TRACG Application for ESBWR Stability -

LTR Review Kickoff Meeting

Open Session

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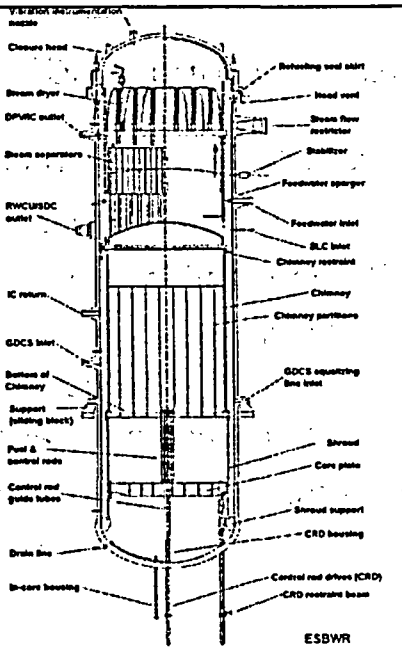
December 14, 2004



Imagination at work

Outline

- Purpose and Scope
- Licensing Requirements and Scope of Application
  - Proposed design bases
- TRACG Application Methodology
  - Compliance with CSAU
- Phenomena Identification and Ranking
- Model Applicability
  - Additional model qualification
- Model biases and uncertainties

Outline (continued)

- Plant parameters and initial conditions
- Combination of uncertainties
- Demonstration results
  - Nominal
  - Sensitivity studies
  - Monte Carlo calculations
- Discussion of plant startup

Purpose and Scope

TRACG04 is used for licensing analysis of ESBWR stability

- Demonstrate stability margins during normal operation and anticipated transients

TRACG04 is also used to analyze plant startup trajectories, to assure a smooth ascension in pressure and power with a minimum of flow oscillation. Large MCPR margins are demonstrated for the startup scenario.

GE requests NRC approval of TRACG for analyzing and demonstrating compliance with licensing limits for stability analysis for the ESBWR

Licensing Requirements

General Design Criterion 10 (Reactor Design) requires that:

"..specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences."

Criterion 12 (Suppression of Reactor Power Oscillations) requires that:

"power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed."

ESBWR Stability Licensing Basis

A high degree of confidence is established that oscillations will not occur by imposing conservative design criteria on the channel, core wide (and regional) decay ratios under all conditions of normal operation and anticipated transients.

- As a backup, the ESBWR will implement a Detect-and-Suppress solution as a defense-in-depth system.

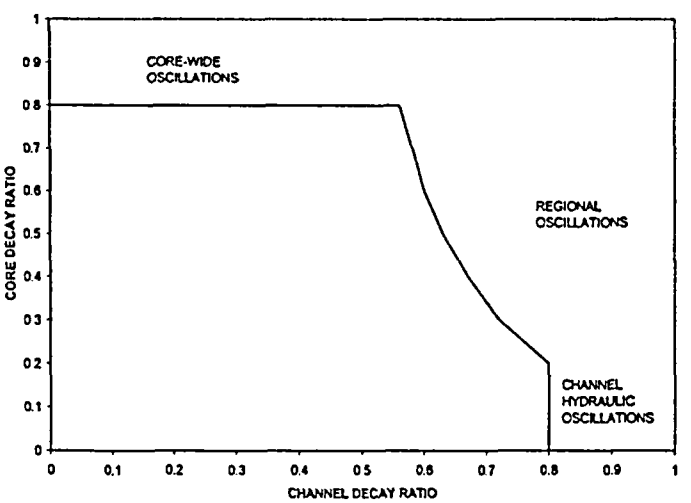
ESBWR Stability Design Criteria

Conventional stability map of core decay ratio vs. channel decay ratio is used

- Uncertainties and statistical limits are calculated for these parameters

Regional decay ratios are calculated for "nominal conditions" to demonstrate reasonableness of stability map

BWR Stability Design Criteria



ESBWR Stability Criteria

BWR design criteria evaluated and modified for ESBWR

TRACG Application Methodology

Calculate figures of merit (core and channel decay ratios) at limiting operating conditions

