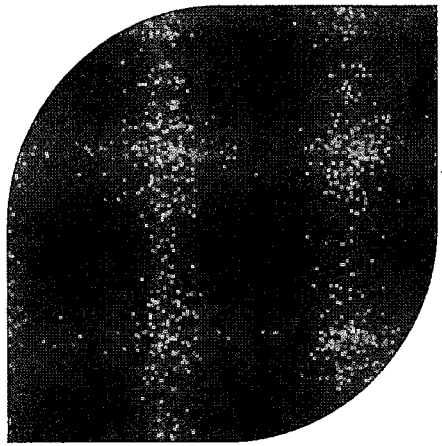


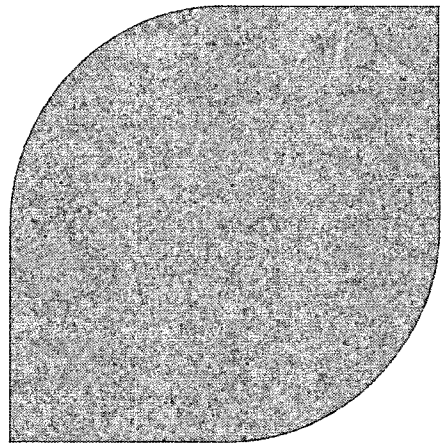
# Anticipated Transient Without Scram – Instability (ATWSi) Pre-Application Overview

## AREVA/NRC Meeting

NRC Two White Flint North
11555 Rockville Pike
Rockville, MD

November 4, 2016

AREVA



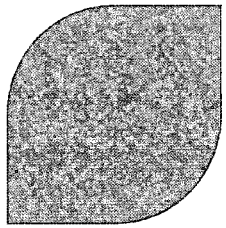
# Anticipated Transient Without Scram – Instability (ATWSi) Pre-Application Overview

Daniel R. Tinkler
Principle Engineer

Yousef M. Farawila
Consultant
Farawila et al., Inc.

AREVA

# Agenda



- **Objectives**
  - Report on the ATWSi development activities for planned licensing topical report
- **Background**
  - History of EFW/MELLLA+
  - Figures of Merit
  - Introduce AREVA new fuel type ATRIUM-11
- **Methodology Elements**
  - Event Scenario
  - Phenomenological discussions
  - Introduce the new methods developed for ATWSi
  - Code Assessments
- **Summary**
- **Next Steps**

# Objectives

## ▶Meeting focus

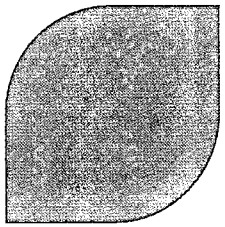
- Generic applicability beyond MNGP EFW ATWSi application as a plant-specific methodology

## ▶Summarize methodology elements

- General applicability (beyond plant specific submittal)
- Host code RAMONA5-A is an improved version of RAMONA5-FA

## ▶Obtain NRC feedback on approach

# NRC's Prioritization Factors



## ▶ Classification

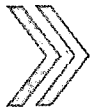
- ◇ **New technology improves safety**
  - First of a kind ATWSi testing provides improved fidelity of models

## ▶ Applicability

- ◇ **Potentially all BWR Licensees that use MELLLA+**
- ◇ **Support AREVA fuel design evaluations for BWR Licensees that use MELLLA+**

## ▶ Implementation Certainty

- ◇ **Currently proposed solution for MELLLA+ and Fuel Transition proposals to Licensees**



**NRC approval is requested by mid of 2019 for ATRIUM-11**

# Background

- **ATWS with Core Instability (ATWSi) defined in Section 15.8 of the Standard Review Plan (NUREG-0800)**
  - Event begins as an Anticipated Operational Occurrence (AOO)
  - Immediately followed by a failure of the reactor protection system
  - Since protection systems must satisfy single-failure criterion, multiple failures or common mode failure must cause the failure to trip
  - Since the probability of multiple failures is much lower, the ATWSi event is not classified as either an AOO or a design-basis accident
- **AREVA is developing a method to demonstrate the impact of the event on AREVA fuel**
  - This is intended to show compliance with GDC 35
    - Fuel and clad damage that could interfere with continued effective core cooling is prevented
    - Clad metal-water reaction is limited to negligible amounts
  - Based on industry-wide PIRT (NUREG/CR-6743)
    - Will expand upon this PIRT by including additional knowledge learned through experience and recent testing

# History of EFW/MELLLA+ ATWSi

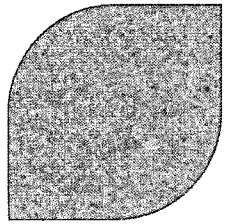
- **Operation in a MELLLA+ domain requires fuel specific ATWSi analyses**
  - Brunswick has currently submitted a MELLLA+ application using ATRIUM 10XM

[ ]

- **Introduction of ATRIUM 11 at MELLLA+ will require new ATWSi analyses**

[ ]

