The Impact of Fuel Thermal Conductivity Degradation on APR1400

- ✓ **Introduction**
- ✓ **Generation of Fuel Temperature Data**
- ✓ **Large Break LOCA**
- ✓ **Small Break LOCA/Long-term Cooling**
- ✓ **Non-LOCA**
- ✓ **Containment Analysis**
- ✓ **TCD Technical Report**
- ✓ **Conclusion**

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Introduction (1/2)

❑ NRC issued Information Notice (IN) 2009-23 on Oct. 8, 2009 on NUCLEAR FUEL THERMAL CONDUCTIVITY DEGRADATION (TCD).

❑ IN 2009-23 notified the irradiation assisted fuel pellet thermal conductivity degradation and possible impact on fuel design, fuel related primary loop and containment accident and transient analysis.

❑ KHNP will submit a separate technical report demonstrating that APR1400 design and safety analyses have a sufficient margin to safety criteria with TCD effect.

Introduction (2/2)

- Pellet conductivity decreases as burnup increases.

- Consequently, stored energy in the pellets increases as burnup increases.

- Current evaluation models for fuel performance and safety analysis do not model this TCD effect.

- In order to evaluate the impact of TCD on APR1400 and safety analyses, the results of NRC fuel performance code FRAPCON-3 are used as input to APR1400 plant evaluation.

TCD

Pellet Centerline

Pellet Surface

<Initial Fuel Temperature Distribution>

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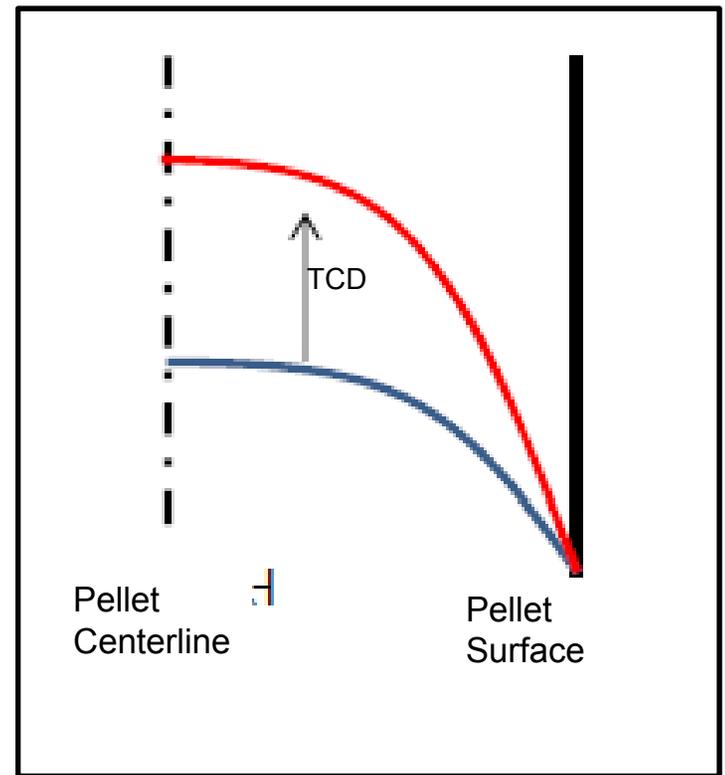
Generation of Fuel Temperature Data (1/3)

