ENCLOSURE 2

MFN 06-035

Presentation Regarding TRACG Application for ESBWR Stability

ACRS Thermal-Hydraulic Phenomena Subcommittee

January 19, 2006

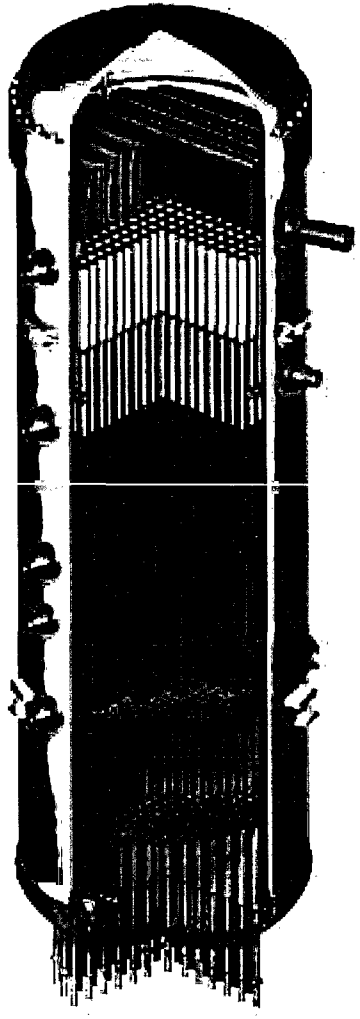
NON PROPRIETARY VERSION

TRACG Application for ESBWR Stability

ACRS Thermal-Hydraulic Phenomena Subcommittee

Bharat Shiralkar

January 19, 2006



imagination at work

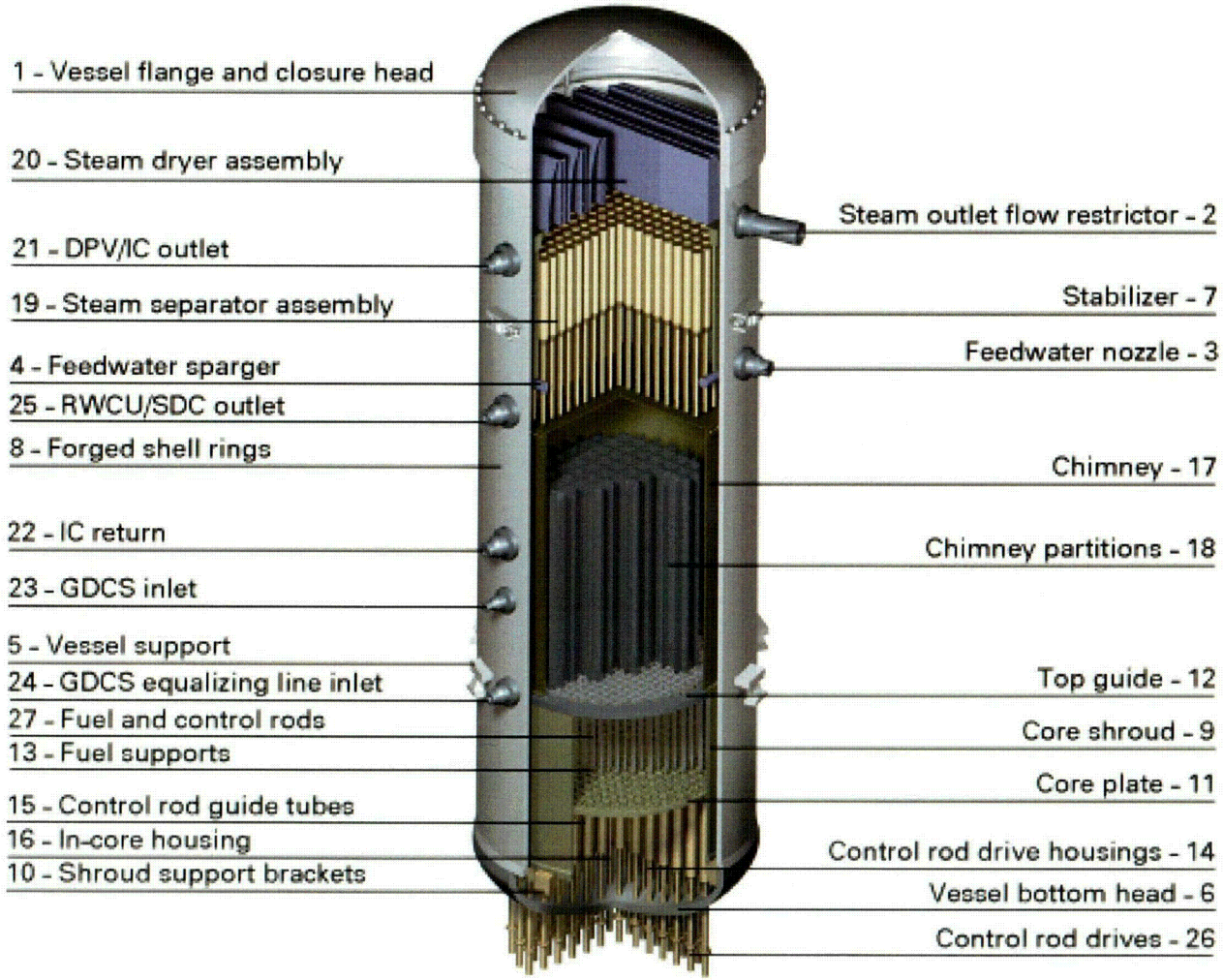
Outline

- Background
- LTR 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 *(Prop. Session)*

Outline (continued)

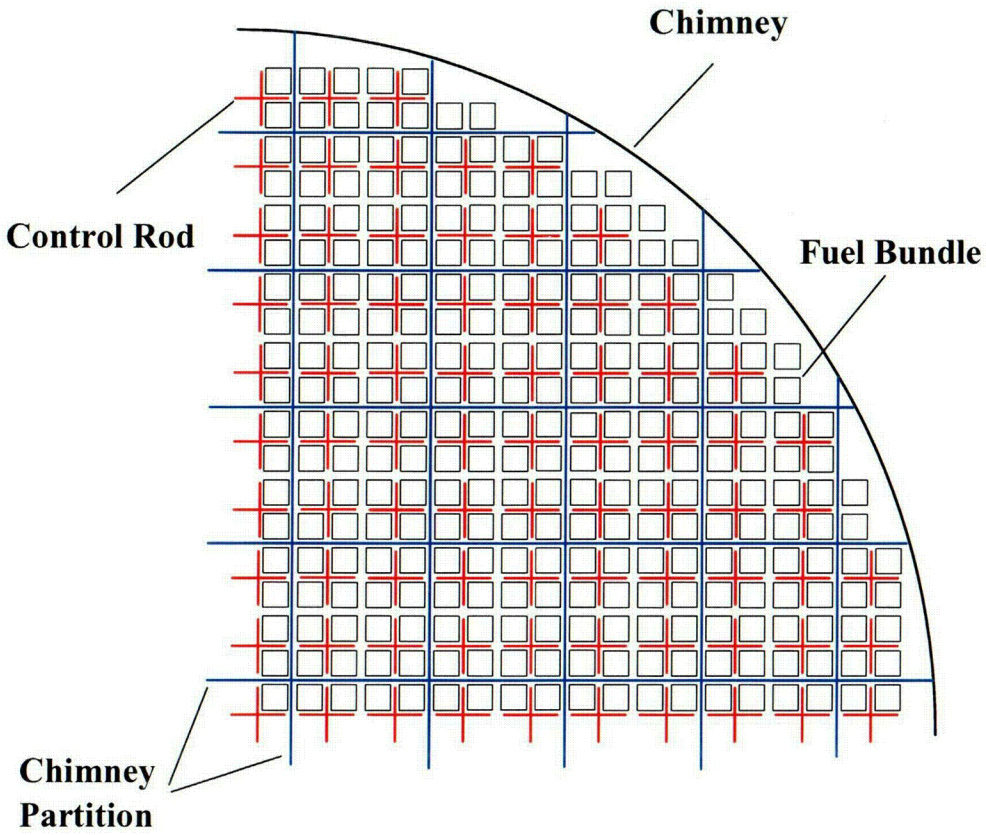
- Model biases and uncertainties *(Prop. Session)*
- Plant parameters and initial conditions *(Prop. Session)*
- Combination of uncertainties *(Prop. Session)*
- Demonstration results *(Prop. Session)*
  - Nominal
  - Monte Carlo calculations
- Discussion of plant startup

ESBWR Reactor Assembly Numbered

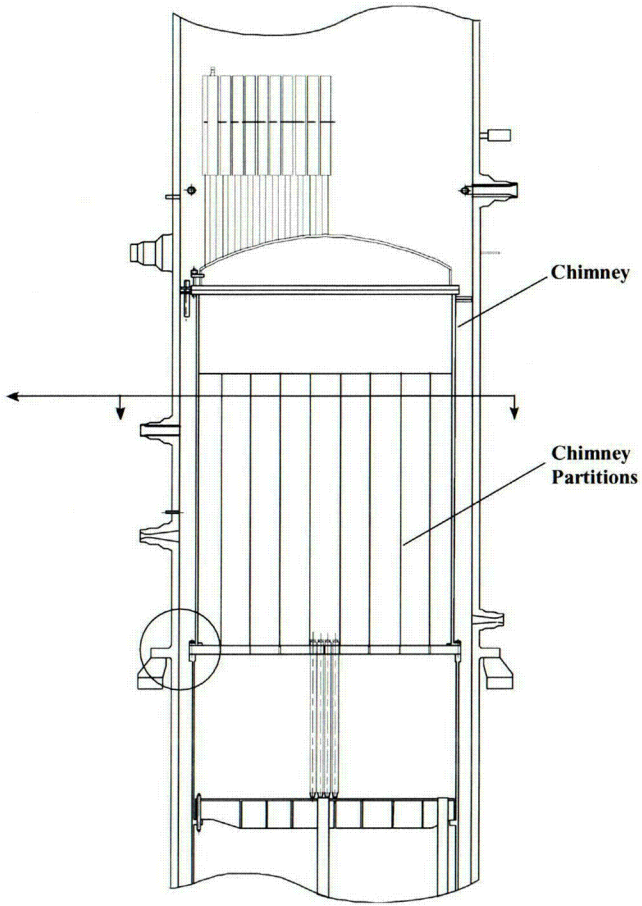


C01

ESBWR Chimney and Partitions



ESBWR 1/4 Core Map



C02

Background

Types of Instability analyzed

ESBWR Natural Circulation performance

Comparison with operating plants

Types of Instability Analyzed

Channel hydrodynamic oscillations

- Density wave propagation
- Constant channel pressure drop
- No power oscillations

