

The Effect of Fuel Thermal Conductivity Degradation on APR1400 Safety Analyses

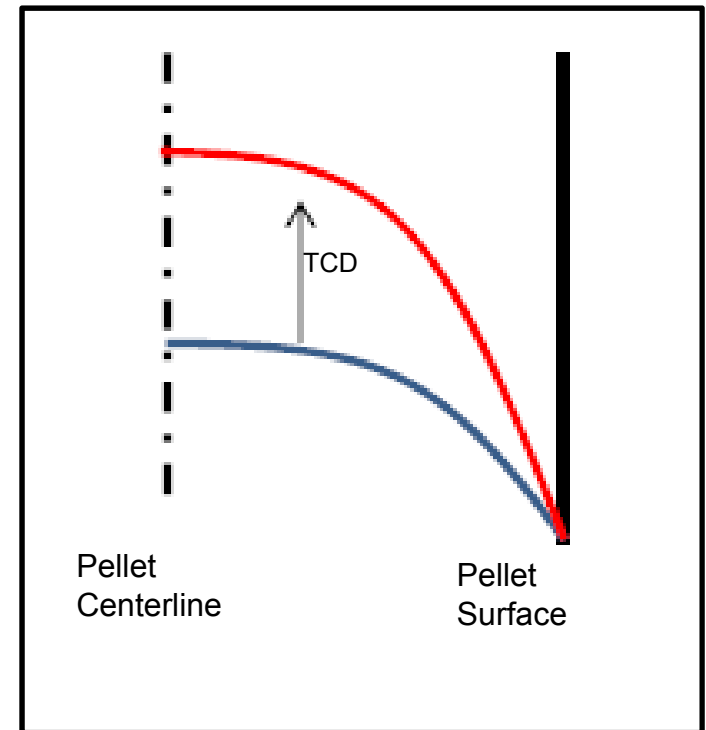
- ✓ Introduction
- ✓ Generation of Fuel Temperature Data
- ✓ Large Break LOCA
- ✓ Small Break LOCA/Long-term Cooling
- ✓ Non-LOCA
- ✓ Containment Analysis
- ✓ TCD Technical Report
- ✓ Conclusion

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.
- ❑ Therefore, KHNP studies the effects of TCD on APR1400 safety analyses in separate technical report which will be submitted to the NRC.

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 analyses do not model this TCD effect.
- ❑ Therefore, fuel temperature and fuel thermal conductivity from FRAPCON-3 are used as input to APR1400 safety analyses.



<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)

