

Demonstration of BEPU Analysis of LB-LOCA with RELAP5-3D for High Burnup Fuel

Presented by: Haihua Zhao

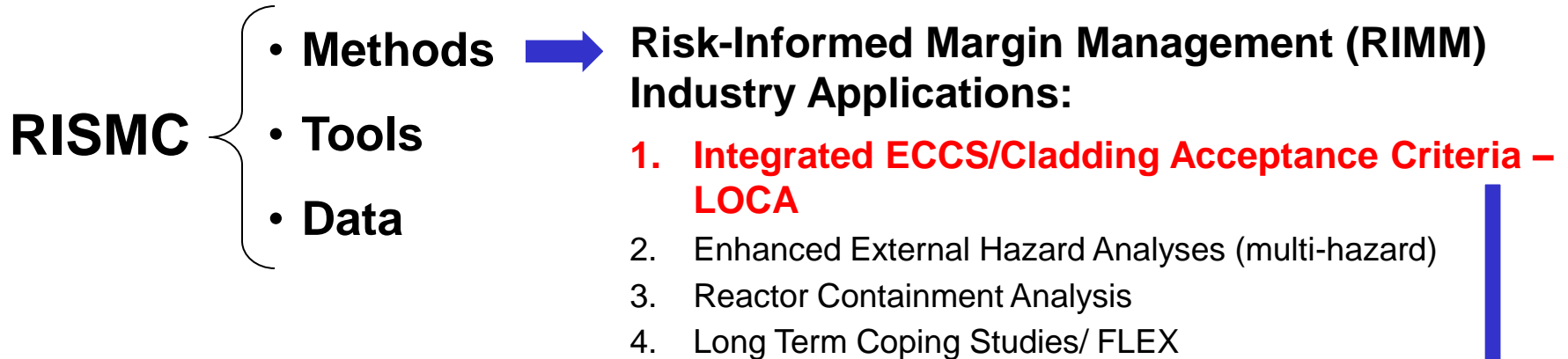
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Review of Industry Applications under RISMC

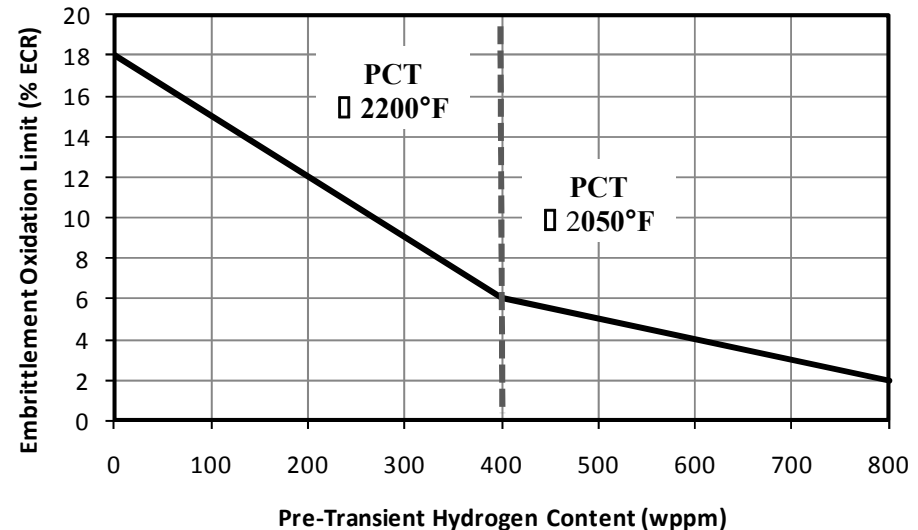


Implementation Strategy – Industry Application #1 Phases

1. Initial assessment / Problem definition (**completed in 2Q15**)
2. Early Demonstration (eDemo) (**2Q15–2Q16**)
3. Full Demonstration, Advanced Applications and Validation (Stakeholder participation, Long Term Methods, Advanced Tools, Data, implement R&D recommendations) (**FY16–18**)

