# ENCLOSURE 2

## MFN 06-138

Presentation Regarding TRACG Application for ESBWR Stability

ACRS Thermal-Hydraulic Phenomena Subcommittee

March 14, 2006

**Non Proprietary Version**

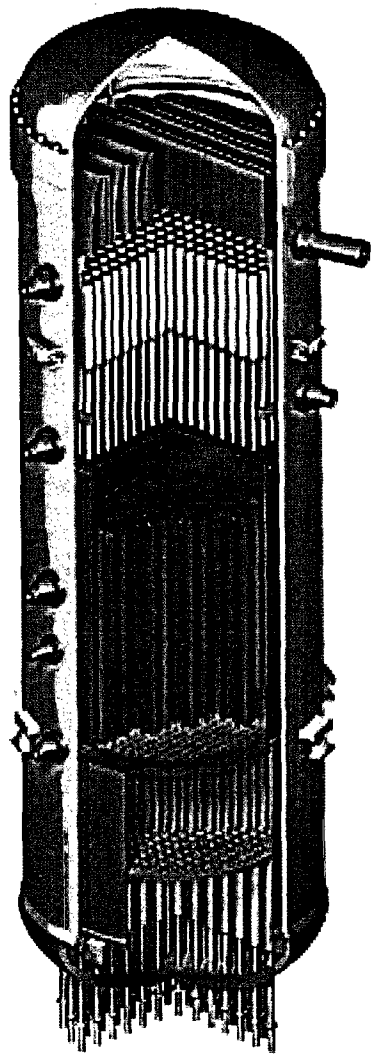
# TRACG Application for ESBWR Stability

ACRS Thermal-Hydraulic Phenomena Subcommittee

Non Proprietary Version

Bharat Shiralkar

March 14, 2006



imagination at work

# Agenda

- Follow-up on issues from January meeting
  - Role of chimney height on ESBWR stability
  - Effect of possible periodic behavior in chimney due to flow regime
  - Decay ratio calculation algorithm
- TRACG qualification for stability

# Role of the chimney height

Chimney height and void fraction determine natural circulation flow

However, chimney height plays minimal role in stability characteristics for density wave oscillations

- Oscillation frequency is determined by void transport through core alone
- Varying chimney height with constant recirculation flow does not affect decay ratio

Perturbations in frictional $\Delta P$ much larger than perturbations in static head