❑ Modified NFI Fuel Thermal Conductivity Model in FRAPCON-3

$$K_{95} = \frac{1}{A + a \cdot gad + BT + f(Bu) + (1 - 0.9\exp(-0.04Bu))g(Bu)h(T)} + \frac{E}{T^2}\exp\left(-\frac{F}{T}\right)$$
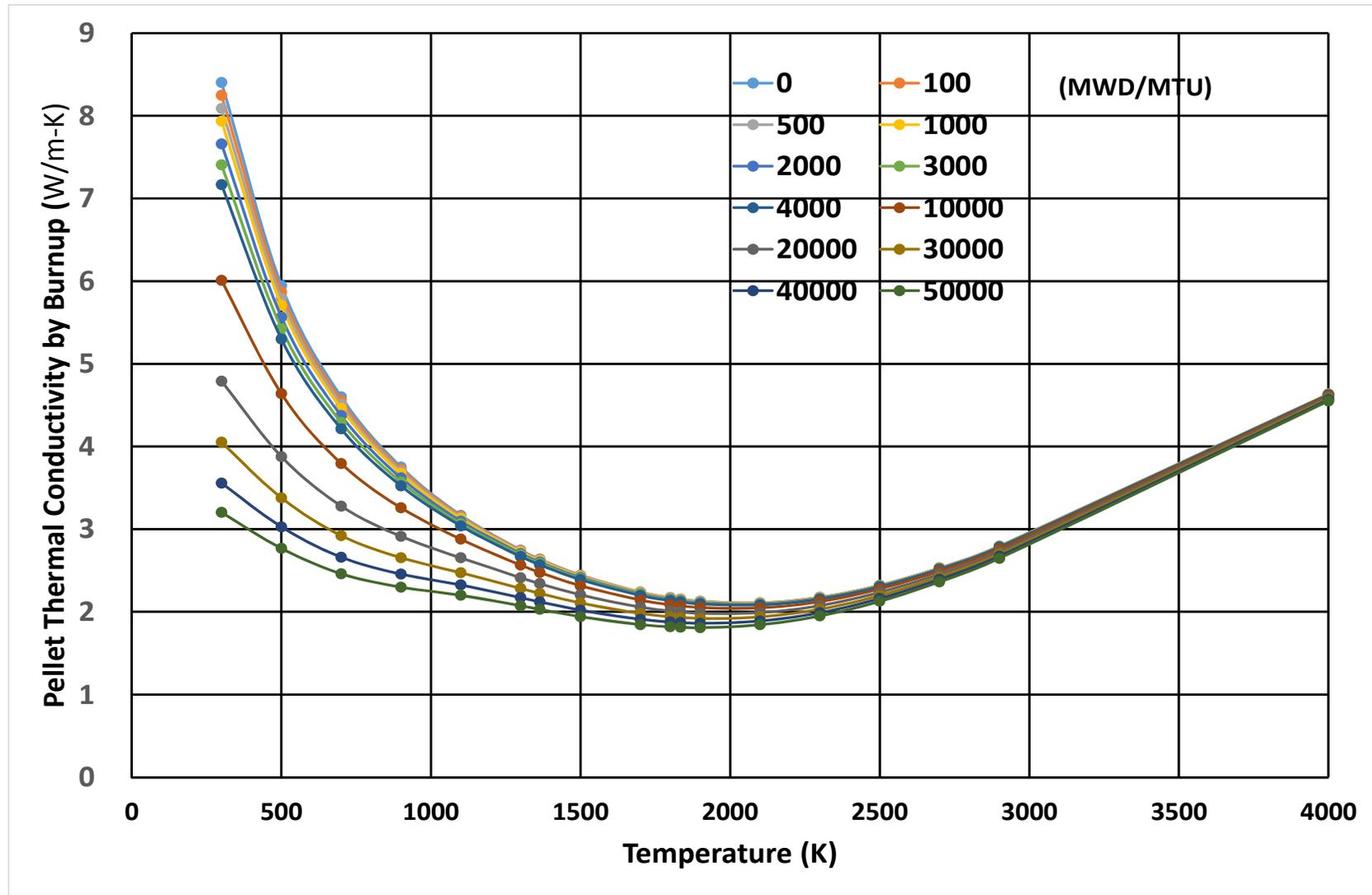
K_{95} = thermal conductivity for 95% TD fuel (W/m-K)

T = temperature (K), Bu = burnup (GWd/MTU), gad = gadolinia weight fraction

f(Bu) = 0.00187 x Bu , G(Bu) = 0.038 x Bu $^{0.28}$, h(T) = 1/(1+396 exp(-Q/T))

Q = temperature dependent parameter, A, a, B, E, F = constants

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Generation of Fuel Temperature Data (2/3)

