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MITIGATION OF LOCAL POWER PEAKING BY INTRODUCING HF SPACER PINS IN THE VVER-440 FOLLOWER FUEL ASSEMBLY

Akif Abdullayev, Jan Höglund

Westinghouse Electric Sweden

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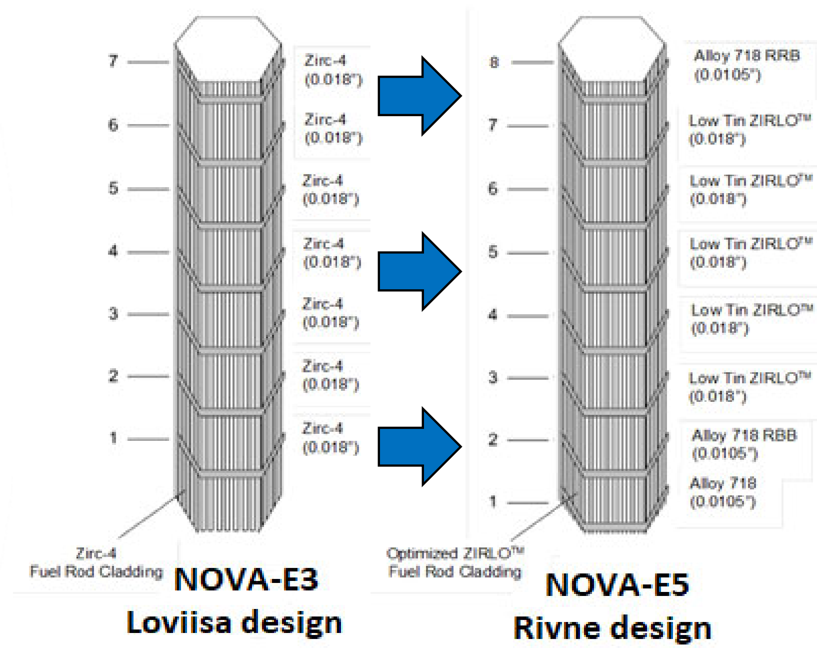
APIS

Background

- After the Russian full-scale invasion of Ukraine, a joint program between utilities and Westinghouse aiming to diversify fuel deliveries and enhance the security of VVER-440 fuel supply was established with co-funding by the European Union through the Horizon program.
- Westinghouse VVER-440 fuel design was upgraded with new materials and new grid configuration to mitigate grid-to-rod-fretting.
- The upgraded Fixed VVER-440 design was denoted NOVA E-5 and the Follower design was denoted NOVCC
- VVER-440 customer feedback on power uprates, margin limitations and Follower operation initiated a fuel development program including a longer pellet stack and power peak mitigation features in the follower assemblies.
- The Follower with power peak mitigation features is denoted NOVCD while the corresponding Fixed assembly is called NOVA E-6