Statistically account for the uncertainties and biases in the models and plant parameters using a Monte Carlo method

- Normal Distribution One-Sided Upper Tolerance Limit (ND-OSUTL) if the output distribution is normal, or the Order Statistics method if it is not
- Demonstrate that decay ratios meet design criteria with sufficient margin for uncertainties (95/95 level)

Application Methodology (continued)

Uncertainties and biases considered include

- Model uncertainties
- Experimental uncertainties (inherent in data comparisons)
- Uncertainties related to test scale-up
- Plant uncertainties
- Process measurement errors
- Manufacturing tolerances

Conformance with CSAU Process

CSAU Step	Description	Addressed in
1	Scenario Specification	Normal operation, AOOs, plant startup
2	Nuclear Power Plant Selection	ESBWR 4500 MWt
3	Phenomena Identification and Ranking	Error! Reference source not found.
4	Frozen Code Version Selection	TRACG04
5	Code Documentation	References [1,2,6,7,11]
6	Determination of Code Applicability	Error! Reference source not found.
7	Establishment of Assessment Matrix	Error! Reference source not found.
8	Nuclear Power Plant Nodalization Definition	Section 5
9	Definition of Code and Experimental Accuracy	Section 5
10	Determination of Effect of Scale	Section 5
11	Determination of the Effect of Reactor Input Parameters and State	Section 6
12	Performance of Nuclear Power Plant Sensitivity Calculations	Section 8
13	Determination of Combined Bias and Uncertainty	Section 8
14	Determination of Total Uncertainty	Section 8

Sections & Table nos. refer to LTR

PIRT

- ESBWR stability PIRT builds on stability PIRT for operating plants in TRACG LTR supporting DSS-CD
- Differences highlighted in next chart

PIRT – Differences from Operating BWRs

LOWER PLENUM						
LOWER PLENUM RADIAL RESISTANCE	M	M	M	M	1	Affects natural circulation flow
BYPASS						
AXIAL AND RADIAL RESISTANCES	M	M	M	M	1	Affects bypass and chimney flow distribution
CORE / BUNDLE						
DOPPLER COEFFICIENT	NA	L	L	L		No fuel temperature changes in the absence of oscillations
MARGIN TO DRYOUT-BT (steady-state and transient effects)	L	L	L	L		Criteria based on margin to stability. margin to dryout not impacted.
CHIMNEY & UPPER PLENUM						
VOID DISTRIBUTION	H	H	H	H	1	Affects natural circulation flow
FLOW OSCILLATION DURING STARTUP	NA	NA	NA	NA		See Section 9 for discussion of plant startup.
INTERACTIONS BETWEEN CHIMNEY CELLS	H	H	H	H	1	Affects stability of 16 bundles together with a chimney cell
SEPARATOR						
SEPARATOR UA	L	L	L	L		Not important for small perturbations at low frequency.

Applicability of TRACG for ESBWR Stability Analysis

TRACG models adequate – Model LTR, Section 4

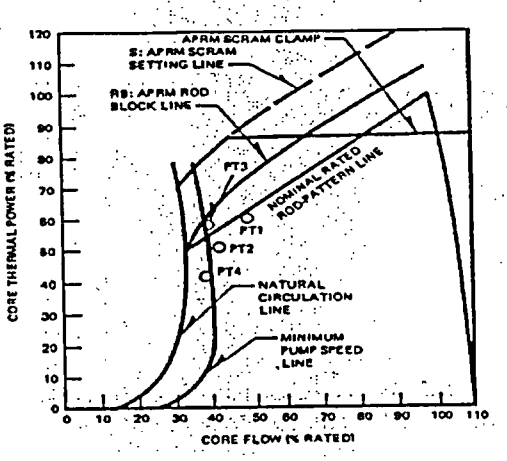
TRACG qualified vs extensive data base

- Separate effects, component, integral tests, BWR transient and stability data
- Additional qualification performed vs. low decay ratio plant tests

TRACG Qualification (Sample)