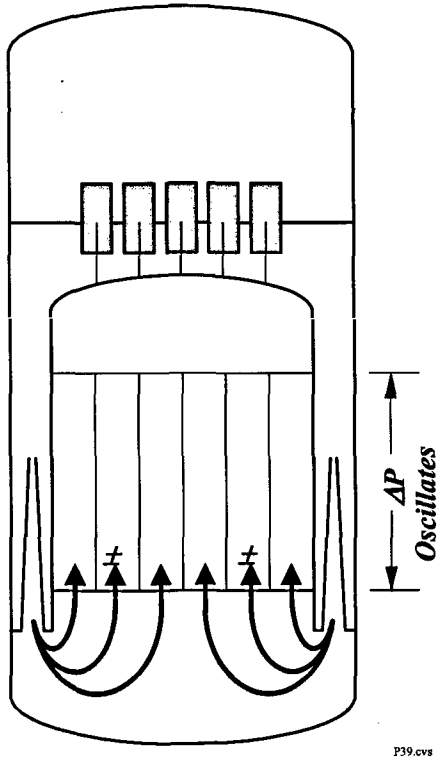
Core wide oscillations

- Depend on neutronics fundamental mode response to moderator density changes and thermal hydraulic effects
- Fluxes and flows oscillate in-phase across the core

Regional oscillations

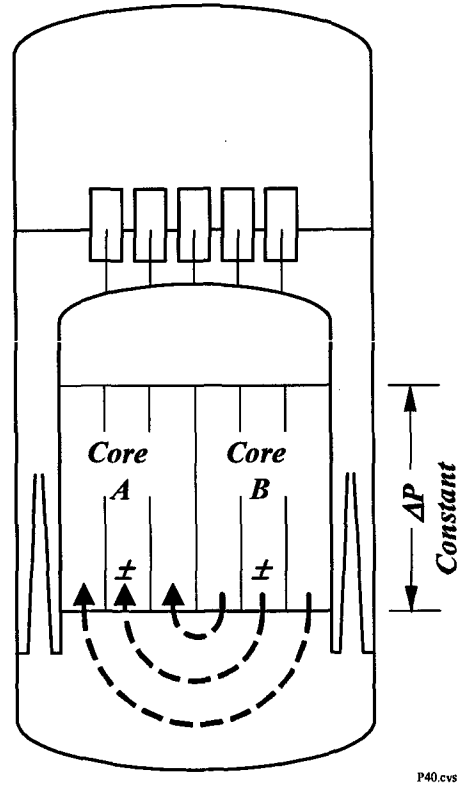
- Depend on channel hydrodynamics exciting higher modes of neutronics (March-Leuba, 1981)
- Fluxes and flows in regions oscillate out-of-phase with other symmetrically located regions

Core Wide Oscillations



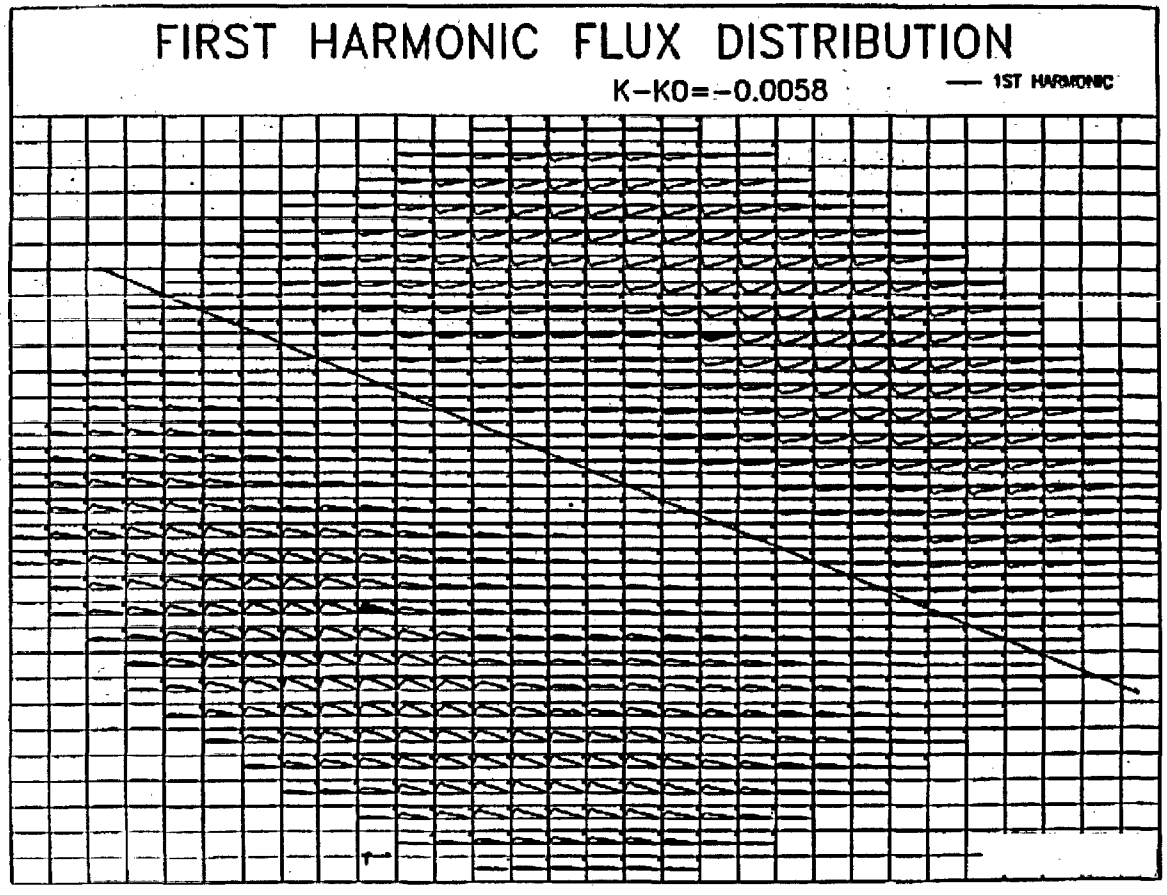
- ***Flow and power oscillations are in-phase across core***
- ***Excites fundamental mode of neutronics***

Regional (Out-of-phase) Oscillations

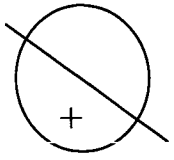
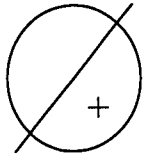
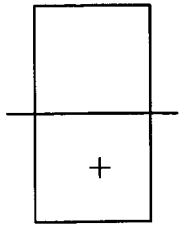
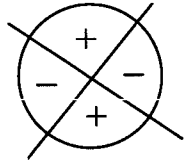
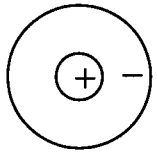


- *Different regions of core oscillate out-of-phase*
- *Total core flow and power almost constant*
- *Large local oscillations in power possible*
- *Excites higher order neutronic modes*