RIMM Industry Application #1 – Scope and Impact

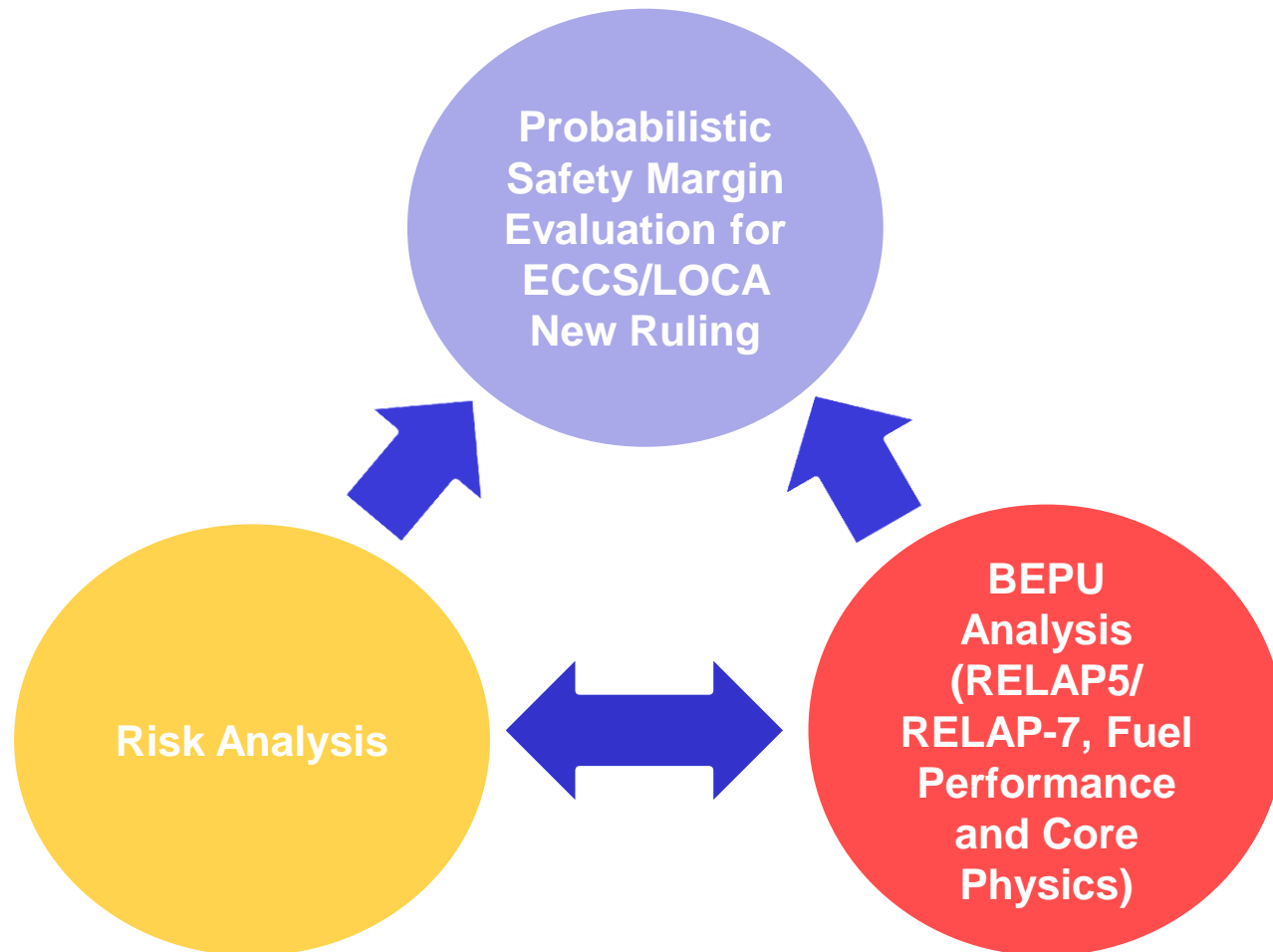
- Background & Motivation:
 - Proposed 50.46c rule (~April 2016) introduces new (more restrictive) performance-based requirements. This may require re-analysis of all existing US fleet LOCA bases
- Potential Impact:
 - cost of re-analysis
 - loss of margin
 - increased fuel costs
 - operation flexibility impact
- Proposition:
 - Re-analysis can be used to better understand/manage margins
 - Quick assessment of margins
 - opportunity for reload design and operations processes improvements



An acceptable analytical limit on peak cladding temperature and integral time at temperature (credit of U.S. NRC)

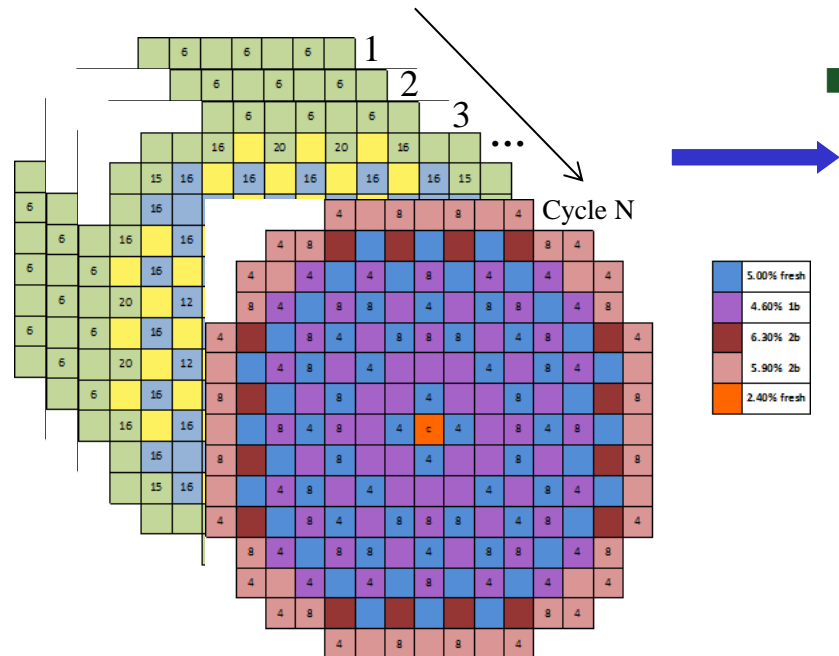
Fully Integrated Evaluation Model

Multi-physics Simulation Based RISMC Demo LOCA Analysis



Core Design (Steady-State)

