REINSTATEMENT OF VVER-440 FUEL PRODUCTION CAPABILITY AT JUZBADO FUEL FACTORY

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ABSTRACT

Twenty Russian-designed VVER reactors exist in the European Union and fifteen in Ukraine whose operation depends mainly on Russian-produced nuclear fuel. Following Russia's invasion of Ukraine, operators of VVER reactors have identified the need of reinforcing the security of supply of nuclear fuel for these nuclear power plants.

Consequently, ENUSA and Westinghouse Electric Sweden AB (WSE) have entered into a VVER-440 Cooperation Agreement, which sets out the terms and conditions for the ENUSA access to the VVER-440 fuel manufacturing.

In parallel with the Cooperation Agreement, WSE and ENUSA have entered into a Fuel Technology Licensing Agreement, which sets out the terms and conditions for the ENUSA access, as Licensee, to the VVER-440 fuel technology owned by Westinghouse and provided, as Licensor, to ENUSA.

ENUSA, in virtue of the existing agreements with Westinghouse, has carried out a project to reinstate the VVER-440 fuel production capacity at its Juzbado fuel Fabrication Plant with the objective of having this capability ready for manufacturing in the year 2024. This project ranges from the equipment procurement to the qualification of the manufacturing process, including all the authorizations from the CSN (Spanish Regulatory Body).

The new VVER-440 fuel production line builds upon the experience in the supply of fuel reloads to the Loviisa Nuclear Power Plant (2001-2007). It comprises the following steps:

- Pellets manufacturing and pellets quality inspection.
- Fuel rod quality inspection.
- Fuel rod accumulation.
- Skeleton manufacturing.
- Fuel rod loading into the skeleton.
- Bottom nozzle welding.
- Washing.
- Shroud and Fuel Bundle assembling.
- Envelope inspection.
- Packaging for shipping.

Furthermore, the European Atomic Energy Commission (EURATOM) has awarded a grant to a Consortium led by WSE, where ENUSA participates, which finances part of the activities required to ensure this European alternative fuel supply. The name of the Consortium is APIS, short for “Accelerated Program for Implementation of secure VVER fuel Supply”. APIS was started in January 2023 and has a duration of 36 months.

1. Introduction and background

The acronym VVER (transliterated in Russian vodo-vodyanoi energetichesky reactor, meaning water-water power reactor) refers to a series of pressurized water reactors developed in the Soviet Union (Russia) by the Rosatom Consortium and its nuclear fuel manufacturer TVEL. TVEL is a company involved in all stages of the nuclear fuel cycle.

Currently, there are more than 30 VVER-440 or VVER-1000 reactors operating in the European Union and in Ukraine, whose fuel is mainly produced in Russia. These reactors are summarized in Table 1 [1]. Both types of reactors use hexagonal fuel as shown in Figure 1, but the VVER-440 fuel design is smaller and has much fewer fuel rods compared to the VVER-1000.

Country	Name of station and reactor unit	Type of unit
Bulgaria	Kozloduy 5-6	VVER-1000
Czech Republic	Dukovany 1-4	VVER-440
	Temelin 1-2	VVER-1000
Finland	Loviisa 1-2	VVER-440
Hungary	Paks 1-4	VVER-440
Slovakia	Bohunice 3-4	VVER-440
	Mochovce 1-2 Mochovce 3 in operation since January 2023 Mochovce 4 under construction	VVER-440
Ukranie	Khmelnitsky 1-2	VVER-1000
	Rivne 1-2	VVER-440
	Rivne 3-4	VVER-1000
	South Ukraine 1-3	VVER-1000
	Zaporizhzhia 1-6	VVER-1000