# Stability Modes analyzed

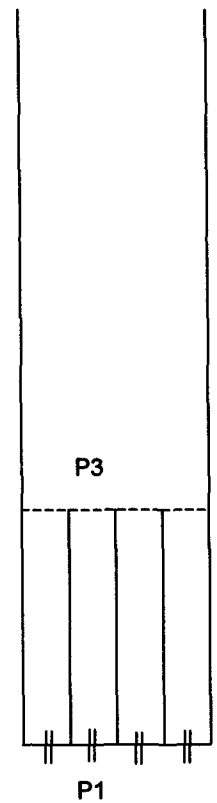
Single channel hydrodynamic stability

"Superbundle" – sixteen bundles and associated chimney cell

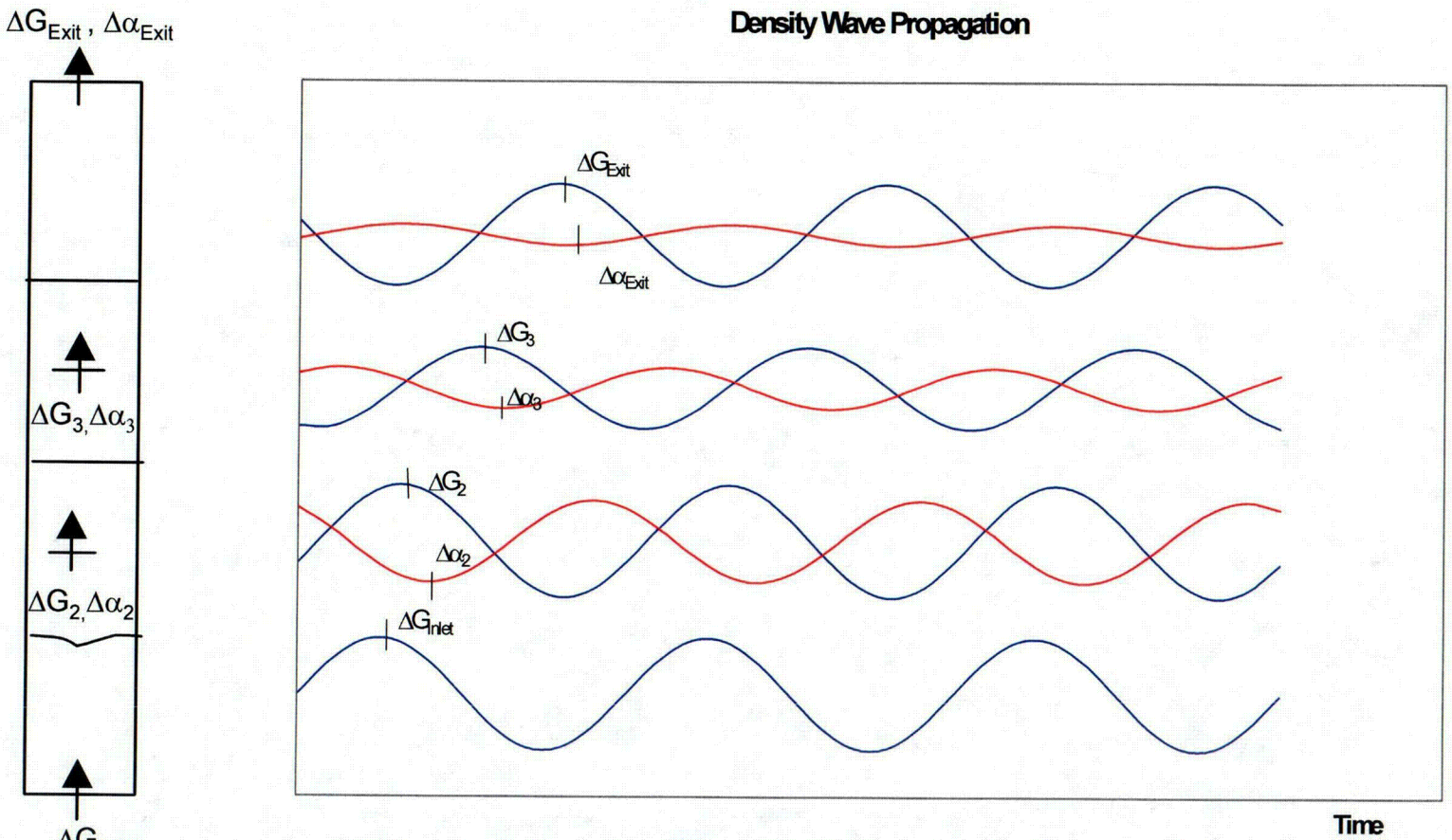
Core stability with neutronic feedback

# Stability Mode – Single Channel

- Constant pressure drop ($P_1$-$P_3$) imposed by other 15 channels
- Constant power



# Density Wave Propagation




$\Delta G$ at exit more than $180^0$ out of phase with inlet flow

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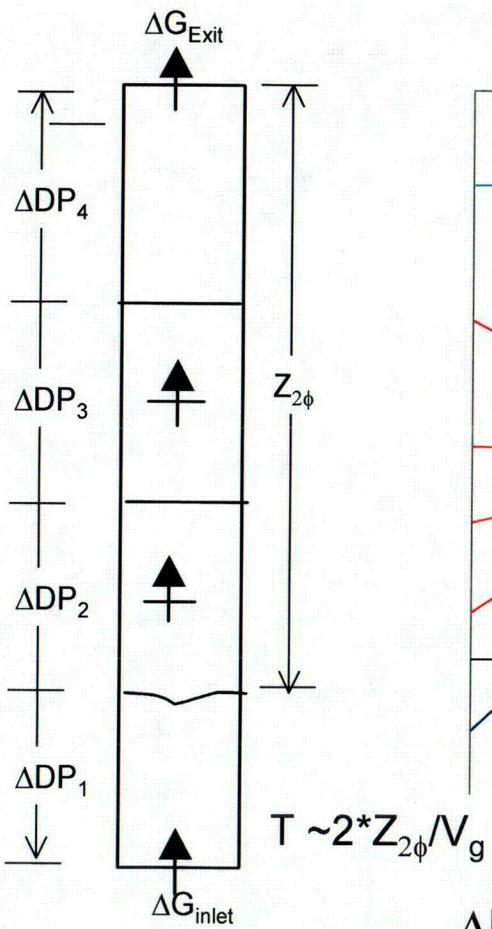
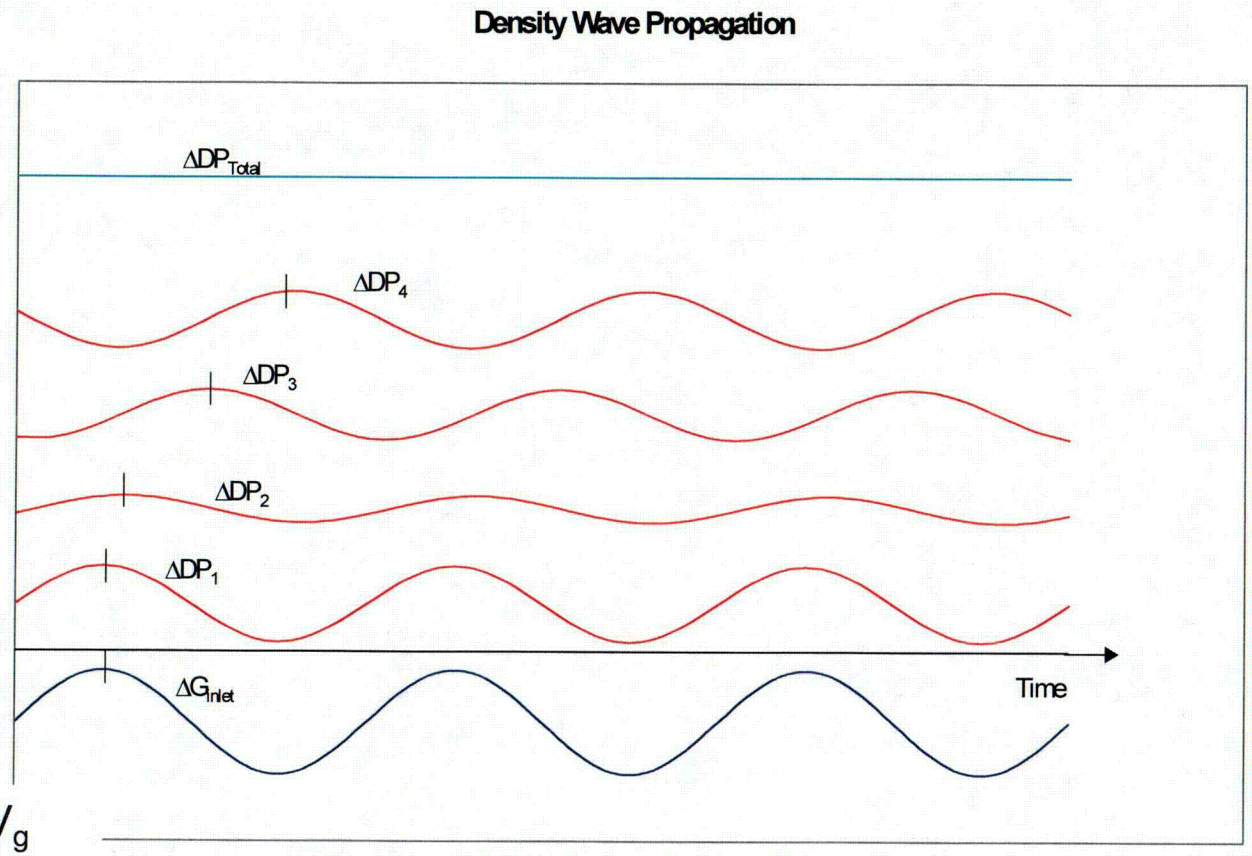
# Density Wave Propagation – Pressure Drop Balance




