Westinghouse VVER Fuel Development Programs

VVER 2016 – Power Uprates, Long Term Operation and New Builds

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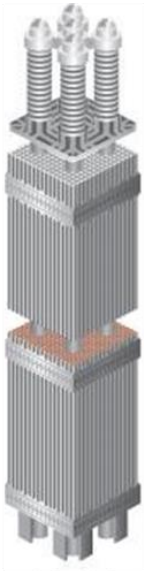
Fuel Designs in Westinghouse' Portfolio

Pressurized Water Reactors (PWRs)

W-PWR

14x14
15x15
16x16
17x17

CE-PWR

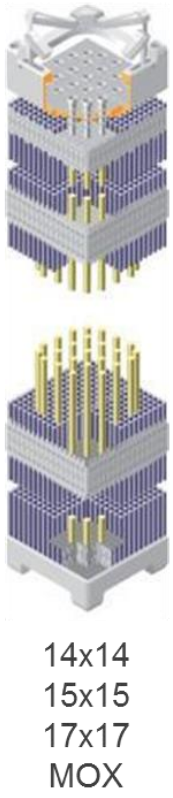


14x14
16x16

KWU/Siemens PWR

14x14
16x16
18x18

NFI PWR



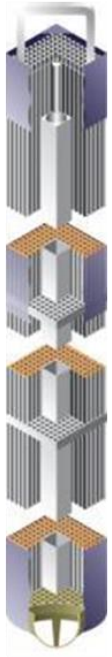
14x14
15x15
17x17
MOX

Boiling Water Reactors (BWRs)

W-BWR

Optima2
Optima3

NFI BWR



9x9
MOX

VVER (PWR)

VVER-1000
VVER-440

Advanced Gas Reactors (AGRs)

AGR Fuel

Westinghouse is the only western fuel supplier to VVER-440 and VVER-1000 reactors

Westinghouse VVER-1000 Fuel Development

Temelin - VVER 9-Grid Design			
Original VVANTAGE 6	**Modified VVANTAGE 6**	**Phase 0**	**Phase 1X**
2000 →	2005 →	2006 →	2007

- Westinghouse delivered first cores to Temelín 1 and 2 in 1997 and 1998 and annual reloads until 2010.
- Issues with bow resulting in Incomplete Rod Insertion (IRI).
- Phase 1X design removed IRI problem.
- ČEZ decided to transition to new supplier.

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Ukraine Nuclear Fuel Qualification Project

- The Ukraine Nuclear Fuel Qualification Project (UNFQP) was created to develop the infrastructure for a competitive nuclear fuel market in Ukraine, with the specific goal of achieving diversity in its nuclear fuel source
- The UNFQP was made a part of the International Nuclear Safety Program (INSP) in 1998.
- The UNFQP selected Westinghouse to transfer technology and expertise and to become an alternate supplier of nuclear fuel to Ukraine.

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Westinghouse VVER-1000 Fuel Development

Temelin - VVER 9-Grid Design				South Ukraine - VVER 16-Grid Design		
Original VVANTAGE 6	Modified VVANTAGE 6	Phase 0	Phase 1X	LTA	WFA	RWFA
2000 ⇨	2005 ⇨	2006 ⇨	2007	2005 ➡	2009 ➡	2015 -

- Temelín experience and Westinghouse general PWR experience were used in the design of the first Lead Test Assemblies and the Westinghouse Fuel Assembly (WFA) design for South Ukraine.
- Success of the UNFQP was key contributor to commercial contract for nuclear fuel between WEC and NNEGC Energoatom in 2008
- Modifications of the WFA design were developed based on the loading issues at South Ukraine in 2012 resulting in the Robust Westinghouse Fuel Assembly (RWFA) design currently delivered to Ukraine.

