NUCLEAR FUEL FOR VVER REACTORS. ACTUAL STATE AND TRENDS

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deputy executive director

8th International Conference on VVER Fuel Performance, Modeling and Experimental Support
27.09–02.10.2009, Helena Resort, Bulgaria
TVEL Corporation Prime Objectives

Development, fabrication and implementation of new generation of fuel assemblies for VVER-type reactors

Satisfaction of Customer needs regarding nuclear fuel performance and value improvement

Competitive advantages and marketing development

Providing enhanced safety of fabrication and use of nuclear fuel
Tasks to be solved and Methods of Solution

- Increasing of FA service lifetime
- Improving reliability (demountable FA, debris filters, chatter-resistant FA)
- Implementation of safe and cost-effective fuel cycles
- Increasing of fuel burn-up
- Implementation of 5-6–years fuel cycles
- Uprate
- Decreasing of irradiation impact on the rector vessel
VVER-440 Nuclear Fuel: sales geography

Number of operating units: 23
Advantages of 2\textsuperscript{nd} generation of VVER-440 FA

- 20% decrease of number of FA in reload batch
- Enhanced parameters of nuclear safety for fresh U-Gd fuel handling
- Cost cutting for spent fuel handling
- 10% decrease of natural uranium rate consumption
- Possibility of withdrawing of failed pin (with necessary equipment)
Substantiation and Implementation of VVER-440 FA

Unit 1: Implementation of FA with chatter-resistant design (since 2009)

Unit 2: Commercial operation of FA with chatter-resistant design (since 2008)

Unit 3: Commercial operation of FA and followers of 2\textsuperscript{nd} generation (since 2008)

Unit 4: Commercial operation of FA and followers of 2\textsuperscript{nd} generation (since 2008)
Implementation of VVER-440 Nuclear Fuel

- **Dukovany 105%**
  - Implementation of 2nd generation of FA

- **Bogunice 107%**
  - Power uprate

- **Mohovce 107%**
  - Substantiation of nuclear fuel operation in “load follow” modes

- **Paks 108%**
  - Development of demountable follower design

- **Rivne 108% (planned)**
  - 

- **Loviisa 110%**
  - 

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Next step forward: 3rd generation of VVER-440 FA

Development of the 3rd generation of FA is based on operation experience of 2nd generation of FA and results derived from development of FA for VVER-440, TVSA type and TVS-2 type for VVER-1000.

The water-uranium ratio was significantly improved due to use of angle bars in combination with water tubes and increasing of fuel rod lattice pitch up to 12.6 mm.

Fuel cycle: 6-years.

Expected result of 3rd generation implementation – more effective fuel utilization (up to 10%).

Project design was issued in 2007.

# Development of VVER-440 Nuclear Fuel

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>FA Type</strong></td>
<td>Conventional FA with wrapper</td>
<td>Conventional FA with wrapper</td>
<td>FA of the 2nd generation, with wrapper</td>
<td>FA of the 2nd / 3rd generation, with wrapper</td>
</tr>
<tr>
<td><strong>Type of fuel rod bundle</strong></td>
<td>Non-shaped</td>
<td>Shaped</td>
<td>Shaped, U-Gd</td>
<td>Shaped, U-Gd</td>
</tr>
<tr>
<td><strong>Average reload batch enrichment, w/o U^{235}</strong></td>
<td>3.60</td>
<td>3.82</td>
<td>4.25 / 4.38</td>
<td>up to 4.87</td>
</tr>
<tr>
<td><strong>Number of FA in reload batch</strong></td>
<td>105</td>
<td>84</td>
<td>66</td>
<td>60</td>
</tr>
<tr>
<td><strong>Burn-up, GW×d/tHM</strong></td>
<td>36</td>
<td>45</td>
<td>57</td>
<td>65</td>
</tr>
<tr>
<td><strong>Fuel cycle</strong></td>
<td>3-year</td>
<td>4-year</td>
<td>5-year</td>
<td>6-year</td>
</tr>
<tr>
<td><strong>Natural Uranium consumption, tHM/GW×d</strong></td>
<td>0.256</td>
<td>0.209</td>
<td>0.184</td>
<td>0.180</td>
</tr>
</tbody>
</table>
VVER-1000 Nuclear Fuel: sales geography

Number of units (operating / under construction) 28 / 4
VVER-1000 Nuclear Fuel for Novovoronezh-5

1. Casing construction
2. U-Gd fuel, average assembly enrichment – 4,3 w/o $^{235}$U
3. Fuel cycle 4×300 EFPD

Fabrication of FA using unified parts since 2010
VVER-1000 Nuclear Fuel for B-320, B-338, B-302
New generation of FA

1. Stable geometric behaviour
2. Fail-safe operation of RCCA

3. Provided features
   - enhanced burn-up
   - enhanced FA life-time up to 6 years
   - improved reliability
   - new generation of fuel rod
   - load follow mode
   - safe performance under power uprate conditions (Nnom=107%)
**VVER-1000 Nuclear Fuel Today**

