Emergency safety review - EU stress tests following the accident at the Fukushima NPP in Japan (2011). Raising of flood embankments to ensure flood safety of NPP (2012). Completion of projects under the Safety Upgrade Programme - Alternative cooling of the containment dome and spent fuel pool (2020) (NPP, 2021).

Maintenance is the periodic shutdown of the plant every 18 months. At that time, extensive equipment maintenance, plant upgrades, safety system tests are carried out and the energy potential is restored by replacing about half of the 121 fuel elements that make up the reactor core. During the refurbishment, all fuel elements are moved to the spent fuel pool for further inspection and a comprehensive assessment of their suitability for re-entry into the reactor core. The removal and transfer of fuel is carried out by our operators (NEK, 2021).

Uranium, which is used to make nuclear fuel to generate electricity in nuclear power stations, is mainly found in rocks and seawater. Over the last decade, the amount of known uranium resources has increased by at least a quarter, exceeding current and projected needs. Uranium also has the advantage of being located in economically and politically stable countries where supply problems are very unlikely.

1.2 NEC - BASIC UP-TO-DATE INFORMATION

- NEK d.o.o.
- Vrbina 12, 8270 Krško
- Between 500 and 1000 employees
- Founded 1974
- Founders GEN Energija d.o.o. and Hrvatska elektroprivreda d.d.
- Chairman of the Management Board Stane Rožman



Image 2: Current plant data (NEK, 2021)

1.3 CORPORATE SOCIAL RESPONSIBILITY

They pursue the sustainability concept by achieving long-term positive operational, economic, environmental, environmental and social impacts from their operations. NEK achieves a high level of operational and economic efficiency through careful operational control, increasing plant capacity, proper risk assessment, careful preventive maintenance and long-term investment planning, and continuous training and motivation of employees. Environmental responsibility and climate change mitigation are achieved by ensuring safe operations and a proactive environmental management policy. They carefully control emissions and manage radioactive waste and nuclear fuel with care. They monitor the status of water, land and air through comprehensive independent monitoring of the wider environment. The environmental impacts of NPP operations are minimal and far below regulatory limits. By ensuring long-term operation, they support the commitments to move towards climate neutrality and make sustainable use of natural resources. They are committed to social welfare and development, as the largest economic operator in the region for more than 35 years, providing secure and quality jobs and economic development. They strive for mutual respect and trust among employees and with service providers and the local community. We work in a legal, transparent and cooperative manner with our stakeholders. (NEK, 2021) The
Krško Nuclear Power Plant has no excess negative environmental impacts. Information is publicly available. The operation of the plant does not release $C0_2$ into the atmosphere, so nuclear power plants save (compared to thermal power plants) as much as 800 million tonnes of $C0_2$, which is the same as removing 200 million vehicles. Radioactivity is ubiquitous on Earth and is thousands of times greater than the radiation from NEK's operation. Their operation raises the temperature of the river Krka, which they use for steam cooling, by several degrees.

2. STORAGE OF RADIOACTIVE MATERIAL IN A

Most of the radioactive waste in Slovenia, 90%, is generated by nuclear power plants. Radioactive waste is objects, equipment or substances for which no further use is foreseen and whose radioactivity exceeds the limit allowed by law. Ionising radiation emitted by radioactive waste and other radioactive substances may be dangerous to humans and other living beings because of its radioactivity. If the radiation energy is significantly higher than the radiation normally present in the environment, it can cause temporary or permanent damage to cells. As with other radioactive substances, radioactive waste must therefore be handled in such a way as to prevent exposure of living beings to ionising radiation and the release of radioactive substances into the environment. This is why the radioactive waste we dispose of is always in solid form.˝ (ARAO, 2015) The radioactivity of a substance decreases over time, depending on the half-lives of the chemical elements in the process.

Radioactive waste is divided into two basic groups:

- "Low- and intermediate-level radioactive waste (LLRW) emits ionising radiation, but not significant amounts of heat. Therefore, they do not need to be cooled, but they must be prevented from spreading into the environment through water or other streams by packaging or other barriers. This is also how we contain the radiation. Additional radiation shielding is not usually needed for low-level waste, but is usually needed for intermediate-level waste. The radioactivity of NSRAW containing short-lived elements with a half-life of less than 30 years will be comparable to that of the natural environment after a maximum of 300 years due to radioactive decay. Long-lived NSRAO containing higher concentrations of long-lived radioactive elements with half-lives longer than 30 years will be radioactive for more than 300 years. They are stored like other NSRAW and permanently disposed of with LLW. For example, NSRW are: items, tools and clothing contaminated with radioactive substances; sealed sources; reactor coolant purification filters, ionisation fire detectors, etc.˝ (ARAO, 2015).
- In addition to strong radiation, high-level radioactive waste (HLW) and spent fuel also give off a lot of heat. They can remain radioactive for more than 10,000 years. This makes them difficult to handle: they are cooled and surrounded by a thick layer of dense material (water, metal, concrete) that keeps out the strong radiation and prevents mixing of radioactive waste and environmental material. High-level radioactive waste is also generated by prolonged irradiation of certain materials in the core of a nuclear reactor (ARAO, 2015).