ID	REGION or PHENOMENA DESCRIPTION	Channel Thermal Hydraulic Stability	Core-wide Stability	Regional Stability	Higher Modes	Critical Safety Parameter	1. Decay Ratio - controls stability margin/growth rate of perturbations COMMENTS	Qualification Basis Reference to Section Number in the TRACG Qualification, LTR NEDE-32177, (Reference 3) Separate Effects Qualification	Component Performance Qualification	Integral System Qualification	Plant Data Qualification
A	LOWER PLENUM										
A19	LOWER PLENUM RADIAL RESISTANCE	M	M	M	M		Affects natural circulation flow				
B	BYPASS										
B2	VOID FRACTION	L	M	M	M		Bypass voiding affects overall void coefficient	3.1.5, 3.4.2		5.1.2, 5.1.3, 5.1.6, 5.2.2	
B13	DIRECT MODERATOR HEATING	NA	M	M	M		Affects bypass void and core void coefficient				7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7
B14	AXIAL AND RADIAL RESISTANCES	L	M	M	M		Determines shortwave and bypass flow distribution				
C	CORE/FUEL										
C1AX	VOID COEFFICIENT	NA	H	H	H	1	Determines reactivity and power due to void fraction change. Determines forward loop "gain" for void perturbations				7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9
C1BX	DOPPLER COEFFICIENT	NA	M	M	M		Determines reactivity and power due to fuel temperature change.	3.3			7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9
C1DX	3-D KINETICS	NA	M	H	H	1	Power distribution from 3D reactivity distribution affects total power, hot region power, axial power shape and CPR. 3D effects primarily important for regional evaluations				7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9
C1EX	DELAYED NEUTRON FRACTION	NA	H	H	H	1	Improves stability by reducing prompt gain	3.3			7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9
C1FX	SUBCRITICALITY OF FIRST HARMONIC MODE	NA	L	H	H	1	Represents "damping" effects thermal hydraulic gain for regional modes				7.5, 7.7

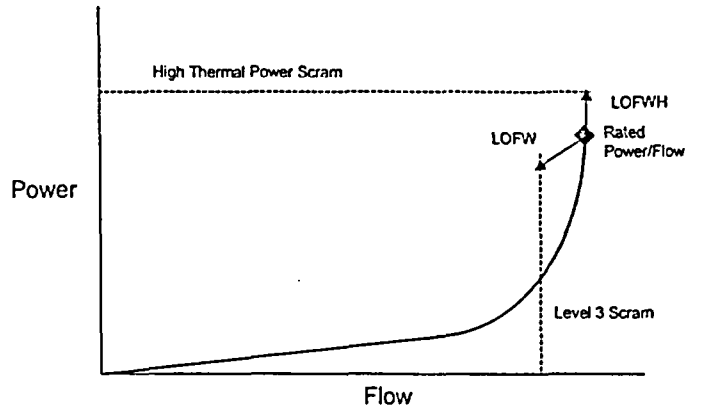
TRACG Qualification vs. PB2 Stability Tests



Results of Peach Bottom Qualification

TRACG calculated Beach Bottom results with acceptable accuracy

Limiting Conditions for Stability



Types of Stability Analyses

Single channel hydrodynamic analysis

- Flow response to inlet flow perturbation to single channel in core

"Super Bundle" hydrodynamic analysis

- Flow response to inlet flow perturbation to group of 16 bundles under common chimney partition cell

