The Application of TRACE/PARCS to BWR Stability Analysis

Y. Xu **T. Downar**
Purdue University UC Berkeley

K. Ivanov
Penn State

J. Staudenmeier
U.S. NRC

Jose March-Leuba
ORNL

RIC Meeting
Rockville, MD
March 13, 2008

Outline

- TRACE
- Application to Stability
  - Peach Bottom
  - Ringhals
- Future Work

TRACE for Stability Analysis

- After initiation of the project TRACE version rc3 were released and all calculations reported here were performed with TRACEv5rc3.
- During the course of the work, it was found that three minor modifications to the code improved the channel void/power profile and were included in the code:
  - e - bug fix in direct energy deposition currently in holding bin and not in rc3
  - p – PARCS mods currently in holding bin and not in rc3
  - L - two phase multipliers for local loss
- All results shown in the following will be for TRACE v5rc3 with these three mods and will be referred to as **TRACE v5rc3epl**.

BWR Stability Methods

Frequency domain (e.g. LAPUR)

- Expand equations in perturbation form
- Linearize equations to first order in perturbations
- Laplace Transform of linearized equations
- Solve linear eigenvalue problem for eigenvalues (frequency and decay ratio) and eigenvectors (mode of oscillation)

Time domain (e.g. TRACE/PARCS)

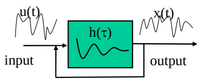
- Linear stability
  - Add perturbation to quasi-steady solution
  - Perform signal processing on response to perturbation
    - Single perturbation – fit to damped or growing harmonic oscillator to perturbation response.
    - Random noise perturbations – use autoregressive moving average (ARMA) method to extract signal from noise response.
- Nonlinear transient calculations (e.g. instability after a pump trip)

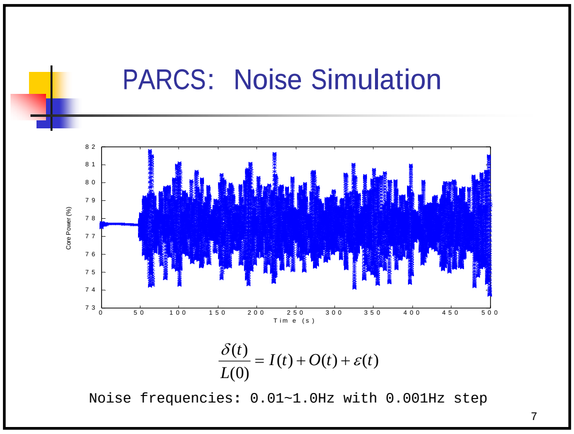
TRACE Stability Methods: Initiation of Instability

- Standalone initialization of TRACE with fixed power power distribution followed by null transient w/ TRACE/PARCS for 50 seconds.
- One of three excitations then used to initiate the transient
  - Control Rod Perturbation: Insert/Remove Single Rod (center/south) in 0.2 seconds (insertion 2/3 of core)
  - Pressure Perturbation: 0.2MPa “triangular” Pulse in Steam Line in 1.0 secs
  - Noise Method implemented in PARCS

PARCS: Noise Simulation

- Decay ratios and frequencies from the Ringhals stability tests were obtained from Noise analysis
- In order to perform noise analysis with PARCE/TRACE, a new type of transient was introduced into PARCS
  - During the transient, cross sections are perturbed by changing the value of the moderator density. This change is only for cross section evaluation, the real thermal hydraulic solution is not changed.
  - The changes in the moderator density are specified as a combination of several spatial modes: random background noise, fundamental mode, and harmonics.