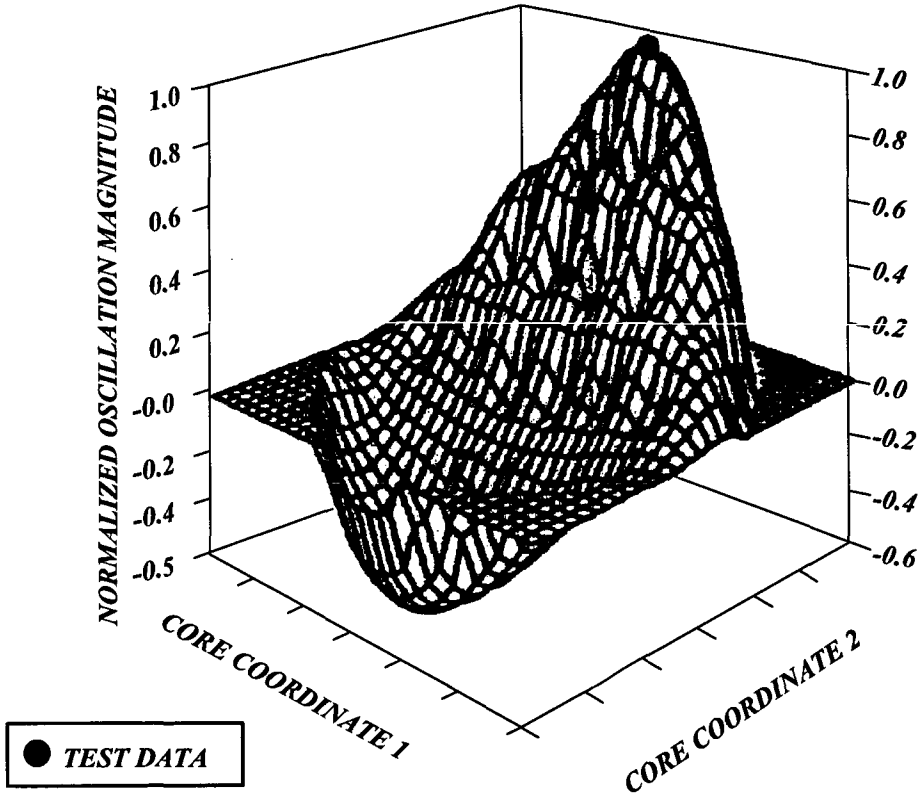
First Harmonic Flux Distribution

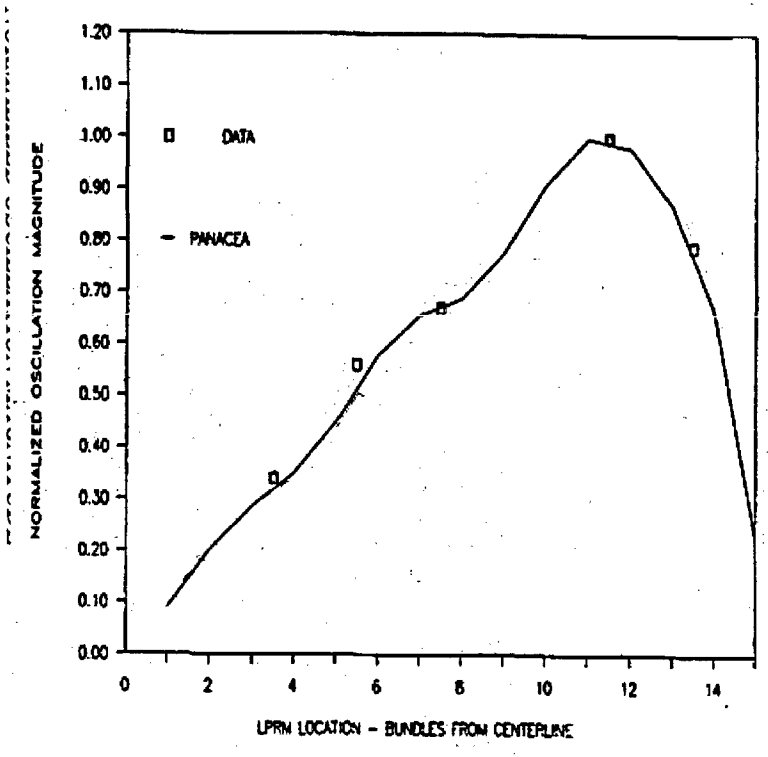


Subcriticality for Various Harmonic Modes (typical)

	Mode	Eigenvalue Separation
	Azimuthal	- 0.85 $
	Azimuthal	- 0.85 $
	Axial	- 1.5 $
	Azimuthal Higher Order	- 2.1 $
	Radial	- 4.1 $

Prediction of Regional Oscillation





Harmonics drive regional oscillations

ESBWR Natural Circulation Calculation

Core flow depends on

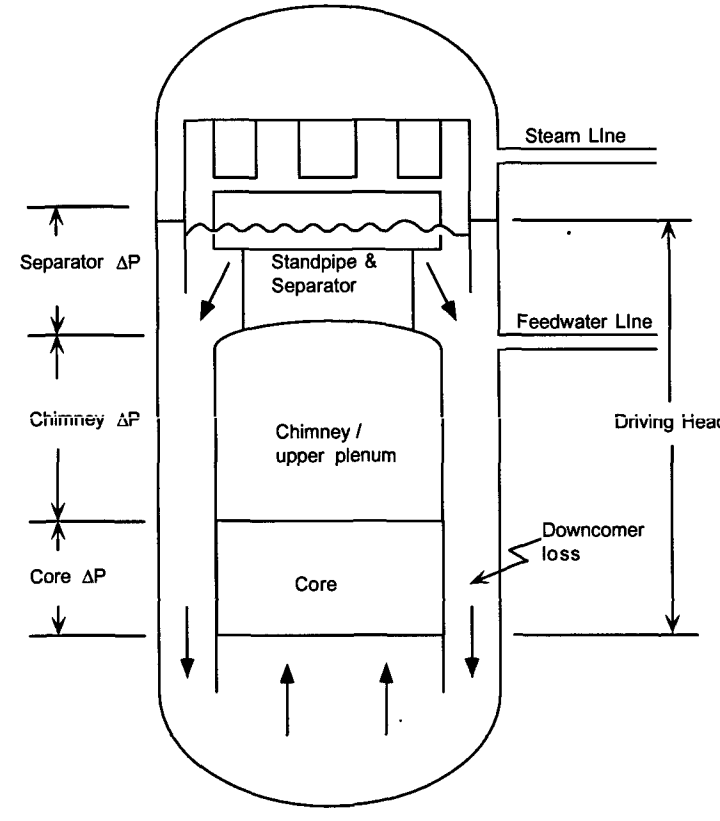
- losses through the loop
- driving head

Loop losses

- downcomer ~ small in ESBWR
  - **Single-phase Δp**
- core (fuel bundle)
  - **SEO, Core two-phase Δp (data)**
- chimney ~ small
- Separator
  - **Two-phase Δp (data)**

Driving head

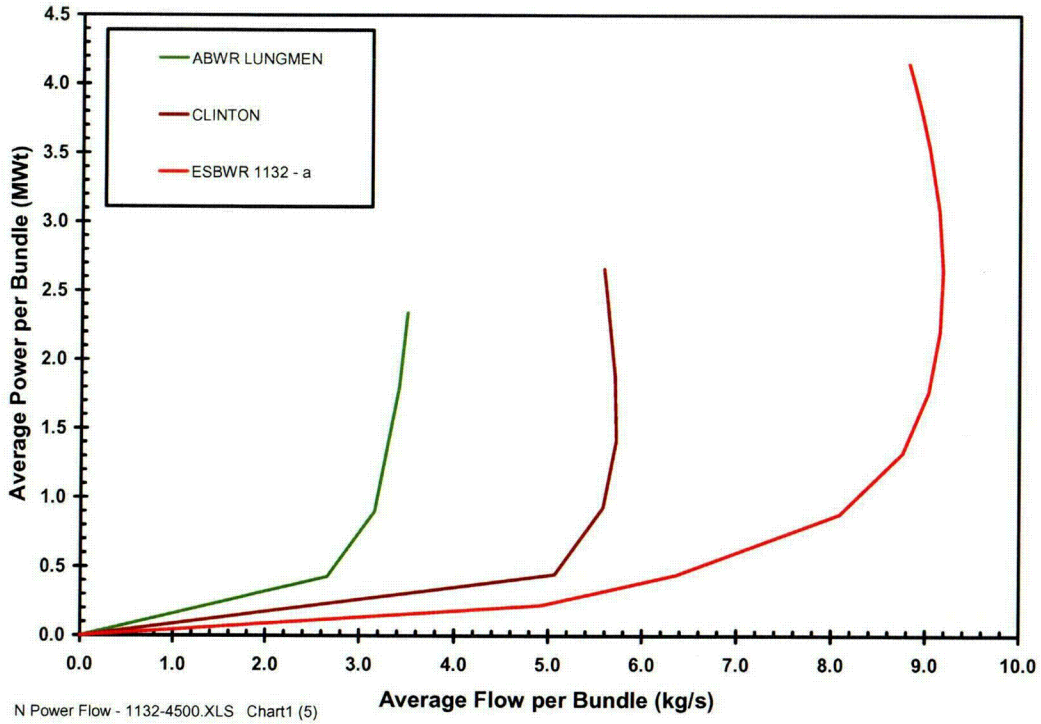
- proportional to core + chimney height
  - **Void Fraction (data in large pipes)**

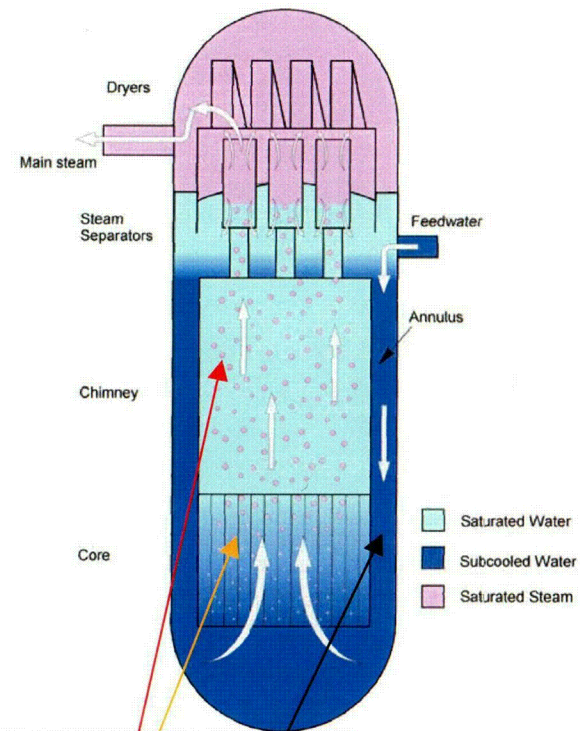


Schematic of Flow and Pressure Drops in a Reactor

Core flow uncertainty (1σ) ~ 3-4%

Enhanced Natural Circulation





- Higher driving head
  - Chimney/taller vessel
- Reduced flow restrictions
  - Shorter core
  - Open downcomer

C03

Factors Important to Stability

Power/flow ratio (Zuber number)

Fuel thermal time constant

Neutronic parameters

- Void coefficent
- Direct moderator heating

Axial and radial peaking

Ratio of single-phase to two-phase pressure drop

Subcriticality of higher harmonic neutronics mode

Range of ESBWR Parameters versus Operating Reactors

KEY PARAMETRS AFFECTING STABILITY	Range of values in plant data	Range of values for ESBWR	Comment
DYNAMIC VOID COEFFICIENT	-5 to -19 c/% *rated void*	-7 to -10 c/% *rated void*	In range
CORE AVERAGE EXIT QUALITY (RATIO OF CORE POWER TO CORE FLOW)	~ 0.30 at natural circulation	< 0.25	Favorable
HOT BUNDLE EXIT QUALITY (RATIO OF HOT BUNDLE POWER TO BUNDLE FLOW)	~ 0.40 at natural circulation	< 0.35	Favorable
RATIO OF FUEL TIME CONSTANT TO FLOW TRANSIT TIME	3.5 to 6	~ 6 to 7	Favorable
RATIO OF HARMONIC SUB-CRITICALITY TO DELAYED NEUTRON FRACTION	> $1	$ 0.75 to $ 0.95	Unfavorable
RATIO OF SINGLE PHASE TO TWO-PHASE PRESSURE DROP	0.3 to 0.45	0.55	Favorable

Improved stability relative to operating BWRs at natural circulation

LTR 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.

