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Westinghouse VVER-440 Design Upgrade

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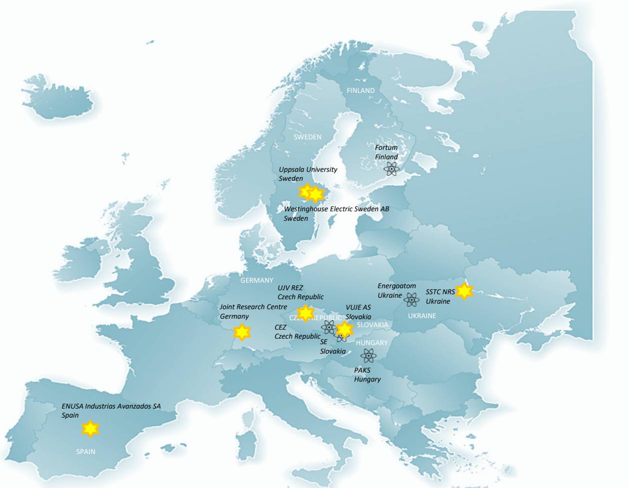
APIS

Accelerated Program for Implementation of secure VVER fuel Supply

Co-funded by the European Union

(APIS = Bee in latin)

After Russian full-scale invasion a joint program between utilities and Westinghouse aiming to diversify the fuel deliveries and enhance the security of VVER-440 fuel supply was established



Participant #	APIS participant organisation name	Country
1 (Coordinator)	WESTINGHOUSE ELECTRIC SWEDEN AB	SE
2	ENUSA INDUSTRIAS AVANZADA SA	ES
3	JRC - JOINT RESEARCH CENTRE	BE
4	VUJE AS	SK
5	SSTC NRS	UA
6	NRI / ÚJV Řež	CZ
7	PAKSI ATOM	HU
8	SLOVENSKE ELEKTRARNE AS	SK
9	ČEZ a. s.	CZ
10	UPPSALA UNIVERSITY	SE
11	FORTUM POWER AND HEAT OY	FI
12	SE «NNEGC «Energoatom»	UA

WP#	APIS Work Package Title	Lead Participant Short Name	Person-Months
1	Emergent VVER-440 fuel design	Westinghouse	104
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NOVA E-3 Operation Experience

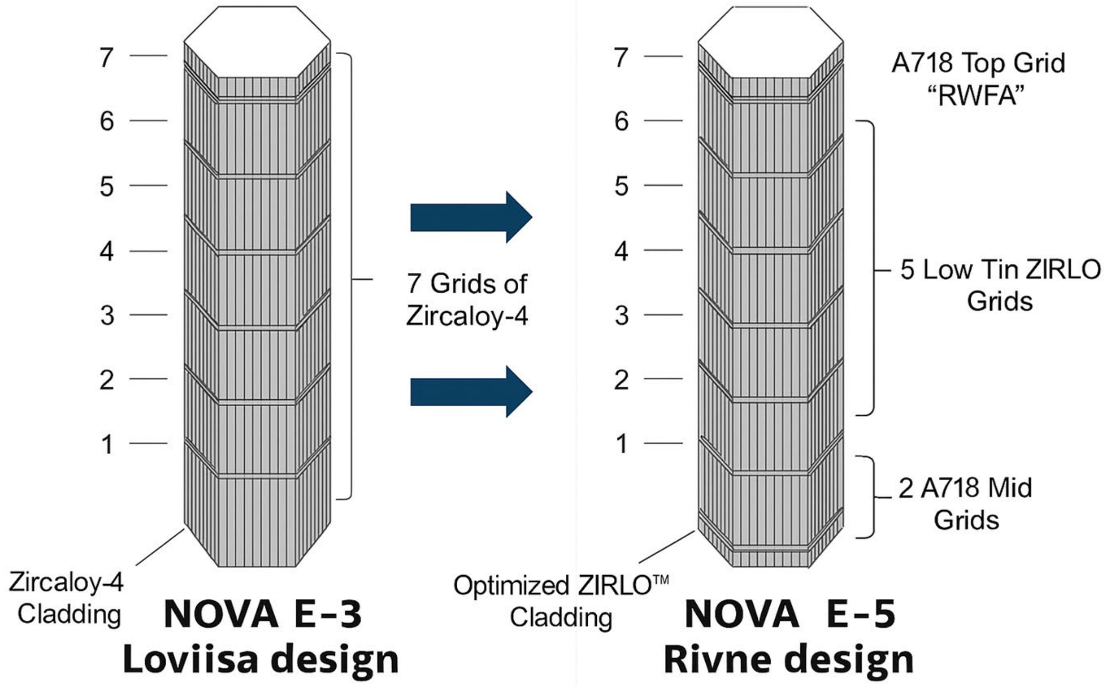
- NOVA E-3 in Loviisa
  - Reloads operated in 4-cycle regime
  - 1 LTA operated in 5 annual cycles
  - Maximum FA burnup 55.3 MWd/kgU
- Generally, very good operating experience with 1 leaker out of 741 FAs
  - Cause of failure identified in 2014 as grid-to-rod fretting (GTRF)
  - GTRF marks observed below first mid-grid on several fuel assemblies

