Enclosure 4

Westinghouse Closed Session Slide Package for the ACRS Thermal-Hydraulic Phenomena Subcommittee Meeting on WCAP-18482-P/NP

(Non-Proprietary)

(25 pages including this cover page)

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Westinghouse Advanced Doped Pellet Technology (**ADOPT**™) Fuel, WCAP-18482-P/NP

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Agenda

- Introduction to **ADOPT** Fuel
- Topical Report Overview
- Qualification Data
- Analytical Methods
  - Fuel Performance
  - Nuclear Design
  - Thermal-Hydraulic Design
  - Safety Analyses
- Conclusions

Introduction to **ADOPT** Fuel

Introduction to ADOPT Fuel

- **ADOPT** (Advanced DOped Pellet Technology) fuel is a standard UO_2 fuel that has been doped with [ ]a,c Cr_2O_3 and [ ]a,c Al_2O_3.
- The additives facilitate densification and diffusion during sintering resulting in a higher density and enlarged grain size compared to undoped UO_2.

[ ]a,c

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The ADOPT pellet is characterized by its increased density and larger grain size

Operating Experience

- **ADOPT** fuel is a commercial product for the European market with extensive operating experience and superior performance
  - ✓ 23 years of irradiation data
  - ✓ 17 years of reloads
  - ✓ [ ]a,c burnup
  - ✓ 3400 fuel assemblies
  - ✓ 680 metric tons

- Current efforts are focused on bringing **ADOPT** technology to the US PWR market

Deliveries of ADOPT Fuel in European Market

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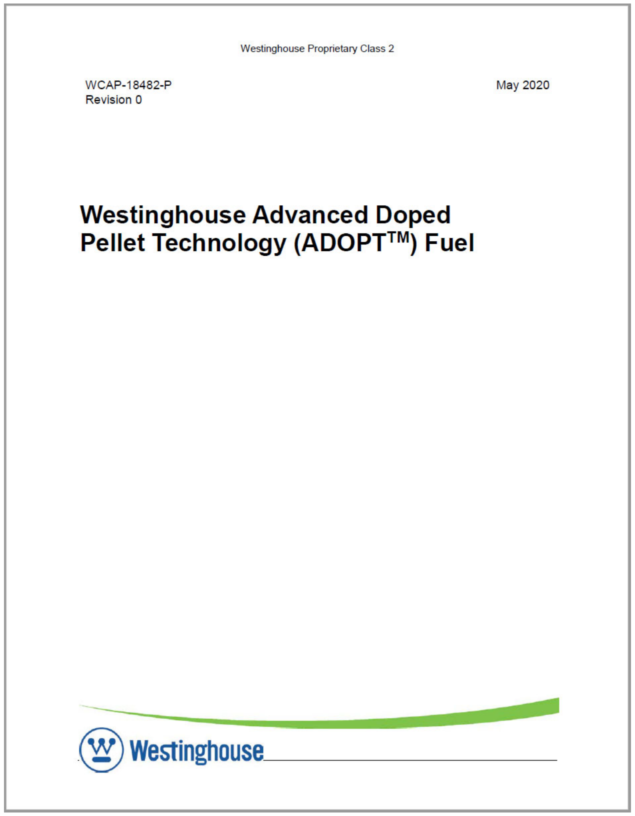
ADOPT fuel is a mature technology

Topical Report Overview

WCAP-18482-P/NP

- WCAP-18482-P/NP is a topical report to enable efficient licensing and implementation of Westinghouse Advanced Doped Pellet Technology (**ADOPT™**) Fuel
- Describes licensing topical report for region implementation of the Westinghouse **ADOPT** fuel material
  - Proposed limits of applicability
  - Discusses interaction with other topical reports and licensing considerations for implementation
  - Discusses available qualification data
  - Demonstrates applicability of existing analytical methods and models including:
    - Nuclear Design
    - Fuel Rod Design
    - Thermal-Hydraulics
    - and Safety Analysis


Westinghouse Proprietary Class 2

WCAP-18482-P
Revision 0

May 2020

Westinghouse Advanced Doped Pellet Technology (ADOPT™) Fuel

Requested Limits of Applicability

Reactor & Fuel Assembly Design Constraints

For use with NRC-approved:

- ✓ PWR reactor designs
- ✓ Westinghouse and CE fuel designs with corresponding pellet dimensions
- ✓ Zirconium-based cladding materials

Fuel Design Constraints

- ✓ Fuel burnup up to 62 MWd/kgU peak rod average
- ✓ With or without annular pellets
- ✓ With or without application of ZrB_2 integral fuel burnable absorber (IFBA)
- ✓ Nominal pellet density ranging from [ ][a,c]
- ✓ Fuel grain sizes ranging from [ ][a,c]
- ✓ Inclusion of Cr ranging from [ ][a,c]
- ✓ Inclusion of Al ranging from [ ][a,c]

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Qualification Data Overview

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ADOPT behavior relative to UO_2

