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IDENTIFICATION AND QUALITATIVE ANALYSIS OF LIQUID EFFLUENTS IN THE SPATIAL PLANNING STAGE OF A NEW NUCLEAR POWER PLANT PROJECT

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Abstract The planned JEK2 will generate liquid effluents during normal operation, categorised as radioactive and non-radioactive. The radioactive releases will consist mainly of tritium, while other radionuclides will be present only in trace amounts, all below the authorised limits. The non-radioactive effluents, originating from the cooling and service water systems, will be treated by filtration, pH adjustment and biocide neutralisation. The thermal load of the non-radioactive emissions to the Sava will be minimal to negligible levels, as the cooling tower serves as a heat sink. All the effluents from JEK2 will be managed by design through defence in depth: multi-barrier treatment and holdup, controlled storage and release, and comprehensive monitoring under the ALARA principle to keep the impacts low and within the strict regulatory limits.

Keywords
JEK2,
Nuclear power plant,
liquid effluents,
radioactive discharges,
non-radioactive discharges,
ALARA principle,
effluent management,
regulatory compliance

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1 Liquid Effluents from Nuclear Power Plants

The operation of nuclear power plants (NPPs) involves inherently the generation of liquid effluents, that must be carefully managed carefully to ensure environmental and radiological protection. These effluents arise from various plant systems and processes associated with power production, maintenance and auxiliary operations. Depending on their origin and characteristics, they are classified into three categories: radioactive, non-radioactive and thermal discharges. Each category requires specific collection, treatment and monitoring measures, to maintain compliance with the regulatory limits and prevent environmental contamination [5].

The radioactive liquid releases originate primarily from the Reactor Coolant System (RCS), the Chemical and Volume Control System (CVCS), the Liquid Waste Processing System (LWPS), and auxiliary systems where small quantities of radioactive substances are transferred to the water streams. The activity of these liquids results from fission products, neutron activation of the structural materials and nuclear reactions, with tritium (^3H) as the main radionuclide formed. The collected liquids are treated through filtration, ion exchange, evaporation and decay storage, and subsequently discharged under the strictly controlled and authorised conditions defined in the environmental permit [4], [5], [9].

The non-radioactive effluents originate primarily from the plant's circulating and auxiliary water systems. These waters may contain the dissolved minerals, metals and chemical additives used to maintain the system`s integrity. Prior to discharge, the non-radioactive effluents are treated through processes such as filtration, chemical adjustment, or sedimentation, to ensure compliance with the environmental regulations and permit requirements [2].

The thermal discharges represent another category of effluents. During operation the reactor core generates heat through fission, which is transferred to the primary and secondary cooling systems. This residual thermal energy must be dissipated to a heat sink to maintain safe operation. Depending on the plant design, the heat may be released to a water body, or to the atmosphere via cooling towers [2].

The management of all the liquid and thermal effluents is an integral part of a nuclear power plant's safety and environmental protection strategy. The International and National Regulations require continuous monitoring, optimisation in accordance with the As Low As Reasonably Achievable (ALARA) principle, and transparent reporting to ensure that the discharges remain within the authorised limits, and to ensure the protection of both people and the environment [7].

2 Regulatory Framework

The management of liquid effluents from nuclear power plants is governed by a combination of international recommendations and national legislation, to ensure radiological and environmental protection. The responsibility for implementing and maintaining compliance lies with the plant operator under the supervision of the competent regulatory authorities.

2.1 International Standards and Guidelines

At the international level, the International Atomic Energy Agency (IAEA) provides the basis for regulating radioactive discharges through the safety guide GSG-9: Regulatory Control of Radioactive Discharges to the Environment. This document defines the requirements for national regulatory frameworks, dose constraints for members of the public, and the optimisation of discharges in line with the ALARA principle [5] .

The European Utility Requirements (EUR, Revision E) complement the IAEA guidance by defining the design objectives for new nuclear power plants. For a reference 1500 MWe Pressurised Water Reactor (PWR), the recommended annual limit for liquid radioactive discharges excluding tritium is 10 GBq, while the typical design objectives aim to keep the tritium releases below 40 TBq per year. These limits serve as design reference points, ensuring that the overall radiological impact of normal operation remains negligible [1].