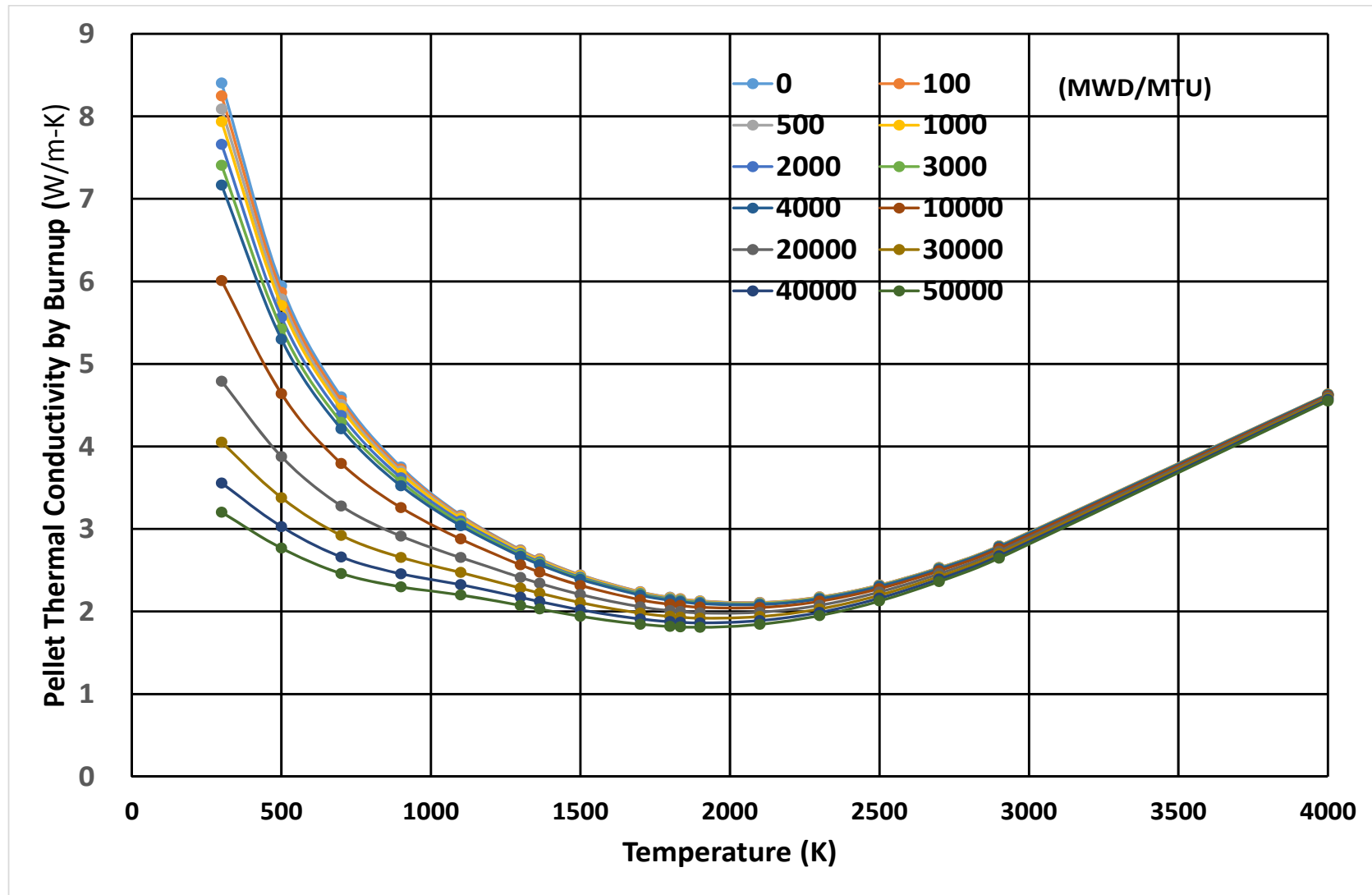
T = temperature (K), Bu = burnup (GWd/MTU), gad = gadolinia weight fraction

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

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

Generation of Fuel Temperature Data (2/3)

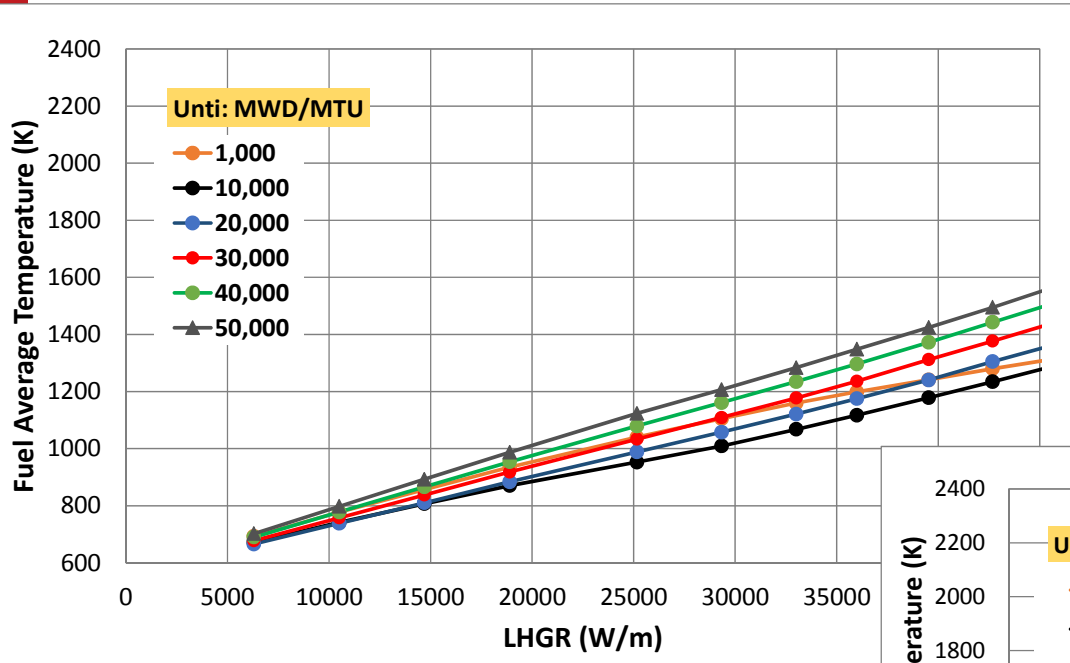
□ Pellet Conductivity calculated by Modified NFI Model