$T \sim 2*Z_{2\phi}/V_g$




$\Delta P$ at exit more than $180^0$ out of phase with inlet flow

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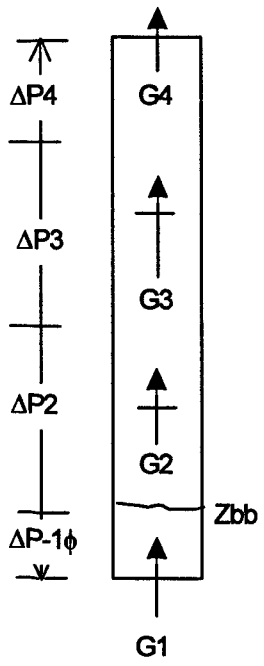
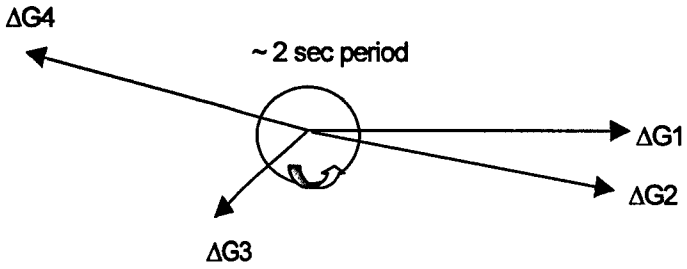
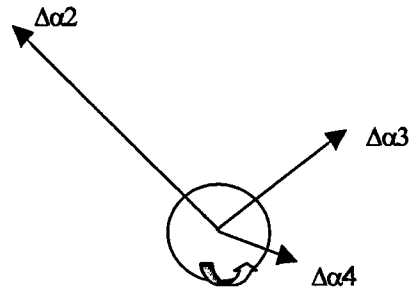
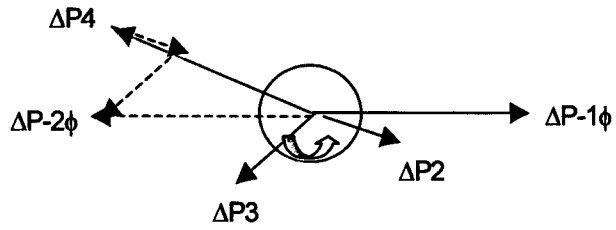
# Phase Relationships for channel



