Non-Proprietary

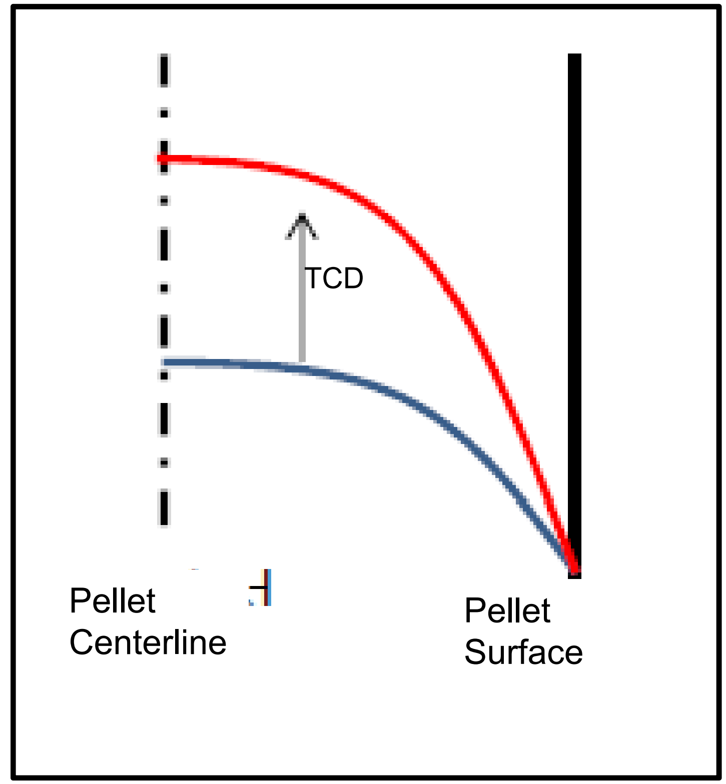
The Impact of Fuel Thermal Conductivity Degradation on APR1400

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.



<Initial Fuel Temperature Distribution>

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)