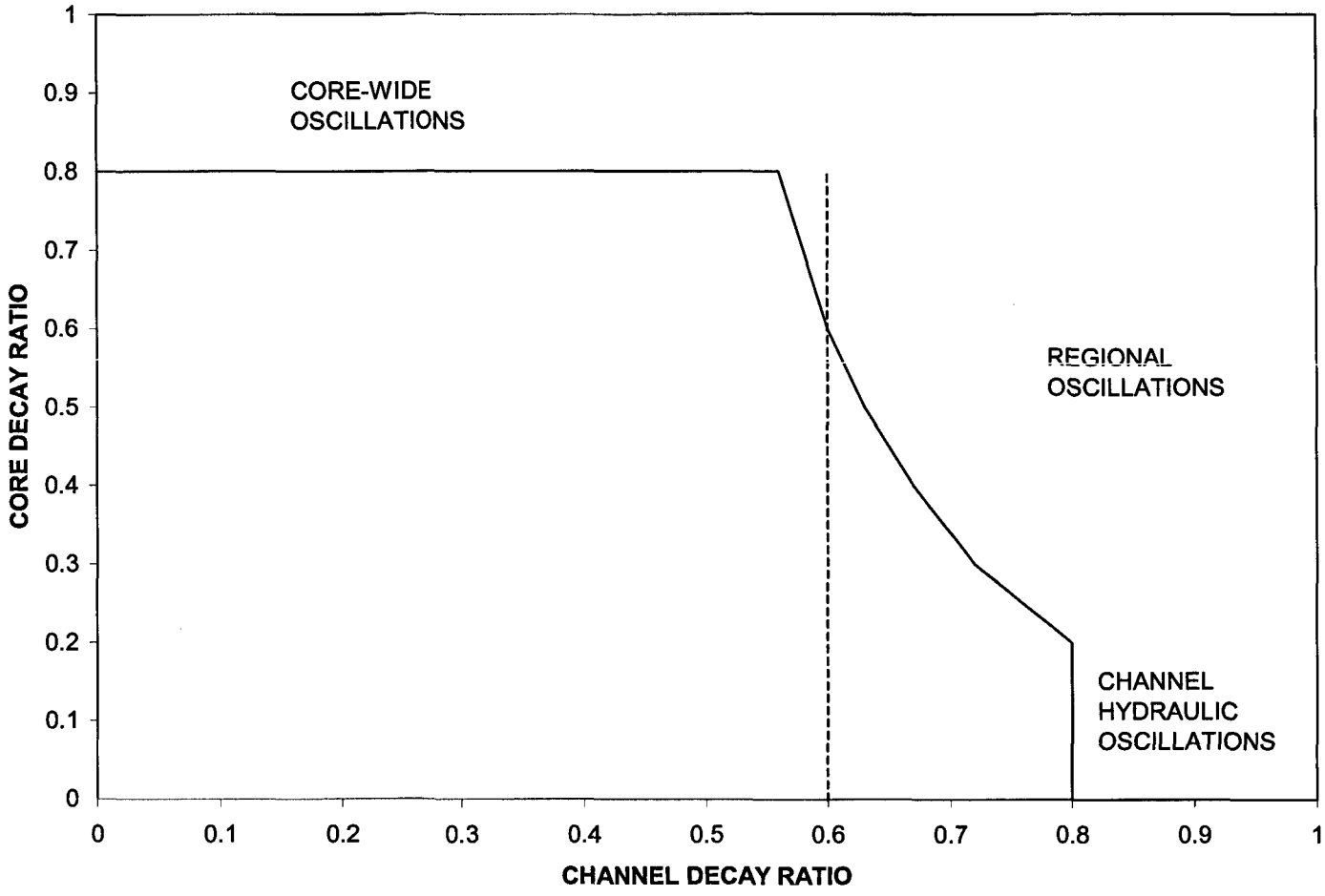
ESBWR Stability Design Criteria

Conventional "stability map" of core decay ratio vs. channel decay ratio was used

- Uncertainties and statistical limits are calculated for these parameters

BWR stability map was modified to account for ESBWR core size

BWR Stability Design Criteria

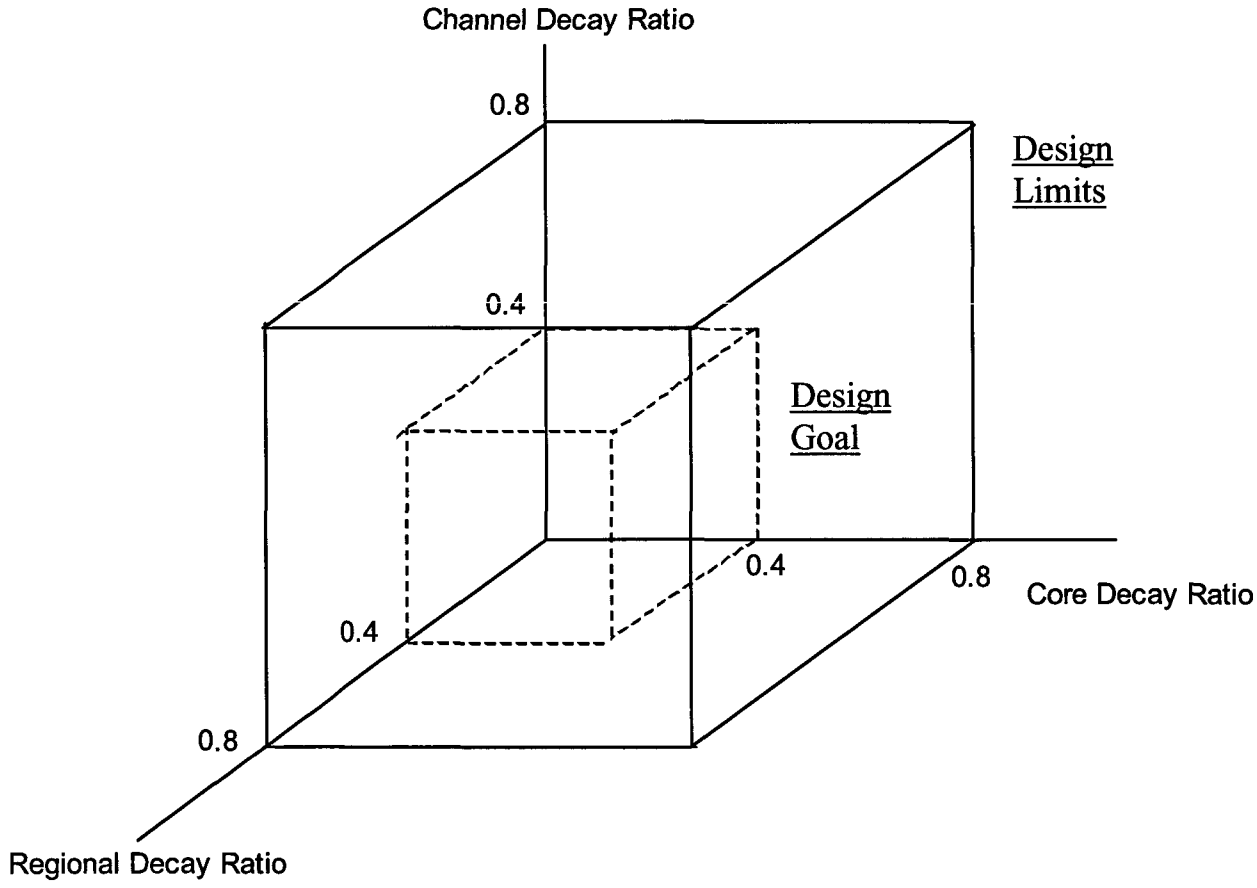


Revised Stability Criteria

As a result of NRC review, stability criteria for ESBWR have been revised

- Direct calculation of regional decay ratio
- Quantification of uncertainty in regional decay ratio
- Comparison with a requirement for regional decay ratio < 0.8

Revised ESBWR Stability Design Criteria



TRACG Application Methodology

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

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

- 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)
- Plant parameter variability
  - » Range of operation
  - » Process measurement errors

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	Table 3.1-1
4	Frozen Code Version Selection	TRACG04
5	Code Documentation	References [1,2,6,7,11]
6	Determination of Code Applicability	Table 4.2-1
7	Establishment of Assessment Matrix	Table 4.2-2
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