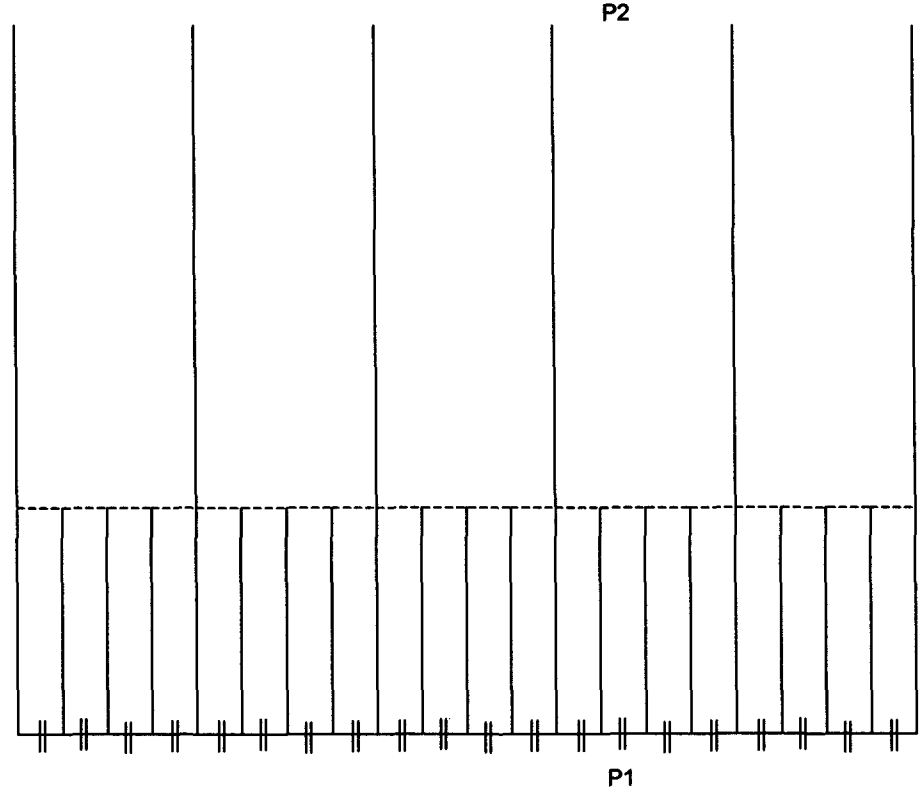




$$d(2\phi\ \Delta p_{core}) = -\ d(1\phi\ \Delta p_{core})$$

# Stability Mode - Superbundle

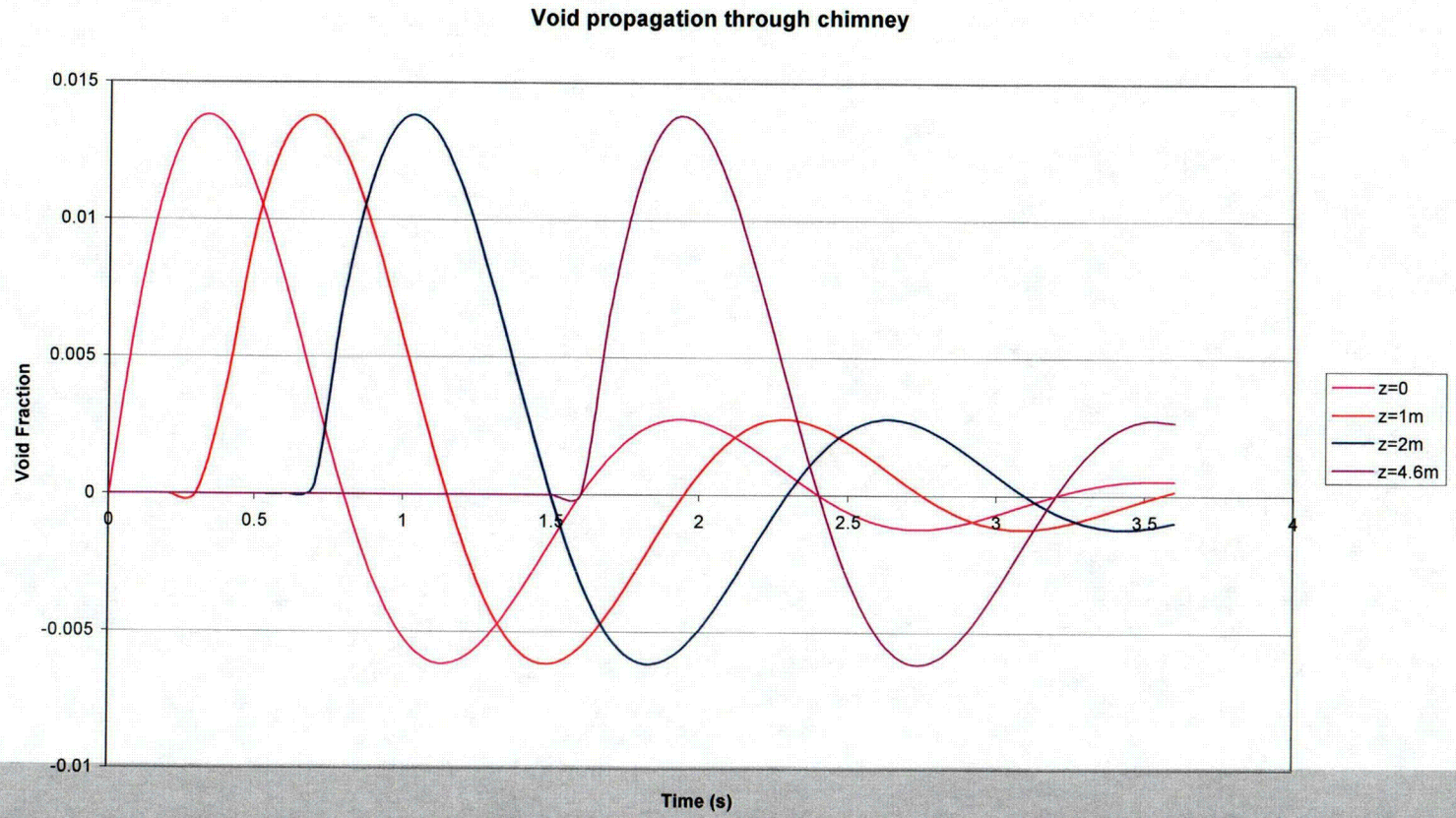
- Combination of 16 bundles and associated chimney cell
- Constant pressure drop (P1-P2) imposed by other channels and chimney cells