# Implementation Planning



# Anticipated Transient Without Scram with Instability (ATWSi)

- **Event Sequence**
  - **Initiating event such as a turbine trip and isolation, turbine bypass (TTWB) or two recirculation pump trip (2RPT)**
  - **Recirculation pumps are tripped for both cases**
  - **Feedwater heating**
    - For TTWB, lose feedwater heating due to loss of steam bled from turbine
    - For 2RPT feedwater heating is maintained at the new equilibrium feedwater temperature
  - **Core operating at natural circulation with increasing inlet subcooling**
  - **Core becomes unstable**
  - **No scram to terminate instability which may grow to severe magnitude**
- **Operator intervenes with lowering water level to suppress oscillations until the event is terminated with boron injection**

# Anticipated Transient Without Scram with Instability (ATWSi)

- Main destabilizing cause is reduction of feedwater heating
  - Higher inlet subcooling is fundamentally destabilizing, and
  - Higher inlet subcooling increases power which is destabilizing
  - Without timely operator action, TTWB expected to be limiting
- Extended Operating Domains result in higher power-to-flow ratio at natural circulation, which is less stable than MELLLA
- Destabilization is expected for multiple global and regional and independent channel oscillation modes
  - Rotational mode when multiple nearly degenerate first azimuthal neutron flux harmonics are excited
  - Large regional (and rotational) oscillations are accompanied by global mode oscillations of double frequency
  - Superposition of decoupled hydraulic oscillations in individual channels at generally different frequencies
  - Axial power shape oscillates

# Anticipated Transient Without Scram with Instability (ATWSi)

- Without scram or other intervention, oscillations will grow
  - Initially at exponential rate while linear effects are dominant
  - Nonlinear neutron reactivity effects slow down global mode growth
  - Nonlinear reactivity effects accelerate regional mode growth
  - Double frequency global mode is excited by large regional oscillations
  - Large global and axial oscillations generate stabilizing negative reactivity bias
  - Oscillation amplitude growth is terminated by thermalhydraulic nonlinear effects accompanied by significant reverse flow at the inlet of few channels
  - Maximum reverse flow magnitude insensitive to oscillation mode
- Thermal effects on fuel rods
  - Cyclical dryout and rewetting
  - Failure to rewet can cause clad temperature excursion

[ ]