- Reference Core Design (HELL) – *Credit to Angelo Zoino and Andrea Alfonsi:*
 - Typical Large PWR (193 Assemblies, 3411 MWth rated power)
 - 4-Loop Westinghouse Design
 - Equilibrium cycle w/ 3-batch fuel loading (fresh, once- and twice-burned fuel)
 - High-energy (HE) fuel cycle 18-month full-power operation (high burn-up)
 - Low-leakage (LL) loading (twice-burned fuel loaded in the periphery)



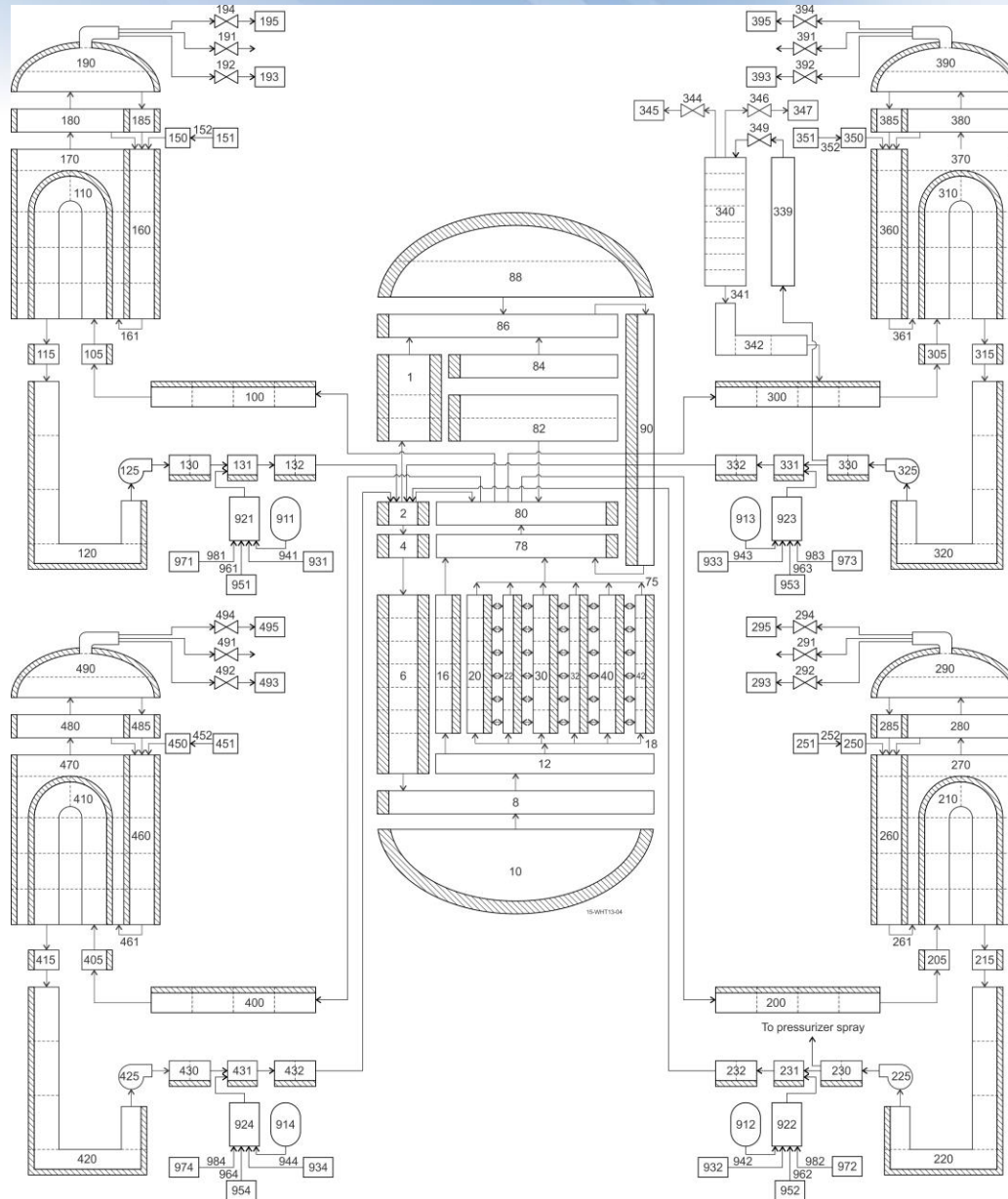
■ **The LOCA accident scenario is initiated from the equilibrium cycle conditions:**

- “Nominal” state points at different exposures are used as initial condition;
- These state points are perturbed to prescribed “limiting conditions”
- For our initial demonstration we will use:
 - Beginning-of-cycle (BOC)
 - 50, 100, 200, 300, 400, 500 Days
 - End-of-cycle (EOC)