❑ Pellet Conductivity calculated by Modified NFI Model
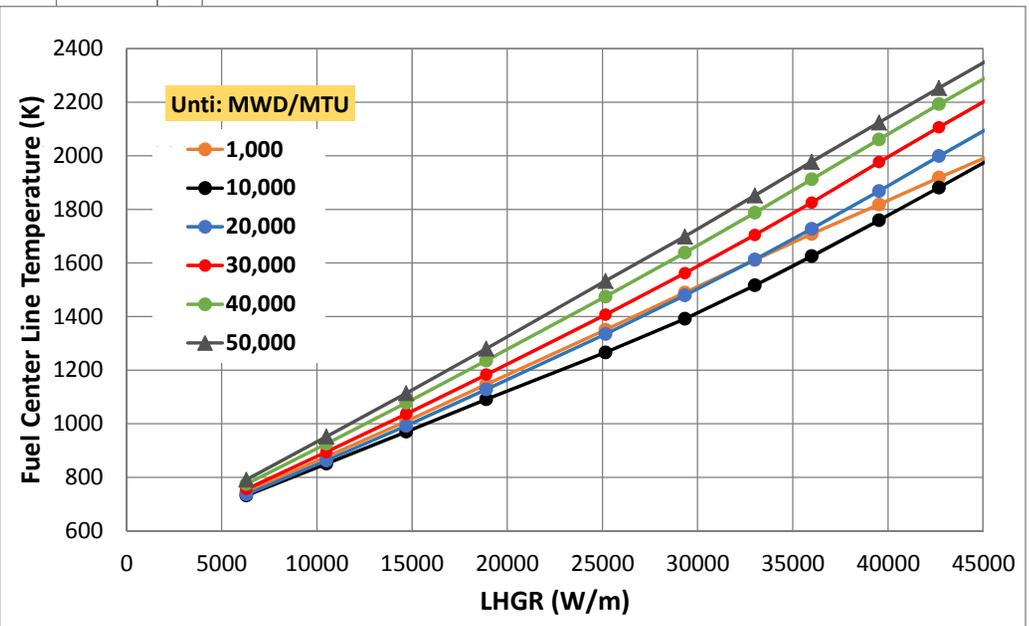
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Generation of Fuel Temperature Data (3/3)

◆ Fuel Temperature Data Generated by FRAPCON-3

❑ Fuel Average Temperature
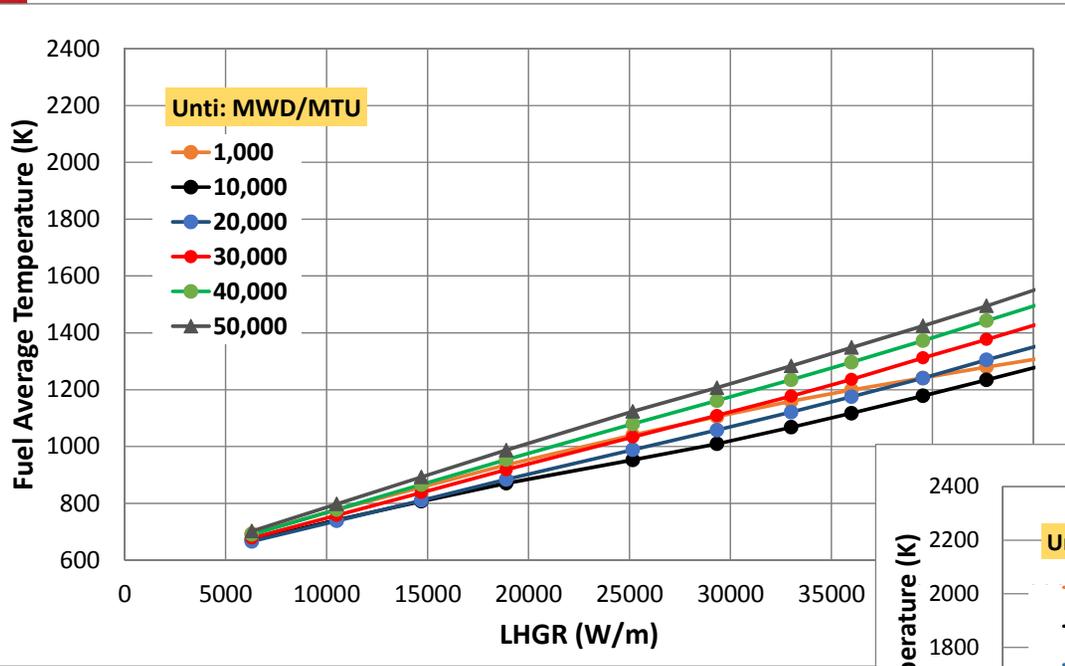
❑ Fuel Centerline Temperature

Large Break LOCA (LBLOCA)   (1/7)

❑ CAREM best estimate Evaluation Model (EM) is used for APR1400 large break

loss-of-coolant accident.

- ● KHNP submitted Topical Report for CAREM to the NRC and this report has

  been accepted for the NRC review at June 2013.

  (CAREM Topical Report: APR1400-F-A-TR-12004-P, Rev.0)

❑ CAREM uses RELAP5/MOD3.3/K for calculation of the thermal-hydraulic and

PCT response to an LBLOCA.