Tab 1: VVER units in the EU and Ukraine

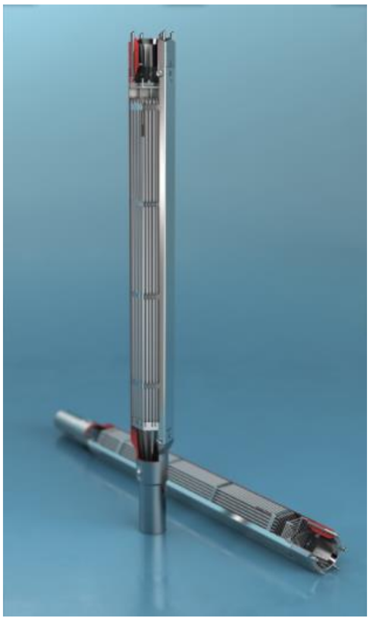

Fig 1. VVER fuel assembly

Following Russia's invasion of Ukraine, EU sanctions made it necessary to strengthen the security of supply for these nuclear power plants to achieve independence from Russia, ensuring energy security to the affected countries.

Westinghouse had previously delivered (a) reloads of VVER-440 fuel to Loviisa in Finland, which were manufactured in Spain by ENUSA, (b) VVER-1000 fuel for both the initial core and follow-on reloads to Temelin in the Czech Republic and (c), more recently, reloads of both VVER-1000 and VVER-440 fuel to Ukraine. Moreover, as other countries with VVER units in the EU showed interest to qualify a second fuel supplier, a consortium led by Westinghouse and other companies, including ENUSA, in eight European countries was launched to develop an alternative nuclear fuel to that coming from Russia.

2. Agreements

In response to this interest, Westinghouse Electric Sweden AB (WSE) and ENUSA have entered into a Cooperation Agreement for the manufacturing of VVER-440 fuel. This agreement establishes a collaboration between both companies, providing support to most countries operating these types of reactors (Finland, Ukraine, Czech Republic, Slovakia, and Hungary). Westinghouse-produced fuel will be manufactured at the Västerås factory in Sweden, while ENUSA-produced fuel will be manufactured at the Juzbado factory in Salamanca (Spain).

The above-mentioned agreement focuses mainly on manufacturing activities but opens the door to a wider collaboration on engineering and licensing activities, as well as on on-site services.

Additionally, Westinghouse and ENUSA have entered into a Fuel Technology Licensing Agreement, which sets out the terms and conditions for the ENUSA access, as Licensee, to the VVER-440 fuel technology owned by Westinghouse and provided, as Licensor, to ENUSA.

Furthermore, the introduction of this new technology in different countries involves significant licensing efforts with several different regulatory bodies. Therefore, Westinghouse and ENUSA have entered into another agreement that covers ENUSA support to Westinghouse in providing engineering services related to VVER fuel, both VVER-440 and VVER-1000. ENUSA experts are closely collaborating with Westinghouse engineering team to complement their capabilities in various design areas, such as thermo-hydraulics and mechanical design.

3. APIS project

The European Union (EU) has selected a consortium led by Westinghouse, with ENUSA as a participant, to develop and deliver a safe and fully European nuclear fuel supply to Russian-designed pressurized water reactors (VVER) operating in the EU and Ukraine, partially funding the necessary activities to ensure this European fuel alternative [2].

The project started in January 2023 and will run through the end of 2025. The consortium, called APIS (Accelerated Program for Implementation of Secure VVER Fuel Supply), is co-funded by the European Union through the Euratom Work Programme 2023-25.

The APIS consortium brings together 12 European partners from 8 countries, including: five nuclear power plant operators such as ČEZ AS (Czech Republic), Energoatom (Ukraine), Fortum (Finland), MVM Paks Nuclear Power Plant (Hungary), and Slovenské Elektrárne (Slovakia); fuel manufacturers such as Westinghouse (Sweden) and ENUSA (Spain); and five fuel research and engineering organizations such as the JRC-Joint Research Centre-European Commission (Belgium/Germany), State Scientific and Technical Center for Nuclear and Radiation Safety (Ukraine), ÚJV Řež AS (Czech Republic), Uppsala University (Sweden), and VUJE a.s. (Slovakia).

As explained on the APIS website, "APIS" means bee in Latin and is used as an analogy to symbolize that the project comprises a large group of hard working and friendly engineers that cooperate to secure nuclear fuel to the VVER cores that have the same hexagonal shape as honeycombs.