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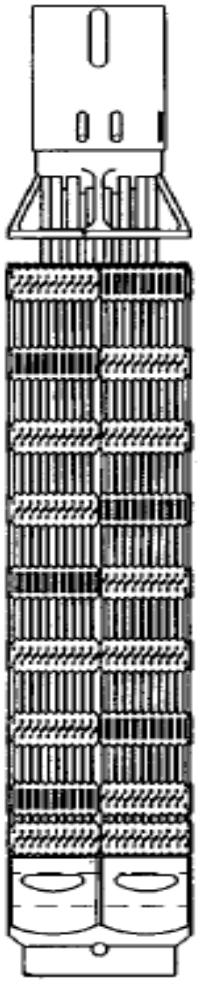
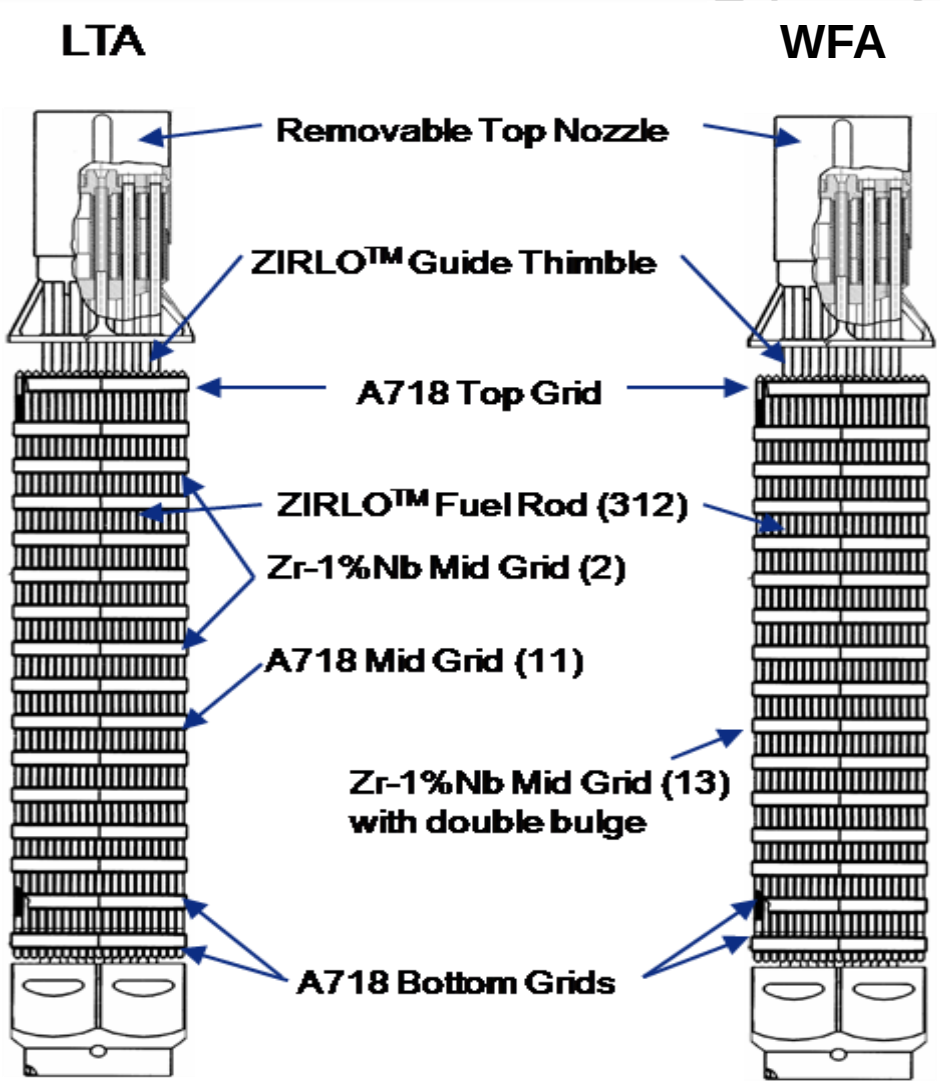
Design Development PHASE 1X - > WFA