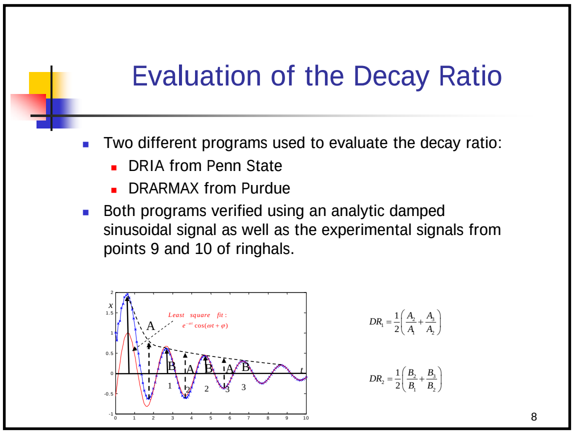




PARCS: Noise Simulation

$$\frac{\delta(t)}{L(0)} = I(t) + O(t) + \varepsilon(t)$$

`Noise frequencies: 0.01~1.0Hz with 0.001Hz step`

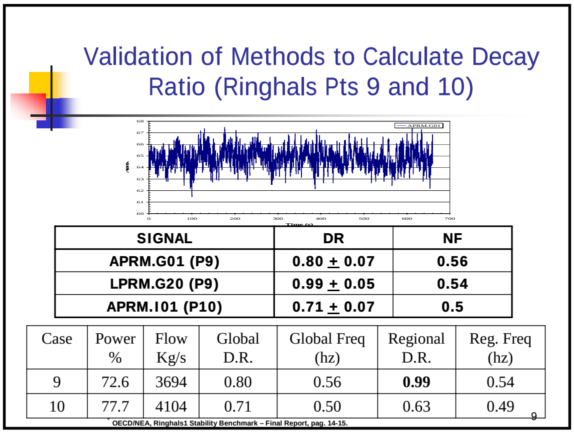


Evaluation of the Decay Ratio

- Two different programs used to evaluate the decay ratio:
  - DRIA from Penn State
  - DRARMAX from Purdue
- Both programs verified using an analytic damped sinusoidal signal as well as the experimental signals from points 9 and 10 of ringhals.

$$DR_1 = \frac{1}{2}\left(\frac{A_2}{A_1} + \frac{A_3}{A_2}\right)$$

$$DR_2 = \frac{1}{2}\left(\frac{B_2}{B_1} + \frac{B_3}{B_2}\right)$$



Validation of Methods to Calculate Decay Ratio (Ringhals Pts 9 and 10)

SIGNAL	DR	NF
APRM.G01 (P9)	**0.80 ± 0.07**	**0.56**
LPRM.G20 (P9)	**0.99 ± 0.05**	**0.54**
APRM.I01 (P10)	**0.71 ± 0.07**	**0.5**

Case	Power %	Flow Kg/s	Global D.R.	Global Freq (hz)	Regional D.R.	Reg. Freq (hz)
9	72.6	3694	0.80	0.56	**0.99**	0.54
10	77.7	4104	0.71	0.50	0.63	0.49

* OECD/NEA, Ringhals1 Stability Benchmark – Final Report, pag. 14-15.

Application to Peach Bottom: EOC2 Stability Tests

	PT1	PT2	PT3	PT4
Core Thermal Power, MWt	1995.00	1702.00	1948.00	1434.00
Initial Power Level,% of rated	60.6	51.7	59.2	43.5
Total Core Flow, kg/s	6753.60	5657.40	5216.40	5203.8
Total reactor flow, % of rated	51.3	42.0	38.0	38.0
Reactor Steam Dome Pressure, Pa	6860286	6814781	6904413	6863044
Core exit pressure, Pa	7063682	7008689	7098052	7056808
Core Inlet Enthalpy, kJ/kg	1183.610	1187.78	1184.610	1183.83
Core Inlet Subcooling, kJ/kg	75.160	79.648	77.442	76.075
Core Inlet Temperature, °C	270.11	270.73	270.09	269.96
Feed Water Mass Flow, kg/s	963.90	808.92	941.22	671.58

Application to Peach Bottom: EOC2 Stability Tests

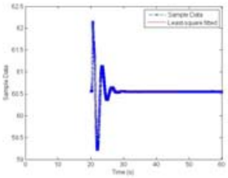
Cycle 2 Decay Ratios

TP	Reference	Calculated DR (Global)	
	DR (Global)	CR	PP
1	0.26	0.35	0.36
2	0.30	0.32	0.49
3	0.33	0.29	0.25

