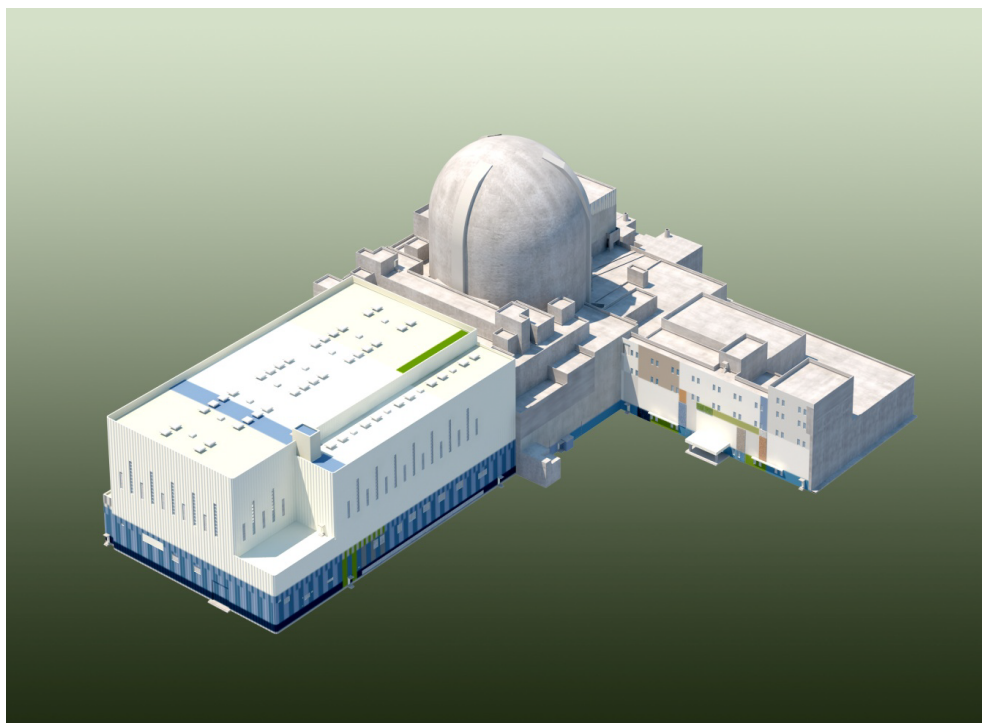


# APR1400 System Design (Fuel Design)



**KEPCO/KHNP**  
**Apr. 20~21. 2016**

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# Introduction

**(Ref. : APR1400-F-M-TR-13001-P Rev.0)**

# Introduction (PLUS7 Fuel Development)

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- PLUS7 fuel design was jointly developed with Westinghouse for APR1400 in Korea (1999~2002).
- PLUS7 fuel was developed to improve the fuel performance compared to Guardian.

(Guardian : Standard fuel design for System80+)

- KEPCO/KHNP submitted PLUS7 Topical Report and Technical Report to NRC for APR1400 DC licensing.
  - PLUS7 Fuel Design : APR1400-F-M-TR-13001-P Rev.0
  - Seismic/LOCA Analysis : APR1400-Z-M-NR-14010-P Rev.0