PHASE 1X



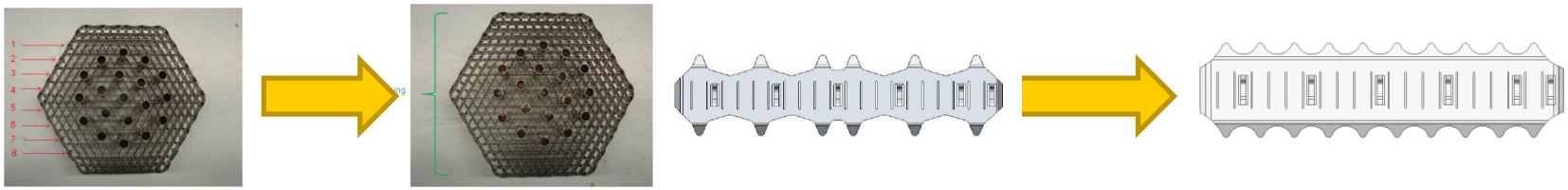
PHASE1X	SU3 LTA
12 HD springs. 1 plunger	19 HD springs.
9 Grids 38 mm	16 Grids 20 mm
A718 Top	A718 Top
6 Zr-4 Mid Grids w MV	2 ZIRLO® Mid Grids w/o MV
1 A718 Mid Grid w/o MV	11 A718 Mid Grid w/o MV
A718 Bottom	2 A718 Bottom
Diagonal spring	Vertical spring
Double bulge 2 sleeves	Single bulge
ZIRLO Tube-in-Tube GT	ZIRLO straight GT. No dashpot
ZIRLO fuel rods	ZIRLO fuel rods
V6 Bottom Nozzle	V6 Bottom Nozzle



Summary of Design Changes for the Robust Westinghouse VVER-1000 Fuel Assembly (RWFA)

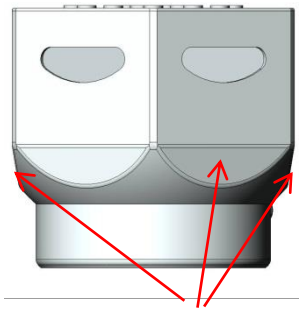
13 mid-grids were modified

- 8 spacer grid straps were added back to increase the static load strength, the shape of the outer strap was changed, its thickness was increased and the material was changed from a Zr1%Nb to Alloy-718

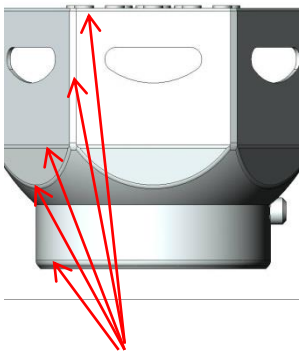


The FA top and bottom nozzles were also modified

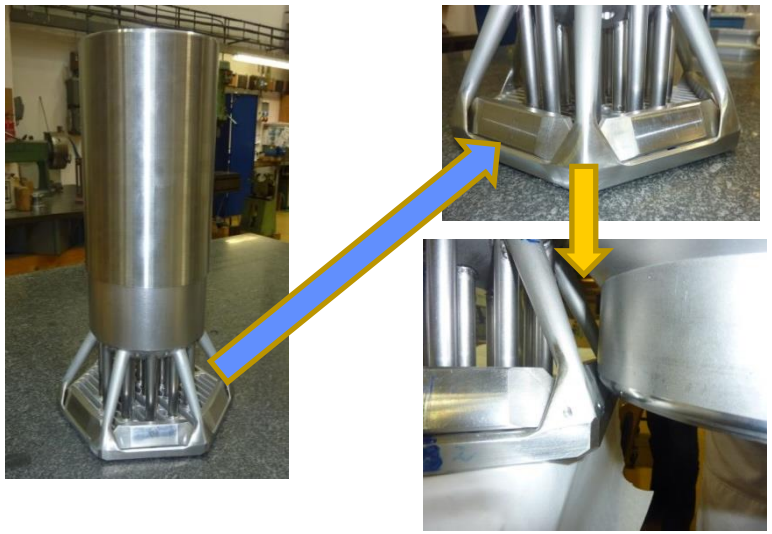
- Chamfers were added on the FA bottom nozzle and plates on the FA top nozzle to facilitate FA loading