ID	GOVERNING PHENOMENA	Channel Thermal Hydraulic Stability	Core wide Stability	Regional Stability	Highest Ranking	Critical Safety Parameter	1. Decay Ratio - controls stability margin/growth rate of perturbations COMMENTS
C1AX	VOID COEFFICIENT	NA	H	H	H	1	Determines reactivity and power due to void fraction change. Determines forward loop "gain" for void perturbations.
C1DX	3-D KINETICS (CORE POWER DISTRIBUTION DURING TRANSIENT)	NA	M	H	H	1	Power distribution from 3D reactivity distribution affects total power, hot region power, and axial power shape. 3D effects primarily important for regional evaluations.
C1EX	DELAYED NEUTRON FRACTION	NA	H	H	H	1	Improves stability by reducing prompt gain
C1FX	SUBCRITICALITY OF FIRST HARMONIC MODE	NA	L	H	H	1	Neutronics "damping" offsets thermal hydraulic gain for regional mode.
C2AX	INTERFACIAL SHEAR	H	H	H	H	1	Determines void fraction which affects void *reactivity and void propagation*
C2BX	SUBCOOLED VOID MODEL	H	H	H	H	1	Determines void fraction for subcooled boiling. Void initiation determines boiling boundary and two-phase region.
C3AX	PELLET HEAT DISTRIBUTION	L	H	H	H	1	*Affects fuel rod power, temperature and* surface heat flux. Determines effective fuel time constant.
C3BX	PELLET HEAT TRANSFER PARAMETERS	L	H	H	H	1	Affects fuel rod power, temperature and surface heat flux. Determines effective fuel *time constant.*
C3CX	GAP CONDUCTANCE	L	H	H	H	1	Affects fuel rod power, temperature and surface heat flux. Determines effective fuel time constant.
C8	*MULTIPLE CHANNEL EFFECTS*	*H*	*H*	*H*	*H*	1	*Affects channel flow distribution*
C10	VOID DISTRIBUTION, AXIALLY AND BETWEEN CHANNELS	H	H	H	H	1	Determines void fraction, which affects fluid volume, void reactivity and power.
C11	BUNDLE-BYPASS LEAKAGE FLOW	H	H	H	H	1	Affects channel flow and voids.
C12	NATURAL CIRCULATION FLOWS	H	H	H	H	1	Affects channel flow.
C24	CORE PRESSURE DROP	H	H	H	H	1	Affects channel flow.

PIRT (continued)

DERIVED CORE STABILITY PARAMETERS						These are parameters relevant to stability that are derived from basic PIRTs
RATIO OF CORE POWER TO CORE FLOW	L	H	H	H	1	Determines core quality; known to be key parameter for core stability. This parameter primarily depends on the parameters that determines the core flow (C1DX, C2AX, C12, C24, E2, F1, I1 and I3)
RATIO OF HOT BUNDLE POWER TO BUNDLE FLOW	H	M	H	H	1	Determines hot bundle quality; known to be key parameter for channel stability. This parameter primarily depends on the parameters that determine the hot bundle flow (C1DX, C2AX, C8, C12, C24, E2, F1, I1 and I3)
RATIO OF FUEL TIME CONSTANT TO FLOW TRANSIT TIME	L	H	H	H	1	Determines phase lag and gain due to fuel rod heat transfer. This parameter primarily depends on the parameters that determine the core flow (C1DX, C2AX, C12, C24, E2, F1, I1 and I3) and fuel heat transfer parameters (C3AX, C3BX, C3CX, C1 and C2)
RATIO OF HARMONIC SUB-CRITICALITY TO DELAYED NEUTRON FRACTION	NA	L	H	H	1	Determines neutronic damping to be overcome by thermal hydraulic gain for regional mode. This parameter is the ratio of C1FX to C1EX
RATIO OF SINGLE PHASE TO TWO-PHASE PRESSURE DROP	H	H	H	H	1	Determines thermal hydraulic stability. This parameter primarily depends on the parameters that determine the distribution of channel pressure drop (C24 which consists of wall friction and form losses in the SEO, LTP, spacers and UTP)
DOWNCOMER ANNULUS						
VOID PROFILE / TWO-PHASE LEVEL	H	H	H	H	1	Water level affects natural circulation flow.
CHIMNEY & UPPER PLENUM						
VOID DISTRIBUTION	H	H	H	H	1	Affects natural circulation flow
INTERACTIONS BETWEEN CHIMNEY CELLS	H	H	H	H	1	Affects stability of 16 bundles together with a chimney cell
SEPARATOR						
SEPARATOR PRESSURE DROP	H	H	H	H	1	Affects total core flow and level. Separator pressure drop affects core stability evaluation.

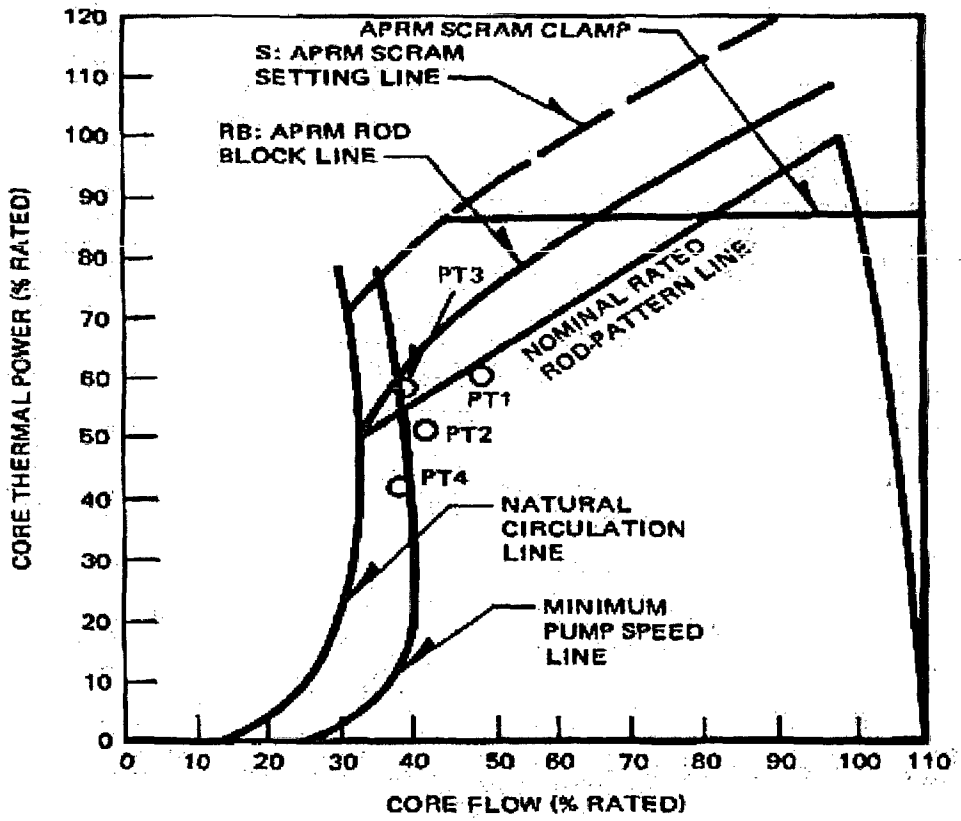
Applicability of TRACG for ESBWR Stability Analysis