The APIS project is structured into eleven work-packages with different focuses, including:

- Completion of the VVER-440 fuel design for short term delivery (WP1)
- Development of improved and advanced VVER-440 and VVER-1000 fuel designs (WP2, WP3)
- Standardization of the fuel licensing (WP4)
- Complete the re-instatement of fuel manufacturing capabilities (WP5)
- Safe operation and improved modelling and methods (WP6, WP8, WP9)
- Analysis of fuel related plant lifetime extension (WP7)
- Communication and project management (WP10, WP11)

The objective of this project is to create stronger security of nuclear fuel supply for Russian-designed VVER reactors, in the EU and Ukraine, thereby guaranteeing the energy security of the affected countries.

ENUSA mainly takes part in the WP5 (Reinstatement of the fuel manufacturing capability), together with WSE, that provides redundancy in security of supply by the involvement of the two fuel-manufacturing plants.

4. Reinstatement of the VVER-440 manufacturing line

As a result of the Cooperation Agreement with Westinghouse, ENUSA has carried out a project to reinstate the VVER-440 fuel production capacity at its Juzbado fuel Fabrication Plant with the objective of having this capability ready for manufacturing in the year 2024. This project includes activities ranging from the equipment procurement to the qualification of the manufacturing process, including all the authorizations from the Spanish Regulatory Body.

The reactor core in the VVER-440 model is composed of fuel assemblies (fixed) and movable control assemblies (follower). Fixed assemblies are the "common" core fuel assemblies, while follower assemblies are partially extractable control rods clusters. ENUSA's new manufacturing line covers the manufacturing of the last two generations of this fuel type designed by Westinghouse: the fixed NOVA E5 and NOVA E6 designs and the followers NOVCC and NOVCD designs, respectively associated with each fixed element. The main improvement implemented in these fuel generations is to optimize the fuel economy during the operation in the nuclear power plants.

The new VVER-440 fuel production line builds upon the experience in the supply of fuel reloads to the Loviisa Nuclear Power Plant. Between 2001 and 2007, BNFL/Westinghouse and ENUSA (as fuel manufacturer), delivered a total of 741 VVER-440 fuel assemblies to the Loviisa NPP in Finland. The designs of the fuel assemblies delivered to Loviisa NPP were NOVA E-3 (fixed assembly) and NOVCA (follower assembly).

The new line installed mainly comprises the stages described hereunder. The fuel rods are loaded with uranium pellets, plugged, welded and sealed. Then they are transferred to the mechanical area and the manufacturing process continues as follows:

- Fuel rod quality inspection. In this stage, a welding quality control is performed. It consists of:
  - *UT inspection*. Control of the plugs union to the tube (weld penetration, tube thickness, porosity, grain boundary separation (GBS) and cracks).
  - *X-ray inspection*. Control of the sealing welding process of the top end plug (weld penetration, porosity, inclusions, cracks and spring fusion).
  - *Leak test*. Control of a possible He leakage on each rod.
  - *Passive gamma scanner inspection*. In this stage, the following parameters are controlled: plenum length, gaps among pellets and gap between pellet and bottom end plug, pellet stack length, mean enrichment, gadolinium content, fissile content deviant pellets, gadolinium deviant pellets, tube outer surface defectology.
  - *Visual inspection*. Rod integrity, end plugs welding visual defects, seal weld, weld diameter, cleanliness.
  - *Dimensional inspection*. Straightness and length, tube/end plug parallelism.

- Skeleton manufacturing and inspection (Fig. 2). The grids are assembled in the correct orientation onto a strongback that holds them in the correct positions and the instrumentation/central tube passes through the centre of the resultant array. A versatile strongback for the different VVER-440 fuel designs has been developed. For each skeleton the position and geometry of all bulges, position and orientation of the grids, integrity, alignment of the entire set, and cleanliness are controlled.