# Void Propagation through Chimney

## Simplified analytical solution

$$\frac{\partial j}{\partial z} = 0; \qquad \frac{D\alpha}{Dt} = 0; \qquad V_\alpha = C_0 j + \overline{V}_{gj}$$

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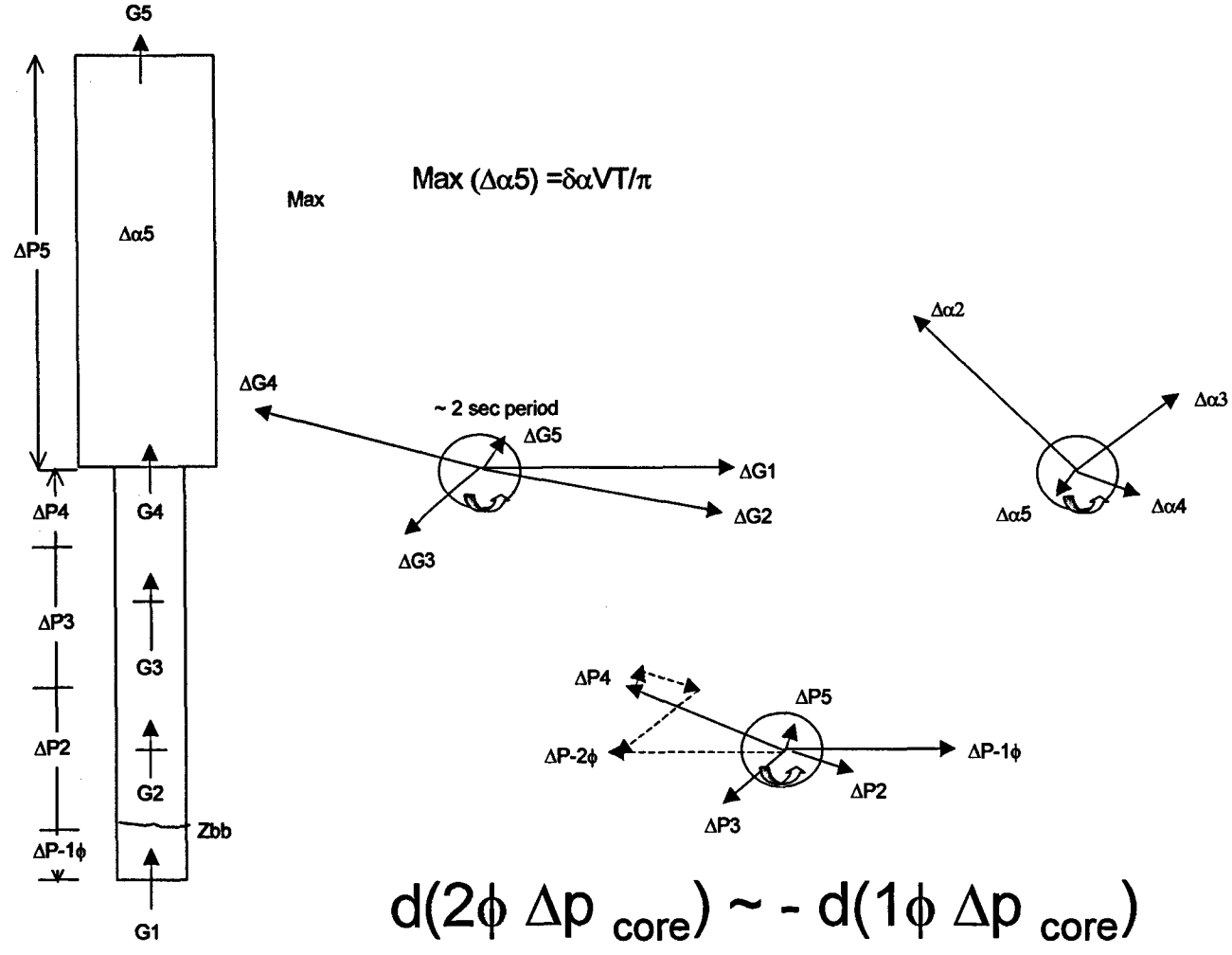
# Void Propagation through Chimney