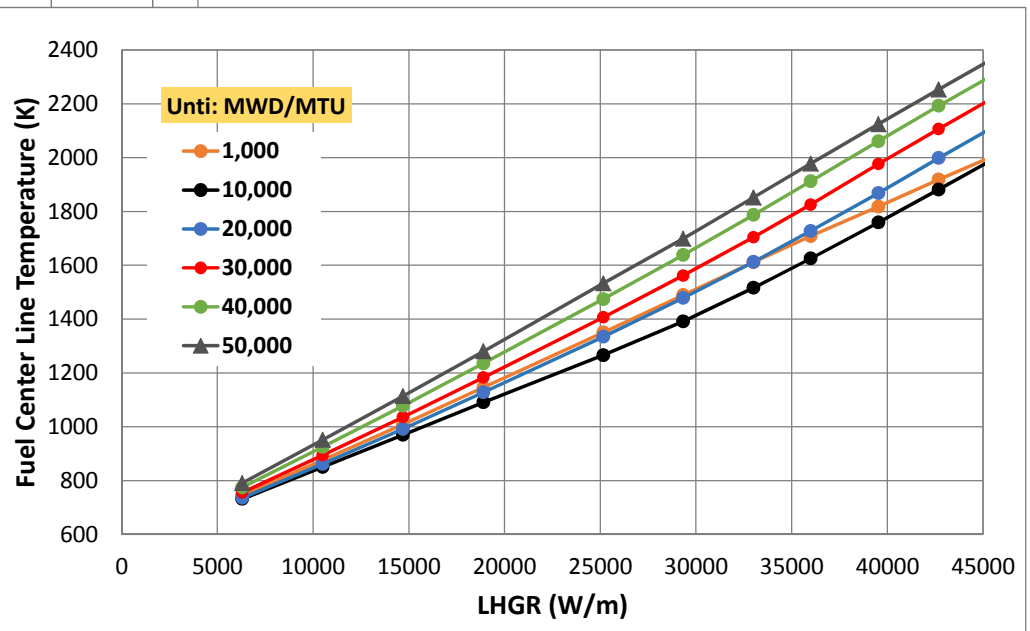
Generation of Fuel Temperature Data (3/3)

Fuel Temperature Data Generated by FRAPCON-3

Fuel Average Temperature



Fuel Centerline Temperature



Large Break LOCA (LBLOCA) (1/6)

- ❑ 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) (2/6)

- ❑ 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 (3/6)

- ❑ Fuel Temperature: FRAPCON vs. LOCA input values

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LBLOCA – Burnup Sensitivity (4/6)

- Burnup dependent Peaking Factor Burndown Effect considered

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LBLOCA – Quantification of Total Uncertainty (5/6)

- ❑ 124 Simple Random Sampling (SRS) calculations were performed at the limiting burnup of []

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LBLOCA – Quantification of Total Uncertainty (6/6)

Evaluation Results

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11th Pre-application Meeting

Small Break LOCA / Long-term Cooling (1/1)

- ❑ 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 uncover.
 - Considering more than [] PCT margin, PCT will meet the acceptance criteria even with TCD effect.

- ❑ 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.
- ❑ The RIA is selected as the most limiting accident in terms of fuel temperature increase due to power excursion.
- ❑ Due to increased initial fuel centerline/average temperature, detailed analyses for fuel melting during RIA has been performed.

Non-LOCA (2/3)

RIA Calculation:

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Non-LOCA (3/3)

❑ Other Non-LOCA Events

- Performing the detailed Non-LOCA transient analysis (except RIA) 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 (1/5)

☐ 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.

Containment Analysis – M/E (2/5)

- Results of ME calculation

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- TCD has minor impact on M/E analysis.