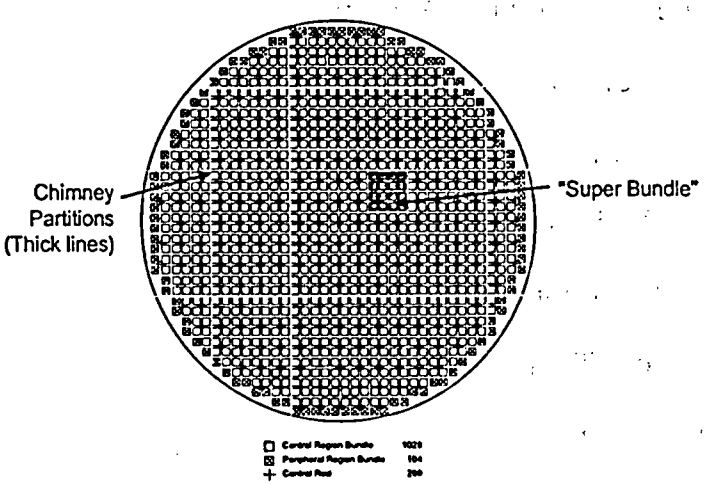
Core stability

- Power response to core wide pressure perturbation

Regional stability

- Power response to symmetric out-of-phase flow perturbations

Top View of Chimney and Core Region



Design Criteria

$$OSUTL - DR_{CH\,95,95} =$$
$$DR_{CH} + z_{95,95} \cdot s_{DR-CH} < Design\ Limit$$

$$OSUTL - DR_{Core95,95} =$$
$$DR_{Core} + z_{95,95} \cdot s_{DR-Core} < Design\ Limit$$

Demonstration Calculations

Nodalization For Stability Analysis

Channel Grouping

Initial Conditions

Core-wide & Channel Stability

Sensitivity to Channel Grouping

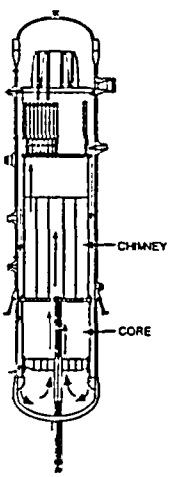
Sensitivity to Initial Perturbation

Regional Stability

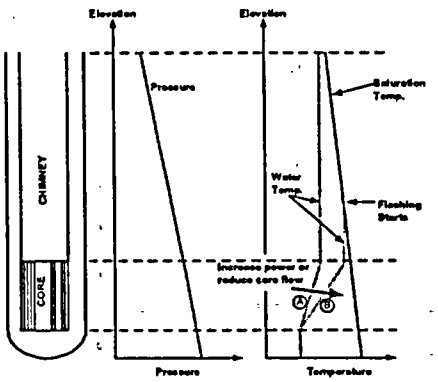
PIRT Analysis & Monte-Carlo Analysis

Startup - Background

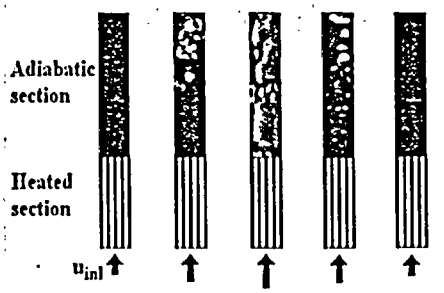
- **ESBWR natural circulation startup**
  - –Generally follow established procedure from Dodewaard plant
  - –Heat up reactor coolant to ~ 80 - 90 C with Shutdown Cooling System auxiliary heater and decay heat
  - –Deaerate reactor coolant by drawing vacuum on main condenser with steam drain line open
  - –Withdraw control rods to criticality
  - –Increase power at controlled heatup rate
  - –As pressure increases, open turbine bypass valve to control pressure



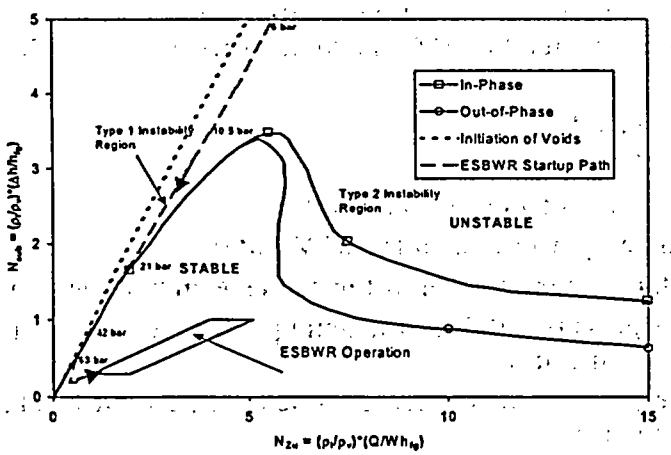
Pressure and Temperature at Startup Pressures