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

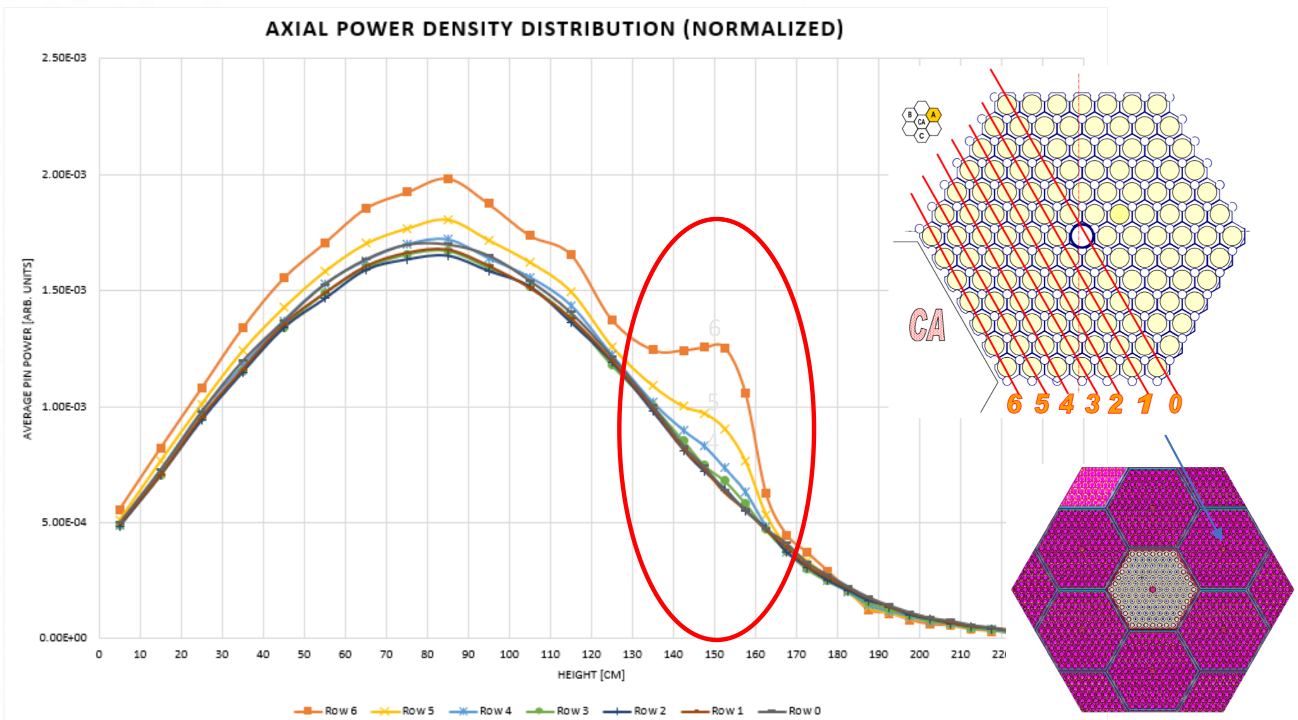
- Design and material enhancements increasing grid-to-rod fretting operation resistance
  - One additional grid: 7-grid → 8-grid design
  - Material in top- and two lowermost grids: Inconel A718
  - **Standard and well proven GTRF mitigation feature used in PWR and VVER designs**
- Material upgrades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

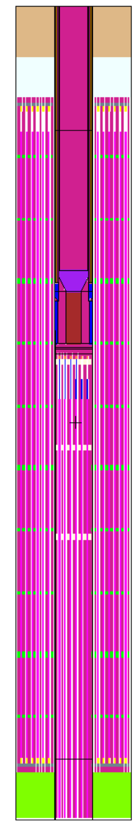


Design changes focus on increase of grid-to-rod-fretting resistance

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

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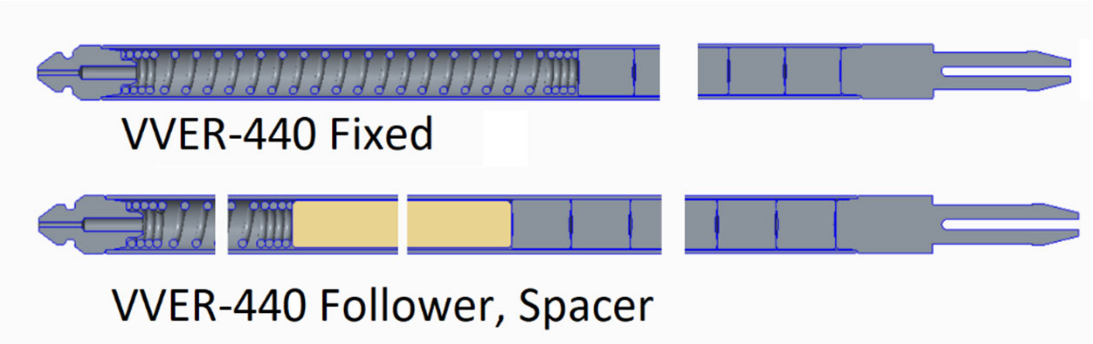
Next Developed VVER-440 Design NOVA E-6/NOVCD (APIS WP2)

Design differences are pellet stack length and power peaking mitigation feature in the Follower