❑ The calculations for TCD evaluation use RELAP5/MOD3.3/K.

❑ The final PCT is quantified by way of 124 Simple Random Sampling (SRS)

calculations using determined uncertainty parameters.

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❑ Burnup study to determine a limiting burnup

- TCD leads to an increase in fuel temperature as the fuel is burned.

- Peaking factor burndown leads to a reduction in fuel temperature as the fuel is burned.

- Since the effects of TCD and peaking factor burndown are inter-related, these effects are considered in the evaluation.

❑ Quantifying total uncertainty at the limiting burnup

- Total uncertainty is quantified by way of 124 SRS calculations.

❑ Peaking Factor Burndown: Conservative assumption applied

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❑ Fuel Temperature: LOCA input values

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❑ Limiting Burnup: 30,000 MWD/MTU

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❑ 124 Simple Random Sampling (SRS) calculations were performed at the limiting burnup of 30,000 MWD/MTU.

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❑ Evaluation Results (at 30,000 MWD/MTU)

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Small Break LOCA / Long-term Cooling

❑ TCD has negligible impact on small break LOCA

- Blowdown process is gradual enough to remove stored energy.
- Most of stored energy is removed before the core uncovery.
- Therefore, the results of small break LOCA analysis will continue to meet the acceptance criteria with sufficient margin.

❑ TCD has no adverse impact on post-LOCA long-term cooling

- The increased stored energy does not persist into long-term cooling period.
- During long-term cooling phase, fuel heat source is decay heat.
- Therefore, TCD has no impact on the long-term cooling analysis and the results of long-term cooling analysis will continue to meet the acceptance criteria.

Non-LOCA (1/3)

- ❑ TCD yields higher fuel centerline temperature which makes larger stored energy in fuel material.
- ❑ Doppler feedback change due to TCD reduces core thermal power during power increase transient such as RIA.
- ❑ Due to increased initial fuel centerline/average temperature, detailed analyses about fuel melting during RIA will be necessary.

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Non-LOCA (2/3)

❑ RIA Calculation:

- ▪ Case : Hot spot maximum fuel temperature/enthalpy

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Non-LOCA (3/3)

❑ Plan for TCD Consideration :

- Review of the Impacts of TCD on Non-LOCA Transient Analysis
- Perform the detailed Non-LOCA transient analysis using fuel rod data considering TCD effects.
- It is expected that the results of Non-LOCA analysis will meet the applicable safety acceptance criteria considering the conservatism and the existing safety margins.
- The details of evaluation will be described in a technical report which will be submitted to the NRC.

Containment Analysis – M/E   (1/6)

❑ TCD Effect on M/E Analysis:

- TCD makes no change in core thermal power.
- TCD yields higher fuel centerline temperature which makes larger stored energy in fuel material.
- The higher fuel temperature may challenge fuel clad to metal-water reaction.
- The larger stored energy has minor adverse effect on M/E release.

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Containment Analysis – M/E   (2/6)

❑ Results of ME calculation

  ● Case : Double-ended Discharge Leg Break with max. SI flow

  ● Code : CEFLASH-4A, FLOOD3 and GOTHIC (P/T)

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▪ Fuel temperature

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❑ **Results of ME calculation**

● TCD has minor impact on M/E analysis.

■ Mass and Energy Release

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❑ Containment Peak Pressure and Temperature

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❑ EQ Pressure Limit

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Containment Analysis – EQ (6/6)

❑ EQ Temperature Limit

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TCD Technical Report

❑ TCD Technical Report will include the evaluation of TCD impact on the following analyses.

- Large Break LOCA

- Small Break LOCA

- Long-term Cooling

- Non-LOCA Events

- Containment Analysis

  - Mass and Energy Release

  - Containment Peak Pressure and Temperature

  - EQ

- PSA

Conclusions

❑ The LBLOCA limiting PCT is 1980 ^{o}F, less than 2200 ^{o}F acceptance criterion, even though TCD effect was considered with conservative assumptions.

⇒ There is sufficient margin to address TCD impacts on PCT.

❑ The calculated hot spot fuel centerline temperature and the maximum average enthalpy at RIA are satisfied the acceptance criteria.

❑ The impact of TCD on other safety analyses was minor.

❑ The evaluation of TCD effect on APR1400 shows that APR1400 design and safety analyses have a sufficient margin to safety criteria.

❑ Technical Report documenting the details of TCD impact on design and safety analyses will be submitted to the NRC.

Thank You

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