# Introduction (Regulatory Bases)

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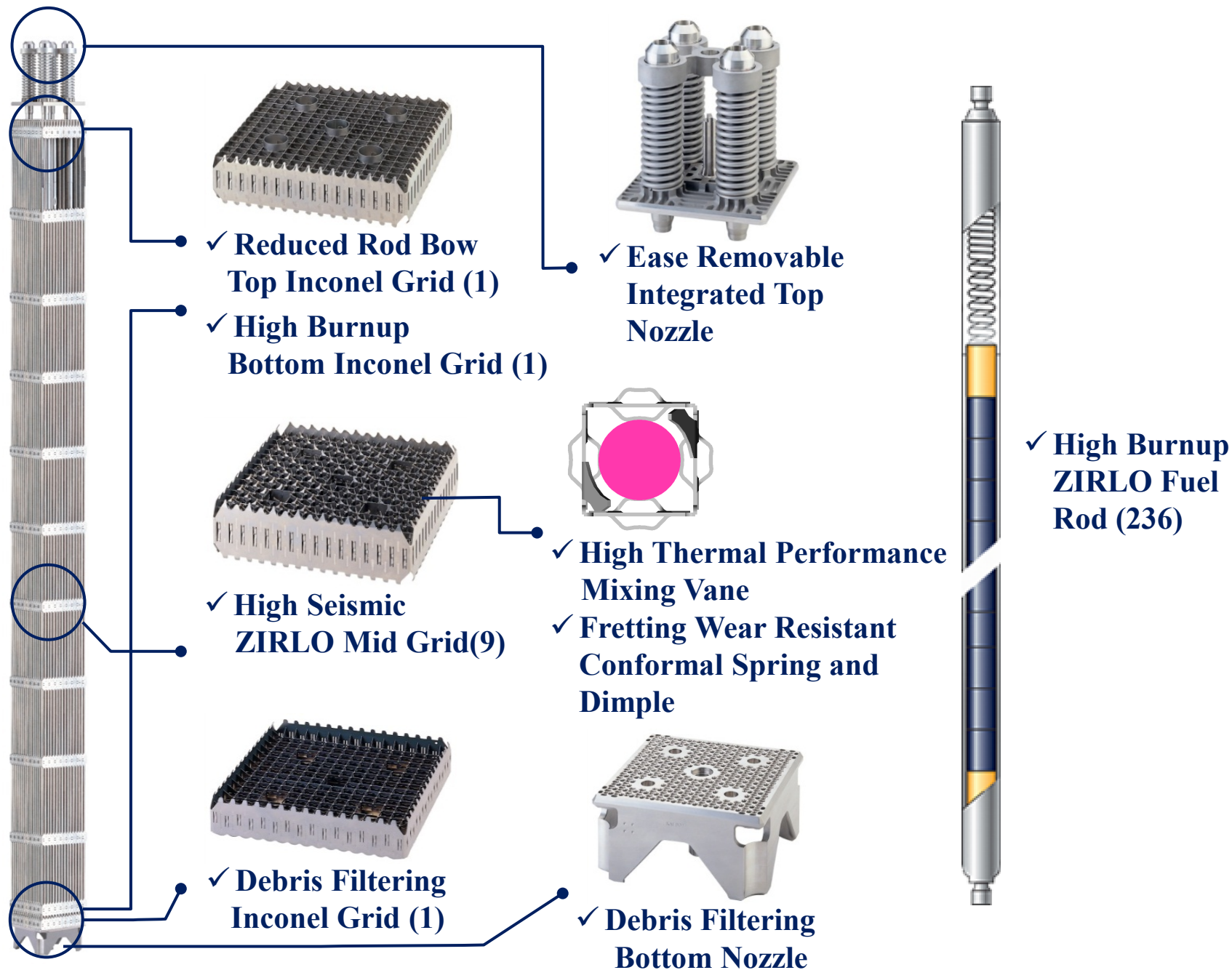
PLUS7 fuel design was developed to comply with following code of federal regulations, NRC regulatory documents, and industrial code and standards.

- **Code of Federal Regulations**
  - 10 CFR 50 Appendix A. GDC 10 Reactor Design
- **NRC Regulatory Documents**
  - NUREG-0800, SRP 4.2 Fuel System Design
  - IN 2012-09 Irradiation Effects on Fuel Assembly Spacer Grid Crush Strength, etc.
- **Industrial Code and Standards**
  - ASME B&PV Code Section III
  - ANSI ANS 57.5 Plant Design Conditions, etc.

