A NEW VVER-440 FUEL DESIGN FOR ENERGY SECURITY IN THE EUROPEAN UNION AND UKRAINE

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1. Introduction

Westinghouse delivered VVER-440 fuel to Loviisa NPP between 1998 – 2007 but paused its manufacturing and development of this fuel product due to lost business. The fuel performance in Loviisa had been very good with only one leaking assembly out of 741 operating. Grid-to-rod fretting (GTRF) was considered the leaker cause.

After the Russian full-scale invasion of Ukraine in February 2022 the need became urgent for alternative fuel for the VVER-440 reactors operating in the European Union and Ukraine. To meet this need, Westinghouse initiated a development project targeting a new VVER-440 fuel design based on the Loviisa design.

Due to the long time elapsed since the deliveries to Loviisa there was a need for a complete re-instatement of the supply chain and manufacturing capabilities. The re-instatement program included complete rebuilding of production lines in the Västerås facility, re-establishment of a complete supply chain including diversification for increased capacity, and manufacturing of additional sets of transport containers.

To support a program acceleration and expansion the APIS project was initiated with co-funding by the European Union through the Horizon program. APIS represents an abbreviation for Accelerated Program for Implementation of secure VVER fuel Supply and the objective is to create security of supply of nuclear fuel for VVER plants operating in the EU and Ukraine in full compliance with nuclear safety. The project is reinforcing European capabilities for supply of VVER-440 type of nuclear fuel and aiming towards cooperation among participating countries in the fuel design and licensing.

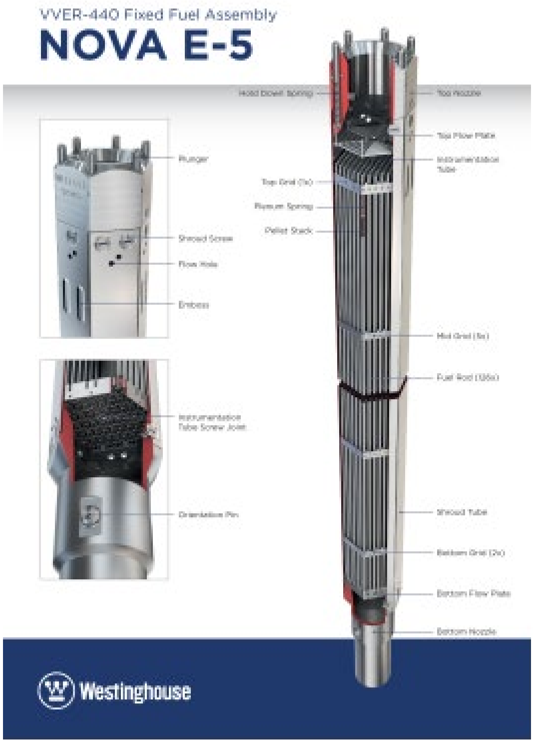
2. Westinghouse Upgraded VVER-440 Fuel Design

With reference to the Loviisa wear indications and the increased fuel resident time required from improved fuel utilization in all European plants, it was concluded necessary to increase the design margins to GTRF to reduce the risk for leakers as well as to upgrade materials to zirconium alloys with enhanced characteristics: **Optimized ZIRLO™** as cladding material, **ZIRLO®** in the central tube and **Low Tin ZIRLO™** in the mid-grids .

A new grid of A718 material based on the excellent experience from VVER-1000 operation was developed and the number of grids in the assembly was increased from 7 to 8 with the new A718 grid located in grid position 1, 2 and 8. This design feature is well proven from other Westinghouse fuel designs to provide significant GTRF margin improvement. The increased number of grids enhances the fuel rod support system and the three A718 grids will maintain better control of rod ends through the whole operation life of the fuel assembly since the material relaxation in A718 is significantly less than in zirconium alloys. The new grid has improved support features and reduced pressure drop.

Since the VVER-440 is a shrouded design there are no compatibility issues with optimized axial grid spacing in the improved VVER-440 design towards adjacent resident fuel assemblies or reactor internals.