The first final disposal site for high-level radioactive waste will be built in Finland. The final spent nuclear fuel repository will be built 400 metres deep into the bedrock where the spent fuel will be disposed of. The facility will consist of two sections. The first, above-ground section will encapsulate the spent fuel in casks, while the second, underground section, interspersed with tunnels, will store it permanently (ESVET, 2015).

One of the main principles of radioactive waste and spent fuel management is to store it first in repositories and then permanently dispose of it in landfills. Both solutions are quite safe, but storage is temporary and disposal is permanent. The key advantage of disposal is passive safety. This means that human intervention is no longer needed to ensure safety, as safety is already ensured by the way the landfill is built and the waste is prepared before disposal. Spent fuel can also be reprocessed and reused, but only the high-level waste generated during reprocessing is disposed of.

The transport of radioactive waste must be carried out under the supervision of experts and the police. Strict legislation must be observed, as well as traffic regulations. NRAO can only be transported by ordinary lorries, and high-level radioactive waste can only be transported in special containers that allow for biological protection. These containers must be able to withstand temperatures of 800 degrees Celsius as well as a drop from a height of several metres. Only a few companies in Europe are authorised to transport radioactive waste. Globally, around 20 million shipments of radioactive material are transported every year on public roads, railways and ships. Of course, radioactive material is not unique to the nuclear fuel cycle. The vast majority, around 95%, of radioactive packages are not related to nuclear power. However, transport is an integral part of the nuclear fuel cycle, as most countries that mine uranium do not produce nuclear energy.

2.1 STORAGE OF LOW- AND INTERMEDIATE-LEVEL RADIOACTIVE MATERIAL IN A NON-RADIOLOGICAL FACILITY

NEK generates technological waste, such as industrial waste and low- and intermediate-level radioactive waste. The latter include those that contain a certain amount of radionuclides above regulatory levels. Depending on their specific activity, they are divided into low- and intermediate-level radioactive waste. They are transformed by appropriate processes into a form that ensures safe storage and transport and protection of people and the environment from ionising radiation. Low- and intermediate-level waste that is in a solid state is stored in a temporary low- and intermediate-level waste storage facility within the plant enclosure. It is the responsibility of the NPP to safely store radioactive materials on a temporary basis, in accordance with the standards in force worldwide. The interim storage facility is an earthquake-resistant reinforced concrete building. A number of measures and upgrades ensure that radioactive waste volumes are kept to a minimum. Permanent final disposal solutions are the responsibility of Slovenia and Croatia, with the Slovenian Agency for Radioactive Waste (ARAO) and the Croatian Fund for Financing the Decommissioning and Disposal of Radioactive Waste and Nuclear Fuel of the Krško Nuclear Power Plant (NPP Krško) being responsible. The amount of low- and intermediate-level radioactive waste generated depends on the stability of the plant's operation and the extent of maintenance interventions. On average, the NPP generates about 30 m3 of low- and intermediate-level radioactive waste per year, which can be thought of as a cube with a side of 3.1 m.
The new building for the handling of equipment and radioactive cargo shipments establishes high standards and improved working conditions for the handling of low- and intermediate-level radioactive waste (LLLMW). Most importantly, it frees up the remaining space in the LLLW storage facility, which will help bridge the period until the construction of the final disposal facility for LLLMW (NEK, 2021). (NEK, 2021)

NRAO TRANSPORT/STORAGE PROCEDURE
NEK has a room for filling 208 litre drums, which are remotely sealed and loaded by a crane onto a remote-controlled trolley that goes into storage. There, the activity and isotopic composition of the material in the drum is measured. The drum is then placed, also remotely controlled, into a tubular container, which is then placed in a designated location in the storage facility. However, as this process alone would quickly fill the storage area, the processes of incineration and super-compaction with a high-pressure press are also used.

A dry storage facility for spent nuclear fuel is being built at the Krško Nuclear Power Plant. This is a project that started as of the first of March this year, as part of the Kr Kr KrNK's own safety upgrades. The spent fuel storage facility, which does not require a cooling medium as is the norm in the existing pool, therefore does not require circulation and does not need any sources of electricity. In short, it is a passive facility within which the fuel is cooled by natural air circulation. The first shipment of these containers is already at the plant, and the rest are being delivered or will be delivered from the United States by the contractor who is their contractual partner.