Cycle 2 Frequencies

TP	Reference	Calculated Fr (Global)	
	FR (Global)	CR	PP
1	0.45	0.38	0.36
2	0.45	0.36	0.38
3	0.43	0.46	0.33

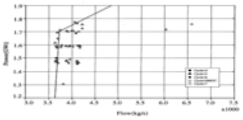
Test Point 1



Uncertainty in Evaluation (Lefvert, 1996)

Decay Ratio	Uncertainty
0.2	+/- 0.15
0.4	+/- 0.09
0.6	+/- 0.07
0.8	+/- 0.05

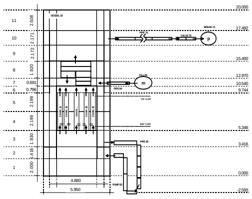
OECD /NEA Ringhals Stability Benchmark



Reference Stability Test Results for Ringhals 1 Cycle 14 (BOC)

TP	Test Time	POWER		Core Flow	Global		Regional	
	year-month-day (time)	Rated (%)	(MW)	(kg/s)	DR	Fr	DR	Fr
1	1990-09-03 (12:34)	65.0	1475.50	4105	0.30	0.43	-	-
3	1990-09-03 (14:40)	65.0	1475.50	3666	0.69	0.43	0.57	0.43
4	1990-09-03 (16:38)	70.0	1589.00	3657	0.79	0.55	0.75	0.52
5	1990-09-03 (17:30)	70.0	1589.00	3868	0.67	0.51	0.60	0.50
6	1990-09-03 (18:29)	70.2	1593.54	4126	0.64	0.52	0.59	0.50
8	1990-09-04 (09:59)	75.1	1704.77	3884	0.78	0.52	0.79	0.50
9	1990-09-03 (20:30)	72.6	1648.02	3694	0.80	0.56	0.99	0.54
10	1990-09-04 (14:53)	77.7	1763.79	4104	0.71	0.50	0.63	0.49

TRACE/PARCS Stability: TRACE Model



325 T-H Channel model which provides explicit "one to one" mapping of each neutronic node to a separate TH channel for a half-core symmetric model. Adequate for in-phase oscillations.

648 T-H Channel model which provides "one to one" mapping of each neutronic node to a separate TH channel. Necessary for out-of-phase oscillations.

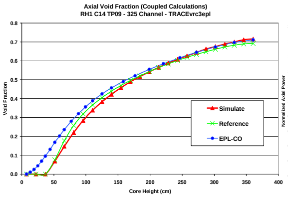
TRACE/PARCS S.S. CPU Requirements vrs Number of TRACE CHANs

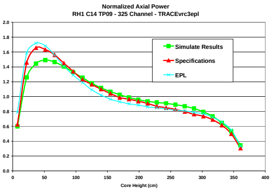
# CHANS ->	325	648
Time step	0.1 s	0.1 s
Simulation time (CONV CRITERIA)	391 s (e-4)	500 (3 e-4)
Cpu time	7800 sec	40000 sec
PARCS/TRACE	2:1	1:1

TRACE Initialization: CY14 Test Point 9 (325 Channels)

TRACE P09 - 325 Channels			Coupled
	Specifications	Measured	EPL
Reactor power (Mw)	1648	N/A	1648
Steam dome pressure (Mpa)	7.01	N/A	7.01
Core flow rate (kg/s)	3694	N/A	3694
Core channel flow rate (kg/s)		3371.2	3382.6
Steam flow rate (kg/s)	N/A	N/A	772.6
Core inlet temperature (K)	533.55	N/A	533.55
Lower plenum pressure (Mpa)	N/A	N/A	7.072
Upper plenum pressure (Mpa)	N/A	N/A	7.022
Collapsed (DC) water level (m)	N/A	N/A	8.67
K-effective	1.000000	N/A	0.995049