TRACG models adequate – Model LTR, Section 4

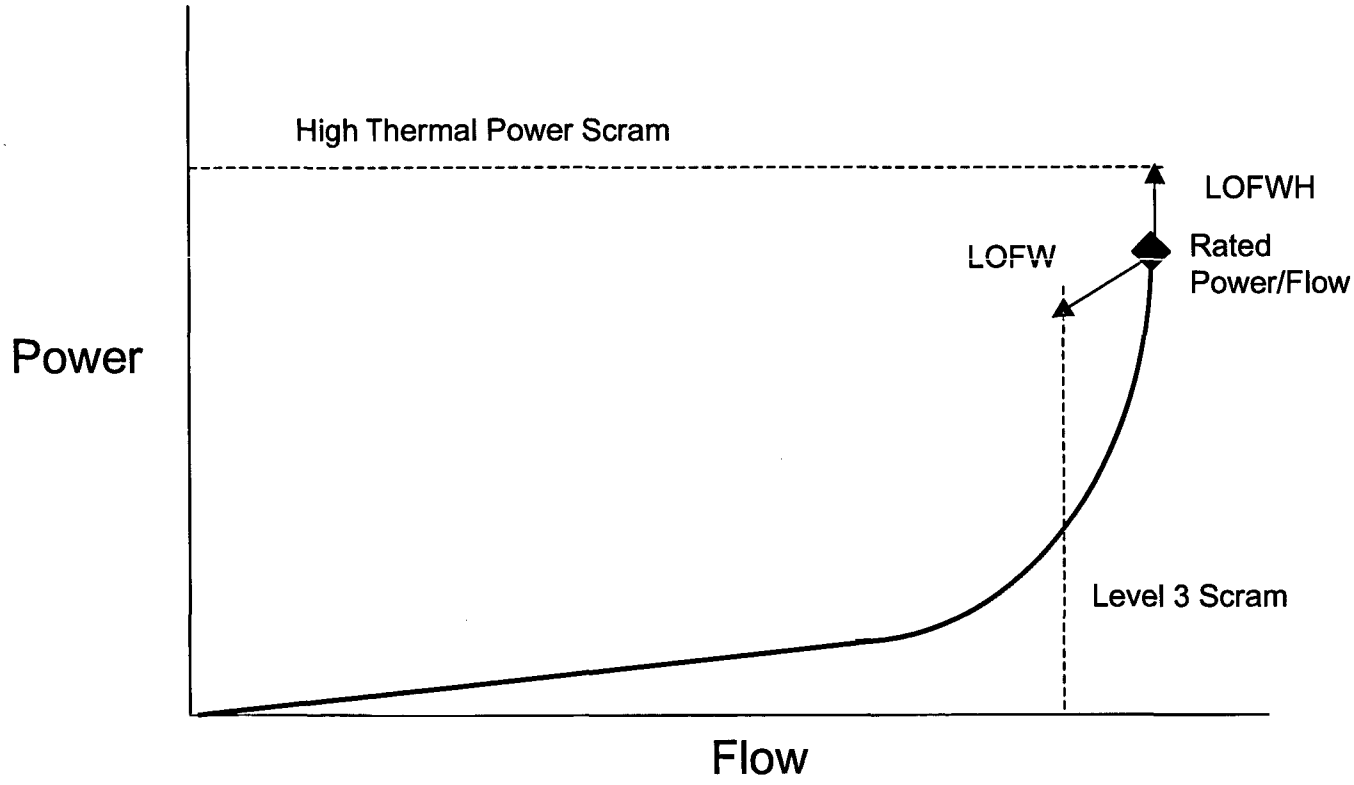
TRACG qualified vs extensive data base

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

TRACG Qualification vs. PB2 Stability Tests



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

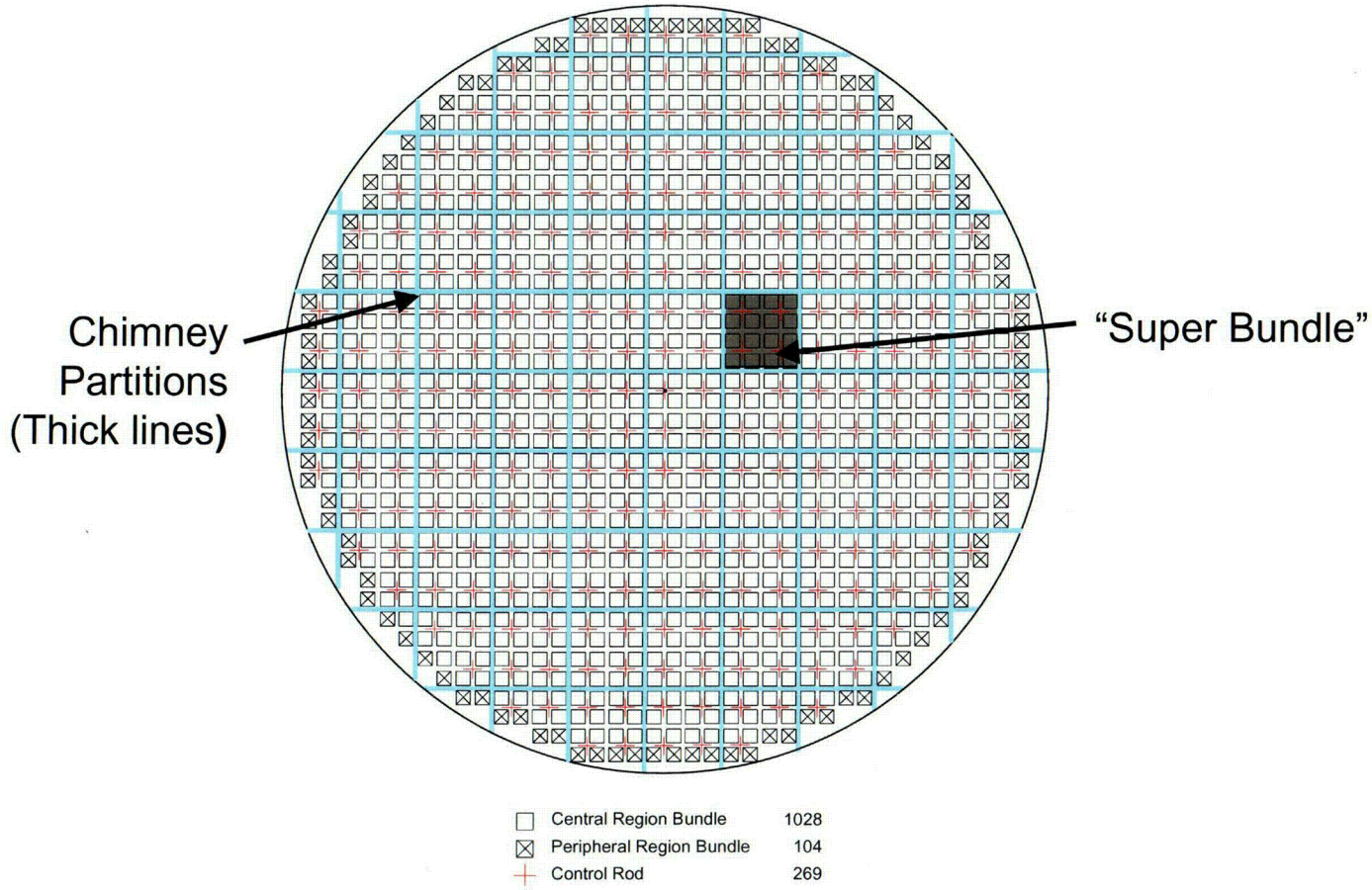
Core stability

- Power response to core wide pressure perturbation

Regional stability

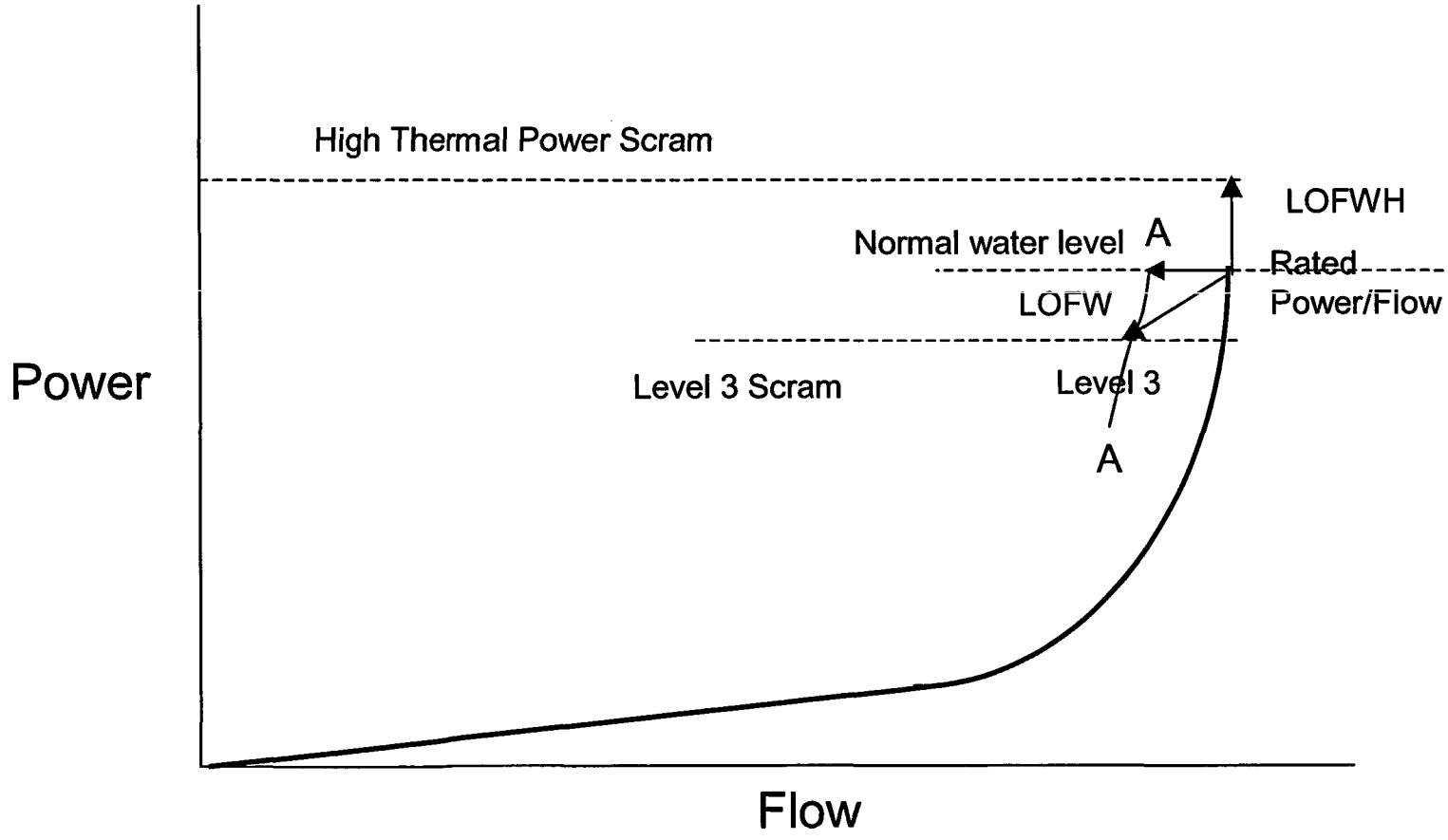
- Power response to symmetric out-of-phase flow perturbations