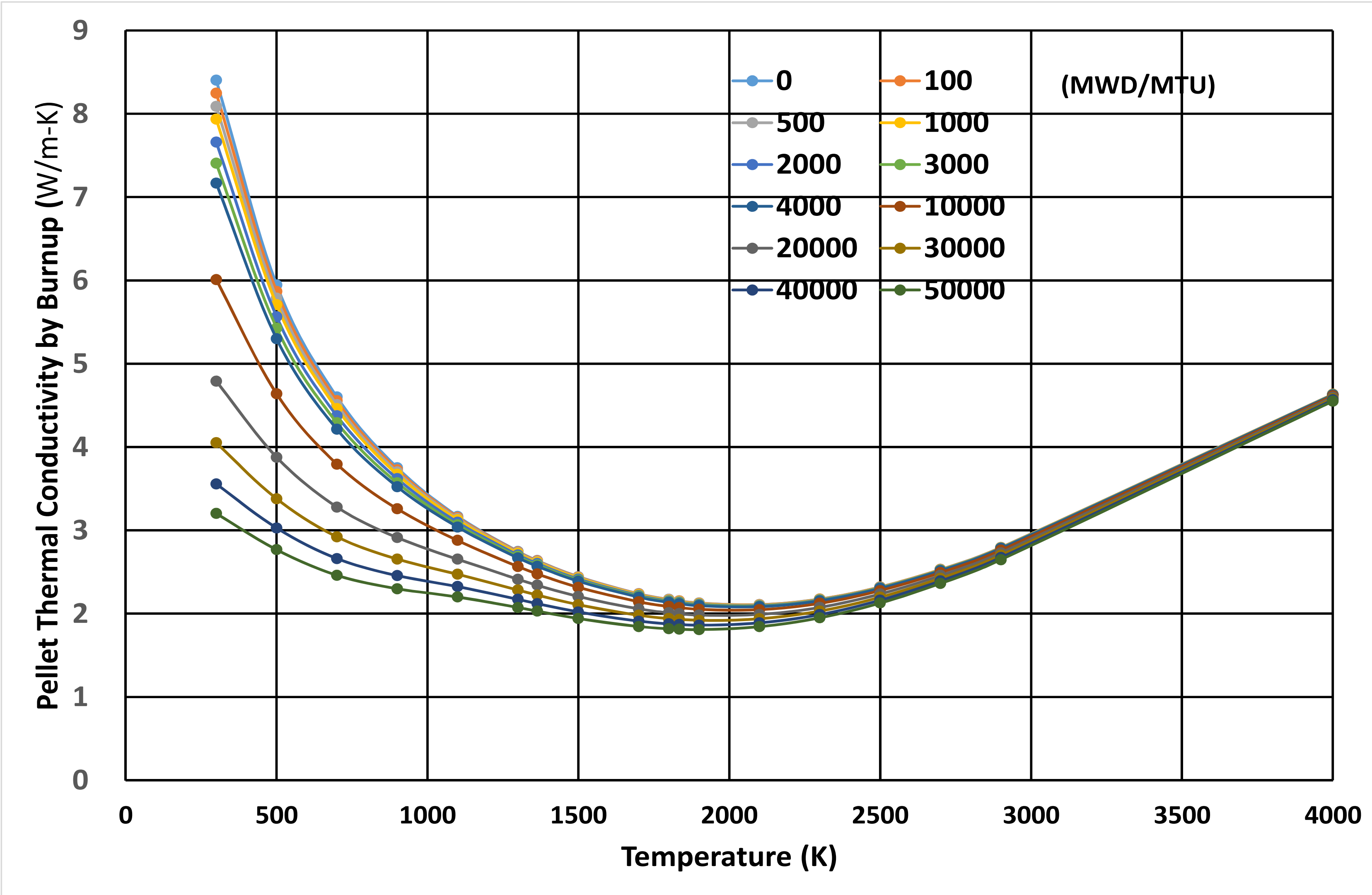
T = temperature (K), Bu = burnup (GWd/MTU), gad = gadolinia weight fraction

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

Generation of Fuel Temperature Data (2/3)

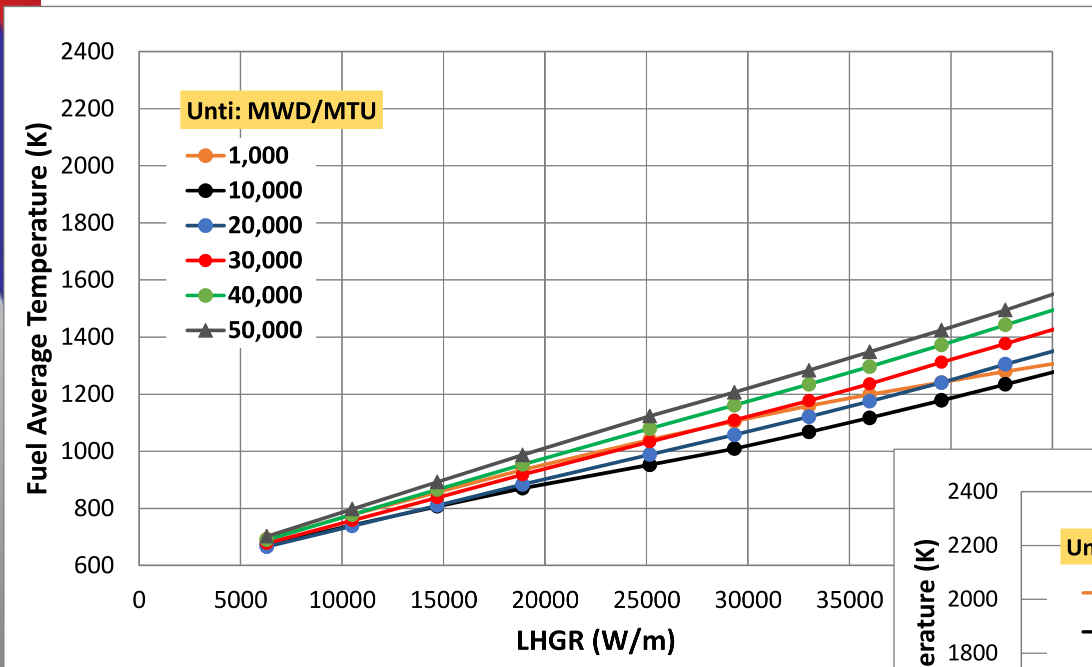
❑ Pellet Conductivity calculated by Modified NFI Model