Considered necessary to increase grid-to-rod-fretting resistance

Westinghouse VVER-440 Fuel Design Upgrade NOVA E-3/NOVCA -> NOVA E-5/NOVCC (APIS WP1)

Design and material enhancements increasing grid-to-rod fretting operation resistance
- One additional grid: 7-grid → 8-grid design
- Material in top- and two lowermost grids: Inconel A718
- **Standard and well proven GTRF mitigatior feature used in PWR and VVER designs**

Material upgrades
- Zr Grids: Zr4 -> **Low Tin ZIRLO™**
- Cladding: Zr4 -> **Optimized ZIRLO™**
- Central Tube: Zr4 -> **ZIRLO®**
- Flow Plates: 304L -> 316L (Additively Manufactured)
- **Well proven state-of-the-art materials in different environments and operation conditions**



Design changes focus on increase of grid-to-rod-fretting resistance

VVER-440 Design Upgrade Project Highlights

- Pressure loss measurements in the EMBLA loop show 9% lower PLC for E-5/E-6 compared to E-3
  - Decreased grid PLC due to improved strap manufacturing and welding process
  - EMBLA loop demonstrates excellent repeatability between NOVA E-5 and NOVCC
- New top- and bottom grid of A718 based on the VVER-1000 grid with excellent operating experience
  - Developed in a very short timeframe
  - Largest part of development project
- Introduction of Additive Manufacturing for Top- and Bottom flow plates in Reload quantities

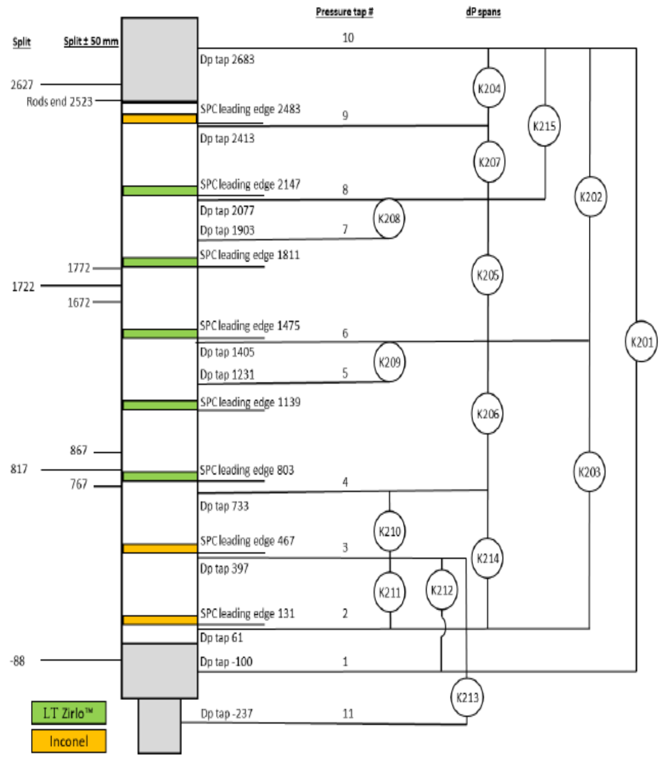
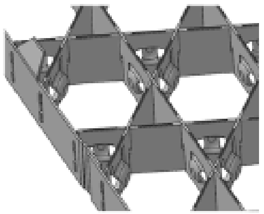
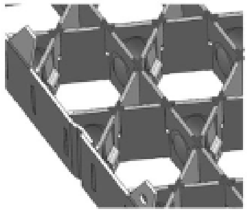


Figure 3: Pressure tap and grid positions relative to the top of the bottom nozzle.





Top and Bottom Flow Plate Adapted to AM-manufacturing (3D-printing).

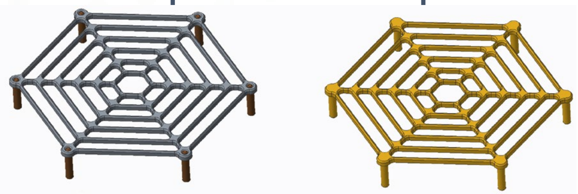
- Material is 316L powder
- Improves the ability to meet tight tolerance requirements
- In-reactor material properties performance after solution heat treatment largely independent of manufacturing techniques
- Bottom flow plate tested with tensile, compressive and tensile cyclic loads.
  - Highest loads during manufacturing and transport

- Ongoing in core AM component irradiation:
  - Thimble plug device
  - BWR Debris Filter (StrongHold)
  - Debris Filtering Bottom Nozzle
  - VVER-440 Flow Plates