Figure 1 shows an overview of the first generation of an upgraded VVER-440 design denoted NOVA E-5.



- Length: 3.2 m
- Total weight: 214 kg
- Weight of U: 127 kg
- Cladding material: Optimized ZIRLO^{TM}
- Shroud material: Zircaloy-4
- Grid Material: Low Tin ZIRLO^{TM} Alloy 718
- No of grids: 8
- No of fuel rods: 126

- Shrouded design (channels)
- Skeleton with one central tube and bulged grids (same as PWR)

The VVER-440 core contains 312 Fixed assemblies and 37 follower assemblies. Followers are withdrawn from core and replaced by control assemblies at plant shutdown and SCRAM.

Figure 1 Westinghouse VVER-440 Fixed Fuel Assembly NOVA E-5

Next development step to meet customer needs for improved fuel utilization in power uprated cores operating with longer cycles was to introduce a longer pellet stack, 60 mm for the fixed assembly and 40 mm for the follower, see Figure 2, and corresponding adjustments to other components to enable the increased stack lengths. In addition, the follower is equipped hafnium spacers in the peripheral rods in the follower assembly, see Figure 2. The power peak occurring from increased moderation in the follower to absorber connection, is efficiently mitigated by this design feature. The fuel design in which these further enhancements were introduced is denoted NOVA E-6 for the fixed assembly and NOVCD for the follower.

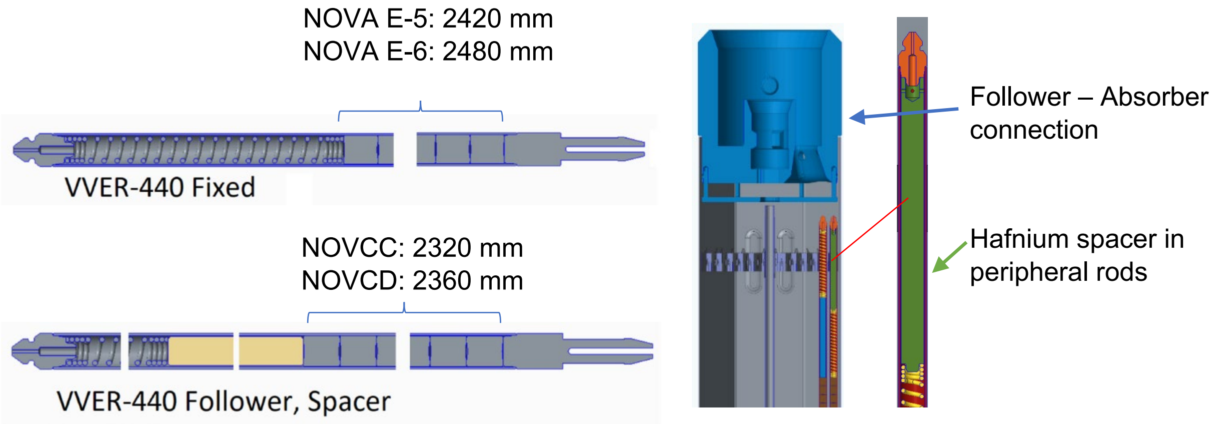


Figure 2 Pellet stack length increase and hafnium spacers in the follower.

Additively Manufactured Top- and Bottom Flow Plates

To improve the manufacturability and the ability to meet tight tolerance requirements of the top- and bottom flow plates Additive Manufacturing (AM) was introduced for these components, see Figure 3. AM also eliminates several welding steps. The top- and bottom flow plates are the world's first additively manufactured commercial nuclear fuel components classified as "safety related" to enter serial production. Today, more than 1 500 flow plates have been manufactured by AM and the TCT Industrial Product Application Award was achieved in 2024.