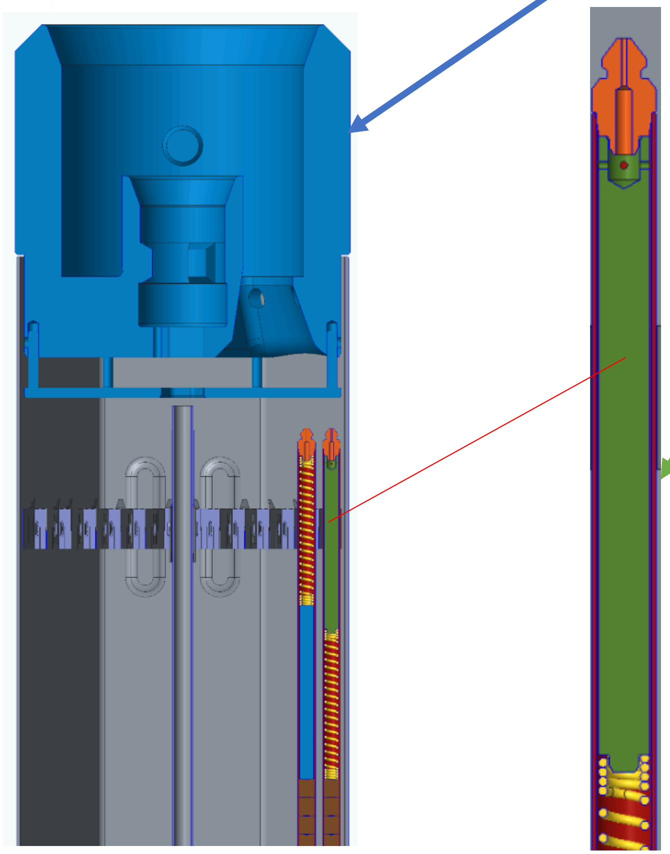
- Pellet Stack is 2 420 mm in NOVA E-5 and 2 480 mm in E-6
- Pellet Stack is 2 320 mm in NOVCC and 2 360 mm in NOVCD
- Length of cladding tubes, end plugs and shroud are adjusted for pellet stack increase
- Spacer is shortened in NOVCD and power peaking mitigation feature is introduced by changing material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



Cladding material is Optimized ZIRLO™

NOVCC → NOVCD Peripheral Fuel Rods

- Power peak mitigation with Hafnium
  - Steel Spacers replaced by Hf pins in peripheral Fuel Rods only
  - Swapped positions of Hf pins and Plenum Springs
  - European Patent EP4343791
  - The Hafnium spacer has the same length as the steel spacer