Summary of Thermophysical Properties

- Experimental data collected for
  - **thermal diffusivity** using laser flash technique
  - **heat capacity** using differential scanning calorimeter
  - **thermal expansion** using a differential dilatometer
  - **melting temperature** using laser-pulse melting
- Data agrees well with the published literature on the thermo-physical properties for UO_2
- Recommend no additional changes to current licensed thermo-physical models to implement **ADOPT** fuel; the current licensed UO_2 models are sufficient

No changes to thermo-physical models to implement ADOPT fuel

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ADOPT behavior relative to UO_2

Summary of Steady State FGR

- The steady state fission gas release (FGR) database contains both thermal and athermal data sets including:
  - Performed poolside measurements, as well as destructive PIE, on commercially irradiated rods
  - Performed online FGR measurements in Halden [ ]a,c experiment
- Data confirms that dominant effect driving steady state FGR is the fuel centerline temperature. Any effect of the larger grains of doped pellets is a much smaller, second order effect.

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No difference in steady-state FGR between ADOPT and standard fuel

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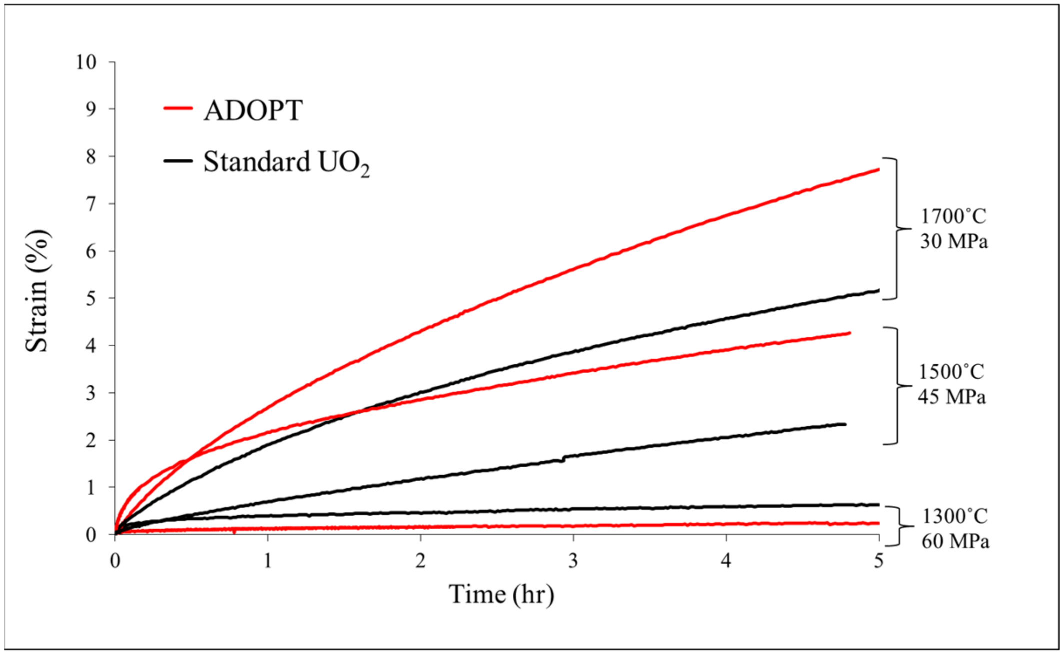
ADOPT behavior relative to UO_2

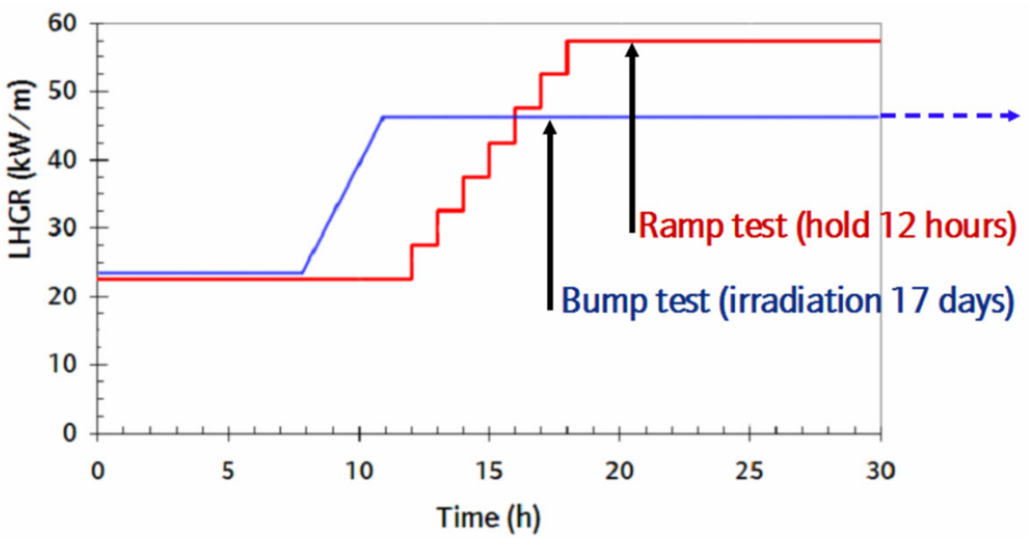
Summary of creep behavior

- Fuel movement in the central high-temperature region of the pellet helps to reduce the pellet-clad stress
- At temperatures greater than 1500°C (i.e. accident conditions or ramp testing), the **ADOPT** fuel exhibits higher visco-plasticity as compared to the reference UO_2 pellets