Dynamic conditions

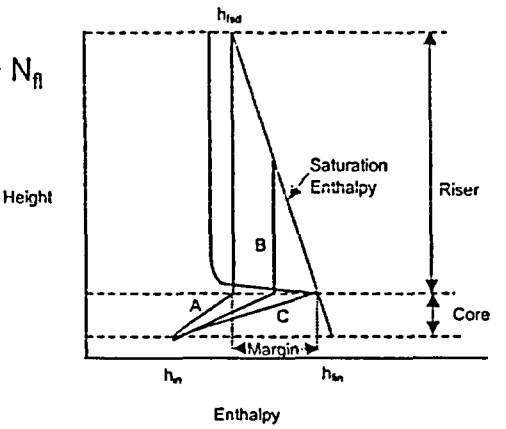


Generalized Stability Map and Plant Startup



Enthalpy Profiles for Different Heatup Rates

Path A : $N_{Zu} = N_{sub}$
Path B: $N_{sub} < N_{Zu} < N_{sub} + N_{fl}$
Path C: $N_{Zu} = N_{sub} + N_{fl}$



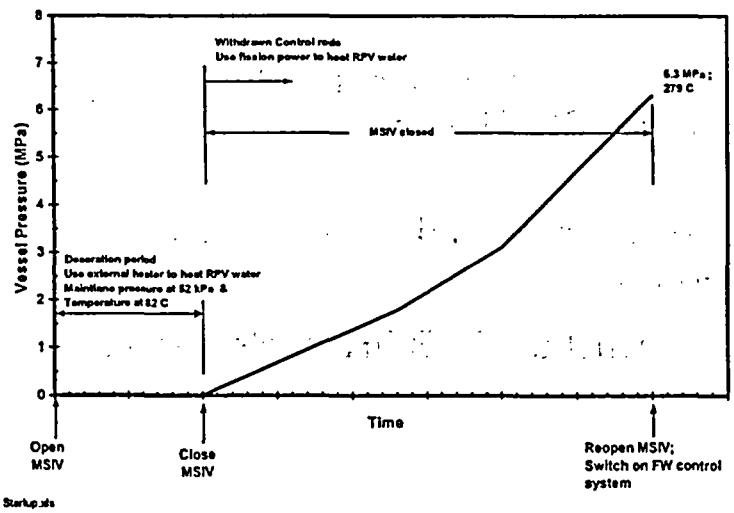
Startup Procedure

- Deaeration period
  - Use mechanical pump to pull vacuum
  - Use external heater and decay heat to maintain water temperature at 80 C (180 F) and pressure at 52 kPa (7.5 psia)
- Startup period
  - Close MSIV
  - Withdraw control rods to criticality
  - Use fission power to heat the RPV water
  - Maintain water level below the main steam line elevation
  - RPV is pressurized due to steaming at the free surface (at top of separators)
  - Core region remains subcooled due to large static head at low pressures

Startup Procedure

- Use RWCU (Reactor Water Cleanup/Shutdown Cooling System) to enhance coolant flow and reduce thermal stratification
- Reopen MSIV at the end of startup period (~ 6.3 MPa, 279 C),
  - open bypass valves to maintain RPV pressure
  - increase RPV power and prepare to roll turbine

ESBWR Startup Procedure



Results of TRACG Calculations

TRACG calculates small flow oscillations when voiding begins in the separators

- During this phase,
  - Core flow is single phase
  - No oscillations in neutron flux
  - Large thermal margins (CPR >30)
- Large power level (2.5 times expected) can lead to early core voids and larger condensation-induced oscillations
  - Beyond design heatup rates

Stable void fraction established in separators and chimney

Smooth ascension to rated pressure and power

Startup flow oscillations pose no threat to any thermal limits

Conclusion

Application Methodology for stability analysis consistent with CSAU approach for realistic analysis

- Accounts for model and plant parameter uncertainties

Results demonstrate ESBWR meets design criteria