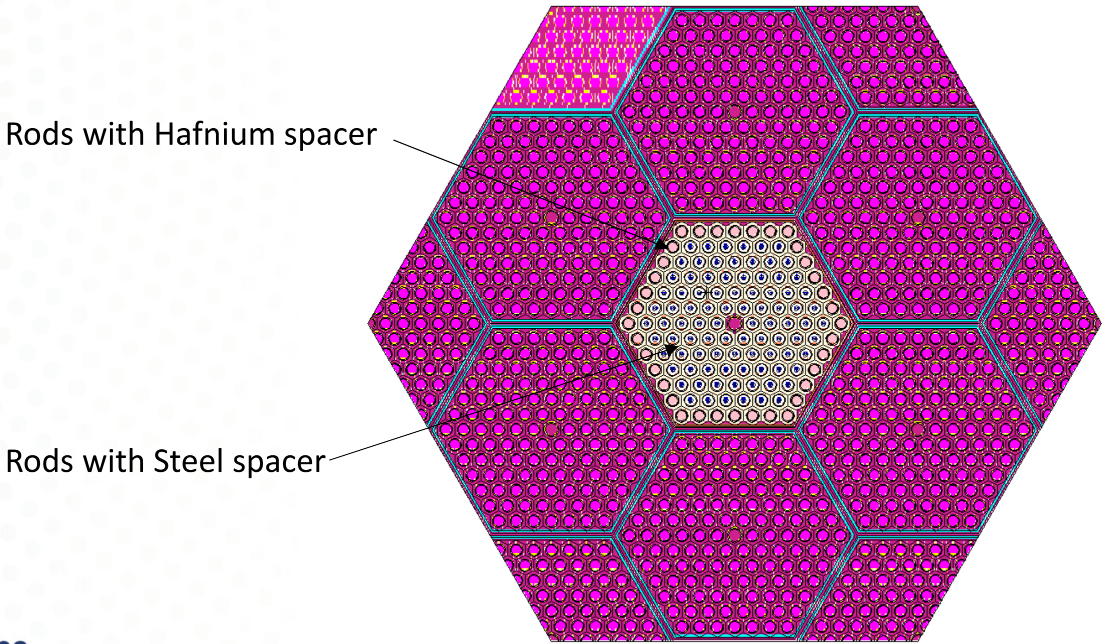


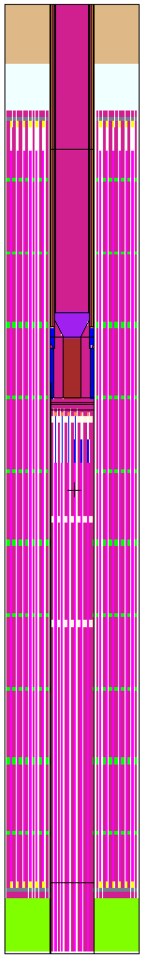
Properties, Experience and Availability of Hf Pins

- Mechanically there are no issues with Hf pins
  - Thermal expansion and irradiation growth is low compared to remaining diametrical gap
  - Good mechanical strength, suitable for machining
  - Westinghouse has significant irradiation experience with Hf pins inside drilled stainless-steel holes in BWR Control Rod Blades(CRBs) and from use in PWR Power Peak Supression Assemblies (PPSAs)
- Hf rod material is currently used in CRBs and is available from multiple Westinghouse suppliers

Geometry of the MCNP Model

- The central VVER-440 follower assembly is surrounded by one ring of VVER-440 fixed assemblies
- Follower fuel assembly is partially inserted





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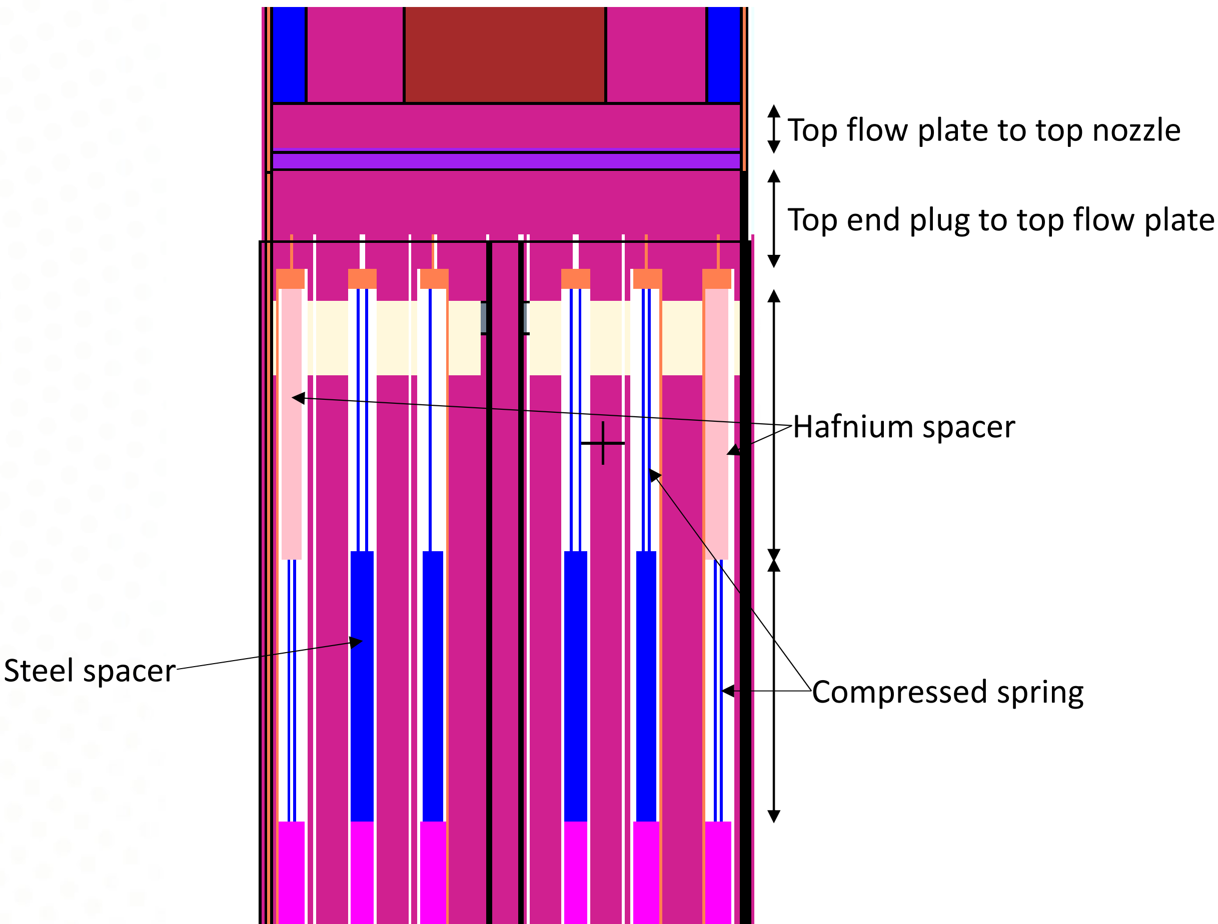
Geometry of MCNP Model
- Top of Follower Fuel Assembly