ADOPT fuel creeps more than UO_2, but only at high temperatures beyond normal operation

ADOPT behavior relative to UO_2



Test	Standard UO_2	ADOPT
Ramp test (57 kW/m)	30.2% (12 hour)	17.2% (7.7 hour)
Bump test (45 kW/m)	29.7% (17 day)	20.5% (17 day)

Transient FGR

- Material base irradiated in Barsebäck
- Ramp tested at R2 reactor; the rodlets were punctured to examine the amount of FGR, and the **ADOPT** pellets have about 30% less FGR than the standard UO_2 pellets.
- A better intragranular gas retention capability anticipated to decrease the rod internal pressure during an accident. This is beneficial in reducing the clad ballooning and (burst) failure risk.

ADOPT pellets have less transient FGR than the standard UO_2 pellets

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ADOPT behavior relative to UO_2

Densification & Fuel Rod Growth

- A reduction in **ADOPT** fuel's densification is observed due to the material already achieving high density during the sintering process.
- As a result of **ADOPT** fuel's reduced in-reactor densification, the pellet-to-clad gap will close earlier than standard UO_2.
  - Operating experience demonstrates that **ADOPT** rods will exhibit slightly higher rod growth due to earlier pellet-cladding contact.

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[ ] b,c

Higher thermal stability will lead to earlier pellet cladding contact and a higher axial growth

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Summary of Data

- The **ADOPT** pellet is characterized by its increased density and larger grain size
- The thermophysical property measurements show a negligible difference between **ADOPT** and standard UO_2 pellets
- **ADOPT** fuel creeps more than UO_2 but only at high temperatures beyond normal operation.
- **ADOPT** fuel is characterized by a higher dimensional stability
  - Operating experience demonstrates that ADOPT rods will exhibit slightly higher rod growth due to earlier pellet-cladding contact.
- **ADOPT** fuel has same steady state FGR behavior as UO_2
- **ADOPT** fuel has lower FGR than UO_2 in transient conditions

Analytical Methods & Modeling

Fuel Performance
Nuclear Design
Thermal-Hydraulic Design
Safety Analyses

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Fuel Performance Key Differences in PAD5

ADOPT fuel properties are largely the same as regular UO_2, however key differences are addressed:

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Minor adjustments in PAD5 fuel rod growth and fission gas swelling models

PAD5 Fuel Rod Growth Model Adjustment

- The rod growth data for **ADOPT** fuel were used to develop a correction to the current PAD5 model for standard UO_2 fuel. Chose UO_2 dataset most similar to data for **ADOPT** fuel (by fabrication and operating conditions) and fit trendline models to both datasets
- Difference was estimated by comparing datasets obtained under similar conditions and fit trendline models to both datasets
  - [ ]a,c
  - [ ]a,c

[ ]a,c

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PAD5 Transient Fission Gas Swelling Model Adjustment

[ ]a,c

Model Development

- Adjusted model uncertainty
  - [ ]a,c
  - Based on 1000ppm $Cr^{2}O^{3}$, which represents the UB Cr dopant (worst possible **ADOPT** performance)
- [ ]a,c

[ ]a,c

A small adjustment in model uncertainty to account for small data set and underprediction of the lower burnup data

Other Analytical Areas

- Material property changes do not impact the approved methods
- Modeling of **ADOPT** pellets can be incorporated through revised input – many areas utilize input from the fuel performance code

Analytical Area	Additional Clarification
Nuclear Design	
LOCA	
Thermal-Hydraulic Design	
Non-LOCA Transient Analysis	
Containment Integrity Analysis	
Radiological Consequences	

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No updates are needed to the other NRC-approved methods to implement ADOPT pellets

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Analytical Methods Summary

- **ADOPT** fuel properties are largely the same as regular UO_2
  - Density and densification differences can be accounted for via input
- Fuel rod growth adder addresses the difference of using the current rod growth model for **ADOPT** fuel
- Gaseous swelling uncertainty is adjusted in recognition of PAD5 under prediction of the diameter change of the lower burnup **ADOPT** fuel ramp tests with non-typical dopant
- [ ]a,c
- Negligible impact on interface between FRD and downstream/upstream analysis
- With exception of PAD5, no updates are needed to the NRC-approved methods to implement **ADOPT** pellets

Summary and Conclusion

Summary

- Westinghouse has extensive experience manufacturing and deploying **ADOPT** pellets in Europe
- Westinghouse is requesting near-term region implementation of **ADOPT** pellets for PWR applications
  - Significant qualification data and operating experience supports licensing activities
- Existing analytical methods and models including Nuclear Design, Fuel Rod Design, Thermal-Hydraulics, and Safety Analysis have been assessed and are applicable to **ADOPT** fuel with minimal changes.

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