Westinghouse Advanced Doped Pellet – Characteristics and Irradiation behaviour

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Contents

ADOPT overview

Properties that will be discussed

- Density
- Fission gas release
- PCI performance
- Secondary degradation behavior

Conclusion

ADOPT = Advanced Doped Pellet Technology
ADOPT Overview

- High density UO$_2$ pellets with enlarged grain size. ADOPT contains additives of Cr- and Al-oxide less than 1000 ppm total.
- Improved quality: the additives facilitate pellet densification during sintering and are experienced to give a lower rejection rate in the visual inspection after grinding.

<table>
<thead>
<tr>
<th></th>
<th>Standard pellet</th>
<th>ADOPT pellet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain size</td>
<td>9 μm</td>
<td>31 μm</td>
</tr>
<tr>
<td>Density</td>
<td>10.60 g/cm$^3$</td>
<td>10.67 g/cm$^3$</td>
</tr>
<tr>
<td>Density of TD</td>
<td>96.7%</td>
<td>97.4%</td>
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ADOPT Overview

Verification

- An extensive test program performed
- High BU irradiation on-going

Experience

- 10 years of experience from irradiation
- Two full reloads in operation
ADOPT Overview

Density
- Manufactured density mainly influenced by $\text{Cr}_2\text{O}_3$ content.

Grain size
- Strongly influenced by both $\text{Al}_2\text{O}_3$ and $\text{Cr}_2\text{O}_3$ content
Physical Properties

Properties characterized
- Thermal Diffusivity
- Specific Heat
- Thermal Expansion
- Melting Temperature

The difference between ADOPT and Standard UO$_2$ is negligible (within the uncertainty of accurate measurements)
Densification and swelling behaviour
Densification and swelling – Resinter tests

- **ADOPT, density 10.67g/cm³**
  
  0.13% ± 0.13%,
  
  From 18 pellet lots

- **Standard UO₂, density 10.60g/cm³**
  
  0.60% ± 0.40%,
  
  From 65 pellet lots
Fuel rod growth

- Less fuel densification of ADOPT pellets implies earlier pellet cladding contact resulting in a higher rod length increase.

- Same swell rate after densification

- After pellet cladding contact occurs the rod length growth rate is the same.
Fission Gas Release
FGR – Gamma measurements at Oskarshamn

Measurements on 22 fuel rods from 2 FA
10 with ADOPT-pellets
12 with standard pellets

Around 30 % benefit of ADOPT – consistent with Studsvik enhanced power data
FGR – Studsvik data

![Graph showing FGR over time with Ramp and Bump tests]

<table>
<thead>
<tr>
<th>Relative FGR (%)</th>
<th>Standard UO₂</th>
<th>ADOPT</th>
</tr>
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<tbody>
<tr>
<td>RAMP TEST 57kW/m</td>
<td>30.2%</td>
<td>17.2%</td>
</tr>
<tr>
<td>BUMP TEST 45kW/m</td>
<td>29.7%</td>
<td>20.5%</td>
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> Significantly less gas release from the ADOPT fuel
FGR – PIE after ramp test

Standard pellets have pores precipitated mainly in the grain boundary.

The doped pellet have the pores precipitated mainly inside the grain. This is beneficial to FGR.
Halden Test

FGR Estimates from Normalized Rod Pressures

- The rods were operated above the Vitanza FGR threshold
- The timing of the FGR release are linked to big steps in temperature
- The FGR release from the different rods are not comparable due to the completely different power histories they have experienced
Halden test
Results from PIE

Rod 1
ADOPT

Rod 5
ADOPT

Rod 6
Standard UO₂

The PIE examinations show results which is consistent with earlier ADOPT experience
PCI performance
PCI performance – PIE following ramp tests

Standard

Doped
PCI performance – PIE following ramp tests

Standard UO₂

Doped

➢ Formation of central hole and filling of pellets dishes indicates enhanced viscoplasticity
Pellet creep
Constant Stress

Creep test 1500°C 45 MPa

- A higher creep rate indicates a more viscoplastic behavior of the ADOPT pellet compared to the standard pellet.

ADOPT creep rate = 0.5%/h

UO₂ creep rate = 0.4%/h
Resistance to secondary degradation
Secondary degradation – Oxidation resistance test

Thermal microbalance test shows that ADOPT has improved resistance to fuel oxidation

- Oxidation curves, 400°C, 20h, Ar/H₂O
Secondary degradation – Inreactor washout test

BWR rod with a large secondary defect

Standard UO$_2$ pellet after inreactor washout test

- Studsvik inreactor test show less washout caused by erosion and or surface boiling of higher density pellets i.e. ADOPT
Conclusions

Experience with ADOPT
- 10 years of experience including two full reloads
- An extensive test program

Improved properties
- Higher density
- Reduced FGR
- Improved creep – (PCI performance)
- Secondary degradation behavior – in and out of pile test
Thank You!