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Assumptions of MCNP Model

- Hexagonal reflective boundary conditions
- Upper and lower reflector regions
- All assemblies have uniform fuel composition simulating 3.82 wt% U-235 with burnup of 26 MWd/kgU
  - Axial burnup variation is not considered
- Fuel Temperature: 900 K
- Temperature of all other components: 558 K
- Moderator density: 0.75 g/cm^3 (at pressure of 122 bars)
- Zero boron concentration in moderator, simulating EOC conditions

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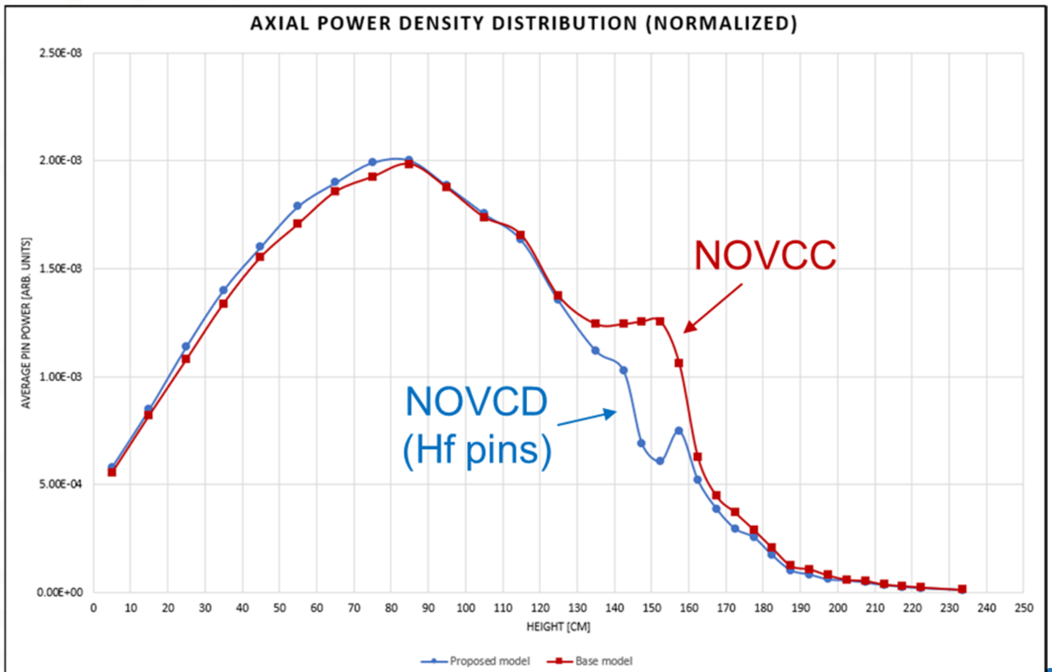
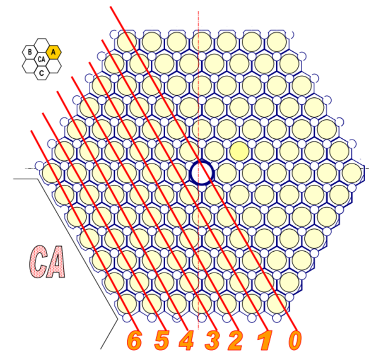
MCNP results
Partial Insertion of Follower Fuel Assembly