# PLUS7 Fuel Design

(Ref. : APR1400-F-M-TR-13001-P Rev.0)

# PLUS7 Fuel Design (Characteristics)



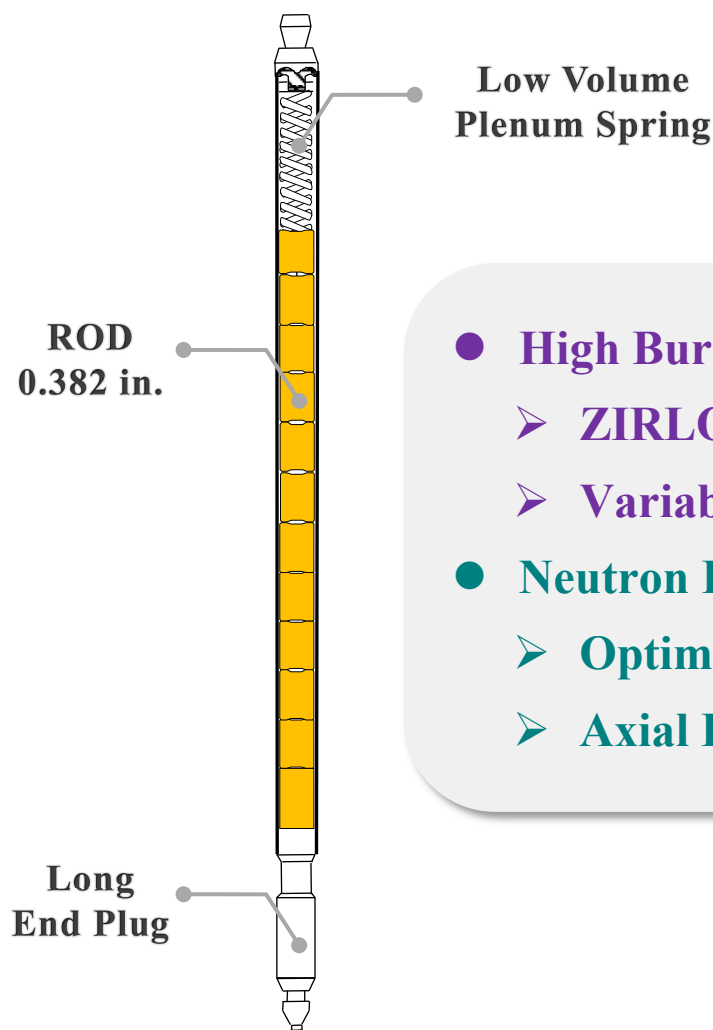
# PLUS7 Fuel Design (Characteristics)

- PLUS7 incorporated the proven Guardian structure and the proven Westinghouse type fuel features to improve fuel performance.

Items		Guardian	PLUS7	Improvements
Cladding		Zry-4	ZIRLO	High Burnup Capability
Rod Diameter		0.382"	0.374"	Enhanced Neutron Economy
Axial Blanket		No	Yes	
Mid Grid	Spring	Cantilever	Conformal	Increased Fretting Wear Resistance
	Dimple	Arched	Conformal	
	Strap	Wavy	Straight	High Seismic Capability
	Mixing Vane	No	Yes	Enhanced Thermal Performance
Top Nozzle		Separated	Assembled	Easy Removable
Bottom nozzle		Large Hole	Small Hole & Slot	Increased Debris Filtering Efficiency