- Simulating regional mode oscillation is appropriate

# Plant Specific Approach (History)

- For Monticello, a plant specific ATWSi methodology was developed

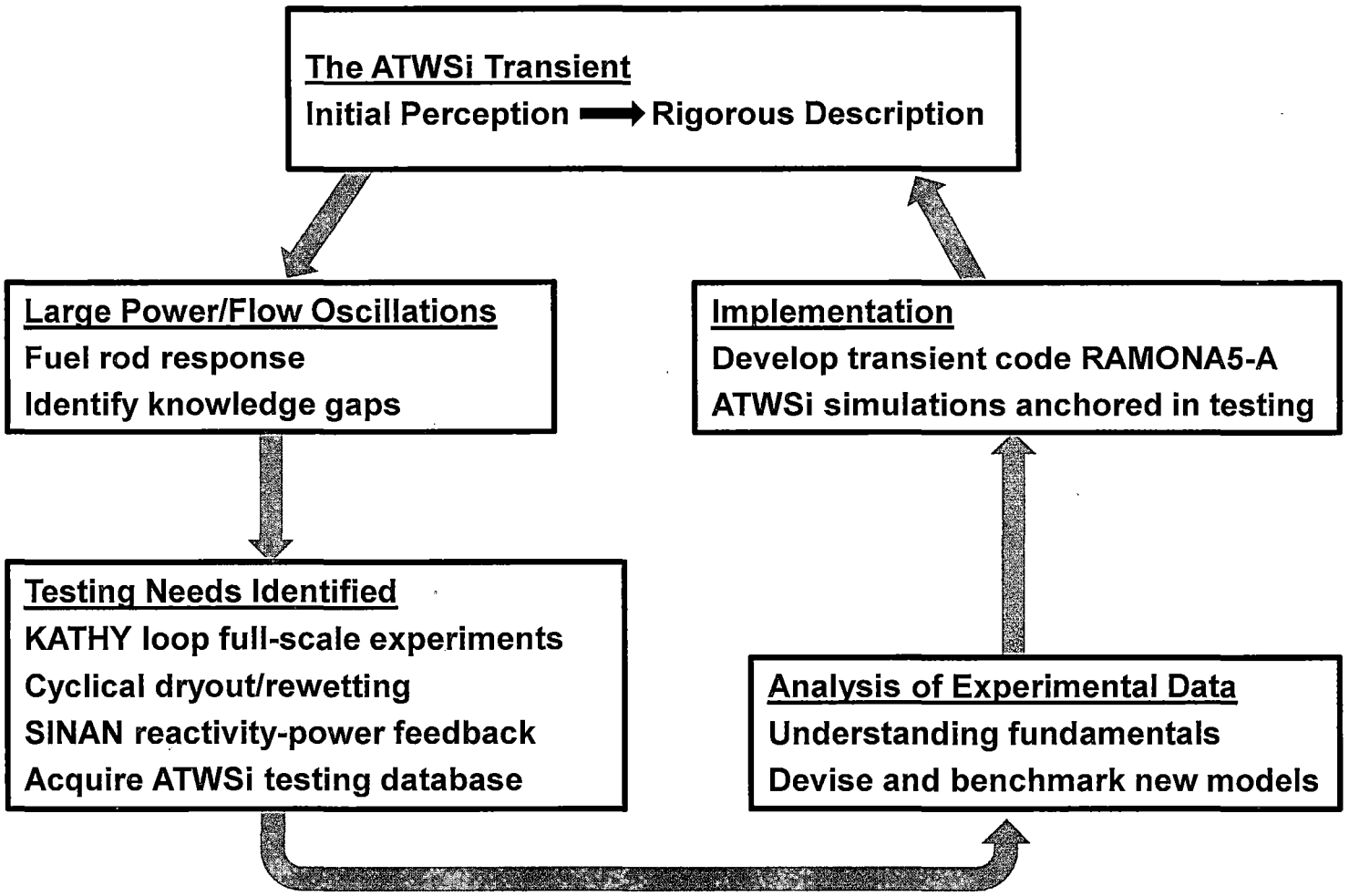
# Generic ATWSi Approach

- **For Monticello, a plant specific ATWSi methodology was developed**
  - **Generic methodology will build upon models and lessons learned from the plant-specific approach**
    - Utilize models and approaches from plant specific methodology that are generically applicable
    - Upgrade models that were limited to plant specific applications
  - **Topical report will closely follow plant specific submittal**
    - PIRT (built off of industry wide ATWSi PIRT NUREG/CR-6743)
    - Theory Description
      - All models will be described, not just improvements
    - Benchmarking
    - Sample Problems

# ATWSi Codes & Information Flow
## For a Specific Plant Application for Fuel Transition

# ATWSi Codes & Information Flow
## For Future Generic Application

# AREVA ATWSi Methods Development Process



# ATRIUM 10XM Stability Tests with Large Oscillations in KATHY Loop

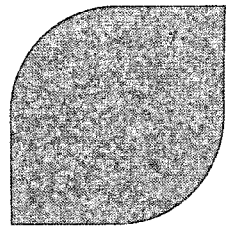
- New KATHY configuration is a realistic BWR simulator with unique test features

[ ]

- Work performed utilizing the test results
  - Study fundamentals of large oscillation dynamics
  - Development & benchmarking of new dryout/rewetting model
  - Basis for ATWSi analysis code package

# SINAN Transforms KATHY Loop into a Test Reactor

# How KATHY + SINAN Simulate Global and Regional Oscillations



# Examples of Rod Temperature Data

**Measured for various rods at different elevations**

# Experimental data collection

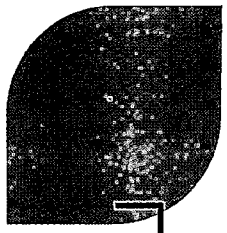
[

]

# Key Parameter: [ ]

[

]