2.2 National Legal Framework in Slovenia

In Slovenia, the effluent discharges are regulated under the Environmental Protection Act (ZVO-2) and the Water Act (ZV-1), which define the emission limits, monitoring obligations and reporting procedures. Environmental permits for non-radioactive discharges are issued by the Ministry of the Environment, Climate and Energy in cooperation with the Slovenian Environment Agency (ARSO). Licensing of the nuclear facility operation, including radionuclide-specific discharges, falls under the scope of the Slovenian Nuclear Safety Administration (SNSA).

For the planned JEK2 unit, all the design and operational requirements will be designed to comply with these regulations, integrating the IAEA and EUR Standards within the national permitting framework.

3 Expected Liquid Effluents from JEK2

During normal operation JEK2 is expected to generate liquid effluents classified as radioactive and non-radioactive. The radioactive effluents will originate primarily from the reactor coolant and liquid waste processing systems, with tritium (^{3}H) as the main radionuclide, while other fission and activation products—such as carbon-14 (^{14}C), strontium-90 (^{90}Sr), cesium-137 (^{137}Cs), and cobalt-60 (^{60}Co)—will be present only in trace amounts [2], [6], [9].

The non-radioactive effluents will originate from the plant's cooling, service and technical water systems, and may contain dissolved minerals, suspended solids, corrosion inhibitors, pH regulators and biocides [2].

The residual thermal energy will be removed via a closed-cycle cooling system with natural-draft wet cooling towers, limiting the heat discharged to the Sava River to a small blowdown flow of approximately 2 m^3/s at around 30 °C. This configuration is expected to dissipate the residual heat effectively while minimising the thermal impacts on the aquatic environment and maintaining efficient plant operation [6].

The effluent management at JEK2 integrates five key elements, which, together, ensure safe, controlled and ALARA-compliant operation:

1. Identification of Radioactive and Non-Radioactive Substances

A comprehensive identification is required of all substances that may occur in liquid effluents during normal operation.

- The radioactive substances include tritium, carbon-14, fission products (e.g., caesium-137, iodine-131) and activation products (e.g., manganese-54, cobalt-60).
- The non-radioactive substances may originate from the cooling and service water systems, and may include dissolved minerals, metals (e.g., copper, iron), the biocides used to prevent biological growth, corrosion-inhibiting chemicals and various organic compounds.

All the radioactive and non-radioactive substances must be evaluated with respect to their properties, potential pathways in the environment, and long-term effects on human health and ecosystems [3], [9].

2. Treatment and Control Systems

Effluent management requires detailed planning and the optimisation of liquid waste treatment systems to minimise environmental impacts. This includes:

- systems for managing liquids containing radionuclides, such as processing, purification and storage in tanks prior to release;
- systems for treating non-radioactive liquids, including filtration, chemical conditioning and dilution before discharge;
- monitoring and automated control, ensuring that the concentrations remain below the authorised limits specified in the operating permit.

It is essential to evaluate the effectiveness of the available technologies and consider the implementation of advanced solutions that reduce the effluent quantities further and improve the overall performance [7].

3. Local Environmental Conditions

The local environmental and hydrodynamic conditions influence the effluent behaviour strongly. For JEK2, this includes a detailed assessment of the Sava River's characteristics, such as dilution factors, seasonal variations in flow and the influence of the existing hydropower plants.
Local ecological components—including fish populations, sediments and riverine habitats—require dedicated evaluation regarding the potential accumulation of radioactive and non-radioactive substances and long-term ecological effects.[6].

4. Regulatory Requirements

During the JEK2 licensing process, the limits for liquid discharges will be established in line with the national legislation and environmental Standards. The Slovenian Nuclear Safety Administration (SNSA) and the Slovenian Environment Agency (ARSO) will determine the authorised discharge limits and monitoring obligations, based on the environmental studies and safety analyses.

These requirements will be included in the operating permit and must be followed strictly by the operator. Continuous monitoring and regulatory reporting will ensure that no unacceptable impacts occur. [5], [8].