Frictional pressure drop in chimney is negligible relative to core

Static head perturbation (for a sinusoidal wave) has a max value of $\Delta\rho g\alpha_0 V_g T/\pi$,

- $\alpha_0$=void perturbation at inlet, $V_g$=chimney vapor velocity, T= time period for oscillation
- Small relative to core frictional pressure drop
- Phase relationships dictate that oscillation time period still determined by core transport

# Phase relationships for channel + chimney




$$d(2\phi\ \Delta p_{core}) \sim -\ d(1\phi\ \Delta p_{core})$$

# Sensitivity to Chimney Height

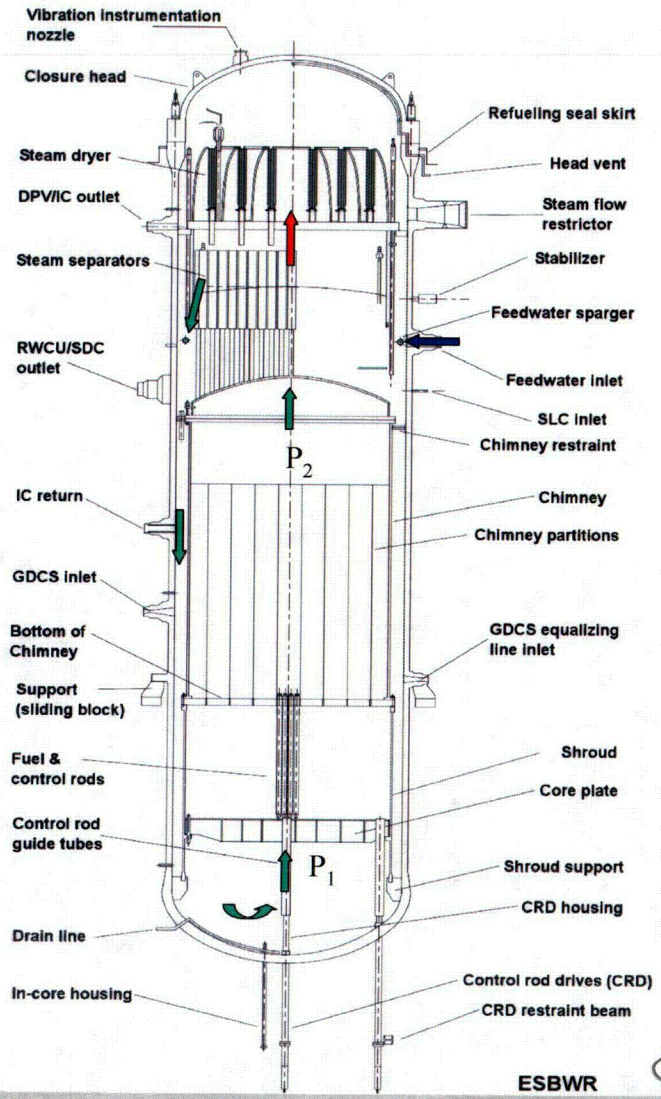
Because chimney pressure drop perturbations are small compared to core pressure drop perturbations, the oscillation frequency and decay ratio are not affected by the chimney height

Sensitivity study was performed for different chimney heights, <u>for the same circulation flow</u>

# Stability Mode – Core Stability

- Loop stability with neutronics feedback
- Pressure drop around loop = 0
- $\delta(P_1-P_2)$ drives changes in recirculation flow