Top Flow Plate

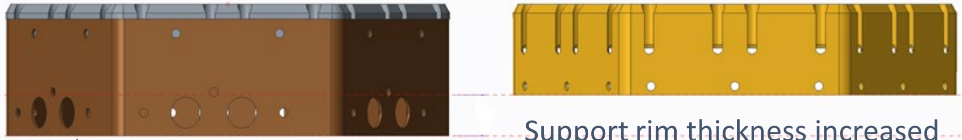
7 components machined and welded

1 AM-printed component



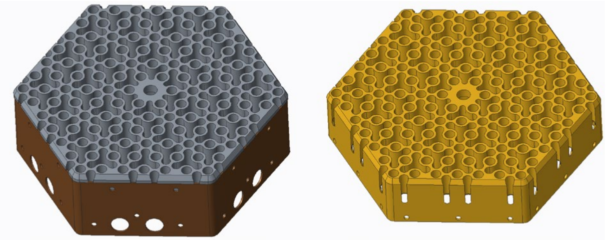
Bottom Flow Plate

NOVA E-3 Design NOVA E-5/E-6



Support rim thickness increased
Height reduced

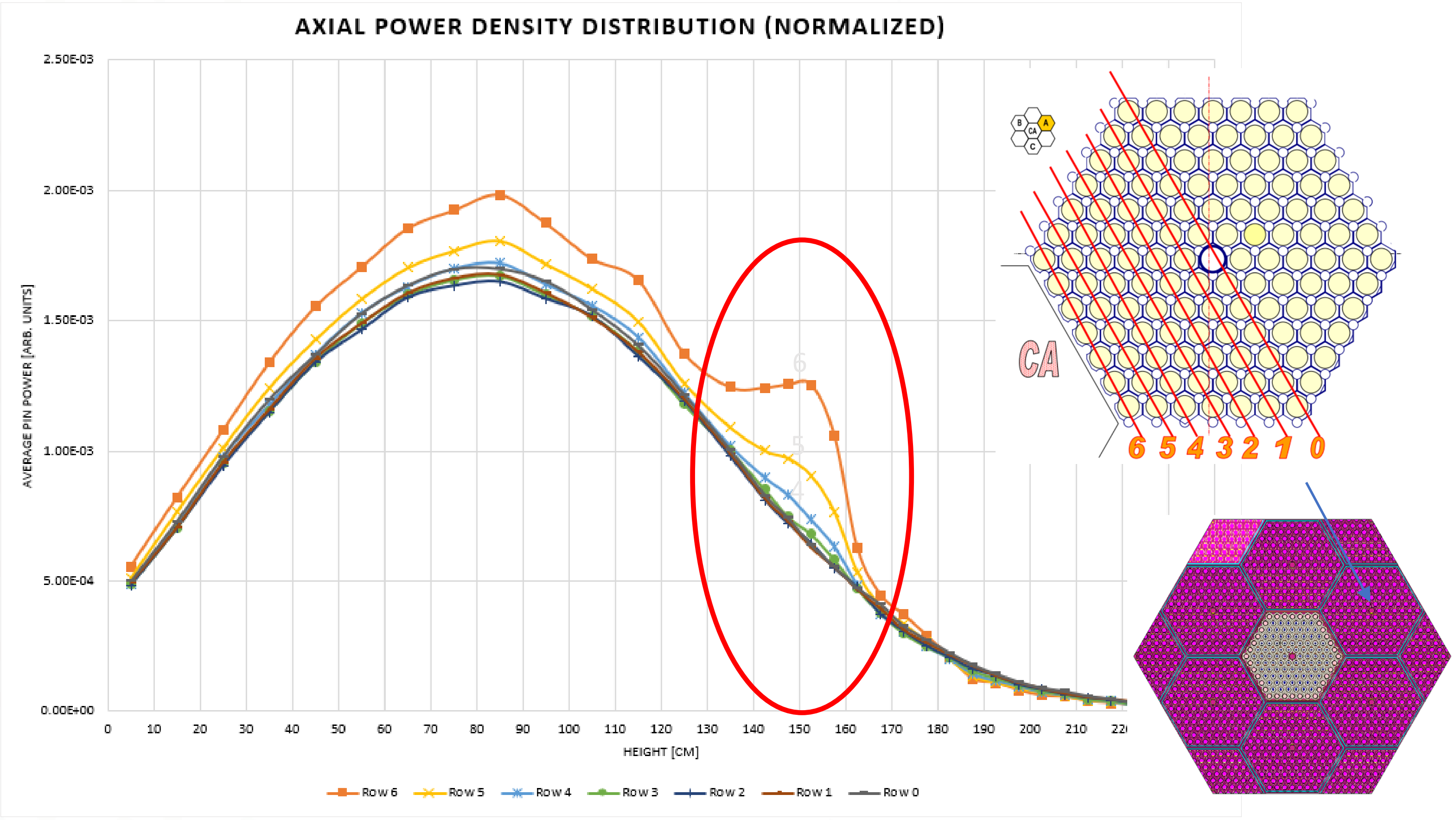
Bypass holes moved to bottom nozzle

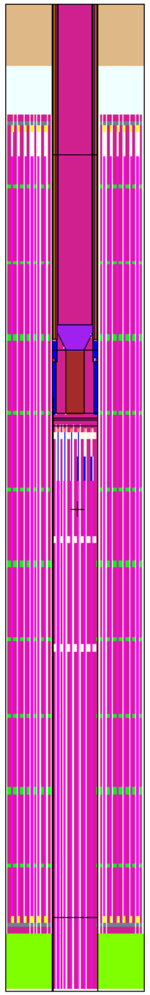


2 components → 1 AM-printed component

Power Peak Issue with NOVCC Design - Partial Insertion of Follower Fuel Assembly

- Power in fuel rods (Rows 0 to 6) of neighboring fixed assembly