Tapers on all the six faces



Chamfers and radius on the sharp edges



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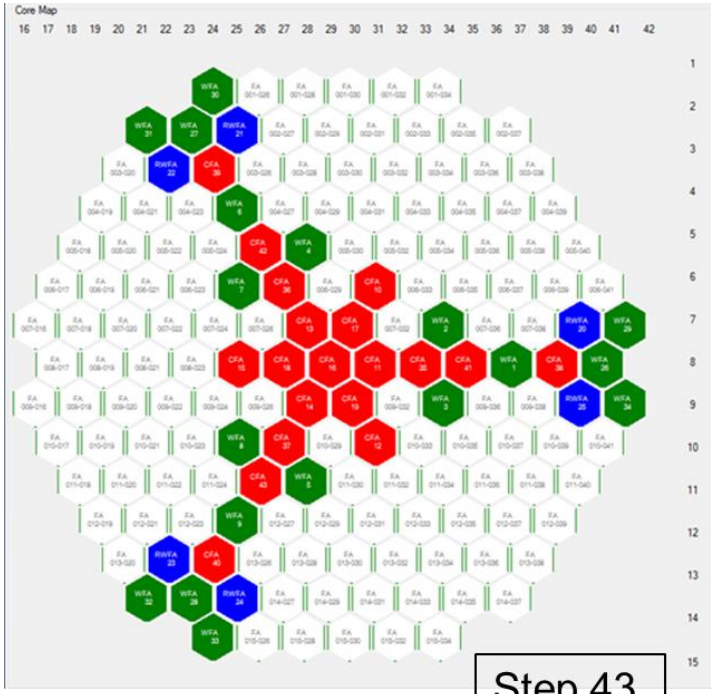
WFA and RWFA Operating Experience

- VVER-1000 WFA
  - 62 WFA with 4 cycles of operation - Burnup >46 MWd/kgU
  - 27 WFA with 2 cycles of operation - Burnup >24 MWd/kgU
- All WFA are found to be non-leaking
- Upgraded VVER-1000 RWFA
  - 42 completed first cycle of operation - Average >12 MWd/kgU
- Excellent irradiation fuel performance has been confirmed by inspections for both WFA and RWFA
- Grid mechanical damages in SU2 and SU3 in 2012 were due to loading issues
  - No incremental grid damage has been observed on any WFA in any consecutive core loading.
- An optimized core loading sequence technique was introduced which significantly reduced loading forces

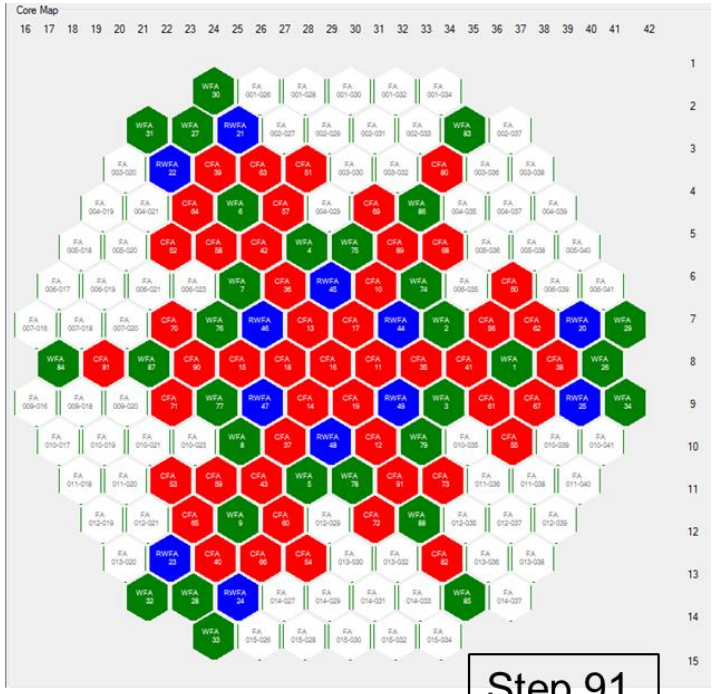
Improvements based on experience have made Westinghouse VVER-1000 product very reliable

