APR1400 System Design (Fuel Design)

KEPCO/KHNP
Contents

• Introduction
  ➢ PLUS7 Fuel Development
  ➢ Regulatory Bases

• PLUS7 Fuel Design
  ➢ PLUS7 Design Characteristics
  ➢ PLUS7 Design Verifications

• PLUS7 Irradiation Experience

• PLUS7 Licensing Status

• Summary
Introduction

(Ref. : APR1400-F-M-TR-13001-P Rev.0)
Introduction (PLUS7 Fuel Development)

- 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+)
  - 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)

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)
PLU57 Fuel Design (Characteristics)

- Reduced Rod Bow Top Inconel Grid (1)
- High Burnup Bottom Inconel Grid (1)
- High Seismic ZIRLO Mid Grid (9)
- High Burnup ZIRLO Fuel Rod (236)
- Ease Removable Integrated Top Nozzle
- High Thermal Performance Mixing Vane
- Fretting Wear Resistant Conformal Spring and Dimple
- Debris Filtering Inconel Grid (1)
- Debris Filtering Bottom Nozzle
PLUS7 Fuel Design (Characteristics)

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

<table>
<thead>
<tr>
<th>Items</th>
<th>Guardian</th>
<th>PLUS7</th>
<th>Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladding</td>
<td>Zry-4</td>
<td>ZIRLO</td>
<td>High Burnup Capability</td>
</tr>
<tr>
<td>Rod Diameter</td>
<td>0.382”</td>
<td>0.374”</td>
<td>Enhanced Neutron Economy</td>
</tr>
<tr>
<td>Axial Blanket</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Mid Grid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>Cantilever</td>
<td>Conformal</td>
<td>Increased Fretting Wear Resistance</td>
</tr>
<tr>
<td>Dimple</td>
<td>Arched</td>
<td>Conformal</td>
<td></td>
</tr>
<tr>
<td>Strap</td>
<td>Wavy</td>
<td>Straight</td>
<td>High Seismic Capability</td>
</tr>
<tr>
<td>Mixing Vane</td>
<td>No</td>
<td>Yes</td>
<td>Enhanced Thermal Performance</td>
</tr>
<tr>
<td>Top Nozzle</td>
<td>Separated</td>
<td>Assembled</td>
<td>Easy Removable</td>
</tr>
<tr>
<td>Bottom nozzle</td>
<td>Large Hole</td>
<td>Small Hole &amp; Slot</td>
<td>Increased Debris Filtering Efficiency</td>
</tr>
</tbody>
</table>
PLUS7 Fuel Design (Characteristics)

High Burnup Capability and Neutron Economy

- High Burnup Capability
  - ZIRLO™ Cladding
  - Variable Pitch Plenum Spring

- Neutron Economy
  - Optimized Rod OD
  - Axial Blanket

Guardian

PLUS7
PLU7 Fuel Design (Characteristics)

Enhanced Thermal Margin and High Seismic Capability

Guardian

PLU7

Wavy Strap

Straight Strap

Mixing Vane

No Mixing Vane

NON-PROPRIETARY
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
- Large Flow Hole Bottom Nozzle
  - Lower Debris Filtering Efficiency

PLUS7
- Small Flow Hole/Slot Bottom Nozzle
  - Increase Debris Filtering Efficiency
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

- 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

- 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

- 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!