RELAP5 Plant Model Selection

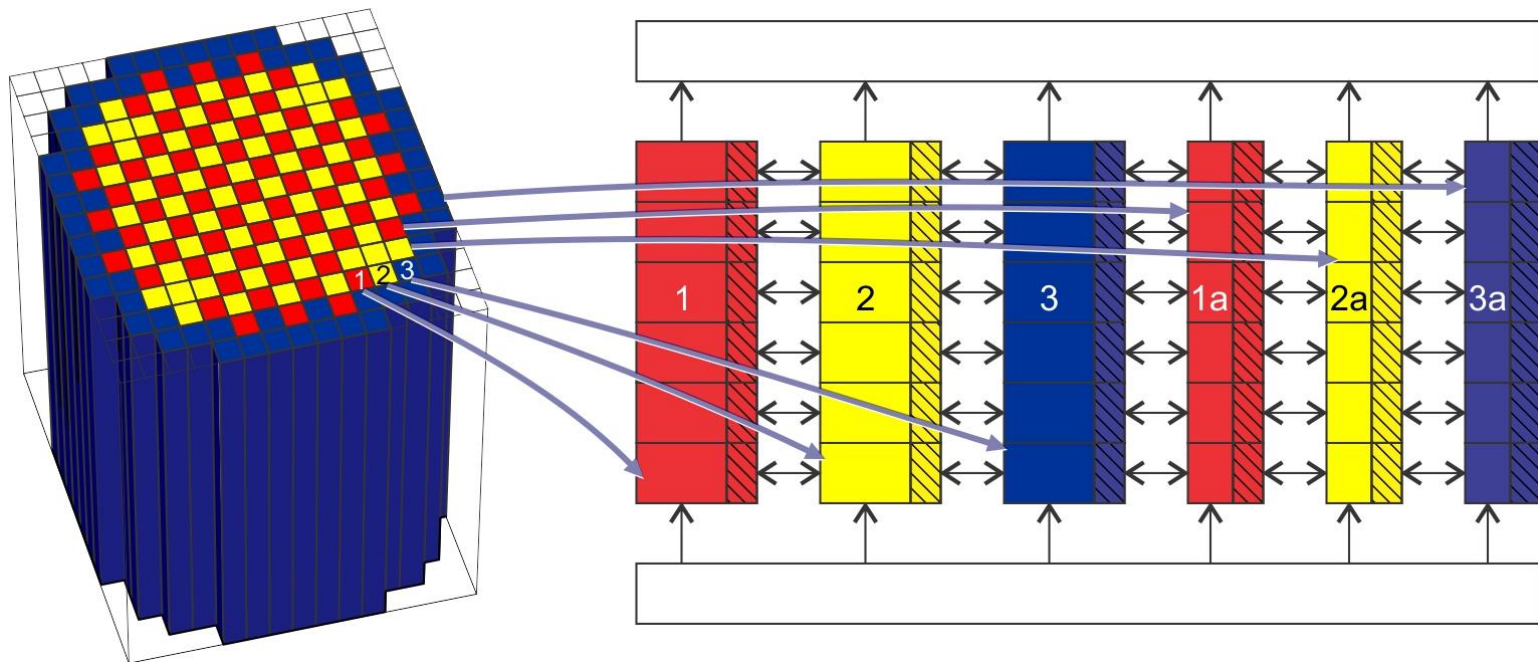
- Each of the four primary coolant loops is represented.
- All the major flow paths for both primary and secondary systems are described including the main steam and feed systems.
- Each loop contains a hot leg, U-tube SG, pump suction leg, pump, cold leg.
- High pressure injection system, low pressure injection system and an accumulator is attached to each cold leg. Charging and letdown are also included.
- Control system: steam dump control system, SG mass/inventory control, pressurizer pressure and level control systems.
- Total number of lines of the input file is close to 30,000.

RELAP5 Nodalization



Core Hydraulic Homogenization - Multi-Channel Strategy

- An existing RELAP5 model is modified to analyze the HELL core:
 - A core hydraulic homogenization is performed;
 - Channels 1, 2, and 3 are the average channels for their respective assembly groups;
 - Channels 1a, 2a, and 3a are the hot channels in each group;



Heat Structure Homogenization Strategy

- There is one heat structure for each assembly. Each heat structure is connected to the average flow channel that represents flow in that group of fuel assemblies. The Peak Clad Temperature in each assembly is captured.
- There are three additional heat structures for the hot rod in each of the three groups.