TRACE Initialization: Test Point 9





Ringhals Cycle 14 **In-Phase** Stability TRACE Results: **Decay Ratio**

Cycle 14 (BOC) Comparisons with RAW Method

	Reference	**Calculated DR (Global)**		
TP	**DR (Global)**	**CR**	**PP**	**NS**
1	0.30	0.52	0.51	0.44
3	0.69	0.71	0.69	0.42
4	0.79	0.79	0.77	0.63
5	0.67	0.72	0.71	0.58
6	0.64	0.64	0.63	0.54
8	0.78	0.84	0.83	0.66
9	0.80	0.83	0.82	0.64
10	0.71	0.73	0.73	0.63

Fr: Natural **F**requency
TP: **T**est **P**oint
RAW: Stability analysis with original data
ACF: **A**uto **C**orrelation **F**unction
IRF: **I**mpulse **R**esponse **F**unction
CR: Control Rod Perturbation
PP: Pressure Perturbation
NS: Noise Analysis

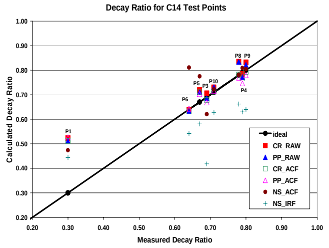
Ringhals Cycle 14 **In-Phase Instability** TRACE Results: **Frequency**

Cycle 14 (BOC) Comparisons with RAW Method

	Reference	**Calculated Fr (Global)**		
TP	**FR (Global)**	**CR**	**PP**	**NS**
1	0.43	0.41	0.41	0.40
3	0.43	0.41	0.41	0.45
4	0.55	0.50	0.50	0.50
5	0.51	0.49	0.49	0.49
6	0.52	0.48	0.48	0.48
8	0.52	0.48	0.48	0.47
9	0.56	0.51	0.51	0.52
10	0.50	0.48	0.48	0.47

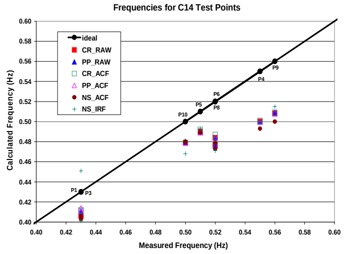
Fr: Natural **F**requency
TP: **T**est **P**oint
RAW: Stability analysis with original data
ACF: **A**uto **C**orrelation **F**unction
IRF: **I**mpulse **R**esponse **F**unction
CR: Control Rod Perturbation
PP: Pressure Perturbation
NS: Noise Analysis

Ringhals Cycle 14 Stability Tests: **Decay Ratio**



Fr: Natural **Fr**equency
TP: **T**est **P**oint
RAW: Stability analysis with original data
ACF: **A**uto **C**orrelation **F**unction
IRF: **I**mpulse **R**esponse **F**unction
CR: Control Rod Perturbation
PP: Pressure Perturbation
NS: Noise Analysis

Ringhals Cycle 14 Stability: TRACE Results: **Frequency**



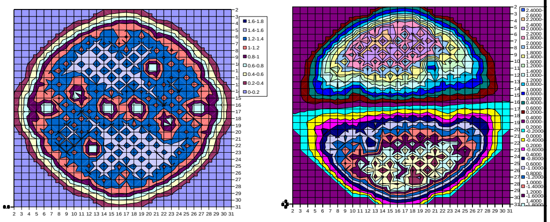
Fr: Natural **Fr**equency
TP: **T**est **P**oint
RAW: Stability analysis with original data
ACF: **A**uto **C**orrelation **F**unction
IRF: **I**mpulse **R**esponse **F**unction
CR: Control Rod Perturbation
PP: Pressure Perturbation
NS: Noise Analysis