# KATHY ATRIUM 10XM
# Oscillation Benchmarking Suite

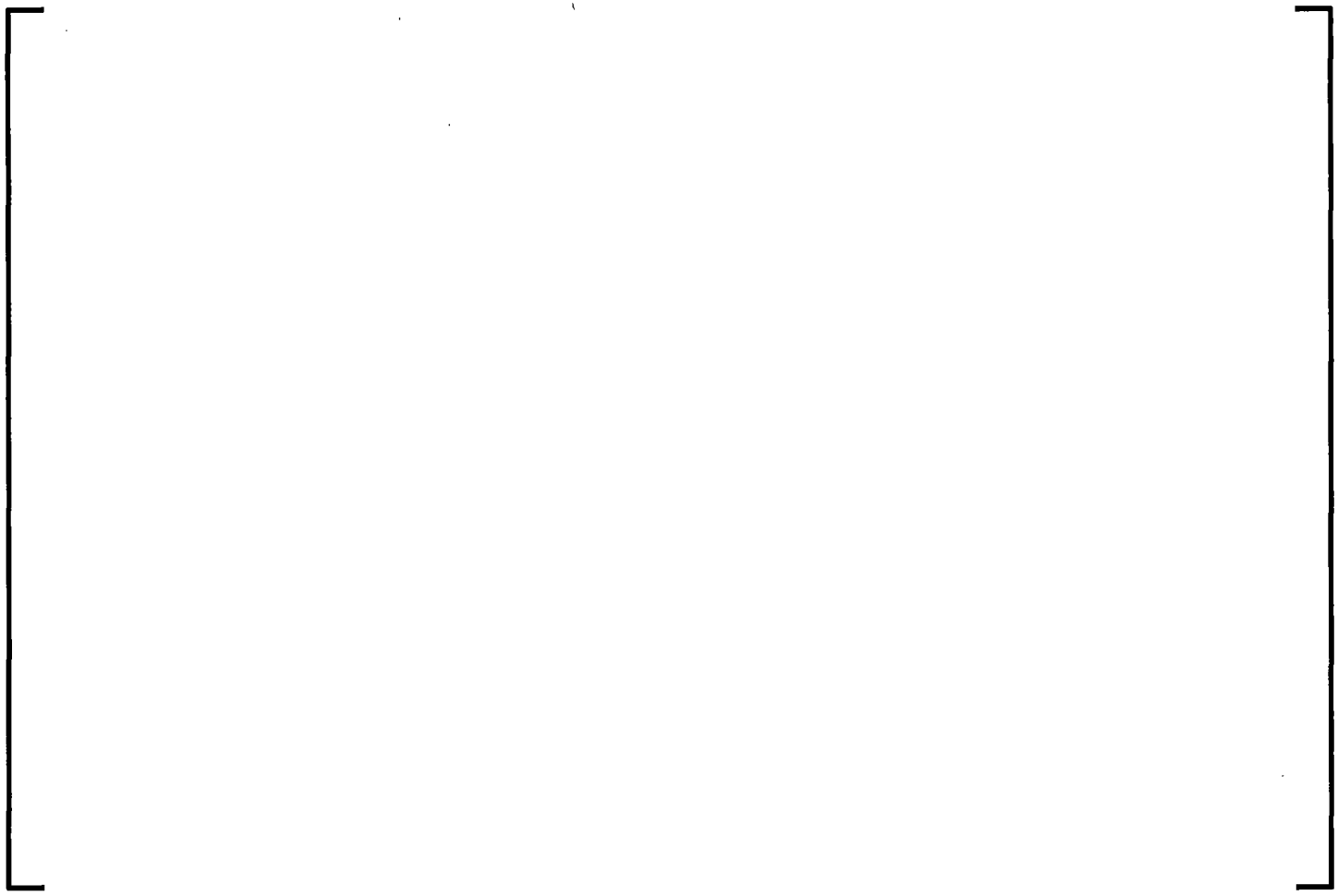
# Analysis of Experimental Data

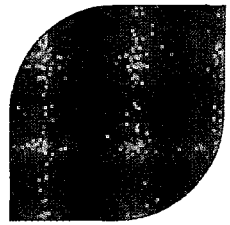
# Analysis of Experimental Data

# Analysis of Experimental Data

# Wetted Wall Heat Transfer Coefficient

[ ]





# ATRIUM 10XM KATHY Example Test

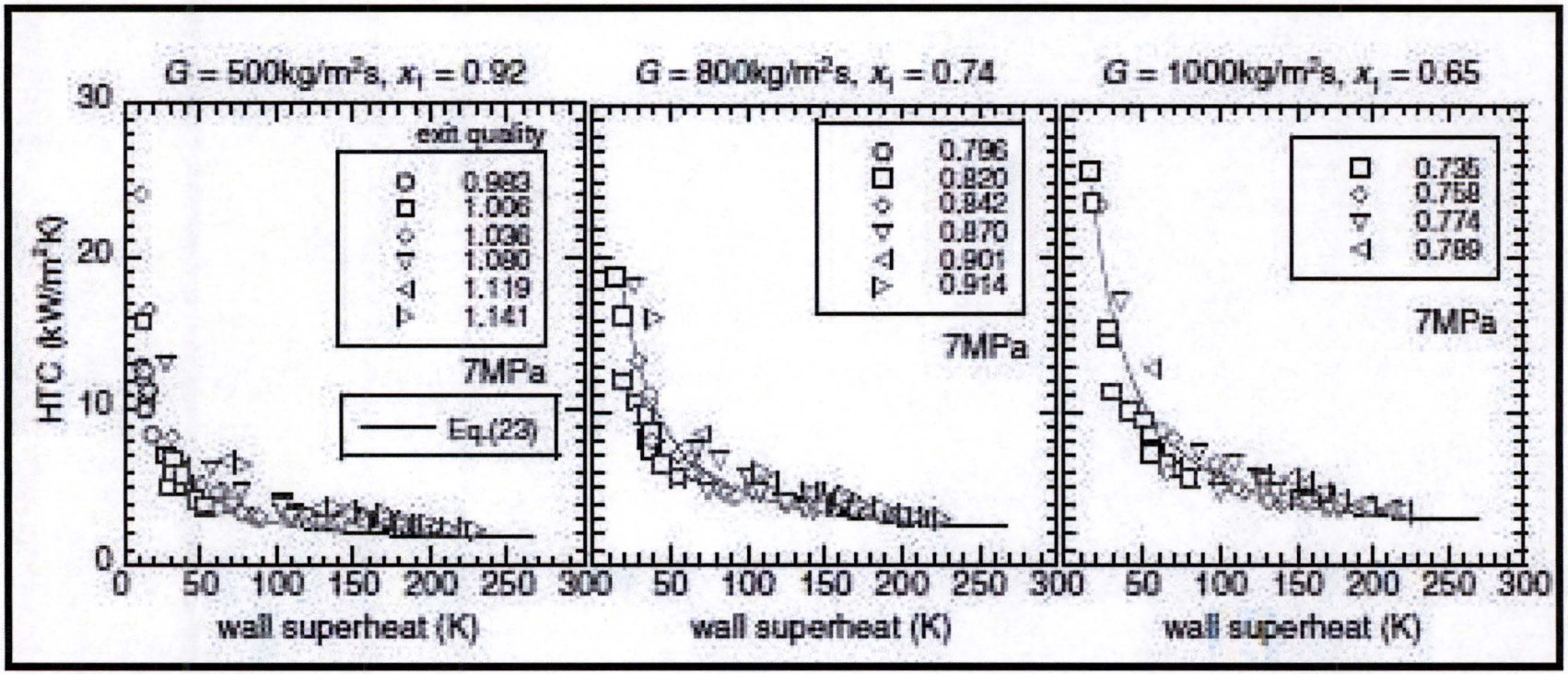
## Boiling Curve versus Dynamical System Representation