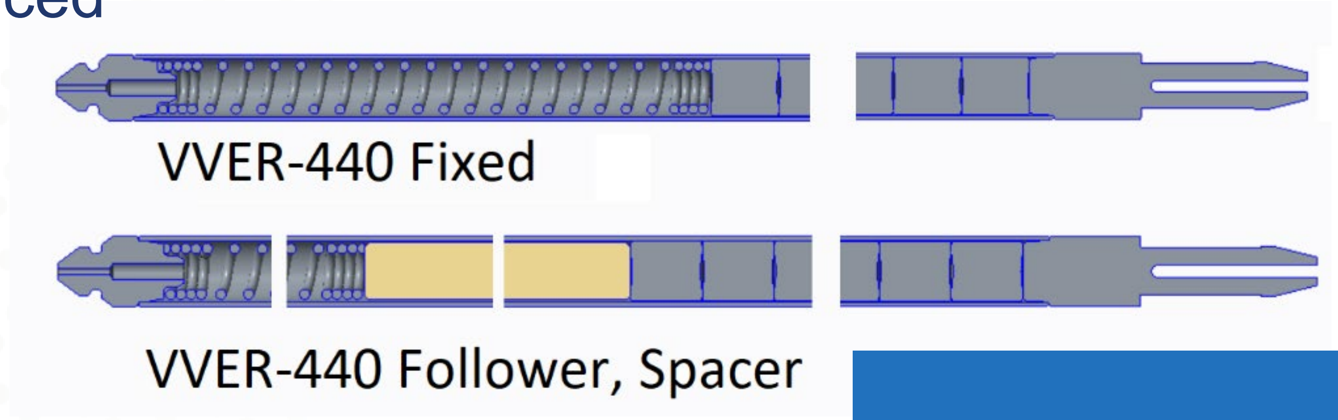


Potential LHGR margin issue at EOC

Next Developed VVER-440 Design NOVA E-6/NOVCD (APIS WP2)

Design differences are mainly in pellet stack length

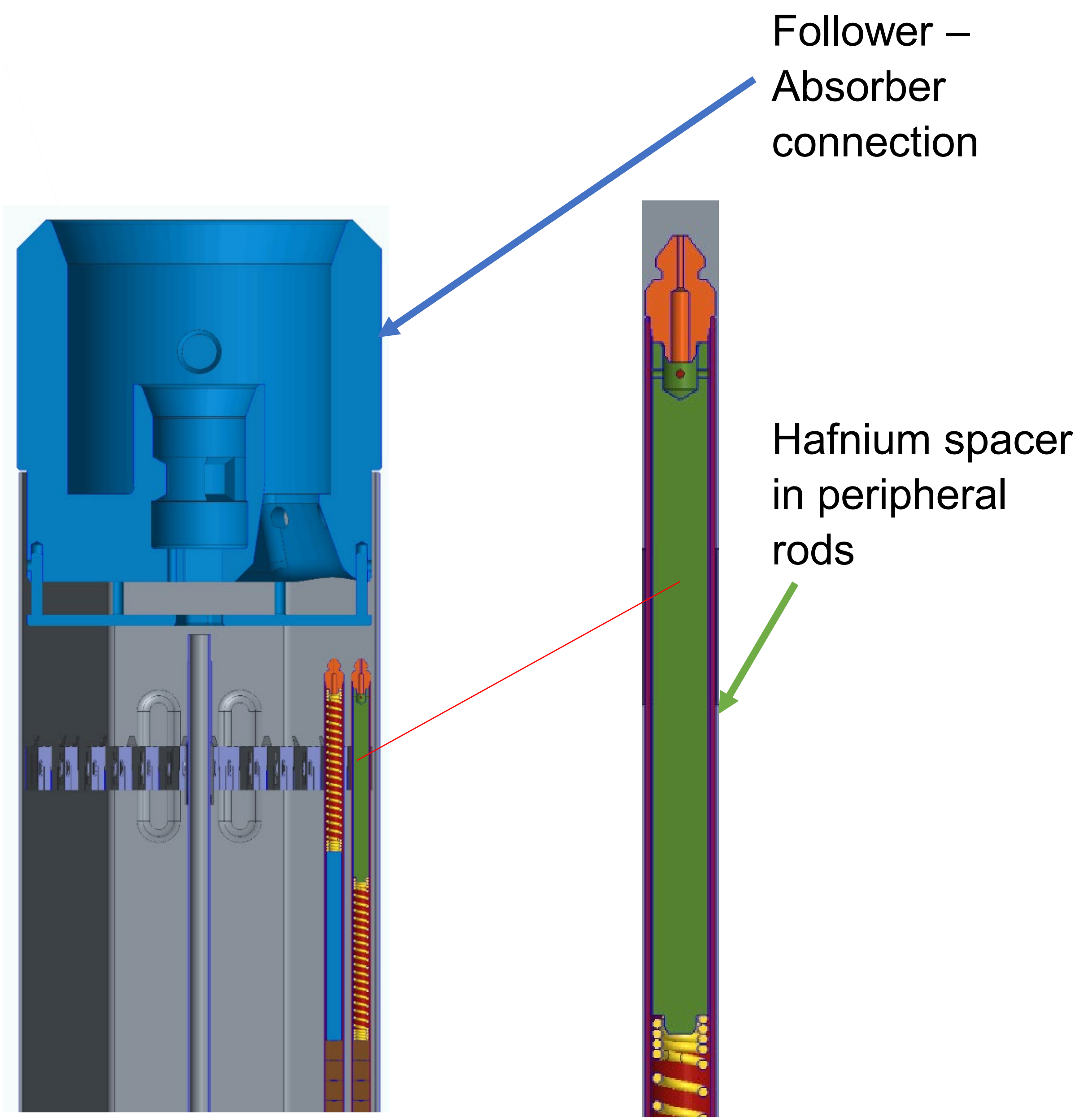
- Pellet Stack is 2 420 mm in NOVA E-5 and 2 480 mm in E-6
- Pellet Stack is 2 320 mm in NOVCC and 2 360 mm in NOVCD
- Length of cladding tubes, end plugs and shroud are adjusted for pellet stack increase
- Spacer is shortened in NOVCD and power peaking mitigation feature introduced