$\delta(P_1-P_2) = I*d(\delta W)/dt$

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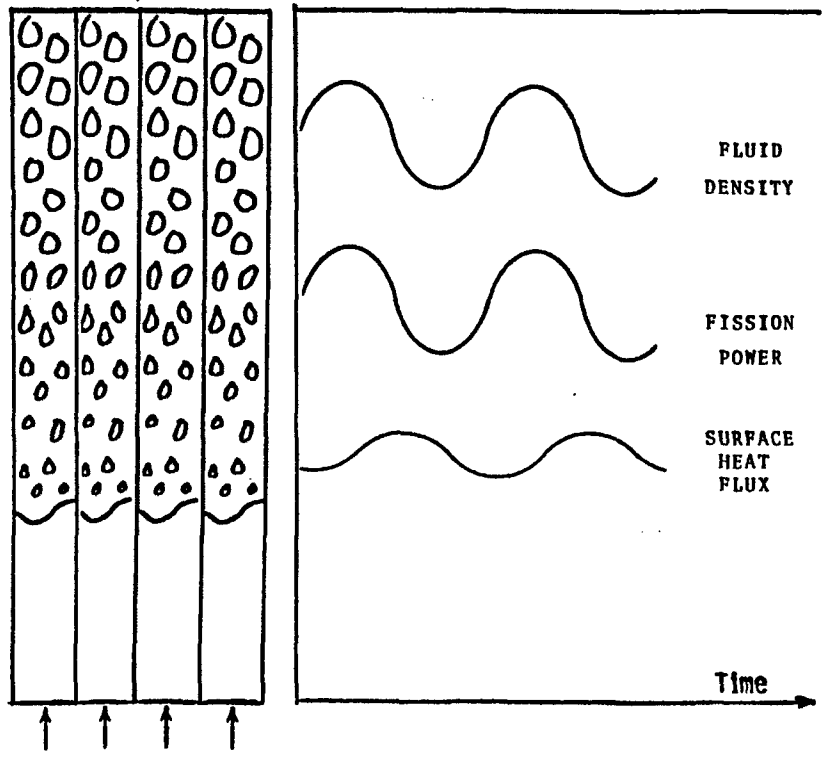
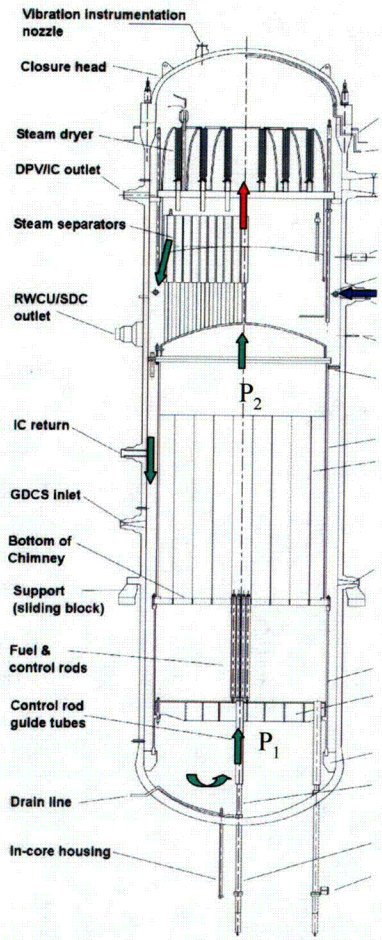
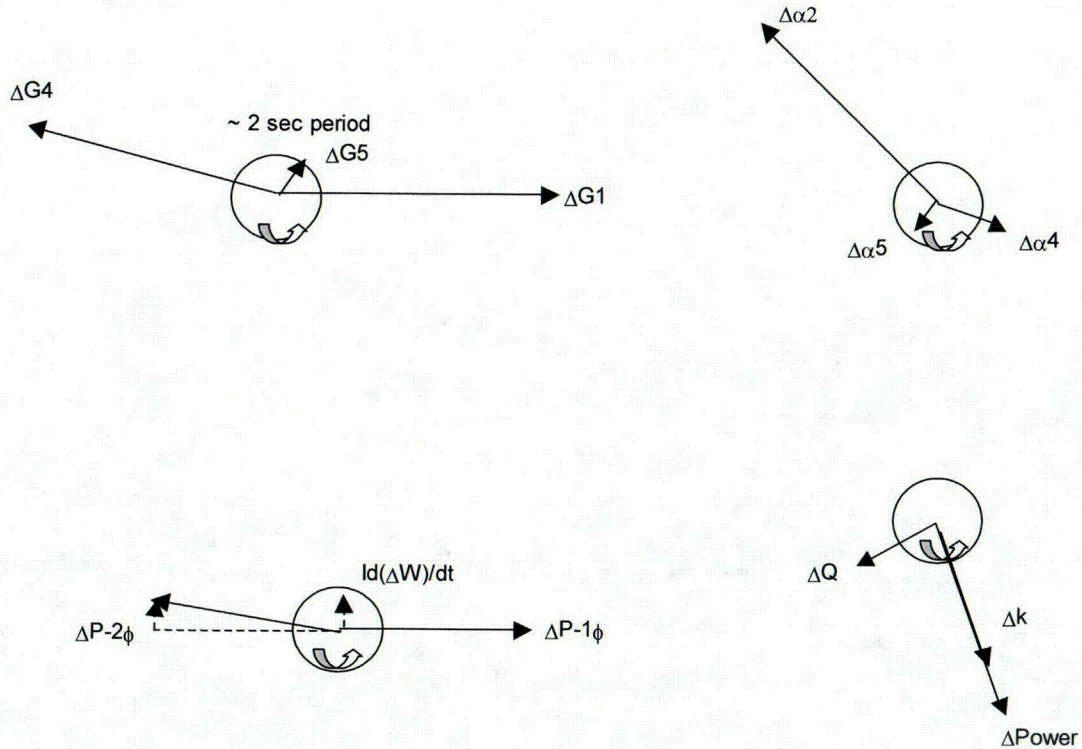
# Neutronic Feedback