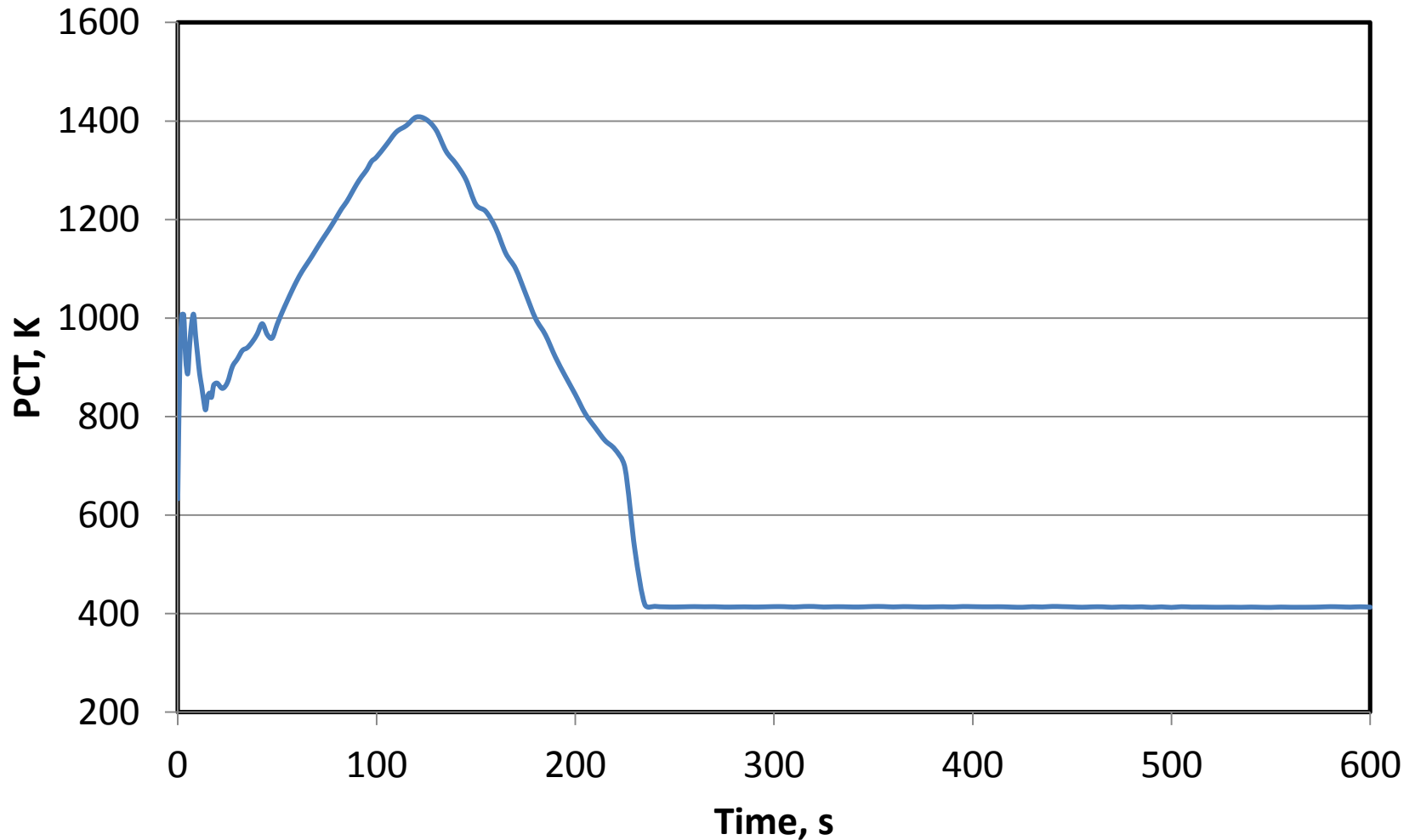
Uncertain Parameters and Their Ranges

Parameter	PDF type	Min	Max	Comments
Reactor thermal power	Uniform	0.98	1.02	Multiplier
Reactor decay heat power multiplier	Uniform	0.94	1.06	Multiplier
Accumulator pressure	Normal	-0.9	1.1	Multiplier
Accumulator liquid volume (ft ³)	Uniform	-8.0	8.0	Additive
Accumulator temperature (°F)	Uniform	-20	30	Additive
Subcooled multiplier for critical flow	Uniform	0.8	1.2	Multiplier
Two-phase multiplier for critical flow	Uniform	0.8	1.2	Multiplier
Superheated vapor multiplier for critical flow	Uniform	0.8	1.2	Multiplier
Fuel thermal conductivity	Normal	0.90	1.10	Multiplier
T _{avg} (°F)	Normal	-6	6	Additive
Clad to coolant heat transfer (CHF, Film boiling and Transition boiling)	Uniform	0.7	1.3	Multiplier
Fuel-clad gap width	Uniform	0.2	1.80	Multiplier
Pump degradation	Uniform	0.5	1.5	Multiplier