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



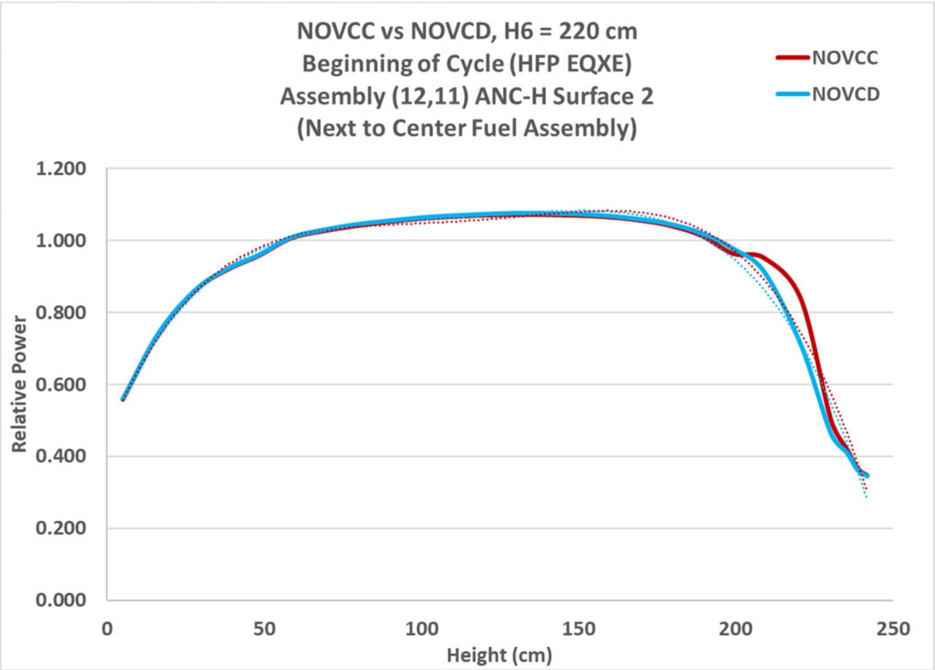


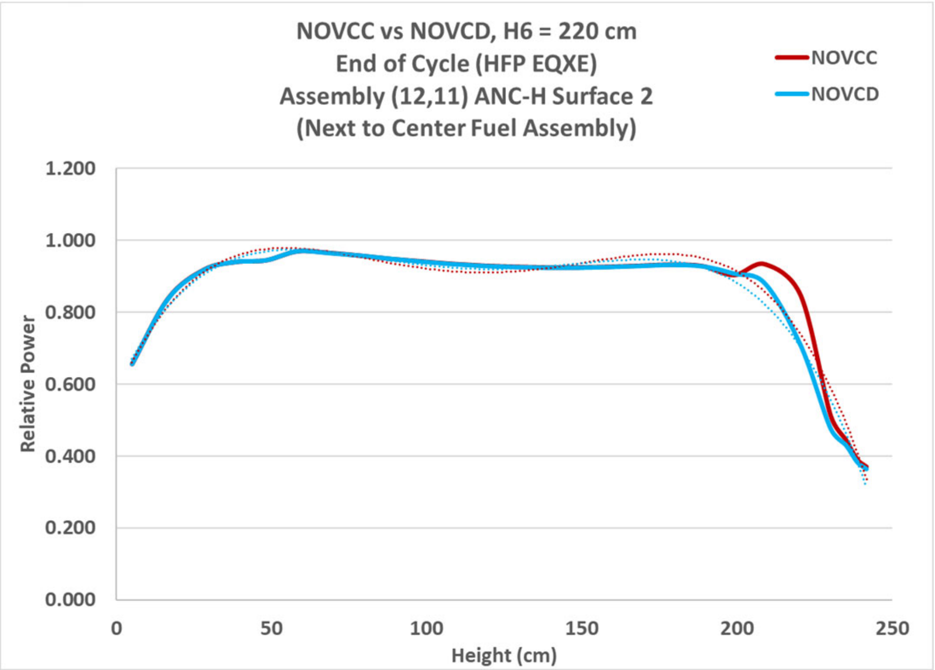
Power peak is effectively mitigated by Hf pins in the NOVCD design
Verified by Core Simulator calculations