# Observations From Experimental Data

# Benchmarking Heat Transfer Coefficients

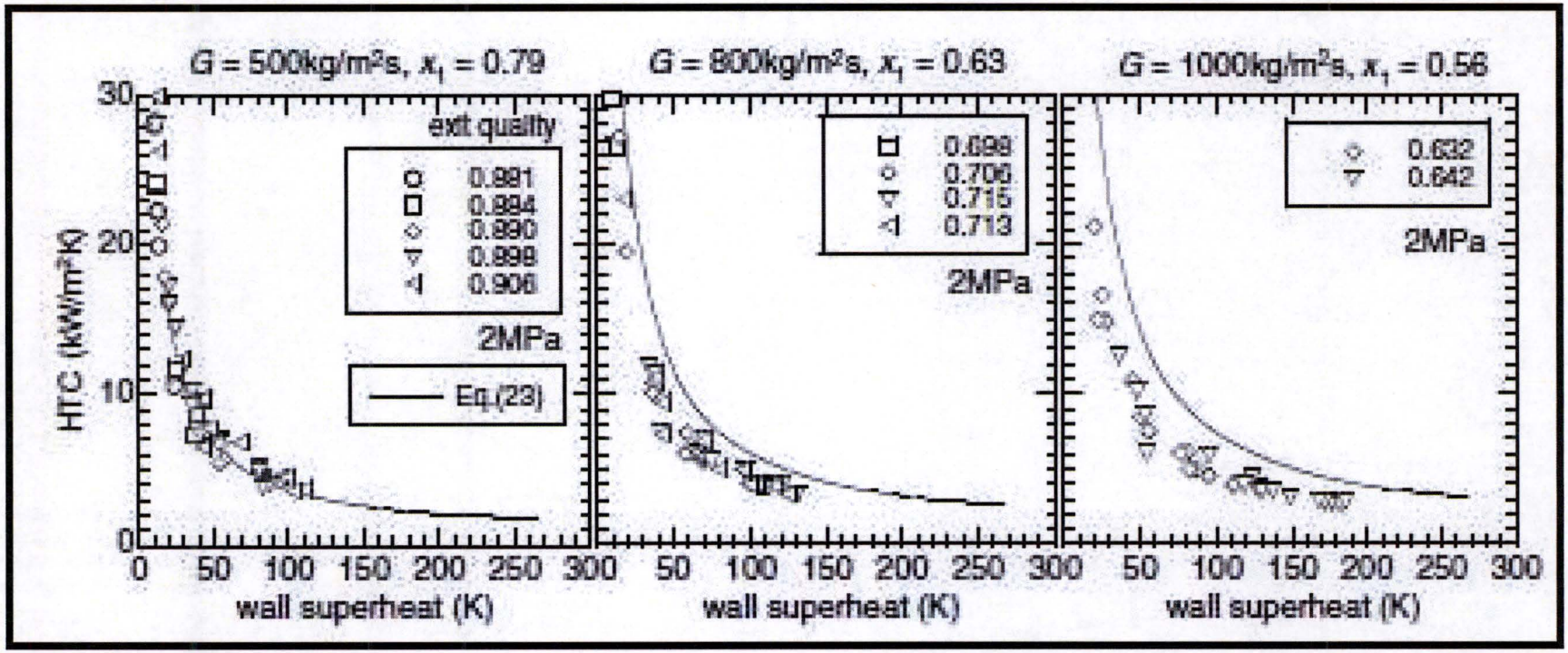
# Benchmarking Heat Transfer Coefficients

- Y. Sibamoto, Y. Maruyama, T. Yonomoto, H. Nakamura, "Core Heat Transfer Coefficients Immediately Downstream of the Rewetting Front during Anticipated Operational Occurrences for BWRs," Journal of Nuclear Science and Technology, V. 48, No. 3, 2011.