# Stability Mode – Core Stability




ESBWR

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# Summary

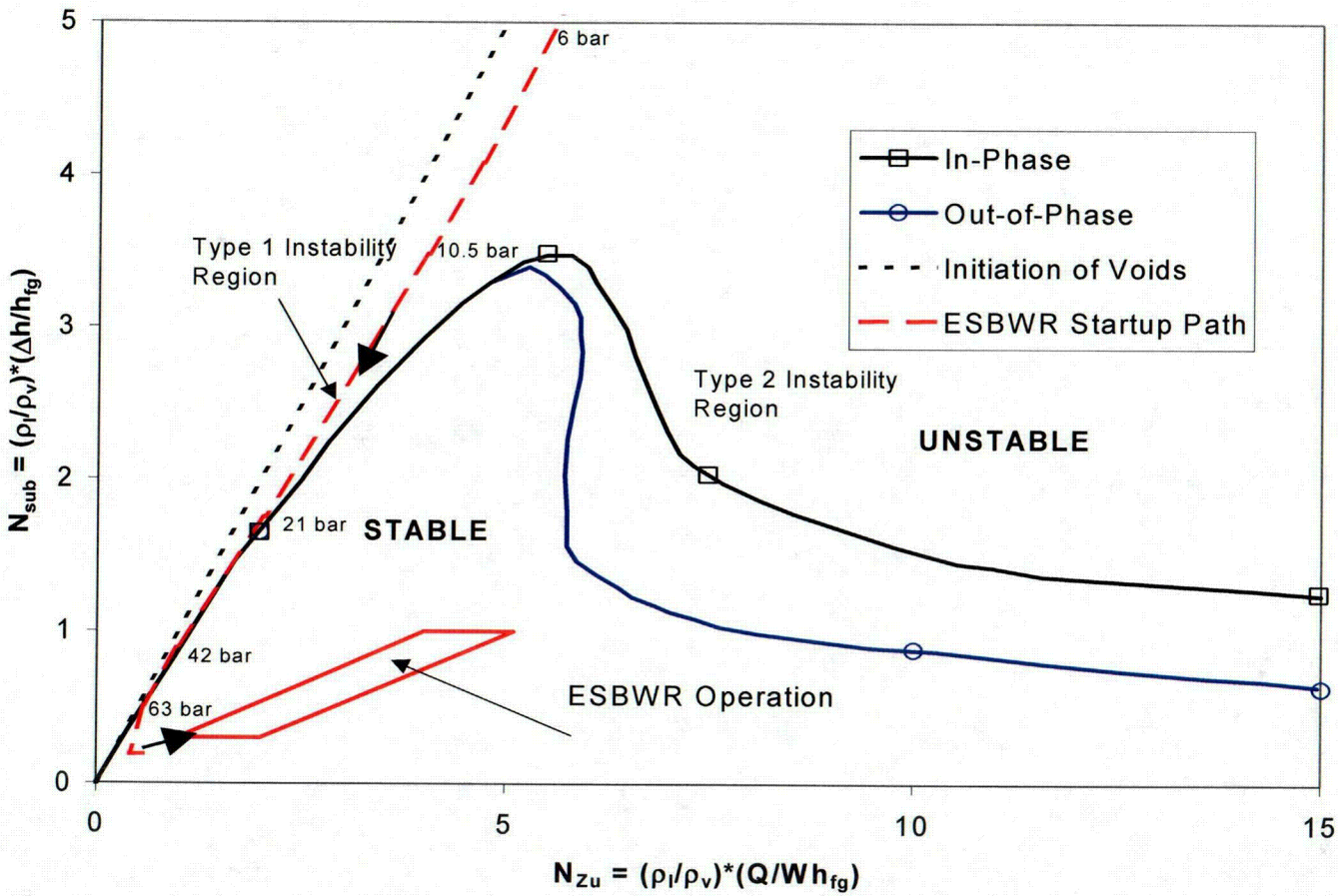
Density wave stability is driven by frictional pressure drops

- Height of chimney has minor impact
- Oscillation period determined by core transport time (~ 1 sec)

Type 1 stability is driven by static head differences at low flow rates and void fractions

- Height of chimney affects stability (flashing margin)
- Oscillation period determined by transport time through core and chimney (~ 15 sec)

# Type 1 and Type 2 Instability

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# Effect of Periodic Flow in Chimney

Chimney void fractions at rated conditions have a fraction ~ 0.75

Ontario Hydro data shows some periodicity in the void fraction measurements (peak–to-peak ~ 0.05 with a period of ~ 5 sec)

This periodicity is not captured in the TRACG analysis of churn-turbulent flow

# Effect of Periodic Flow in Chimney

Effect evaluated by imposing a sinusoidal perturbation on the inlet to the chimney

Pressure drop perturbations in the chimney calculated

Pressure drop perturbations of opposite sign imposed on channel to evaluate impact on inlet flow

# Decay Ratio Calculation

For complex systems, decay ratio not constant

- looking for 'dominant' decay ratio

Approach taken uses first two peaks in oscillation following initial response to perturbation

- Consistent method with consistent perturbation
- Provides a good basis for judging sensitivity to Monte Carlo trials, establishing uncertainty
- Determination has range of uncertainty, but not a major issue when oscillations are clearly damped