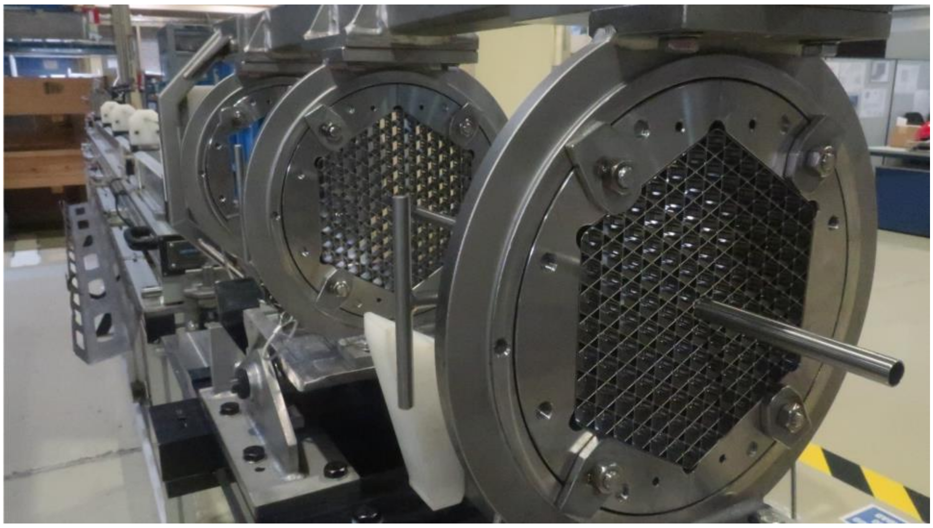

Fig 2. Skeleton manufacturing equipment

- Fuel assembly manufacturing and inspection (Fig. 3, 4 and 5).

  - *Fuel rod accumulation (Fig. 3)*. An automatic preassembly of the fuel assembly in a specific VVER magazine is carried out, simulating the position of the rod in the fuel assembly. The barcode of each fuel rod is read and placed in the required position, avoiding human error.

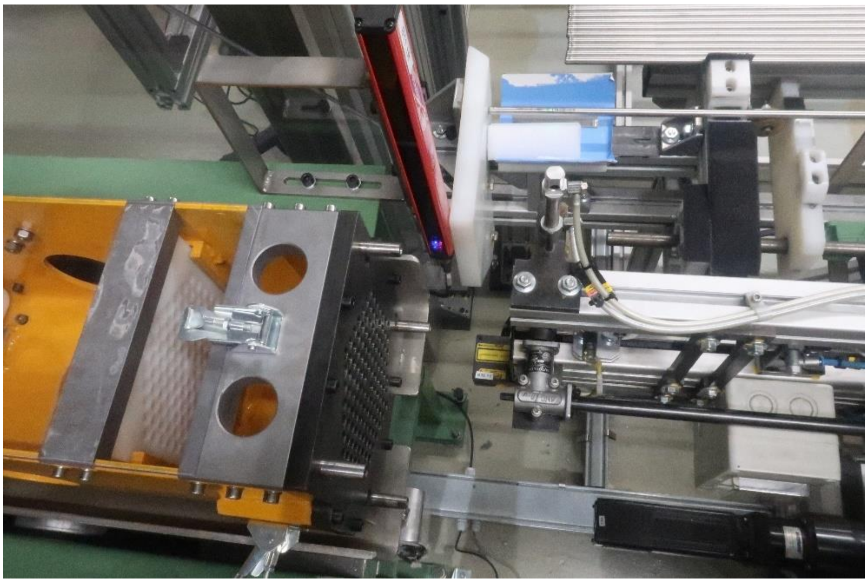

Fig 3. Fuel rod accumulation

- *Fuel rod loading into the skeleton (Fig. 4)*. Rod loading is performed by pulling the fuel rods in a specific sequence, with a qualified rod loading speed.

Fig 4. Fuel rod loading into the skeleton equipment

- *Bottom nozzle welding*. Fit and weld bottom nozzle assembly to bottom flow plate to get the rod bundle (skeleton + rods + bottom nozzle).
- *Washing*. The rod bundle is washed using de-ionized water. The absence of burns, rusts, spots has to be assured, applying a strict policy on foreign material exclusion (FME).
- *Dimensional and visual inspection*. Visually accessible fuel rod surfaces shall be free from dents, nicks, gouges, scratches, unusual marks and other defects.
- *Shroud and Fuel Assembly assembling (Fig. 5).* Careful progression of the strongback up the shroud tube/top-nozzle assembly, over the rod bundle and sequential removal of the strongback grid support clamps as it moves upwards.