Optimized Core Loading Sequence

1. ”Open water” loading
2. Locations with no neighbors or 3-symmetically spaced neighbors
3. “Boxed” locations.
4. Stabilize the core center by building 3-legged bridges
5. Loading lower stiffness fuel first and loading higher stiffness fuel last



Step 43



Step 91

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Lead Test Assemblies to Temelín NPP

- Westinghouse and ČEZ are conduction a Lead Test Assembly (LTA) project for Temelín NPP
- The goal of the Temelín LTA program is to verify:
  - Mechanical compatibility with resident fuel and reactor internals
  - Mixed core operation with resident fuel
  - Material performance in Temelín water chemistry environment.
  - Licensing of the LTA fuel design
  - Manufacturing, transport and fuel receipt
- Fuel Licensing is a split scope between Westinghouse and ČEZ together with sub-suppliers ÚJV Řež and Škoda JS

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LTA Design for Temelín NPP

- The LTA design to be developed for Temelín NPP will be an evolutionary change of the RWFA fuel operating in Ukraine
- The key changes are:
  - The LTA will be a 13-grids (12+1) design compared to the 16-grids RWFA.
  - Grids at higher axial elevations will have mixing vane (MV) features added. RWFA has no MV.
  - A zirconium-based mid-grid design will be implemented. RWFA has all Alloy 718 mid-grids.
  - Cladding material is proposed to be Optimized ZIRLO™. RWFA uses standard ZIRLO®.
  - Pellet stack length is increased.

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Westinghouse VVER-440 History

- BNFL delivered Westinghouse VVER-440 design to Loviisa, Finland.
  - 5 LTAs from Springfields,
  - 7 reloads manufactured at ENUSA from 2001-2007
- Following some unsuccessful attempt to capture new fuel contracts, Westinghouse decided to discontinue the business.

