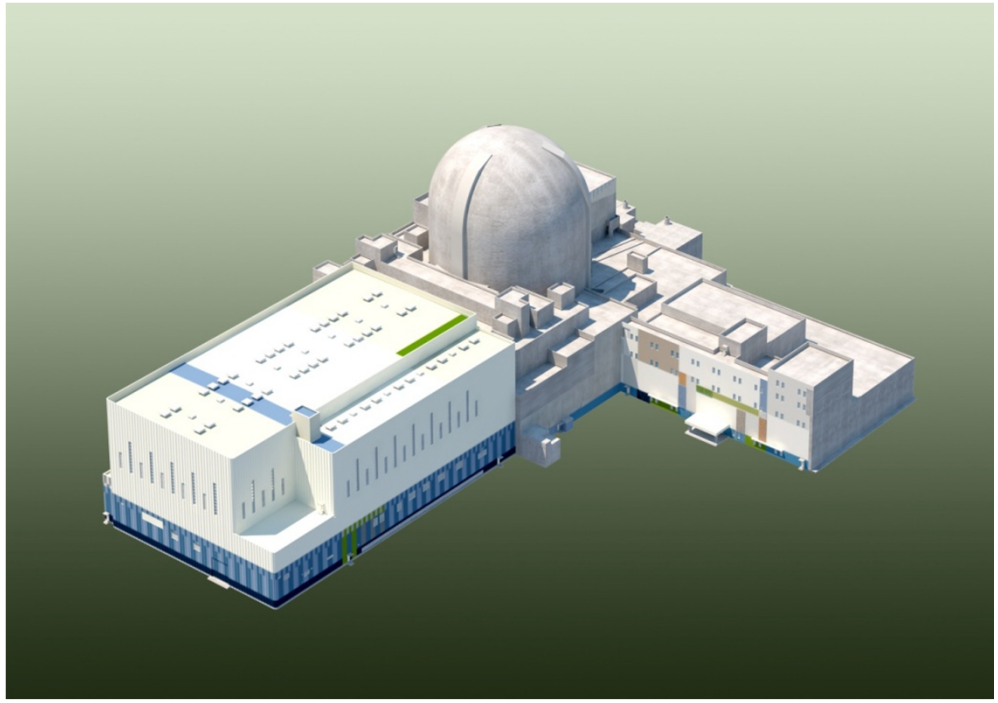
NON-PROPRIETARY

PLUS7 Test Results and Seismic Analysis Plan

(RAI 8405 on Section 4.2 of the APR1400 DCD)



KHNP

December 15, 2016

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- PLUS7 BOL/EOL Fuel Assembly Seismic Analysis
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- Summary

Introduction

Features of PLUS7™ Fuel Design

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Status of Fuel Assembly Seismic TeR Licensing

- KHNP submitted PLUS7 Fuel Assembly (FA) Seismic/LOCA TeR in 2014
- NRC Audit has been conducted for the TeR in 2015
- NRC issued RAI 8405 from the audit
- KHNP presented PLUS7 test and seismic analysis plan in Feb. 2016
- KHNP has been performing grid/FA tests and FA seismic model generation with Westinghouse since May 2016

PLUS7 Test and Seismic Analysis Plan

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PLUS7 Grid and Fuel Assembly Test Results

Grid Test Summary

- **Quantify mechanical characteristics of the PLUS7 fuel design grids:**
  - ✓ Lateral stiffness
  - ✓ Lateral crush strength
  - ✓ Coefficient of Restitution
- **Three separate tests were performed**
  - ✓ Static crush test
    - Used to determine the through-grid stiffness
  - ✓ One-sided drop test
    - Used to determine one-sided crush strength and coefficient of restitution
  - ✓ Through-grid long-pulse test
    - Used to determine the through-grid crush strength

Static Crush Test

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One-side Drop Test

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Through-grid Long Pulse Test

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Fuel Assembly Mechanical Test Summary

- **Testing was performed the PLUS7 fuel design to determine the FA dynamic characteristics at simulated EOL conditions [**

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Fuel Assembly Mechanical Test Data Use

Test data obtained from the following tests will be used as follows:

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Skeleton Lateral Load Deflection Test (Single Grid)

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Fuel Assembly Lateral Load Deflection Test

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Skeleton Lateral Load Deflection Test (Multiple Grid)

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Fuel Assembly Free Vibration Test

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Fuel Assembly Forced Vibration Test

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Fuel Assembly Forced Vibration Test

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Fuel Assembly Lateral Single Grid Impact Test

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Fuel Assembly Lateral Multiple Grid Impact Test

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Flowing Water Damping Test Plan

- **Due to irradiation effects, the FA natural frequencies and grid crush strengths are reduced at EOL conditions. Therefore, the NRC issued IN 2012-09 in June 2012 which challenged approved methods based on BOL assumptions in the Seismic/LOCA analysis.**
- **To improve margins in the Seismic/LOCA analyses at EOL conditions, FA flowing water damping test results allow for the recovery of design margin lost due to EOL conditions.**
  - ✓ **The flowing water damping test objective is to obtain the FA damping coefficients in flowing water conditions for the PLUS7 fuel design.**

Flowing Water Damping Test Plan

- Flowing water damping testing will be performed for a full scale of the PLUS7 FA in an isothermal hydraulic test loop.
- The testing will be performed consistent with similar flowing water damping tests.
- The testing will be performed with still water and with flowing water conditions.