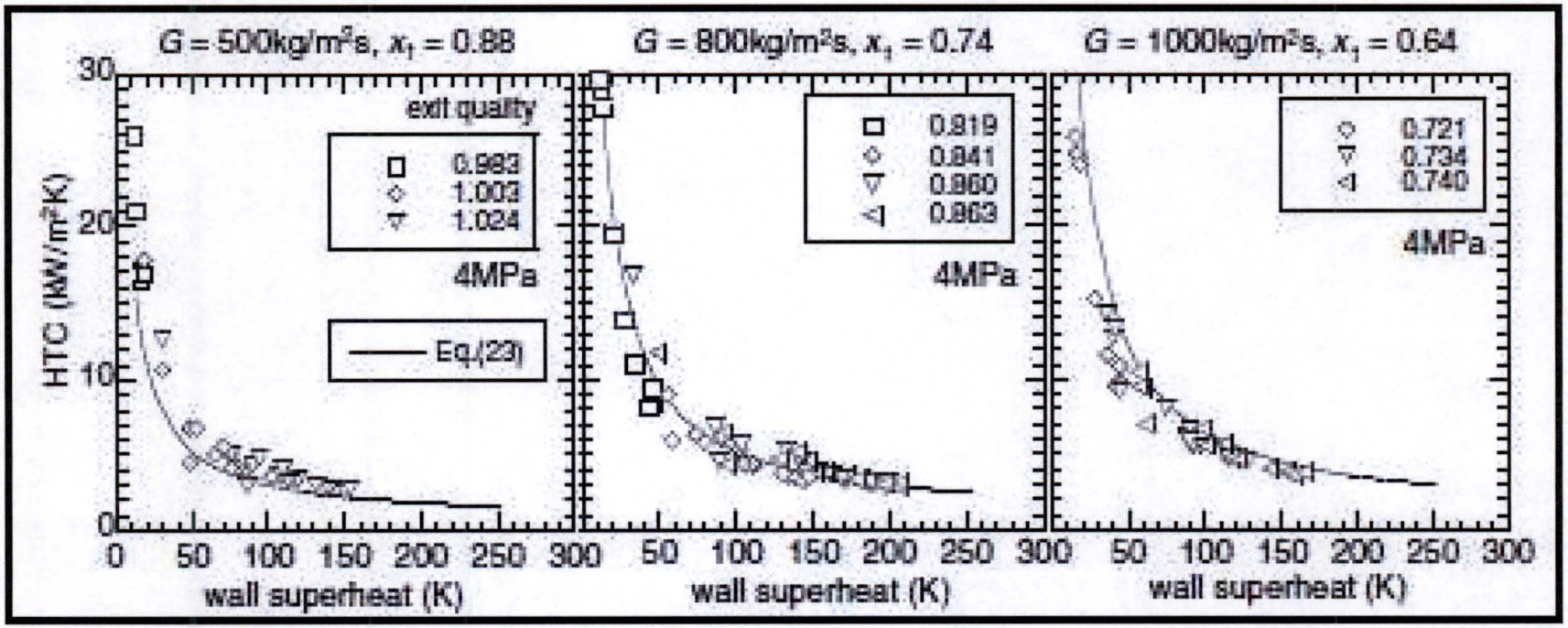
# Benchmarking Heat Transfer Coefficients

- Y. Sibamoto, Y. Maruyama, T. Yonomoto, H. Nakamura, "Core Heat Transfer Coefficients Immediately Downstream of the Rewetting Front during Anticipated Operational Occurrences for BWRs," Journal of Nuclear Science and Technology, V. 48, No. 3, 2011.



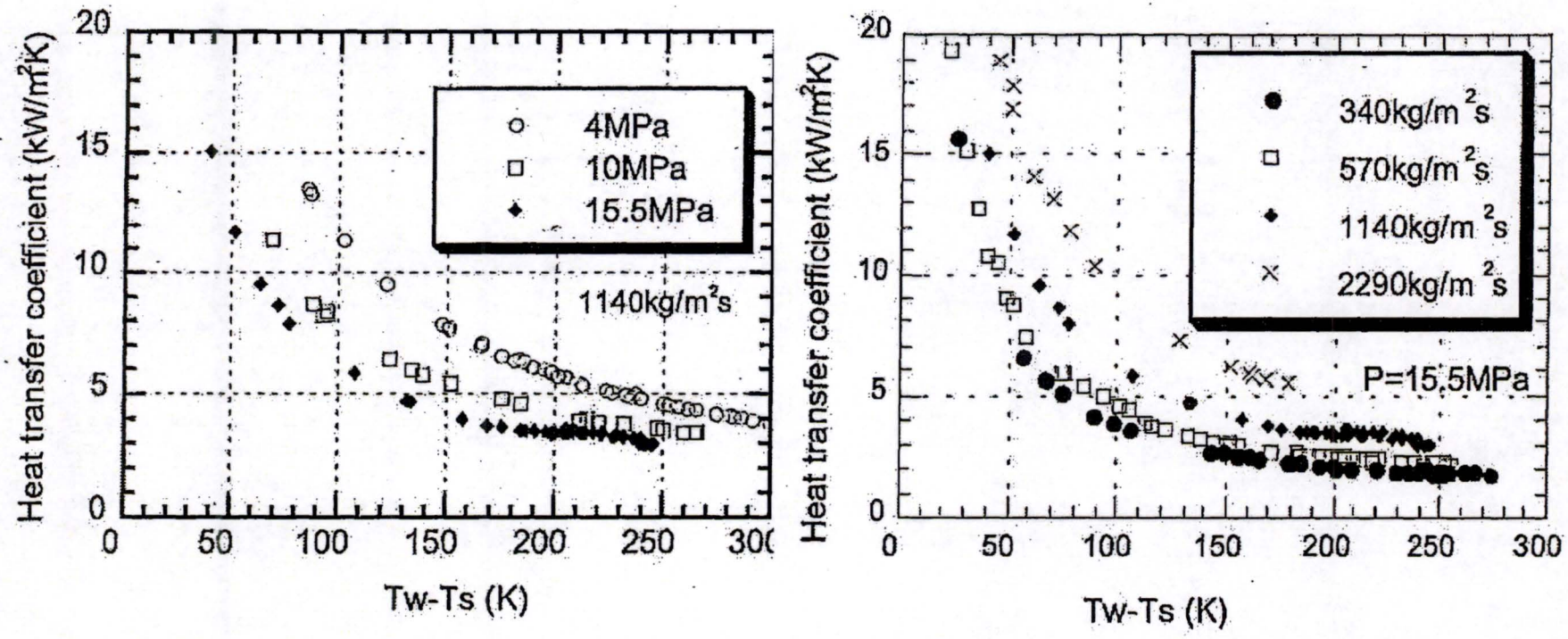
# Benchmarking Heat Transfer Coefficients

- Y. Sibamoto, Y. Maruyama, T. Yonomoto, H. Nakamura, "Core Heat Transfer Coefficients Immediately Downstream of the Rewetting Front during Anticipated Operational Occurrences for BWRs," Journal of Nuclear Science and Technology, V. 48, No. 3, 2011.