Cladding material is Optimized ZIRLO™

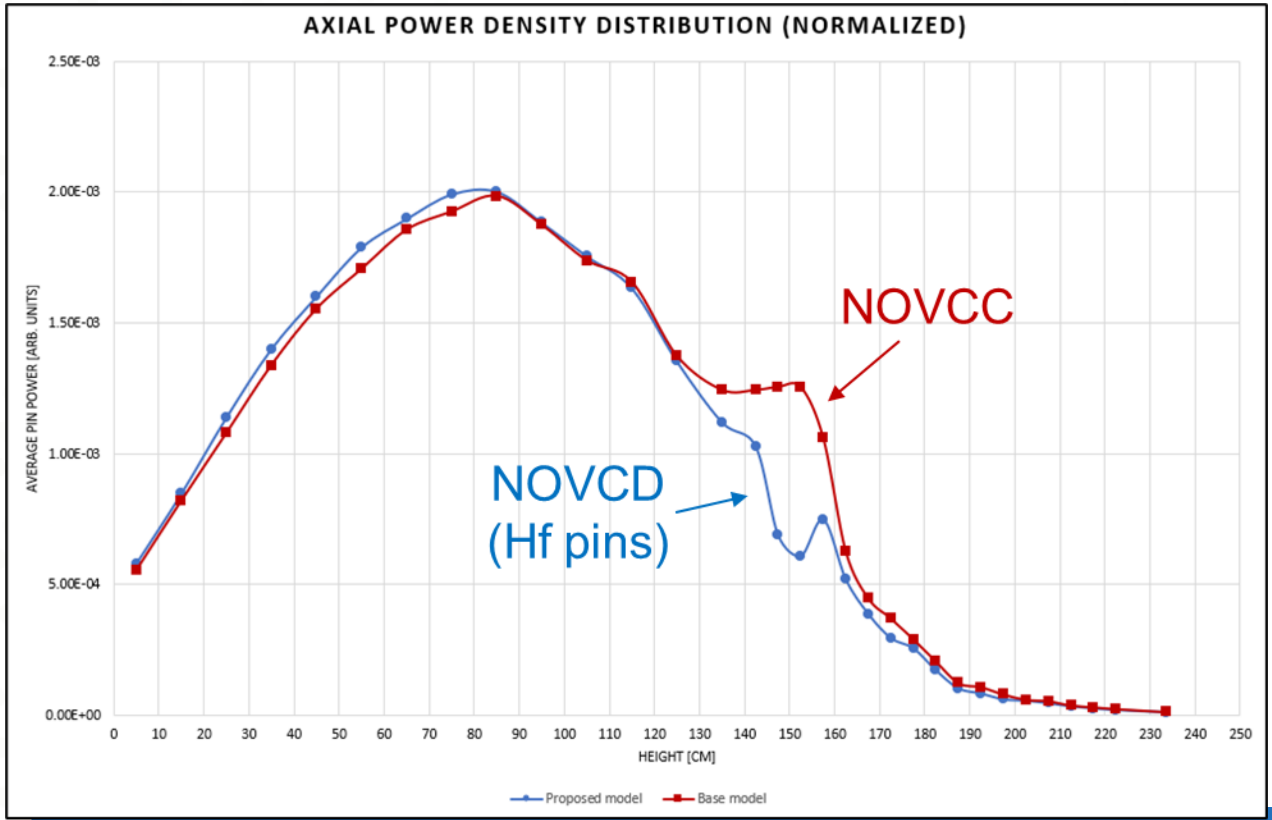
NOVCC → NOVCD Peripheral Fuel Rods

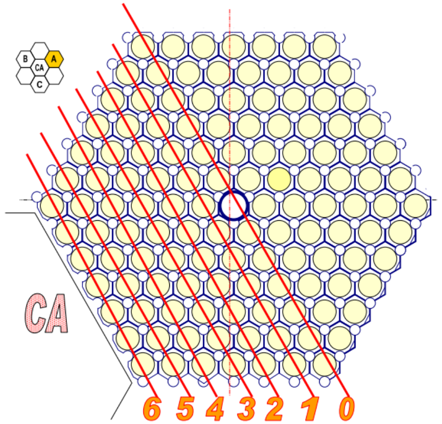
- Power peak mitigation with Hf
  - Steel Spacers replaced by Hf pins <u>in peripheral Fuel Rods only</u>
  - Swapped positions of Hf pins and Plenum Springs
  - Patent pending
- The Hafnium spacer has the same length as the SS spacer

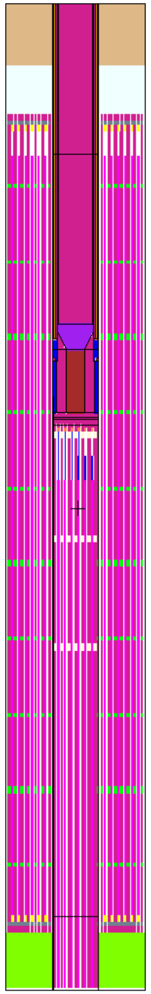


MCNP results - NOVCD
Partial Insertion of Follower Fuel Assembly

- Power peak in neighboring fixed fuel assembly, peripheral fuel rods closest to follower (Row 6)



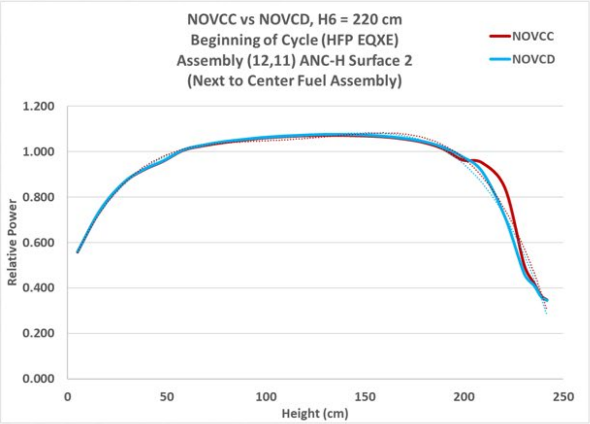


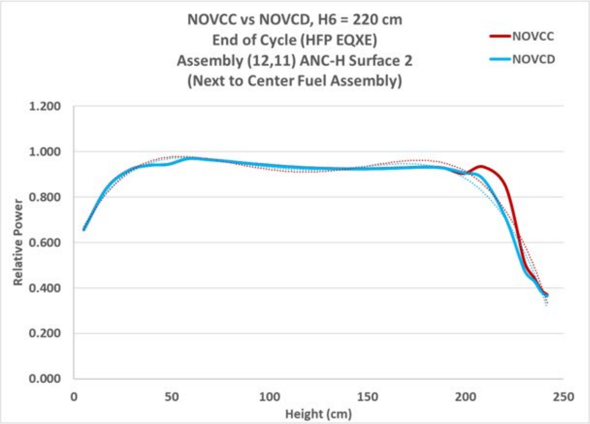


Power peak is effectively mitigated by Hf pins in the NOVCD design
Verified by Core Simulator calculations