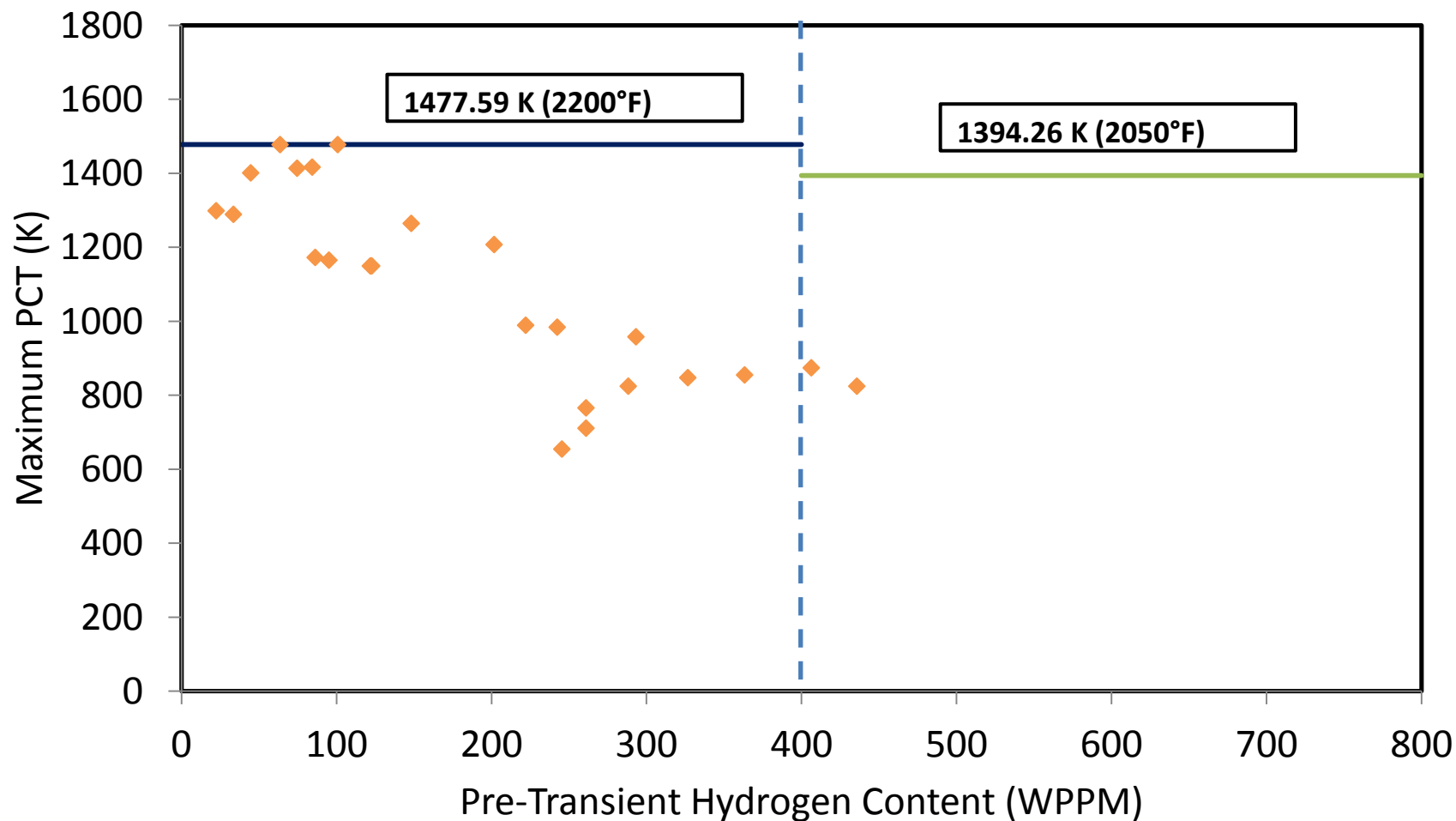
LBLOCA BEPU Demonstration – Nonparametric Statistical Sampling Approach

- The selected cycle exposure points are: BOC, 50, 100, 200, 300, 400, 500 days and EOC.
- 124 RELAP5-3D input files (both steady state and transient runs) are generated at EACH selected cycle exposure point by simultaneously and randomly perturbing the uncertain parameters.
- The RELAP5 models are run to steady state first.
- Double ended guillotine break is assumed to happen at the cold leg of the upper left loop shown in the RELAP5 diagram (previous slide).
- The LBLOCA runs would then ensue.

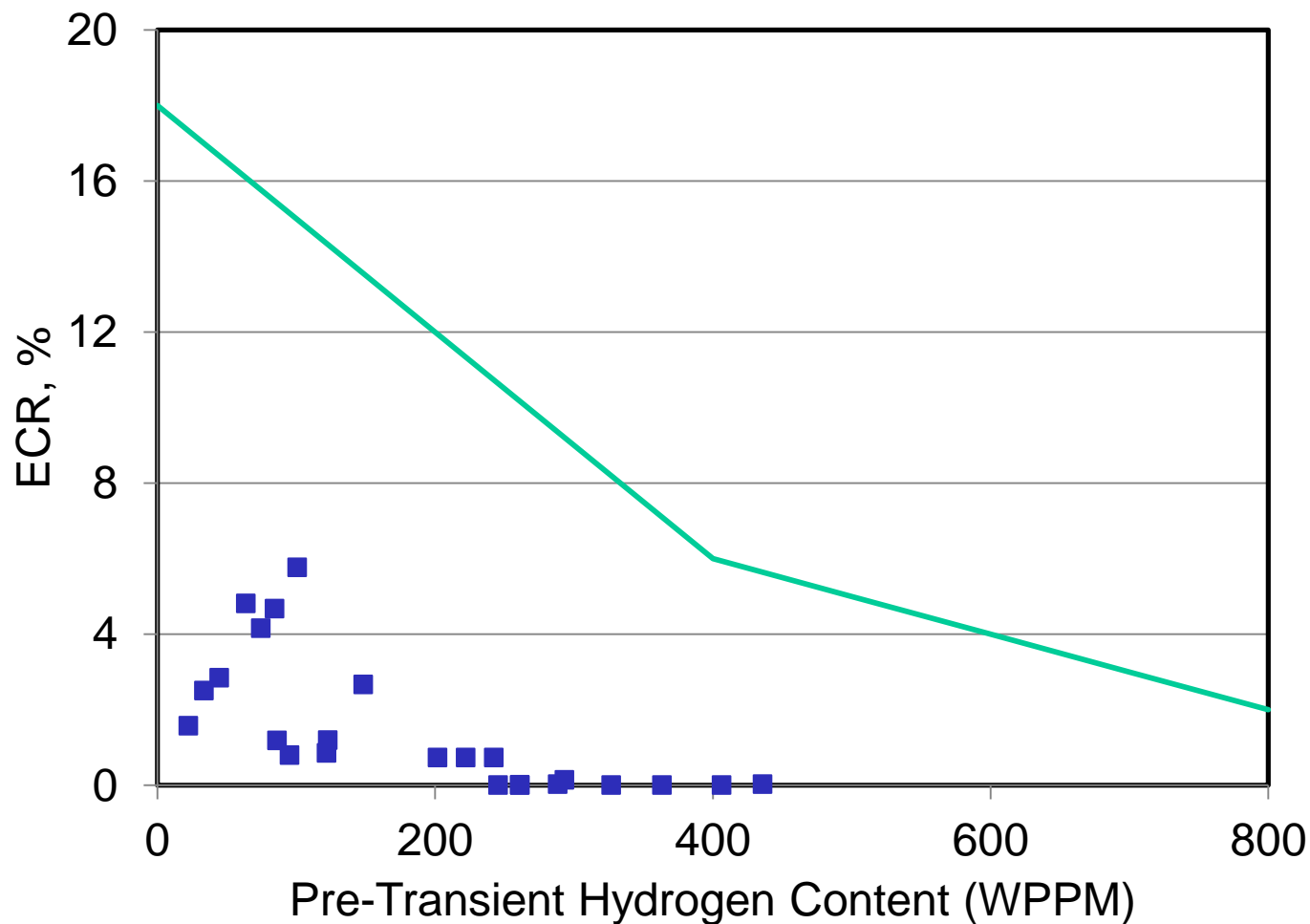
PCT During LBLOCA at 300 Days for the Limiting Case among 124 runs