Fuel diversification - a new and important trend on the market

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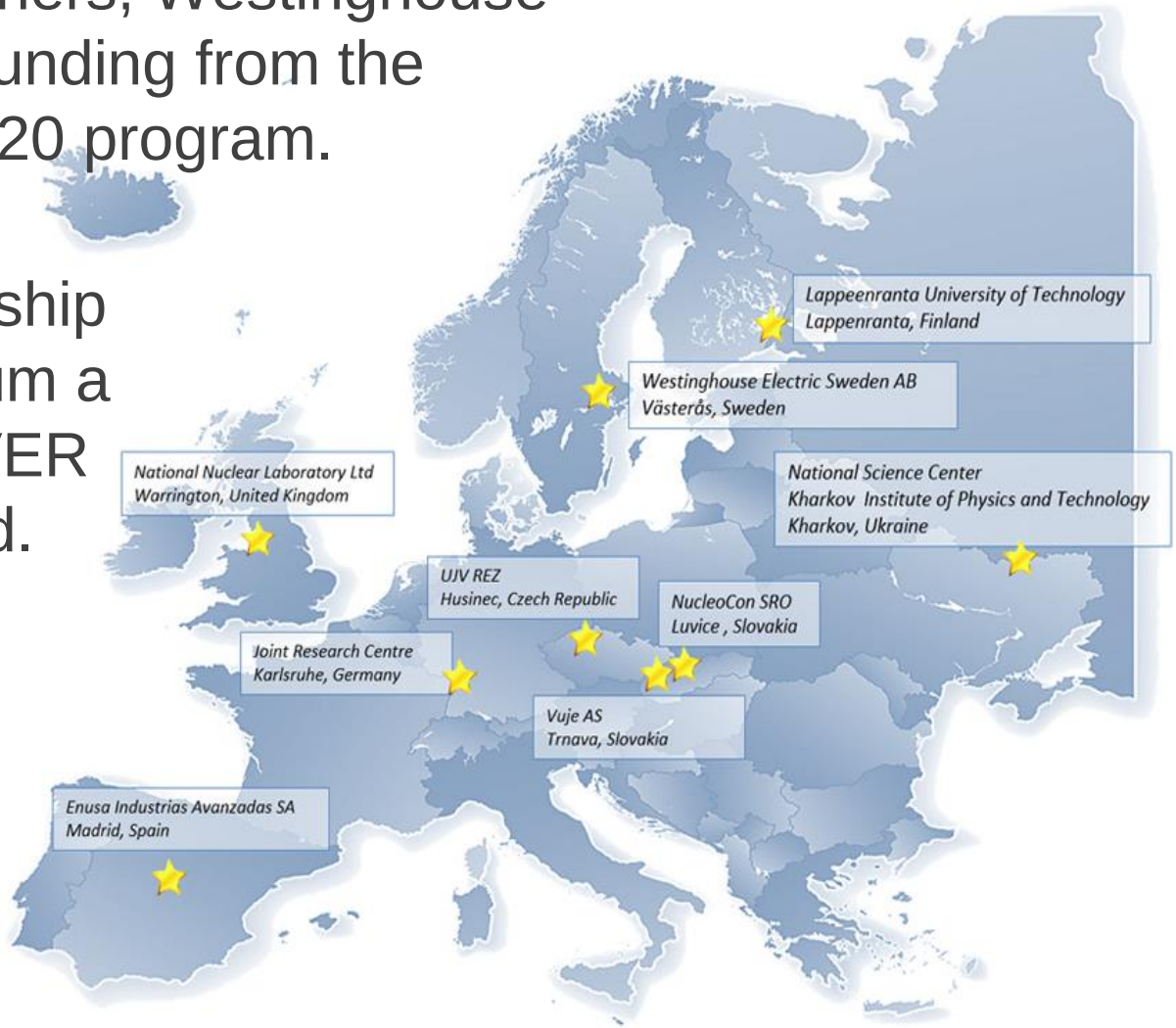
Euratom Horizon 2020 Program

- Together with 8 partners, Westinghouse has been awarded funding from the Euratom Horizon 2020 program.
- Through the partnership built in this consortium a strong European VVER community is formed.



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European Supply of SAfe NUclear Fuel -ESSANUF

- Objective: To create greater security of energy supply and contribute to the security of supply of nuclear fuel for Russian designed pressurized water reactors (VVER) operating in the EU
- The goal of the project is to define all necessary requirements with regards to safety analysis, licensing and fuel assembly design modifications specific for each NPP utility.
- This will enable swift introduction of VVER fuel manufactured by Western suppliers in the European VVER NPPs.
- Project started in 2015

www.essanuf.eu

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ESSANUF – Technical Objectives

The main technical objectives of the project is to

- develop a conceptual enhanced VVER-440 fuel design, including an assessment of the manufacturing capabilities, including sub suppliers,
- define a development program for the conceptual design, which includes design analyses and testing,
- create, to the extent possible, a generic licensing scope for the qualification of the fuel design in Finland, Hungary, Slovakia, Czech Republic and Ukraine, and
- develop the methods and methodology required to qualify the VVER-440 fuel design for operation

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ESSANUF – Feasibility Study for Design Modifications

The following was considered:

- Operational experience
  - Fretting wear indications at EOL in the Loviisa fuel assemblies calls for grid modifications and/or grid repositioning
- Westinghouse material development
  - Upgrade to modern materials: (ZIRLO®, Optimized ZIRLO™, Low Tin ZIRLO™, Zr1%Nb)
- Customer feedback (Grid modifications, fuel rod design)
- Competitor benchmark
  - Modifications from open sources include: fuel rod pitch changes, reduction of wall thickness in the fuel channel, removal of the fuel channel, switch to solid pellets and increased pellet stack.