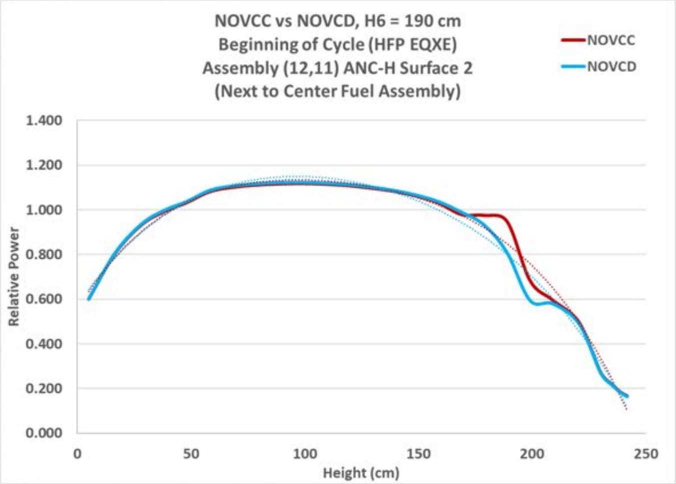
3-D core simulation with ANC-H

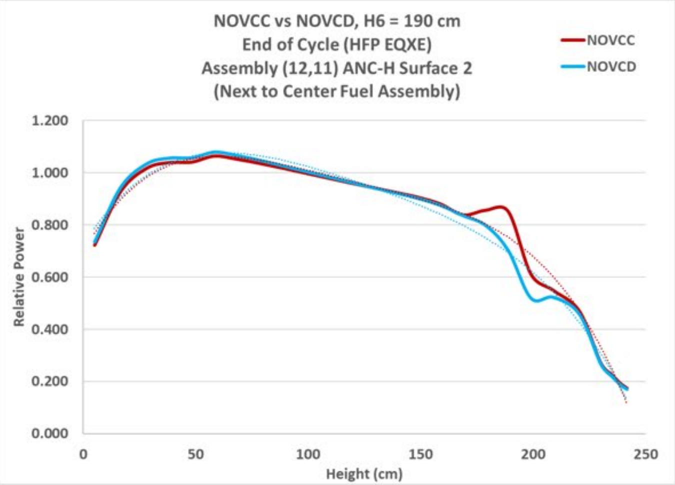
- Core with VVER-440 has been simulated using Westinghouse Nuclear and Core Design code ANC-H (Advanced Nodal Code)





- Cycle depletion is carried out at nominal lead bank –H6 position 225 cm
- Lead bank moved from all – out (250 cm) to all-in (0 cm) at hot full power for beginning and end of cycles
- Axial surface power is collected for every assembly neighboring each H6 lead bank follower
- The hafnium region of NOVCD leveraged cross sections generated for resident fuel design which includes hafnium along the periphery