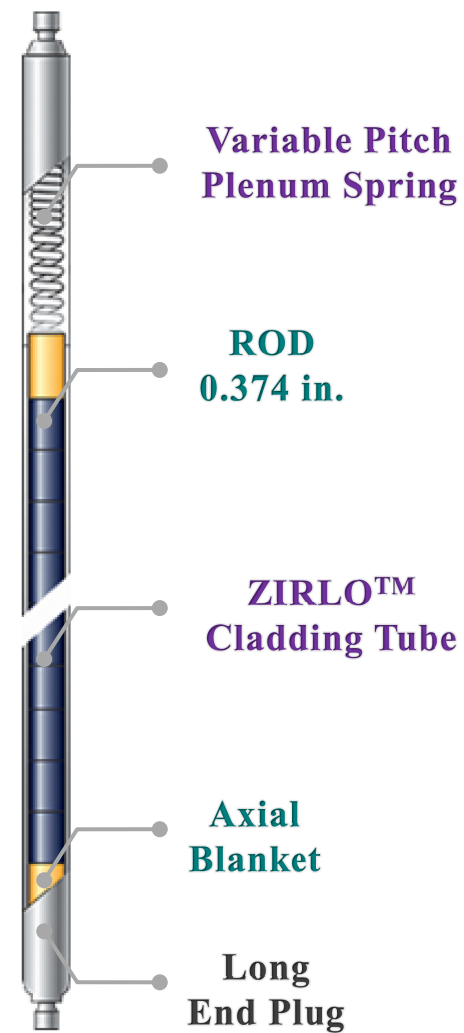
# PLUS7 Fuel Design (Characteristics)

## High Burnup Capability and Neutron Economy



**Guardian**

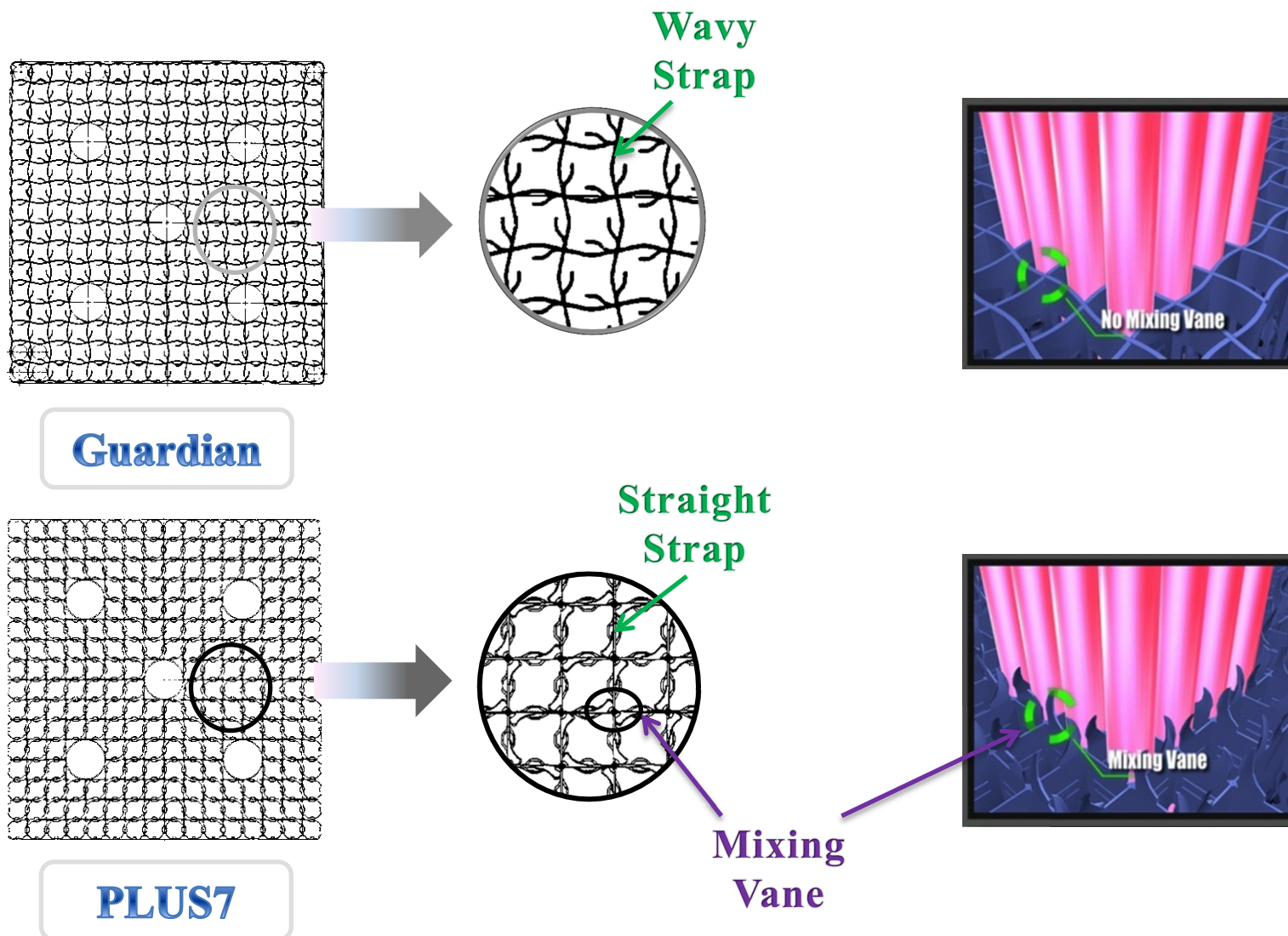
- High Burnup Capability
  - ZIRLO™ Cladding
  - Variable Pitch Plenum Spring
- Neutron Economy
  - Optimized Rod OD
  - Axial Blanket