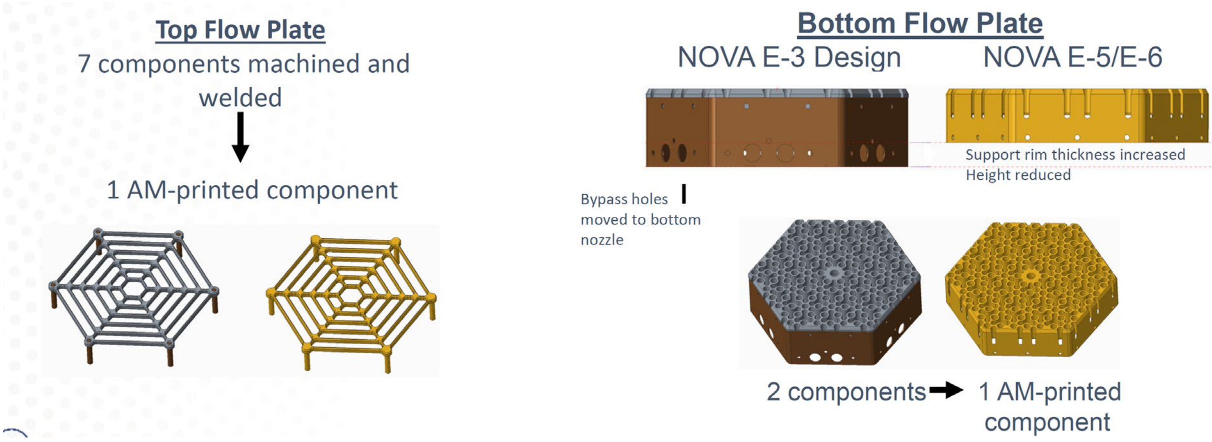


Figure 5 Top and Bottom Flow Plates Adapted to AM-manufacturing (3D-printing)

From several AM development projects by Westinghouse and the operating experience from inserted components, it has been concluded that material properties relevant to in-reactor performance after solution heat treatment are largely independent of manufacturing techniques. With adequate controls, AM material is expected to perform similar to, or better than, the same alloy produced using other conventional manufacturing techniques.

In general, stresses on the flow plates are low during operation and the highest stresses can occur during manufacturing, transport and handling. The "Breakage of Intermediate Rod (BIR)" accident case for follower assembly results in higher forces on the bottom flow plate but for this event minor plastic deformation is allowed.

The flow plates have been mechanically tested with results ensuring robust performance and all necessary controls have been implemented in the manufacturing of AM flow plates to ensure reliable performance.

3. Westinghouse VVER-440 Manufacturing and Supply Chain Reinstatement

The production and supply chain for VVER-440 fuel was partially abandoned after lost business in 2008 and a manufacturing and supply chain re-instatement program needed to be initiated after the need became urgent for alternative fuel for the VVER-440 reactors.

The original VVER-440 design upgrade and manufacturing re-instatement program targeted delivery of 12 LTAs in 2024 and 1-2 reloads going forward but program targets completely changed after the Russian full-scale invasion of Ukraine in spring 2022. A joint program aiming to diversify the fuel deliveries and enhance the security of VVER-440 nuclear fuel supplies across the fleet was established by Westinghouse and utilities. The VVER-440 program was accelerated and extended in size to secure deliveries to all units in case the supplies from the current supplier would have been interrupted.

The manufacturing and supply chain re-instatement program included complete rebuilding of production line in Västerås facility with expedited schedule and diversification of the supply chain for increased capacity and security of supply. Major investments, in total 23 projects, were needed in component and assembly manufacturing where the largest projects were in grids, shrouds and fuel assembly. In addition, a collaboration between ENUSA and Westinghouse on VVER-440 fuel manufacturing was established to further increase the capacity.

4. Readiness

The VVER-440 design upgrade and manufacturing re-instatement have been finalized. A completely new manufacturing process and new equipment have been implemented, and the complete VVER-440 supply chain has been re-established. The production is set up to handle the demand from all European VVER-440 utilities. Reloads have been delivered to Ukraine, Finland and the Czech Republic and the first manufacturing at the ENUSA site will be initiated towards the end of 2025.