Calculated Maximum PCT Versus New Limits During LBLOCA



Calculated Maximum Local Oxidation Versus New Limits During LBLOCA



Status Summary

- Preliminary high energy low leakage core design has been achieved for a typical 4 loop PWR (*Credit to Angelo Zoino and Andrea Alfonsi*).
- Sophisticated RELAP5-3D model has been built.
- LBLOCA runs have been demonstrated for selected burnup points – BOC, 50, 100, 200, 300, 400, 500 Days, EOC - in a cycle.
- The models and processes we have built so far provide us the foundation to perform the eventual analysis of the new ruling for ECCS/LOCA which will challenge the safety margin once more scenarios are considered and combined with the PRA analysis.

Future Work on coupling between TH and Fuel Performance codes

- Coupling with a fuel performance code is necessary to ensure the system analysis has the correct initialization conditions such as correct stored energy, rod international pressure, hydrogen pickup versus burnup, etc.
- We envision four stages of coupling methods between system codes and fuels performance codes with increasing complexity:
 - Early demonstration run: use RELAP5-3D's internal fuels performance models with decoupled inputs from separate runs of FRAPCON-3.4; **(1Q16)**
 - Realistic demonstration run: loosely coupled RELAP5-3D with FRAPCON-3.4 and FRAPTRAN-1.5; **(2Q16)**
 - Advanced demonstration run: loosely coupled RELAP5-3D with BISON; **(3-4Q16)**
 - Advanced demonstration run: strongly coupled RELAP-7 with BISON. **(FY17-18)**