- **Kalinin NPP:** TVSA since 1998
- **Ukrainian NPP:** TVSA since 2003
- **Kozloduy NPP:** TVSA since 2004
- **Balakovo NPP:** TVS-2 since 2003
- **Rostov NPP:** TVS-2 since 2008

- Fuel cycle $4 \times 12$, average assembly burn-up $55 \text{ GWd/THM}$
- Stable geometry during operation (bowing less than 7mm)
- No fretting-wear during operation
- On-site repairable demountable design
VVER-1000 Nuclear Fuel Development: TVS-2M

**Tendencies**
- increased uranium capacity
- improved heat reliability
- enhanced operational safety

**Main features**
- fuel stack is increased on 150 mm
- $\text{UO}_2$ mass – 524.1 kg
- 12 spacer grids
- antivibration grid
- 3 mixing grids – since 2010
- anti-debris filter (restrain particles more than 2 mm size) – since 2010

**In operation at Balakovo-1 since 2006**
**Tendencies**
- increased uranium capacity
- improved heat reliability
- enhanced operational safety

**Main features**
- Fuel stack is increased on 150 mm
- UO₂ mass – 524.1 kg
- 15 spacer grids
- Antivibration grid
- Anti-debris filter (restrain particles more than 2 mm size)

*Operation at Kalinin-2, Kalinin-3 is planned since 2010*
Tendencies

- increased uranium capacity
- improved heat reliability
- enhanced operational safety

Main features

- solid pellet 7.8/0mm
- UO₂ mass – 546 kg
- 8 spacer grids
- antivibration grid
- 3 mixing grids – since 2010
- anti-debris filter (restrain particles more than 2 mm size) – since 2010

In operation at Kalinin-1 since 2006
## VVER-1000 Nuclear Fuel: Advanced Fuel Rods

<table>
<thead>
<tr>
<th></th>
<th>Current value</th>
<th>Advanced value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladding thickness, mm</td>
<td>0.65</td>
<td>0.57</td>
</tr>
<tr>
<td>Pellet diameter, mm</td>
<td>7.57/7.60</td>
<td>7.80</td>
</tr>
<tr>
<td>Central hole, mm</td>
<td>1.4 / 1.2</td>
<td>0</td>
</tr>
<tr>
<td>Average grain size, µm</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

**Design features providing VVER fuel rod service life time:**
- Zr sponge since 2009
- Advanced fuel pellets
- Optimized E110

L = 3530 +150 mm

L = 3530 +200 mm
Fuel Cycles: Uprated Power (104% $N_{nom}$)

- **TVS-2M since 2008**: Fuel cycle $3 \times 18$
  - Balakovo NPP, Rostov NPP

- **TVSA-PLUS since 2010**: Fuel cycle $3 \times 18$
  - Kalinin-2, Kalinin-3

- **TVSA-ALFA since 2008**: Fuel cycle $5 \times 12$
  - Kalinin-1

### Table: Fuel Cycles

<table>
<thead>
<tr>
<th></th>
<th>since 2003</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle length, EFPD</td>
<td>4×310</td>
<td>3×510</td>
</tr>
<tr>
<td></td>
<td>5×310</td>
<td>5×310</td>
</tr>
<tr>
<td>Reload batch, pcs</td>
<td>42</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Assembly burn-up, GW·d/thM</td>
<td>55</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>up to 68</td>
<td></td>
</tr>
</tbody>
</table>
### VVER-1000 Nuclear Fuel: TVSA-T for Temelin NPP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer/ inner pellet diameter, mm</td>
<td>7.6 / 1.2</td>
</tr>
<tr>
<td>Outer / inner cladding diameter, mm</td>
<td>9.1 / 7.73</td>
</tr>
<tr>
<td>Increased fuel stack height, mm</td>
<td>3680</td>
</tr>
<tr>
<td>Spacer grids, pcs</td>
<td>8</td>
</tr>
<tr>
<td>Mixing grids, pcs</td>
<td>6</td>
</tr>
<tr>
<td>Reference fuel cycle, EFPD</td>
<td>5×320</td>
</tr>
<tr>
<td>Lead rod burn-up, GW·d/tHM</td>
<td>up to 72</td>
</tr>
<tr>
<td>Anti-debris filter</td>
<td>yes</td>
</tr>
</tbody>
</table>