3-D core simulation with ANC-H 1 from 4

- 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 cycle
- 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

3-D core simulation with ANC-H 2 from 4





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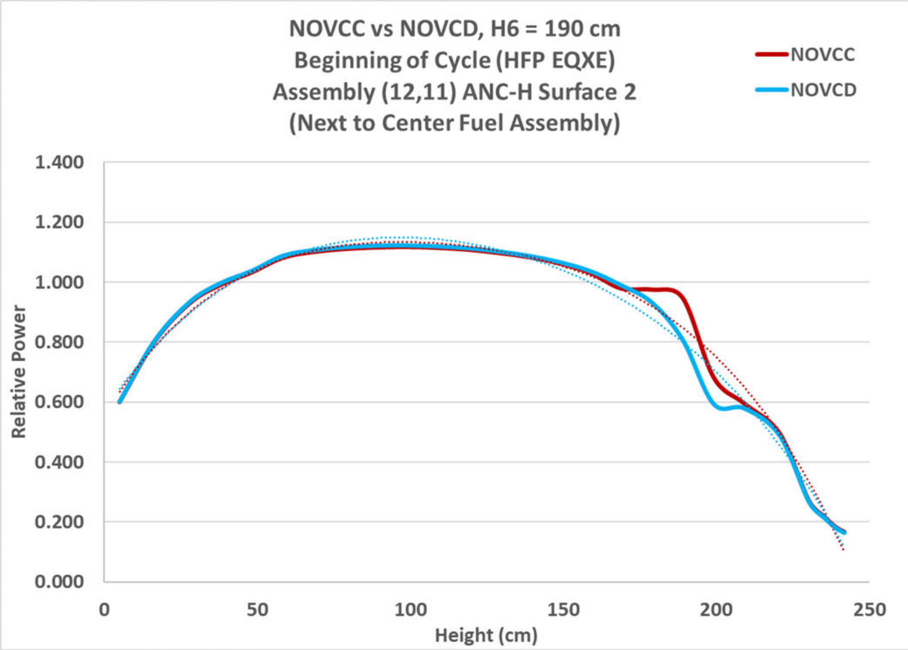
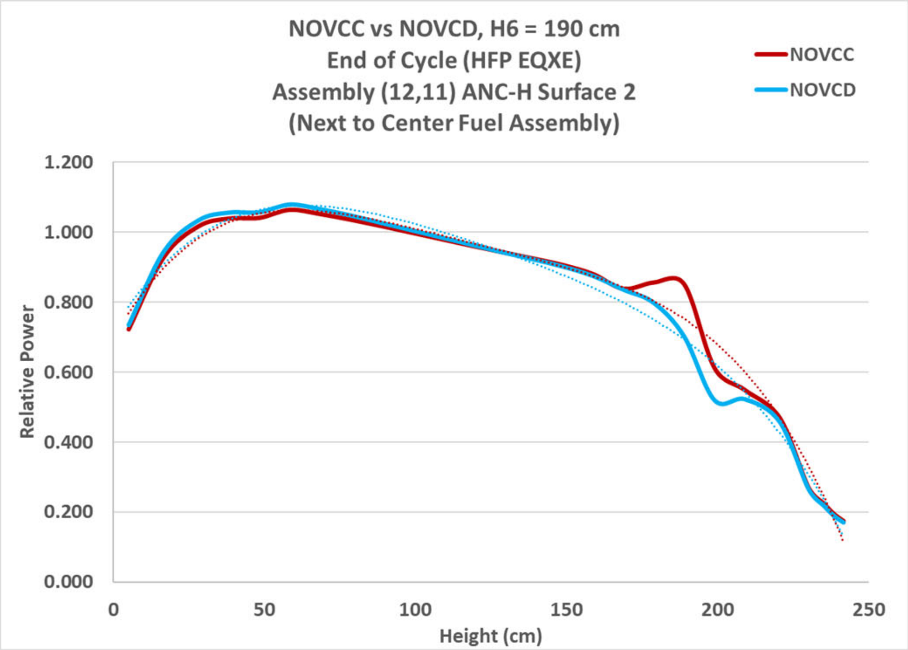
3-D core simulation with ANC-H 3 from 4