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ESSANUF – Design Development

- The proposed design changes will initiate a development program, which includes design analyses and testing.
- A mechanical test program and a thermal hydraulic test program have been identified.
- Manufacturing readiness has been performed by ENUSA considering the existing equipment, tooling and expertise.
- A Concepts & Issues (C&I) Review Meeting will be conducted in the spring of 2017 to validate the feasibility of the design changes and to ensure the validity, accuracy and completeness of requirements
  - Partner organizations and Utilities will be invited.

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ESSANUF – Development of a Fuel Licensing Scope - Scope and Objectives

- To define which licensing analyses will be necessary to qualify an alternative VVER-440 fuel design in Slovakia, Czech Republic, Finland, Hungary and Ukraine with due consideration of international safety standards.

- To create an integrated VVER-440 licensing scope valid for the entire European Union, as well as in Ukraine.

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ESSANUF – VVER-440 Fuel Licensing Workshop

- To gain acceptance for this approach, a VVER-440 Fuel Licensing Workshop was held in Prague, 15-16 June, 2016
- Through the Regulators' and Utilities' presentations, the ESSANUF-project members gained a better knowledge of the fuel licensing process and requirements in the different countries.
- Received feedback on the suggested licensing approach as well as useful information on the countries' fuel licensing process and expectations.

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ESSANUF – Methods and Methodologies

- Establish the design and licensing analyses capabilities with reliable methods and code packages
- Select the most suited set of codes and define the methodology to be applied and prepare data, and interfaces between the codes to enable effective analysis
- Verify and validate each code to ensure it can be used for its intended purpose
- A Methods and Methodologies Workshop will be held in the spring of 2017.
  - Partner organizations and Utilities will be invited.

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Westinghouse VVER Fuel Development Programs Summary

- Through growing experience, Westinghouse today has a VVER-1000 fuel product that is performing very well
- Westinghouse - together with CEZ - is currently conducting a project to develop and qualify Lead Test Assemblies of a modified VVER-1000 fuel design for the Temelín NPP
- Since the fall of 2015, Westinghouse is involved in a consortium with eight other organizations in a program, named ESSANUF, to develop an enhanced VVER-440 fuel design, as well as to define the associated licensing methods needed to qualify the fuel for European utilities

VVER fuel development is given key priority by Westinghouse

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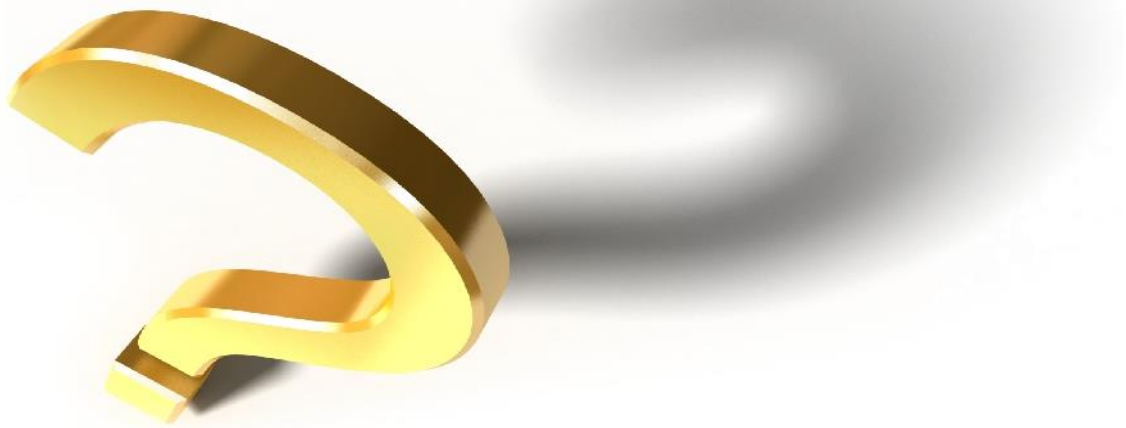

Thank You for Your Attention

Questions?

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