Flowing Water Damping Test Conditions

The objectives of the test are to measure the FA damping coefficients for the PLUS7 FA in still water and in flowing water for the first mode by pluck test.

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Flowing Water Damping Test General Layout

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Flowing Water Damping Test Expected Results

It is expected that the PLUS7 FA flowing water damping testing will demonstrate the following.

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PLUS7 BOL/EOL Fuel Assembly Seismic Analysis

PLUS7 BOL/EOL Seismic Analysis Schedule

ITEMS	2016	2017
BOL FA Model Development	9	
BOL FA Seismic/LOCA Analysis	12	
EOL FA Model Development	1	
EOL FA Seismic/LOCA Analysis		6
Update DCD/ToR Revise TeR	2	
Issue Addendum		7

BOL Fuel Assembly Beam Model Development

- PLUS7 FA beam model has been developed for beginning of life (BOL) conditions.
- This model used the methodology documented in CENPD-178-P-A Revision 1 to develop detailed CESHOCK models for seismic and branch line pipe break (BLPB) analyses.

Simplified Beam Model Development

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Simplified Beam Model Development

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- **Damping parameters were calculated using methods consistent with those developed for other fuel designs.**

Multi-grid Impact Simulation

- The multi-grid impact simulation is used to determine the one-sided impact grid stiffness.

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- The fuel model parameters for beam modeling were used to develop the pluck impact simulation model.
- Nonlinear impact elements were used to represent the impacting of the grids.
- Coefficients of Restitution, determined from one-sided drop test data, were used with the impact elements.

In-Reactor Simplified Beam Model Development

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In-Reactor Simplified Beam Model Development

- **The developed PLUS7 FA BOL dynamic model represents the dynamic response of the actual assembly with reasonable accuracy.**

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- **This same approach will be used for the PLUS7 FA EOL dynamic model development.**

PLUS7 Fuel Assembly Seismic/LOCA Analysis

- **BOL FA Seismic/LOCA analysis**
  - ✓ The BOL Seismic/LOCA analysis will be performed by end of Dec. 2016.
- **EOL FA Seismic/LOCA analysis**
  - ✓ PLUS7 EOL FA Seismic Model will be developed according to CENPD-178-P-A Revision 1 with two clarifications:
    - Use of EOL grid and EOL FA test results
    - Use of flowing water damping
  - ✓ The EOL Seismic/LOCA analysis will be performed by end of June 2017.
- **LOCA analysis will be performed to demonstrate core coolability based on the EOL seismic analysis results in the case of grid crush consistent with SRP 4.2.**

PLUS7 EOL Fuel Assembly Seismic Licensing Plan

Submission of Documents

- **RAI responses will be submitted by Feb. 2017**
  - ✓ RAI 275-8294: 3 questions (4.2-5 ~ 7)
  - ✓ RAI 425-8405: 6 questions (4.2-9 ~ 14)
- **Revised TeR will be submitted by Feb. 2017**
  - ✓ Including BOL analysis results, EOL test results, and EOL FA model
- **Updated DCD 4.2, PLUS7 ToR will be submitted by Feb. 2017**
  - ✓ DCD: TeR revision number in the 4.2.6 Reference will be updated
  - ✓ PLUS7 ToR: Appendix A.2.3 Mid Grid Crush Test will be updated
- **Addendum to revised TeR will be submitted by July 2017**
  - ✓ Including EOL analysis results

PLUS7 Test and Seismic Analysis Schedule

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Summary

Summary

- PLUS7 Grid, Skeleton and FA tests were performed.
- PLUS7 FA flow damping test will be performed in January 2017.
- PLUS7 BOL model was developed and BOL seismic/LOCA analysis will be performed by December 2016.
- PLUS7 EOL model will be developed by January 2017 and EOL seismic/LOCA analysis will be performed by June 2017.

All tests and analyses are on schedule as planned

THANK YOU !

Back Up Slides

Static Crush Test

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One-side Drop Test

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Through-grid Long Pulse Test

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Fuel & Skeleton Lateral Stiffness Test Results

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Fuel Assembly Free Vibration Test Results

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Fuel Assembly Free Vibration Test Results

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Simplified Beam Model Development

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- **The damping parameters were calculated using methods consistent with those developed for other fuel designs.**