Top View of Chimney and Core Region



C04

Stability following AOOs



Conclusion

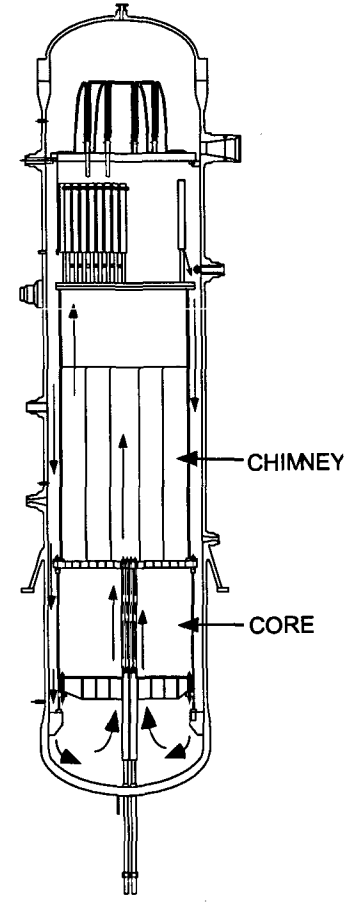
Application Methodology for stability analysis consistent with CSAU approach for realistic analysis

- Accounts for model and plant parameter uncertainties

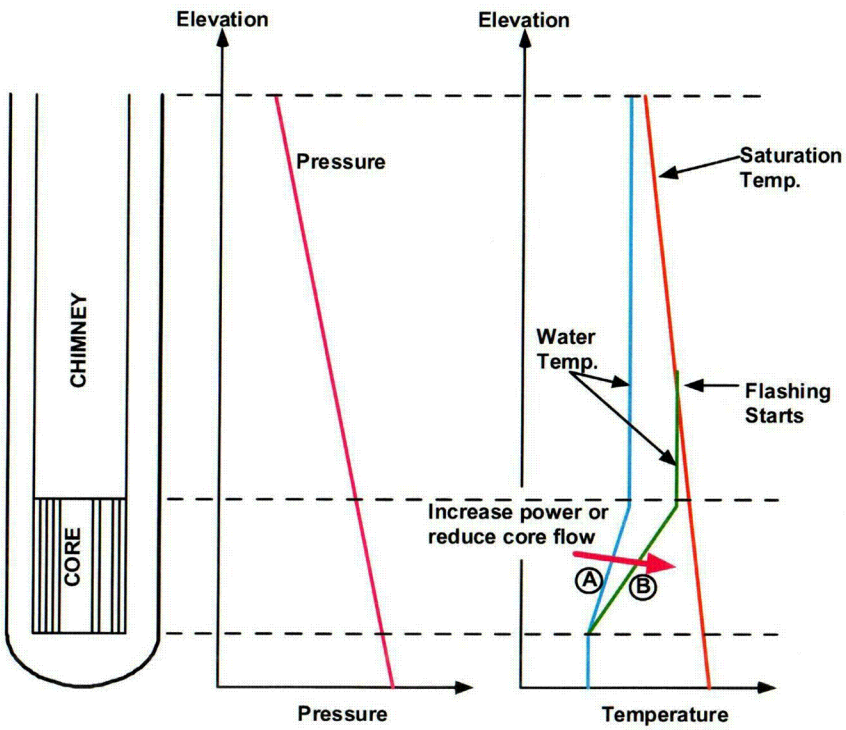
Results demonstrate ESBWR meets design criteria (Proprietary session)

Startup - Background

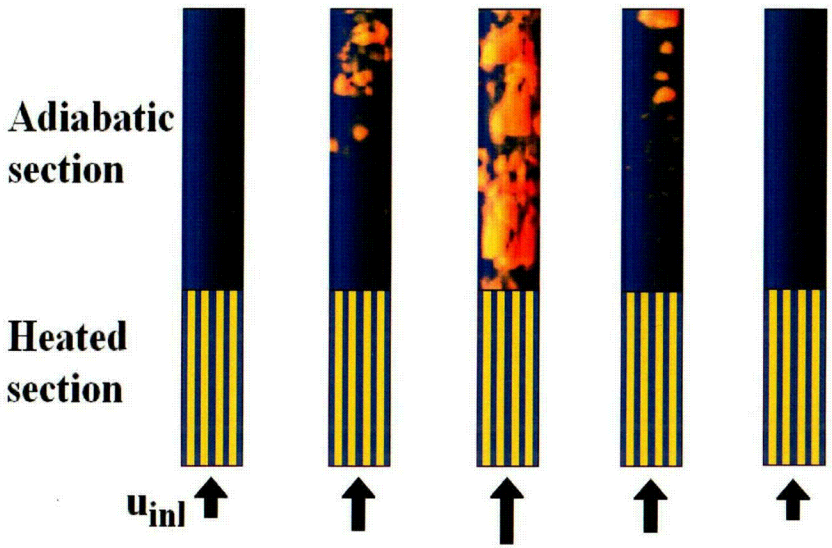
- **ESBWR natural circulation startup**
  - –Generally follow established procedure from Dodewaard plant
  - –Heat up reactor coolant to ~ 80 - 90 C with Shutdown Cooling System auxiliary heater and decay heat
  - –Deaerate reactor coolant by drawing vacuum on main condenser with steam drain line open
  - –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