Design of TVSA-T is based on TVSA-ALFA design
First full core loading at Temelin NPP – in 2010
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FA type</strong></td>
<td>TVS, TVS-M</td>
<td>UTVS</td>
<td>TVSA</td>
<td>TVS-2</td>
<td>TVSA-ALFA</td>
<td>TVS-2M</td>
<td>TVSA-PLUS</td>
</tr>
<tr>
<td><strong>Type of BA</strong></td>
<td>–</td>
<td>U-Gd</td>
<td>U-Gd</td>
<td>U-Gd</td>
<td>U-Gd</td>
<td>U-Gd</td>
<td>U-Gd</td>
</tr>
<tr>
<td><strong>Average enrichment of reload batch, w/o</strong></td>
<td>4.31</td>
<td>3.77</td>
<td>up to 4.4</td>
<td>4.26</td>
<td>4.83</td>
<td>4.88</td>
<td>4.88</td>
</tr>
<tr>
<td><strong>Reload batch, pcs</strong></td>
<td>54</td>
<td>48</td>
<td>42</td>
<td>54</td>
<td>36</td>
<td>60 – 66</td>
<td>60 – 66</td>
</tr>
<tr>
<td><strong>Outer fuel rod diameter, mm</strong></td>
<td>7.57 / 2.3</td>
<td>7.57 / 1.5</td>
<td>7.57 / 1.4</td>
<td>7.57 / 1.4</td>
<td>7.8 / 0.0</td>
<td>7.6 / 1.2</td>
<td>7.6 / 1.2</td>
</tr>
<tr>
<td><strong>Assembly burn-up, GW×d/tHM</strong></td>
<td>49</td>
<td>49</td>
<td>55</td>
<td>55</td>
<td>до 68</td>
<td>до 68</td>
<td>до 68</td>
</tr>
<tr>
<td><strong>Fuel cycle</strong></td>
<td>3×1</td>
<td>3×1</td>
<td>4×(310–320)</td>
<td>3×(350–370)</td>
<td>5×(310–320)</td>
<td>3×(480–510)</td>
<td>3×(480–510)</td>
</tr>
<tr>
<td><strong>Uranium consumption, tHM/GW×d</strong></td>
<td>0.240</td>
<td>0.205</td>
<td>0.199</td>
<td>0.210</td>
<td>0.187</td>
<td>0.230</td>
<td>0.230</td>
</tr>
</tbody>
</table>
VVER-1000 Nuclear Fuel: Load Follow

VVER-1000 nuclear fuel provides load follow modes

Power maneuvering
100–75–100 % N_{el}
rate up to 1% N_{nom}/min
200 cycles through operating period

Primary load follow
within the range of ± 2 % N_{nom}
AES-2006 Nuclear Fuel Development Step-by-Step (1)

AES-2006 Technical Assignment Requirements

- Thermal power – 3200 MW (\(T_{\text{inlet}}=298.8{\,}^\circ\text{C}\), mass steam quality up to 13%)
- Fuel cycles 5x12 and 3x18, maximum assembly burn-up up to 70 GW·d/tHM
- Load Follow Operation – during 90% of operation time within the range 100-20-100 % \(N_{\text{nom}}\) and rate of change 5% \(N_{\text{nom}}/\text{min}\)

R&D, FA based on TVS-2M design:

- Enhanced uranium capacity due to increased fuel stack height and advanced fuel rod design (cladding 9.1 / 7.93 mm, pellet 7.8 / 0.0 mm)
- Improved heat reliability at uprated power
- Modified Zr alloys
Phase #1 (2007 – 2009)

Base FA design development:

- Thermal Power: 3200 MW
- Increased fuel stack height (pellet 7.6 /1.2 mm, grain size 25 μm)
- Average assembly burn-up: 64 GW⋅d/tHM
- Load Follow 100-75-100 % N_{nom}
- Mixing grids
## Phase #1 Results

### 2. Fuel Cycles

<table>
<thead>
<tr>
<th>Fuel Cycle, EFPD</th>
<th>5×310</th>
<th>3×510</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reload batch, pcs</td>
<td>36</td>
<td>72</td>
</tr>
<tr>
<td><strong>Average enrichment of reload batch, w/o (^{235})U</strong></td>
<td>4.83</td>
<td>4.69</td>
</tr>
<tr>
<td><strong>Discharge burn-up, GW·d/tHM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average assembly burn-up</td>
<td>58.4</td>
<td>48.3</td>
</tr>
<tr>
<td>Lead rod burn-up</td>
<td>64.2</td>
<td>57.0</td>
</tr>
</tbody>
</table>
CONCLUSIONS

VVER-440 Nuclear Fuel

Implementation of 2\textsuperscript{nd} generation of FA with the following performance characteristics:

- Average FP failure factor during operation is less than $1 \cdot 10^{-6}$;
- Fuel burn-up: up to 60 GW×d/tHM;
- 5-year fuel cycle;
- Unit thermal power uprate up to 110% $N_{\text{nom}}$;
- Load Follow Mode (97.5±2.5% and 100-75-100% $N_{\text{nom}}$)

3\textsuperscript{rd} generation of FA is developed (RK-3 Type)
VVER-1000 Nuclear Fuel

1) New generation of FA (TVSA and TVS-2) is developed, implemented and successfully operated at Russian, Ukrainian and Bulgarian NPPs providing
   - Safe and reliable operation cycle of 6 years
   - Assembly burn-up – up to 60 GW×d/THM
   - Load Follow Mode

2) For satisfaction of customer needs regarding nuclear fuel performance the following development of FA design is under way:
   - Power uprate up to 104% $N_{\text{nom}}$
   - Fuel cycles length up to 18 months
Thank you for your attention