Fig 5. Shroud and Fuel Assembly assembling station.

- *Envelope inspection*. Centralization of top-nozzle in the jig top ring with the aim to check the whole alignment and overall lengths.
- *Packaging for shipping*. ENUSA has a specific tilt table (Fig. 6) to handle the package. Each transport container has holders for 4 fuel assemblies which are loaded vertically.

Fig 6. Tilt equipment for fuel packaging

Closely related to fuel manufacturing is the fuel logistics. With this regard, Spanish Regulatory Body has issued the validation of the “3525” container (Fig. 7) in Spain for the transportation of NOVA E5 and NOVCC designs. WSE is working on the validation in Sweden of the container for NOVA E6 and NOVCD designs. Once the new license is awarded, ENUSA will apply for the validation in Spain.

Fig 7. 3525 container

5. Product design

As explained before, the new VVER-440 fuel production line builds upon the experience in the supply of fuel reloads to the Loviisa Nuclear Power Plant and some of the ENUSA manufacturing specificities must be considered in the product design.

ENUSA has devoted much effort to evaluate product differences between current WSE VVER-440 NOVA E5 and NOVCC designs and those manufactured previously at ENUSA, VVER-440 NOVA E3 and NOVCA designs. Based on these evaluations a later thorough analysis on manufacturing impact has also been performed.

As a result of this extensive evaluation, differences have been found in most stages of manufacturing, the most important ones relate with pellets and fuel rods manufacturing and inspection processes.

Regarding fuel rods manufacturing, there are two main differences between WSE and ENUSA processes. The first one has to do with the welding type, electron beam weld at WSE and tungsten inert gas (TIG) weld at ENUSA; and the second one relates with the specific manufacturing controls performed to ensure that final product will fulfill all the requirements. The difference in the welding type impacts on the component’s joint configuration and on fuel rods re-workability. The difference in manufacturing controls impacts how the design requirements are translated into drawings.

To face TIG welding joint requirements, new end plugs and tubes drawings have been issued including all the joints modifications needed. Instrumentation and central tube assemblies’ components have also been modified to consider welding type different needs.

To face re-workability needs together with manufacturing control differences, new fuel rods drawings are being issued. These changes are, among others, a wider lower tolerance for fuel rod length, tighter tolerances for plenum length, and the inclusion of a pellet stack length requirement.

Therefore, due to the differences found and the specific nature of the activities to be performed, several meetings have been held between ENUSA and WSE Product Engineering departments focused on modifying the drawings of tubes and end plugs and also the ones of the on-site manufactured assemblies. Both departments are also working hand to hand on the product and process specifications, so that ENUSA manufacturing process specificities are also taken into consideration.

6. Conclusions

Due to the geopolitical situation in Ukraine caused by the Russian invasion, reinforcement of the security of nuclear fuel supply for Russian-designed VVER reactors in the EU and Ukraine with safe and fully European fuel has become a critical necessity.

To achieve this, ENUSA and Westinghouse Electric Sweden AB have entered into a Cooperation Agreement regarding the manufacturing of VVER-440 fuel.

This agreement will allow NPPs operators to diversify the procurement of this nuclear fuel enhance security of VVER-440 fuel supply and reduce dependence on the current supplier, strategically fulfilling the will of the European Union to provide a real alternative in fuel supply.

The paper summarizes the manufacturing equipment, process and product engineering efforts that has been devoted to meet this goal. Achieving manufacturing redundancy in Europe to fabricate VVER-440 fuel requires considering process specificity and differences in the manufacturing equipments. An extensive product engineering evaluation has been carried out to assure this fuel can be produced at Västerås and Juzbado sites in a short period of time.

7. References

[1] «Diversification of the VVER fuel market», Nuclear Engineering International, sept. 2015.
[2] «APIS», Accelerated Program for Implementation of secure VVER fuel Supply. https://apis-project.eu/.