**PLUS7**

# PLUS7 Fuel Design (Characteristics)

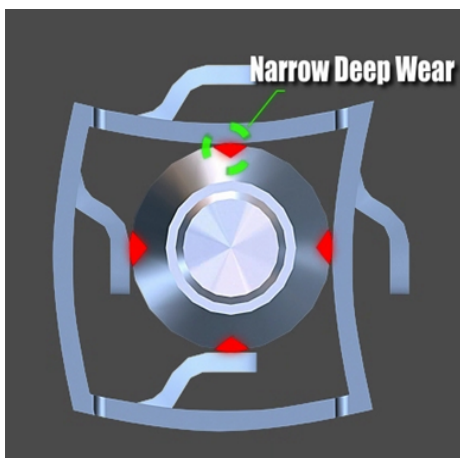
Enhanced Thermal Margin and High Seismic Capability



# PLUS7 Fuel Design (Characteristics)

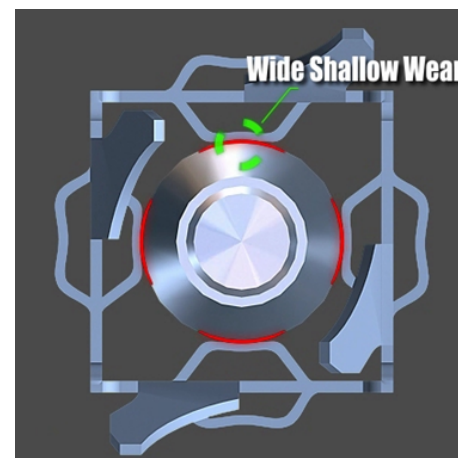
## Enhanced Fuel Integrity - Fretting Wear Resistance

### Guardian



- Cantilever Spring and Arched Dimple
  - Lower Fretting Wear Resistance

### PLUS7

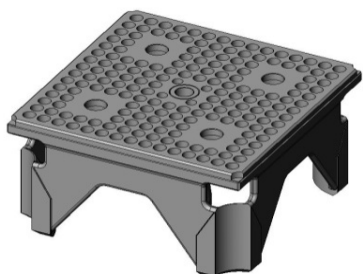
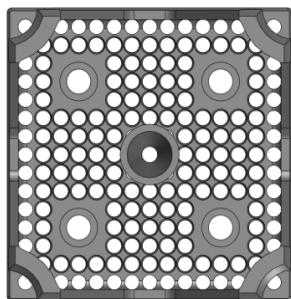


- Conformal Spring and Dimple
  - Improve Fretting Wear Resistance

# PLUS7 Fuel Design (Characteristics)

## Enhanced Fuel Integrity - Debris Filtering Efficiency

**Guardian**



# PLUS7 Fuel Design (Verification)

- **Out-of-Pile Tests**

- **Fuel Assembly Mechanical Tests**

- Load-Deflection, Strength, Vibration, Impact, etc.