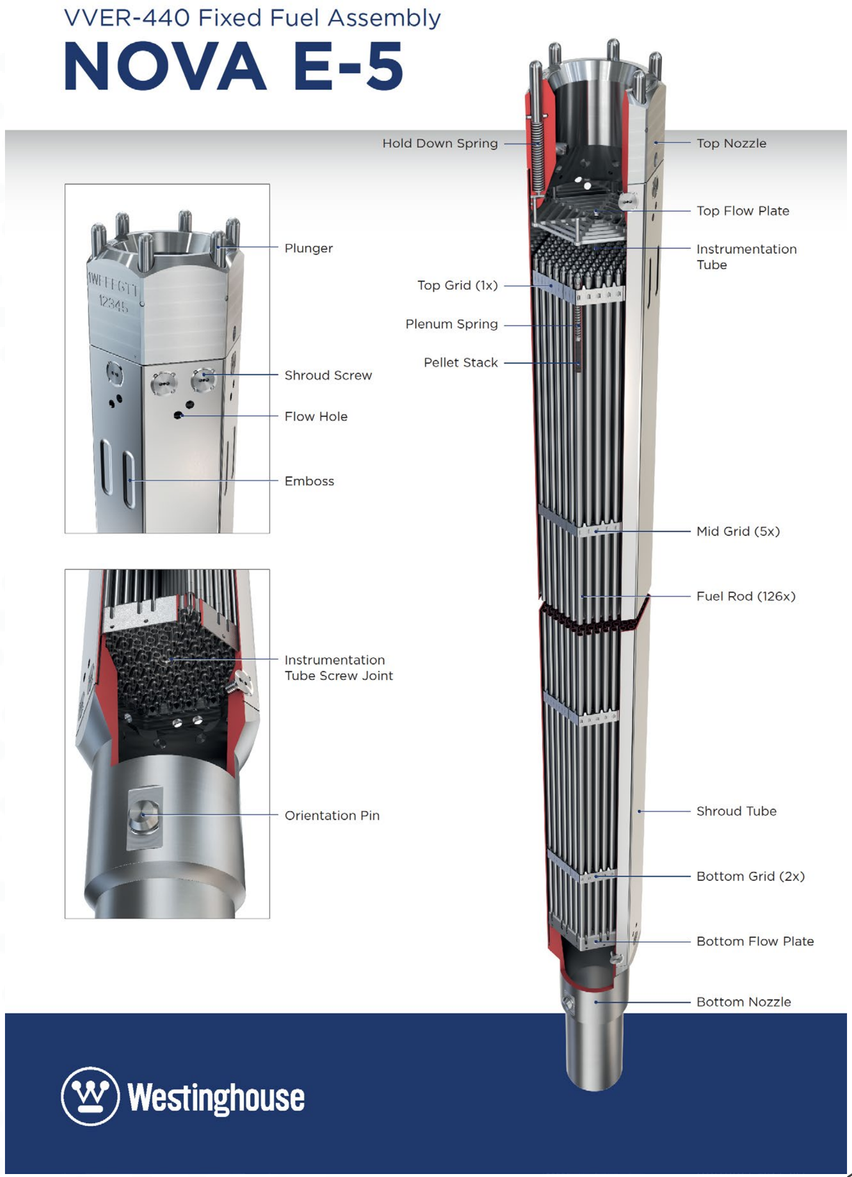


Westinghouse

Conclusions

- In frame of the APIS project with co-funding by the EU, successful design upgrades of Westinghouse VVER-440 fuel design have been finalized.
- Design enhancements include:
  - Material upgrades from Zr4 to Optimized ZIRLO™, ZIRLO®, Low Tin ZIRLO™
  - GTRF improvements in terms of:
    - Increased number of grids from 7 to 8 to shorten the grid span
    - Development of a new grid to stabilize rod ends
  - Additively Manufactured bottom and top flow plate components
- Further enhancements:
- A longer pellet stack to meet operating requirements from power uprates and thermal performance
- Power peak mitigating features in the form of hafnium spacer pins in the follower to absorber rod connection.

Westinghouse VVER-440 Fixed Fuel Assembly



• Length:	3.2 m
• Total weight:	214 kg
• Weight of U:	127 kg
• Cladding material:	Optimized ZIRLO™
• Shroud material:	Zircaloy-4
• Grid Material:	Low Tin ZIRLO™ 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 and 37 Follower fuel assemblies. Followers are withdrawn from core and replaced by control assemblies at plant shutdown and SCRAM.

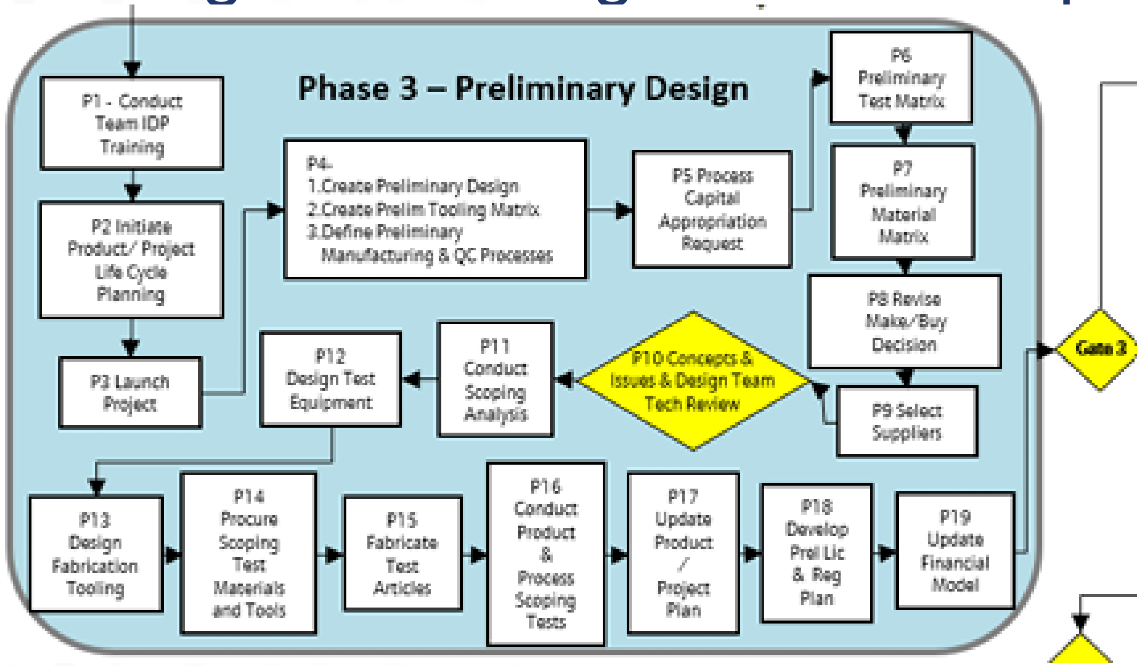
Successful acceleration from delivery of 12 VVER-440 FA in 2024 to full Reload (66 FA) in August 2023

Next Generation VVER-440 Fuel Design – NOVA E-7

- From competitor benchmarks and workshops with customers and Westinghouse manufacturing, concepts have been developed and followed up within APIS WP3 every third months. The following requirements have been established:
  - Fuel reliability is the same or better compared to NOVA E-6. Same or better Grid To Rod Fretting margin.
  - Reduce Fuel Cycle Cost (FCC): at least 2% in FCC savings
  - Compatible with in-core monitoring instrumentation
  - Inspection of Fuel Assembly shall be possible
  - Improve manufacturability
  - Improved fixed FA shall work in all VVER-440 plants – same design to all customers
  - Same or reduced pressure drop
  - Reduce raw material cost & improve environmental sustainability by reduction of raw material

Next Generation VVER-440 Fuel Design – NOVA E-7

- Design concept has reached the Concepts & Issues level in the Westinghouse Integrated Development Project



- **Improved Fuel Cycle Cost achieved through reduction of shroud material and increased rod pitch, leading to improved moderation.**
- **Compatibility and inspectability is assured.**

- Planned LTA introduction is 2029

Thank You

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