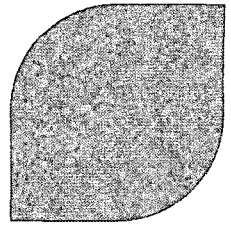


# Benchmarking Heat Transfer Coefficients

- T. Iguchi, A. Ohnuki, C. Iwaki, M. Kureta, H. Akimoto, "Status of Transient Thermal-Hydraulic Demonstration Test Program at JAERI," ICONE5, May, 26-30, 1997.



# The New Mechanistic Post-Dryout Model



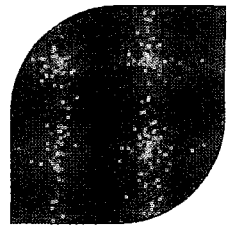
# CPROM Critical Power Correlation is the Basis for the [ ]

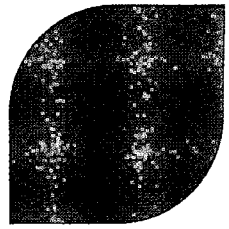
# Dynamic Dryout and Rewetting Model

[ ]

# Critique and Refinement of CPROM

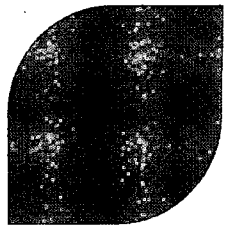
[ ]



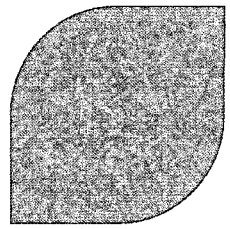


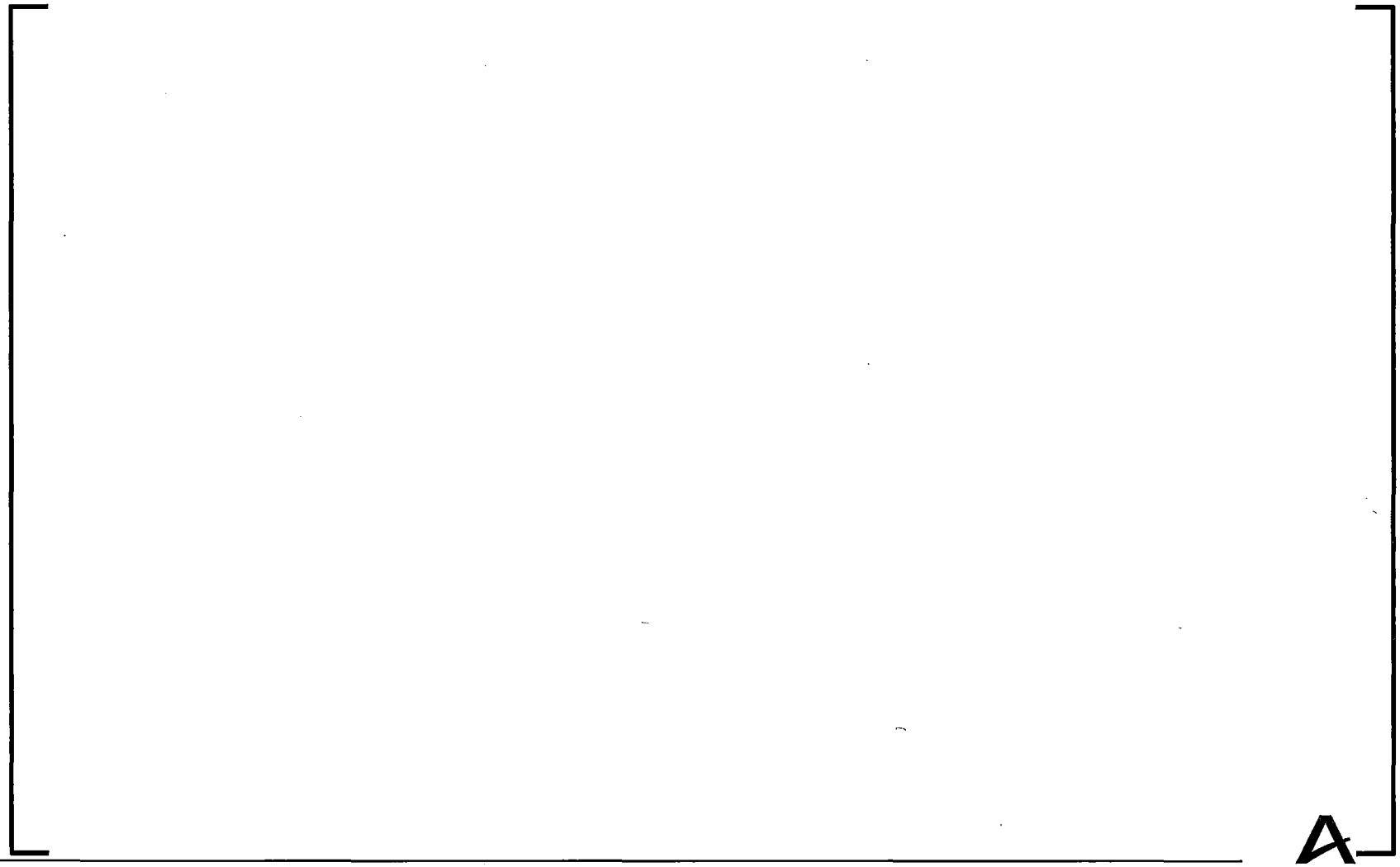
[

]