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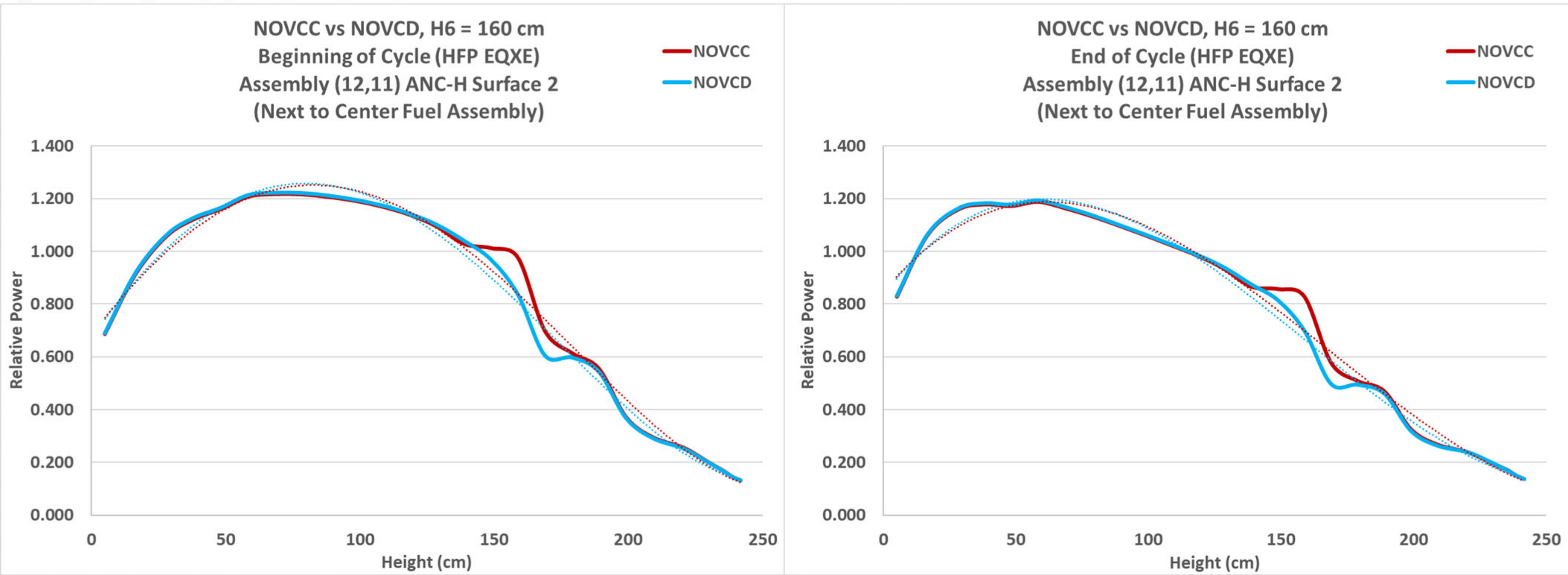
3-D core simulation with ANC-H 4 from 4



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Summary

Monte Carlo and 3-D core simulations confirm that the implemented design feature in the follower fuel assembly - NOVCD effectively mitigates local power peaking in adjacent fixed fuel assemblies.

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Questions?