2.2 HIGH-LEVEL RADIOACTIVE WASTE AND SPENT FUEL IN NON-NUCLEAR WASTE

High-level radioactive waste is even more potentially hazardous than low- and intermediate-level radioactive waste. At the Krško power plant, spent fuel cells in the form of rods filled with so-called depleted uranium tablets are stored in special grids in a pool of cooling water near the reactor. The lattice structure holds 1 694 spent fuel elements, up from 1 096 at the end of last year. Up to 56 spent fuel elements are replaced with fresh ones at each overhaul. It is logical that the spent fuel in the pools will not be able to wait indefinitely, as the year of the nuclear power plant's closure is approaching, despite the extension of its operating life, and Slovenia does not yet have a permanent solution for how to deal with these hazardous items in the future (Klinec, 2015).
Radioactive waste needs to be cared for long after it has been disposed of. Some materials can remain radioactive for tens of thousands of years. In Slovenia, the vast majority of them are produced at the Krško Nuclear Power Plant, but not all of them - they also come from hospitals, research centres and industry, and can even be found in everyday objects that do not look radioactive at first sight. Generating electricity with radioactive materials is extremely efficient, which means that waste is also extremely low. Slovenia, as the world's smallest nuclear-weapon country, has to take care of all the radioactive waste itself. This waste must be stored safely for up to several million years until the harmful radioactivity has faded. Some scientists even wonder how future generations can be warned about hazardous waste, as languages and symbols may change completely and storage facilities may become forgotten.

Dry spent fuel storage is passive, as it does not require additional systems or energy to operate. From a safety point of view, such storage is the best interim technical solution in the world. Advantages of dry storage of spent fuel**:**

- Increased safety or reduced environmental risks compared to existing pool storage;
- long-term guaranteed cooling without running cooling systems - passive cooling with natural airflow;
- minimum maintenance of the facility or containers;

- The container's robust technical solution protects against extreme weather and earthquake hazards, as well as the possible crash of a commercial aircraft;
- Minimal radiological impact on the environment; the new facility will have no impact on the existing environmental limits, which remain unchanged;
- the possibility of transporting fuel elements in the future for a permanent solution (NEK, 2021).

NEK will continue to temporarily store spent fuel from the reactor core immediately after fuel change for at least 5 years in the existing spent fuel pool. The transfer of spent fuel from the pool to dry storage will take place in several campaigns.
The spent fuel elements will be temporarily stored in the spent fuel pool in the fuel handling building. The pool is filled with water with the addition of boric acid to absorb neutrons, ensuring that the chain reaction in the fuel does not take place. The water circulating through the heat exchanger cools the spent fuel. In accordance with the strategy adopted, it is stored on the plant site in a special building, the spent fuel pool. The pool is 16 m long, 8 m wide and 12 m deep, with enough grids (racks) for 1694 spent fuel elements. Boric acid is added to the water. The thick layer of water is both a radiation shield and a heat sink. An eight-metre layer of water over the spent fuel elements provides good radiation shielding. The amount of residual heat and radiation decreases with time, allowing a transition to dry storage of spent fuel after five years of storage in the pool. In the existing so-called wet pool spent fuel storage, heat exchangers and pumps are used to cool the water.

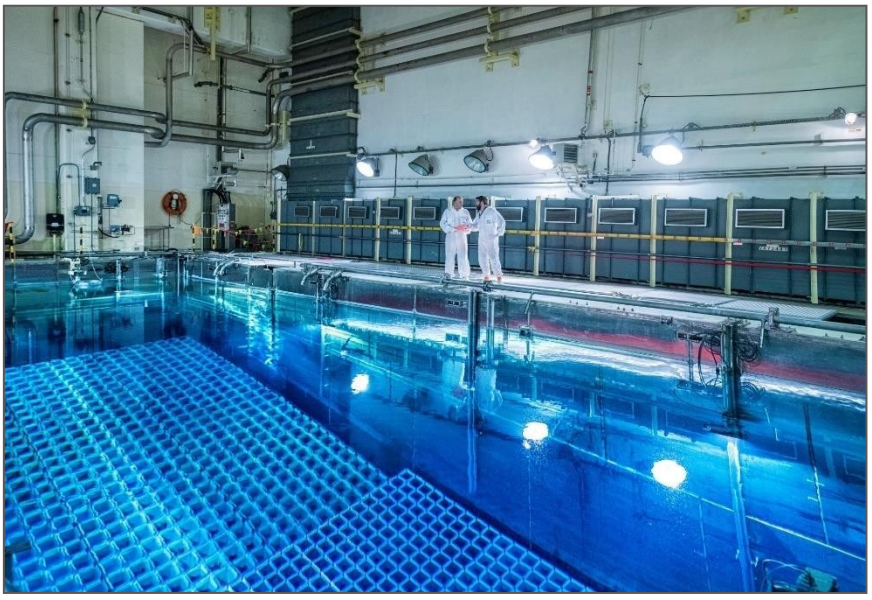


Image 3: Spent Nuclear Fuel Pool (NEK, 2021)

3. LEGISLATION AND PERFORMANCE STANDARDS

Nuclear and radiation safety in Slovenia is regulated by the Act on Protection against Ionising Radiation and Nuclear Safety.
The details of the individual requirements are regulated by by-laws. These are decrees of the Government of the Republic of Slovenia or regulations adopted by each ministry alone or in agreement with other ministries.