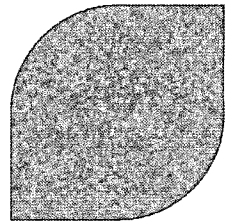


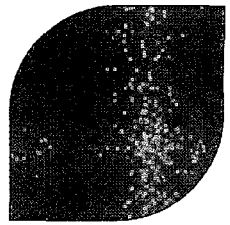
[ ]

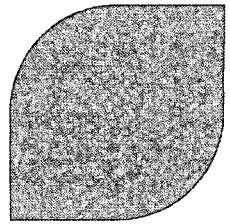




[ ]

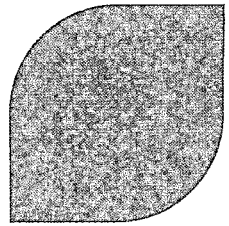






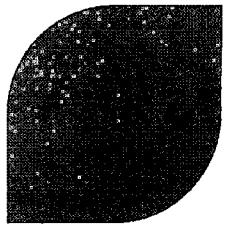
[

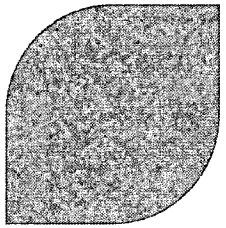
]



[

]





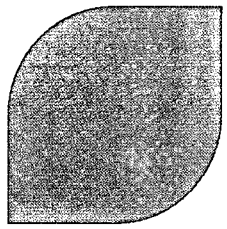
[

]

[

]

# Summary of ATWSi-Related Testing and Modeling



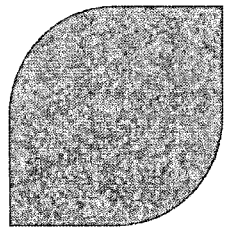
- Extensive testing in KATHY loop represents the ATWSi transient
- Experimental database generated for cyclical dryout and rewetting with ultimate failure to rewet
- New models were developed and qualified for transient dryout and rewetting and fuel rod response including temperature excursions

[ ]

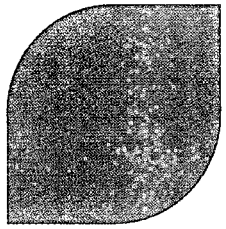
- All these models are integrated in an improved RAMONA5-A code version for ATWSi analysis

# New RAMONA5-A Main Features

# New RAMONA5-A Main Features



# New RAMONA5-A Main Features



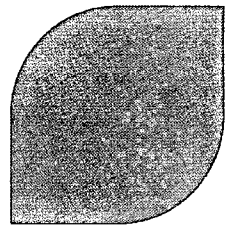
# Other New RAMONA5-A Features

## Improve Robustness Regardless of Phenomena Ranking

- In-depth review resulted in miscellaneous improvements beyond simple integration of AISHA and SINANO in RAMONA5-A. Examples:

# Other New RAMONA5-A Features

## Improve Robustness Regardless of Phenomena Ranking

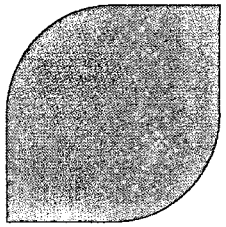


# New RAMONA5-A Benchmarking

[

]

# RAMONA5-A Change Control Process



- AREVA maintains a formal change control process to assure licensing remains consistent with the NRC approval and will propose the following elements:
  - Modification specific testing to verify changes
  - Maintenance of Continuity of Assessment (CoA) test suite as new benchmarking is performed
  - Regression testing using CoA to evaluate changes relative to the previous released version and the NRC approved LTR
  - Definition of "essentially the same" with respect to evaluation of changes

# New RAMONA5-A Sample Problem

- Simulated TTWB with resulting loss of feedwater heating
  - Full core of ATRIUM 10XM

[redacted]

# ATRIUM 10XM Example ATWSi Simulation

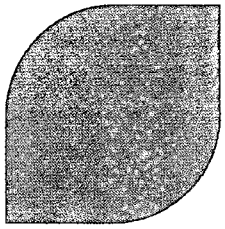
# Concluding Summary

- New KATHY ATRIUM 10XM stability tests simulate an ATWSi event
  - Power feedback experimentally reproduces realistic ATWSi conditions
  - Allows for quantitative understanding & modeling of ATWSi phenomena
- New RAMONA5-A code version developed to include enabling features for ATWSi analysis
  - Leaverage knowledge gained and lessons learned from plant-specific ATWSi analysis (AISHA/SINANO)
  - Expand capabilities to model the full event through water level reduction
  - Incorporate suggested improvements from plant-specific review and ACRS feedback

[ ]

- Expanded benchmarking suite

# Next Steps



[ ]