5. Impact Modelling and Risk Assessment

Advanced mathematical models will be applied to evaluate the potential impacts of the liquid effluents. This includes:

- calculating the dilution and dispersion of radionuclides and non-radioactive substances in the aquatic environment,
- simulating different operational scenarios, including power variations and start-up/shutdown conditions,
- assessing the long-term effects on the aquatic ecosystem and human health, considering bioaccumulation, potential exposure pathways and the combined effects of multiple pollutants.

Limits for the liquid discharges and water abstraction will be specified in the environmental permit. When these limits are respected, the overall impact of JEK2 on surface waters is expected to remain negligible [6], [8].

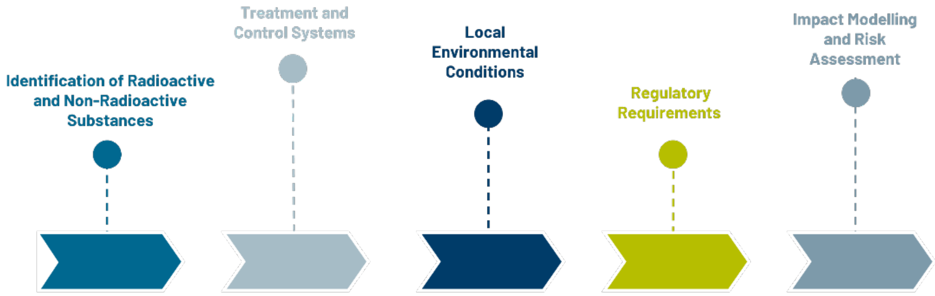

Figure 1: Key Elements of the Liquid Effluent Management at JEK2
Source: own.

This integrated approach ensures that all the liquid discharges remain within the authorised limits, comply with ALARA, and protect both the environment and public health.

Importantly, the effluent releases from JEK2 are planned and managed in a way that minimises the potential influence on the existing Krško NPP (NEK), ensuring that NEK's operational and environmental permits remain fully respected, including under low-flow river conditions.

4 Conclusions

JEK2 is designed to operate with minimal environmental impact while complying fully with international and national safety requirements. Based on the current design documentation for the planned JEK2 unit:

- Effluent management: The planned systems are expected to ensure that all radioactive and non-radioactive liquid discharges can be collected, treated, monitored and released under controlled conditions.

- Thermal impact: The planned closed-cycle cooling system with natural-draft towers is expected to limit the heat discharge to the Sava River effectively (~2 m³/s at ~30 °C), with a negligible ecological impact [6].

- Safety and regulatory compliance: The design will adhere to the IAEA Safety Standards, EUR design objectives and Slovenian legislation. The effluent generation and release will be optimised according to the ALARA principle, and advanced operational procedures and monitoring systems will ensure safe plant operation with minimal risk of significant radioactive release.

- NEK protection: The effluent management is designed to minimise the impacts on the existing Krško NPP, preserving its operational and environmental permits.

In summary, JEK2's liquid effluent management integrates technological, regulatory and operational measures, to guarantee environmental protection and radiological safety. During normal operation, JEK2 is expected to have a negligible impact on the environment, consistent with the International Standards for safe and sustainable nuclear power generation.

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Povzetek v slovenskem jeziku

Identifikacija in kvalitativna analiza tekočinskih izpustov v fazi prostorskega načrtovanja nove jedrske elektrarne. Načrtovana jedrska elektrarna JEK2 bo med normalnim obratovanjem proizvajala tekočinske izpuste, ki so razvrščeni na radioaktivne in neradioaktivne. Radioaktivni izpusti bodo pretežno vsebovali tritij, medtem ko bodo ostali radionuklidi prisotni le v sledovih oziroma bo njihova aktivnost zelo nizka. Neradioaktivni izpusti bodo izvirali iz tehnoloških vod in bodo pred izpustom obdelani s filtracijo, uravnavanjem pH in nevtralizacijo. Toplotne obremenitve reke Save bodo minimalne, saj je za hlajenje predviden hladilni stolp na naravni vlek. Upravljanje tekočinskih izpustov bo zasnovano na principu večplastne zaščite, ki vključuje obdelavo in zadrževanje odpadnih vod, kontrolirano izpuščanje ter celovito spremljanje skladno z načelom ALARA (As Low As Reasonably Achievable), s čimer se zagotavlja minimalen vpliv na okolje in skladnost z zakonodajnimi zahtevami.