Containment Analysis – Peak P/T (3/5)

- Containment Peak Pressure and Temperature

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Containment Analysis – EQ (4/5)

EQ Pressure Limit

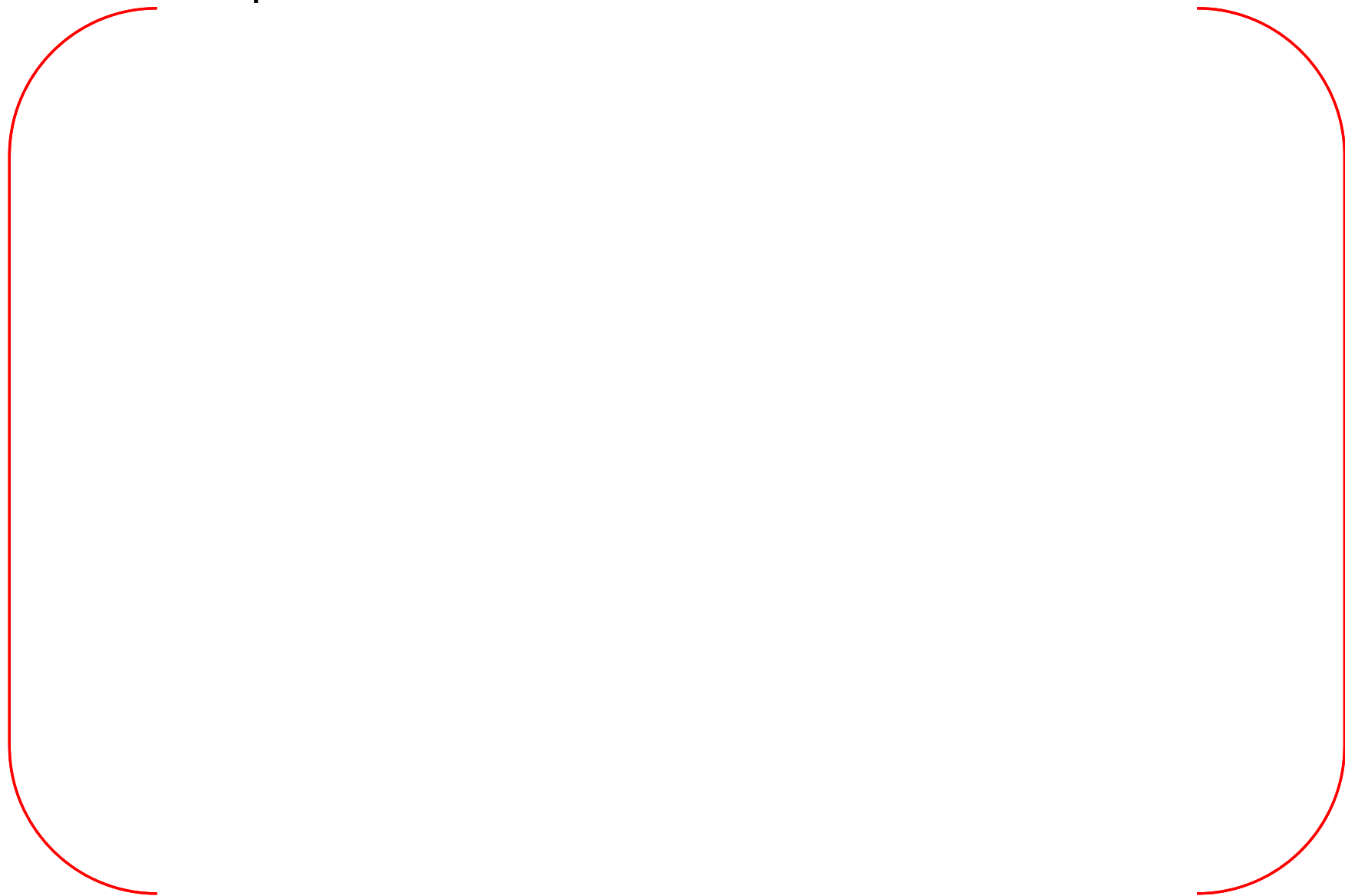
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Containment Analysis – EQ (5/5)

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

Conclusions

- ❑ The LBLOCA limiting PCT is (), less than 2200 °F acceptance criterion, even though TCD effect is considered.
 - ➔ There is sufficient margin (more than ()) 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.

Submittal Plan of Modified FATES3B with TCD model (1/2)

Submittal Plan of Modified FATES3B with TCD model (2/2)