TRACE Application to **OUT-OF-PHASE** Instability Analysis

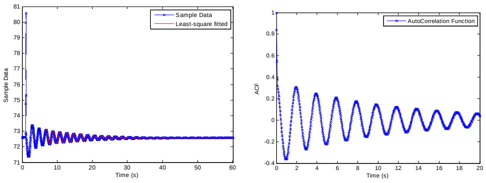
- Analysis was then initiated on the out-of-phase instability and the limit cycle analysis using Point 9.
- For the out-of-phase instability it was necessary to use the **648 channel** TRACE model

Case	Power %	Flow Kg/s	Global D.R.	Global Freq (hz)	Regional D.R.	Reg. Freq (hz)
9	72.6	3694	0.80	0.56	**0.99**	0.54
10	77.7	4104	0.71	0.50	0.63	0.49

C14P09 Radial Fundamental Power and First Harmonic



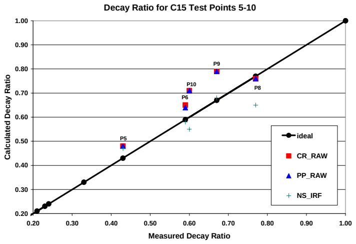
P09 Core Power Response (Control Rod Perturbation)



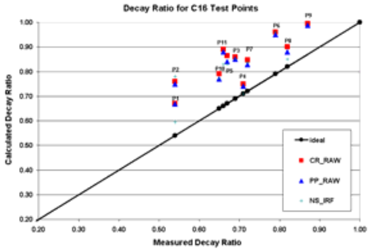
Global (In-Phase)

	Ref	Cal
DR	0.80	0.841
FR	0.56	0.505

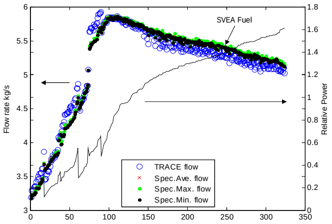
Decay Ratios for Cycle 15



Decay Ratios for Cycle 16



Underprediction of flow in SVEA Fuel high power channels causes overprediction of decay ratio

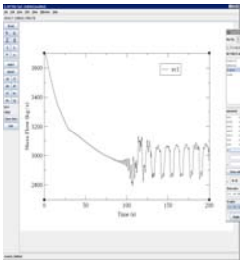


Grid spacer k-factor in benchmark specification is more than 50% too high for SVEA fuel design

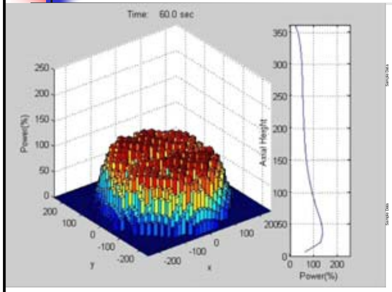
---

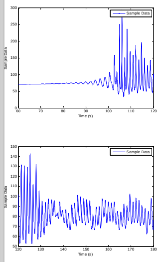
Application to Limit Cycle Analysis: Simulation of PT09 Recirc Pump Trip

- All recirculation pumps lose their torques at 1 second
- Feed water temperature coasts down to 350K in 60 second
- The pressure controller is switched off
- The new controller is used for the downcomer water level



Power Response After Recirc Pump Trip (> 60 sec)





Validation of TRACE for BWR Stability Limit Cycle Performance

- All OECD/NEA stability benchmark data is currently based on noise analysis with decay ratios < 1
- Need work to validate the performance of TRACE in the nonlinear oscillation regime with plant data

---

Summary/Conclusions

- The OECD Peach Bottom Turbine Trip and Stability tests 1, 2, and 3 and the OECD Ringhals Stability tests from Cycle 14,15,16 were performed with TRACE v5.0RC3epl.
- The Peach Bottom results were in reasonably good agreement for the stability tests.
- A 325 channel TRACE model was used to perform the Ringhals in-phase stability. Both steady-state and the transient results were in reasonable agreement with measured data for each of the points investigated.
- A 648 channel model was developed to perform the out-of-phase oscillation. The decay ratio and frequency predicted for the out-of-phase oscillation were in reasonable agreement with the measure data.
- Need to calculate a plant stability event to validate TRACE for nonlinear oscillations