The most important regulations for NEK are:

- Radiation and nuclear safety factors regulation
- Regulations on ensuring safety after the commissioning of radiological or nuclear installations
- Regulations on ensuring the competence of workers in radiation and nuclear installations
- Regulations on radioactive waste and spent fuel management
- Radioactivity Monitoring Regulations (NEK, 2021)

Article 13 of the Regulations on the Management of Radioactive Waste and Spent Fuel specifically deals with storage; ˝Radioactive waste is stored in a radioactive waste storage facility and spent fuel is stored in a spent fuel storage facility. The holder shall provide storage for all radioactive waste and spent fuel not undergoing reprocessing, transfer or storage. Radioactive waste or spent fuel meeting the acceptance criteria for acceptance for storage set out in Article 20 of these Regulations may be stored in a storage facility. Radioactive waste or spent fuel may be stored only in packaging approved for storage. The holder shall store spent fuel and HLW in such a way that criticality is prevented and residual heat removal is ensured. The holder, who is bound by international obligations relating to the safeguarding and record-keeping of nuclear material, shall store radioactive waste and spent fuel in such a way as to enable those obligations to be fulfilled.

4. NUCLEAR SAFETY

Nuclear safety is a priority in the mission of the Krško Nuclear Power Plant. It is continuously improved, taking into account operational experience, advice from national and international expert organisations and administrative requirements. The first step in nuclear safety is to maintain high quality during the design, construction and operation of the facility. Safety systems are designed to perform their safety functions under all operating conditions, including in the event of equipment failure. The effectiveness of the safety systems is ensured by their redundancy and parallel operation. The physical laws of the pressurised water reactor, with which NPP is equipped, ensure that the reactor stabilises itself or shuts down if there is a sudden increase in power or temperature. Four successive safety barriers are also part of the technological design to prevent the release of radioactivity into the environment. Independent monitoring at NEK is carried out by a special

organisational unit for independent monitoring of nuclear safety, the Krško Safety Committee, and international missions organised by the World Association of Nuclear Operators and the International Atomic Energy Agency. The preparedness and management of an emergency at the plant is ensured by the Krško Nuclear Power Plant Protection and Rescue Plan (NPPP). The nuclear emergency protection and rescue plans of the municipalities of Krško, Brežice, the Posavje region and the Republic of Slovenia ensure coordinated management of an emergency at the plant and in the environment (NEK, 2021).

5. SOURCES AND LITERATURE

- URL: https://www.nek.si/kako-deluje-nek (27.11.2021)
- URL: https://www.nek.si/o-jedrski-energiji/od-urana-do-jedrskega-goriva (27.11.2021)
- URL: https://www.nek.si/aktualni-podatki (28.11.2021)
- URL: https://www.nek.si/nase-zaveze/jedrska-varnost (28.11.2021)
- NEA, IAEA. 2018.
  URL: https://www.oecd-nea.org/jcms/pl_15080 (27.11.2021)
- Kišek, M. (2013). Renovation of the storage of low and intermediate level radioactive materials after use at the Krško Nuclear Power Plant (Diploma thesis). Krško. Retrieved 27.11.2021 from https://dk.um.si/Dokument.php?id=59979
- Vodopivec, P. (2017). Radioactive Waste Issues-Comparison between Slovenia and Italy (Diploma thesis). Ljubljana. Retrieved 27.11.2021 from https://core.ac.uk/download/pdf/129400164.pdf
- Čopič, M. and Gabrovšek, Z. (1999). *Nuklearna elektrarna Krško*. Krško.
- *Regulations on radioactive waste and spent fuel management* (2021). Official Journal of the Republic of Slovenia No 125/2021 (30.7.2021). Pridobljeno s https://www.uradni-list.si/glasilo-uradni-list-rs/vsebina/2021-01-2652?sop=2021-01-2652
- Grilc, J. and Peček, M. 2018. No disposal sites for high-level radioactive waste in the world yet. Wave 202.
  URL: https://val202.rtvslo.si/2018/01/frekvenca-x-106/ (27.11.2021)
- ARAO. 2015. Radioactive waste. URL:
  https://arao.si/images/pdf/ARAO_RAOkjekolikokako_160x200_web%281%29.pdf
  (27.11.2021)