Future Work Continues - Characterization

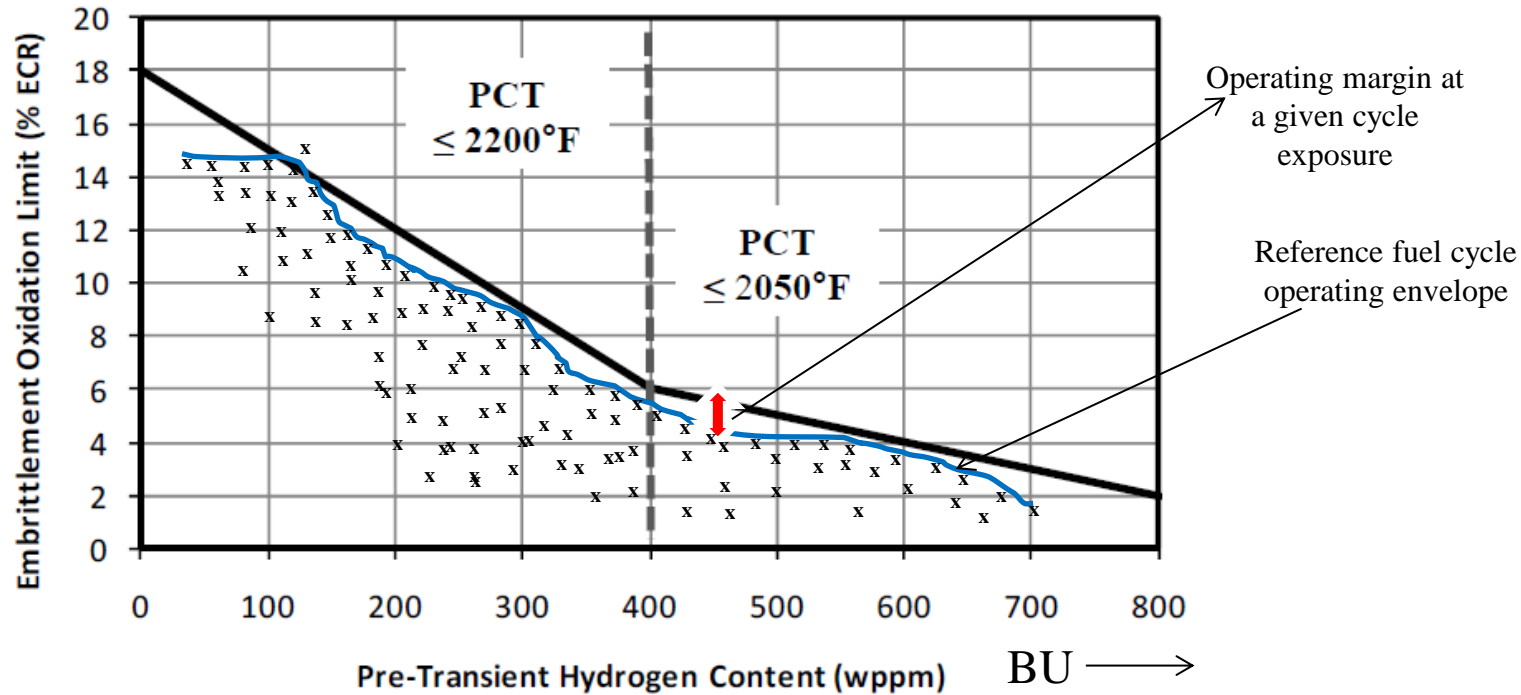
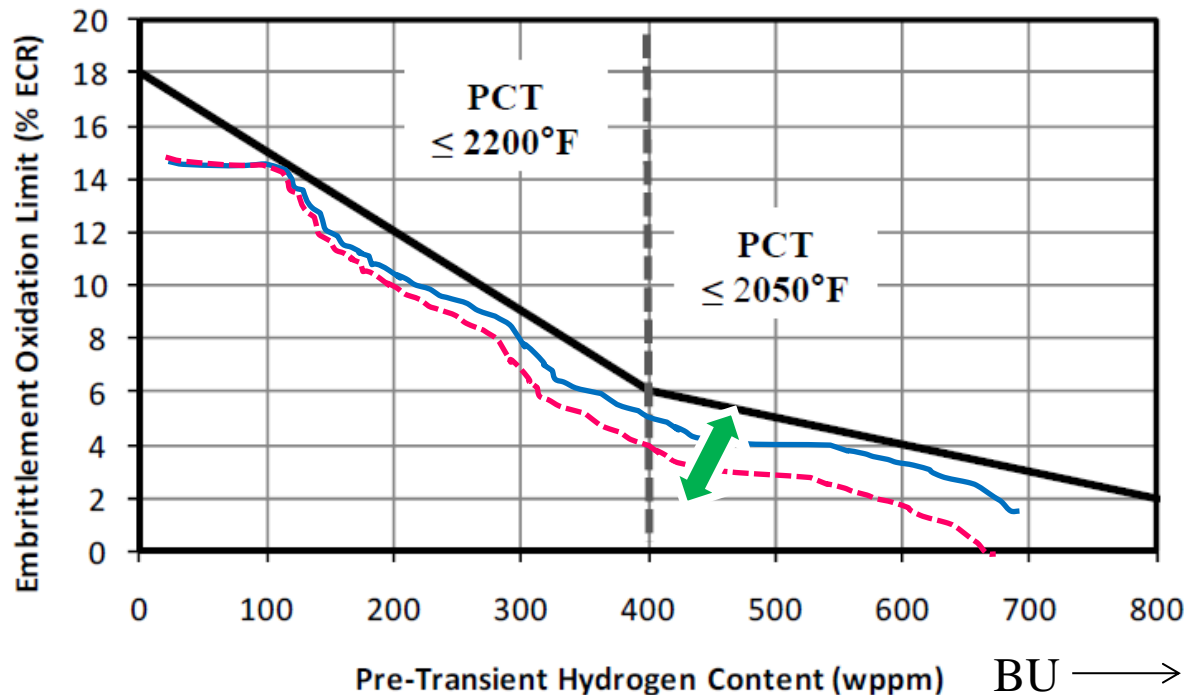


Figure 2. An acceptable analytical limit on peak cladding temperature and integral time at temperature (as calculated in local oxidation calculations using the CP correlation (Ref. 11))

A more realistic assessment of an operating core ready for quick response analysis if needed

Future Work Continues - Optimization

- Integrated Evaluation Model Full Implementation
- Construct model for quick margin assessment
- Optimization models – margin improvement; operational flexibility



Acknowledgement

- RELAP5 team's support is highly appreciated.
- Special thanks to Cliff Davis for helping us debugging and improving the RELAP5 model.
- Thanks to CeSare Frepoli for reviewing the LOCA analysis results.
- The core design is performed by Angelo Zoino and Andrea Alfonsi.

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