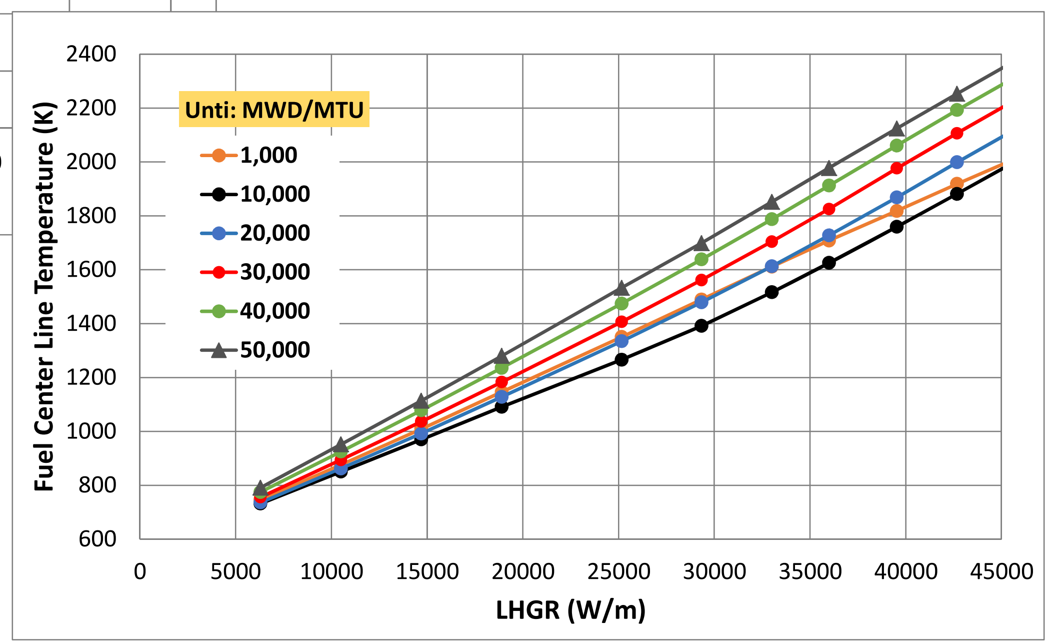
Generation of Fuel Temperature Data (3/3)

- 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.

Large Break LOCA (LBLOCA) (2/7)

- 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.

LBLOCA – Burnup Sensitivity (3/7)

- Peaking Factor Burndown: Conservative assumption applied

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LBLOCA – Burnup Sensitivity (4/7)

- Fuel Temperature: LOCA input values

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LBLOCA – Burnup Sensitivity (5/7)

- Limiting Burnup: 30,000 MWD/MTU

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LBLOCA – Quantification of Total Uncertainty (6/7)

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

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LBLOCA – Quantification of Total Uncertainty (7/7)

❑ 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.

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.

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

Containment Analysis – M/E (3/6)

❑ Results of ME calculation

- TCD has minor impact on M/E analysis.

▪ Mass and Energy Release

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Containment Analysis – Peak P/T (4/6)

❑ Containment Peak Pressure and Temperature

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Containment Analysis – EQ (5/6)

- 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 °F, less than 2200 °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