- **Fuel Assembly Hydraulic Tests**

- Pressure Drop, Flow-Induced Vibration, Long-Term Wear, etc.

- **Critical Heat Flux Test**

- Critical Heat Flux

- **In-Reactor Verification Tests**

- **PSE(Pool Side Examination)**

- **Hot Cell Examination**

# PLUS7 Fuel Design (Verification)

- **Out-of-Pile Tests**
  - **PLUS7 fuel assembly mechanical and hydraulic tests were performed using test facilities(FACTS, VIPER, etc.) located at Westinghouse Columbia Plant.**
  - **Critical heat flux test was performed using HTRF(Heat Transfer Research Facility) located at Columbia University.**
  - **Based on the fuel assembly mechanical and hydraulic test results, the mechanical and hydraulic performance of PLUS7 fuel design was verified.**
  - **KCE-1 correlation was developed based on the critical heat flux test results and the correlation was applied to PLUS7 design analysis. (KCE-1 Topical Report : APR1400-F-C-TR-12002-P Rev.0)**

# PLUS7 Fuel Design (Verification)

- **In-Reactor Verification Tests (LTA and CSA Program)**
  - **4 LTAs(Lead Test Assemblies) were manufactured and loaded at Ulchin Unit 3 Cycle 5 ~ Cycle 7.**
  - **4 CSAs(Commercial Surveillance Assemblies) were selected from commercially supplied fuels at Yonggwang Unit 5 Cycle 5.**
  - **PSE(Pool Side Examination) and hot cell examination has been successfully completed after the LTAs and CSAs irradiation.**
- **Based on the PSE and hot cell examination results, it was confirmed that the measured data were within the design limit of PLUS7 fuel design.**

# PLUS7 Irradiation Experience

(Ref. : APR1400-F-M-TR-13001-P Rev.0)

# PLUS7 Irradiation Experience

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- Based on the out-of-pile test and in-reactor verification test results, more than 4,000 PLUS7 fuel assemblies were supplied since 2006.
- Status of Commercial Supply for PLUS7 Fuel
  - Supplied 4,250 fuel assemblies(1,003,000 fuel rods) to 13 reactors in KOREA with 18 month cycle
  - Maximum Fuel Rod Discharge Burnup : 59,547 MWD/MTU
  - 302 fuel assemblies are ready to ship for Barakah Unit 1

# PLUS7 Licensing Status

(Ref. : APR1400-Z-M-NR-14010-P Rev.0)

# PLUS7 Licensing Status

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- **KEPCO/KHNP submitted PLUS7 Topical Report and fuel assembly seismic Technical Report in 2014.**
- **NRC Audit was performed for fuel assembly seismic Technical Report in 2015 and there were some issues related to fuel assembly EOL seismic analysis(IN 2012-09).**
- **KEPCO/KHNP is working on the fuel assembly EOL test and seismic analysis, and the issues will be resolved by end of July 2017 based on the additional test and analysis results.**

# Summary

# Summary

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- PLUS7 fuel assembly design was jointly developed with Westinghouse for APR1400 in Korea(1999~2002).
- PLUS7 design evaluation was performed to comply with code of federal regulations and NRC regulatory documents.
- PLUS7 fuel design was verified through the out-of-pile tests, critical heat flux tests, in-reactor verification tests.
- Fuel assembly EOL seismic analysis related issues will be resolved by end of July 2017 based on the additional test and analysis results.
- More than 4,000 PLUS7 fuel assemblies were supplied since 2006 and excellent in-reactor performance was demonstrated.

# THANK YOU !