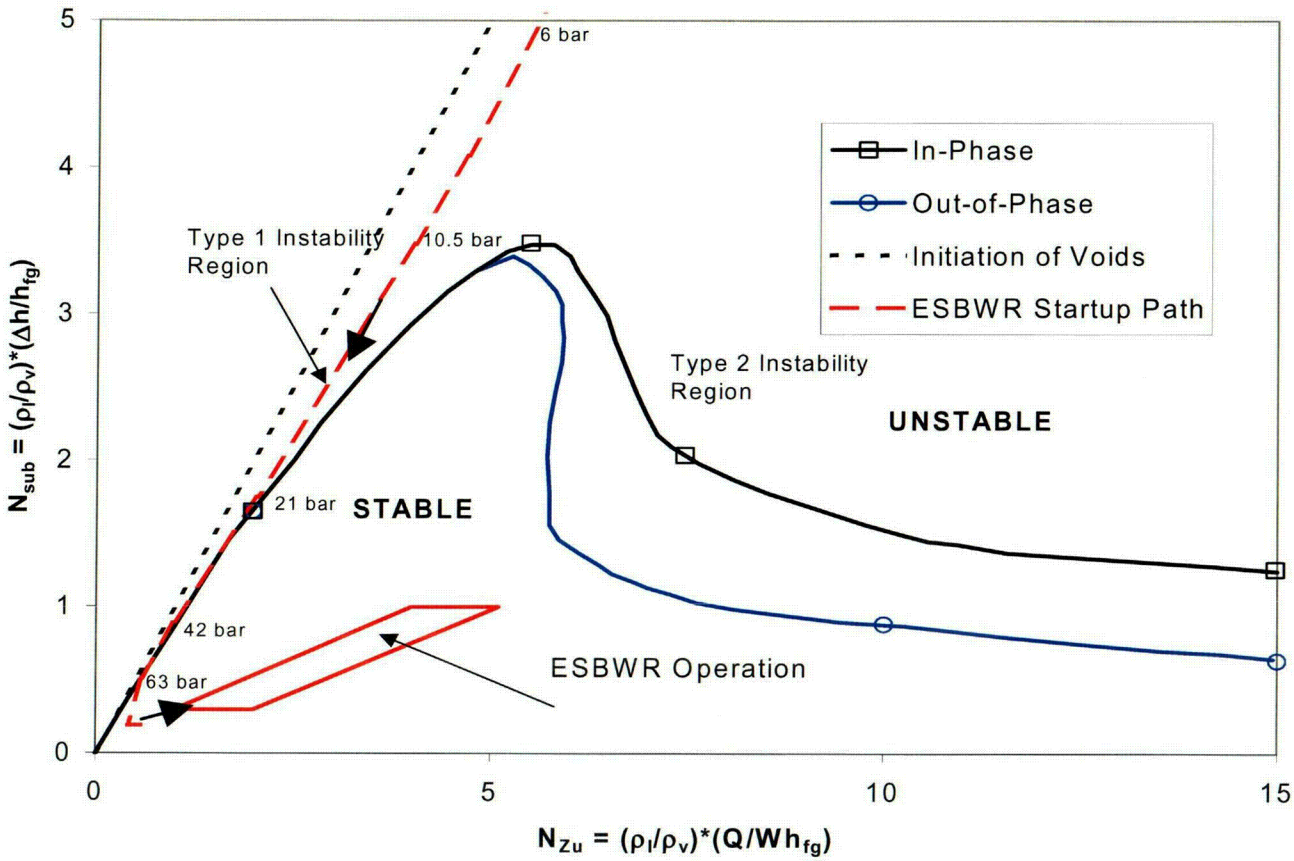


Dynamic conditions



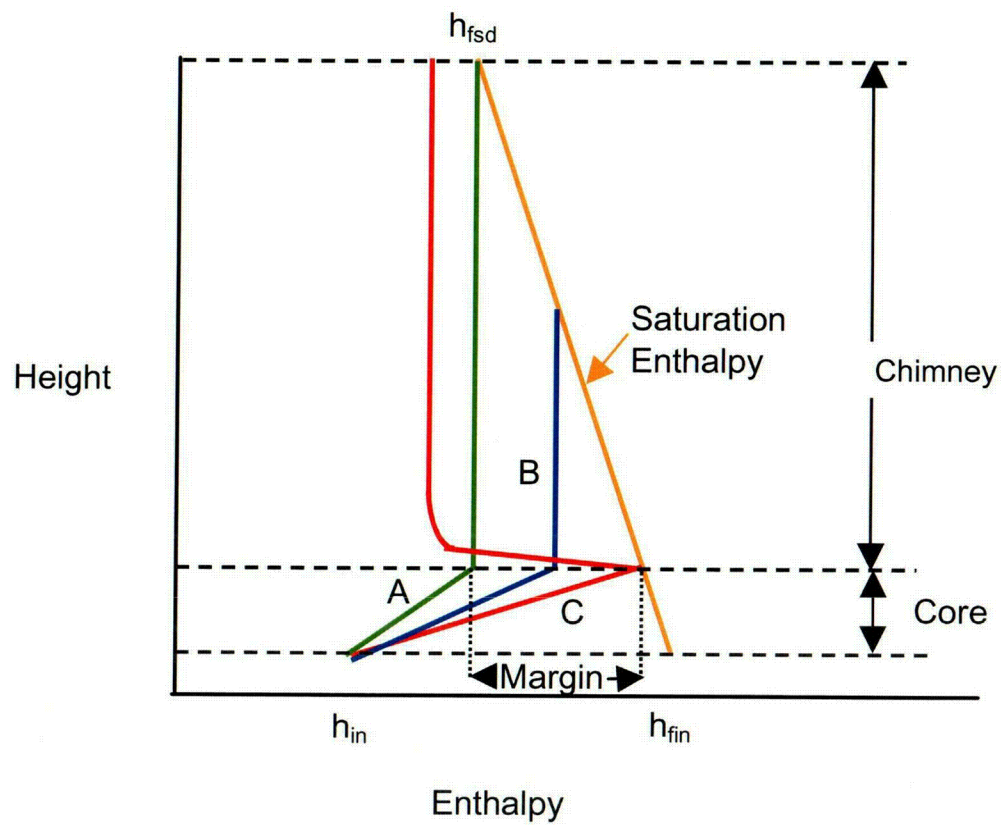
C05

Conceptual Stability Map and Plant Startup



C06

Enthalpy Profiles for Different Heatup Rates



C07

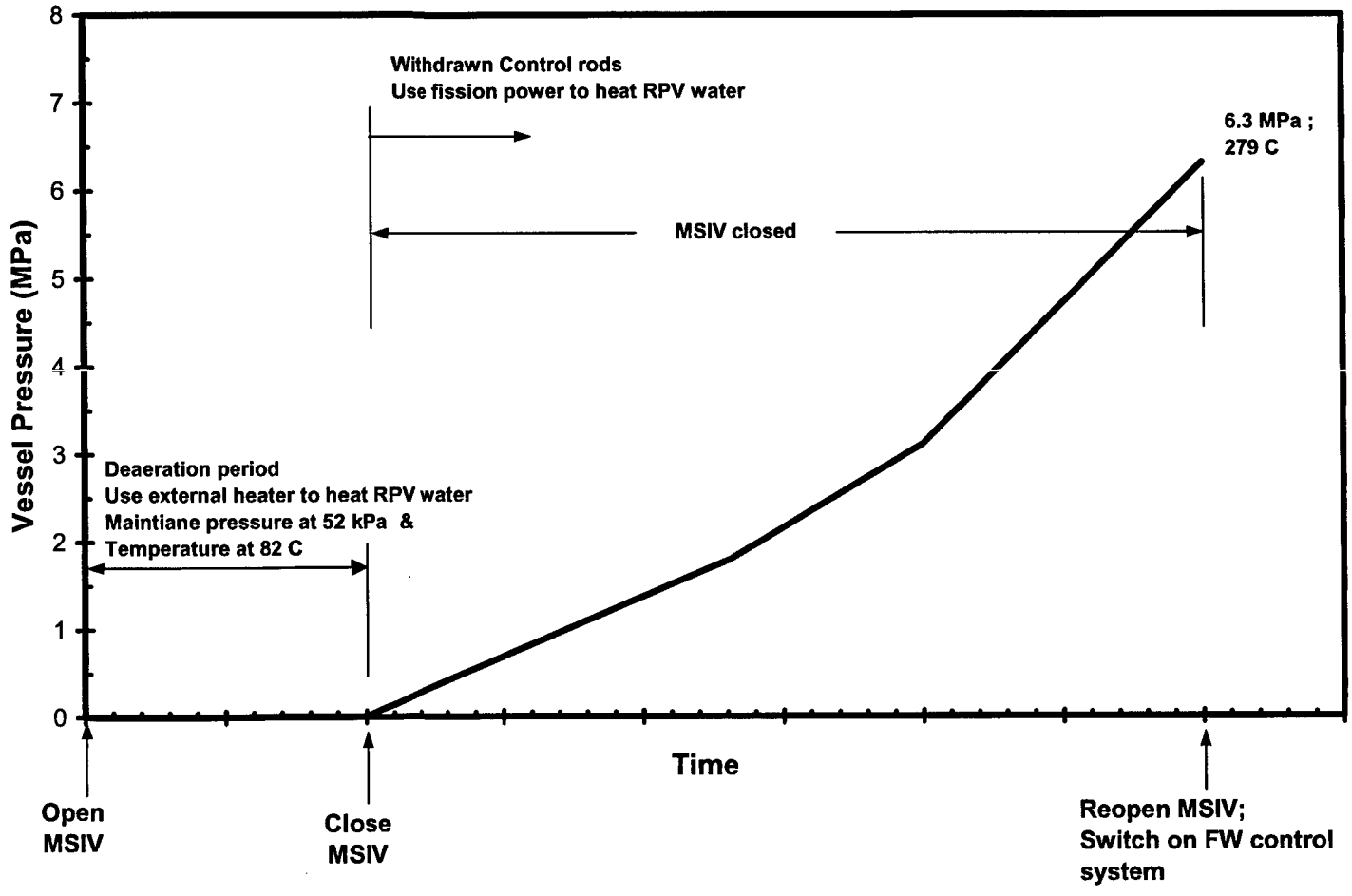
Startup Procedure

- **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 pressure**

Startup Procedure

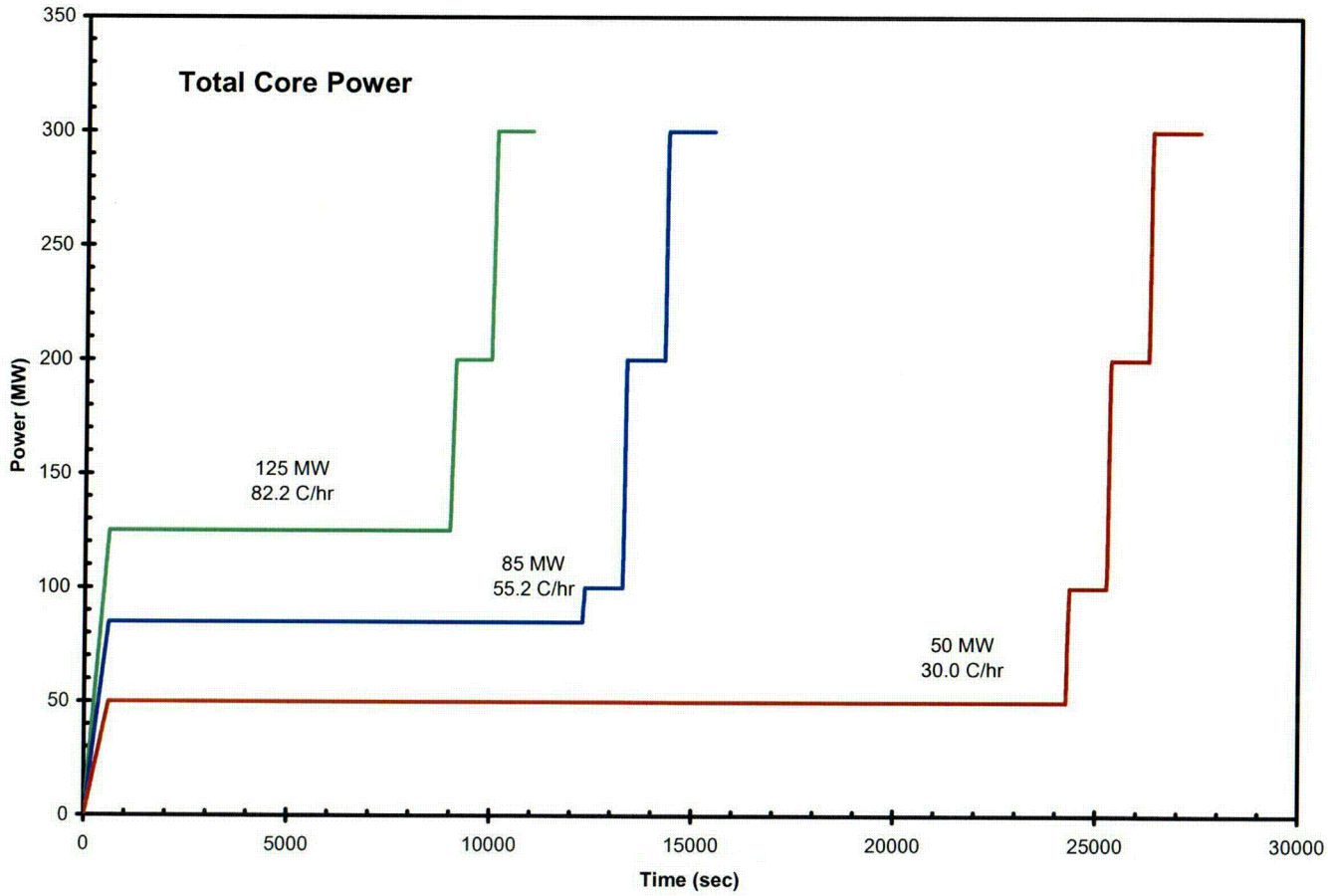
- Use RWCU (Reactor Water Cleanup/Shutdown Cooling System) to enhance coolant flow and reduce thermal stratification
- Reopen MSIV at the end of startup period (~ 6.3 MPa, 279 C),
  - open bypass valves to maintain RPV pressure
  - increase RPV power and prepare to roll turbine

ESBWR Startup Procedure



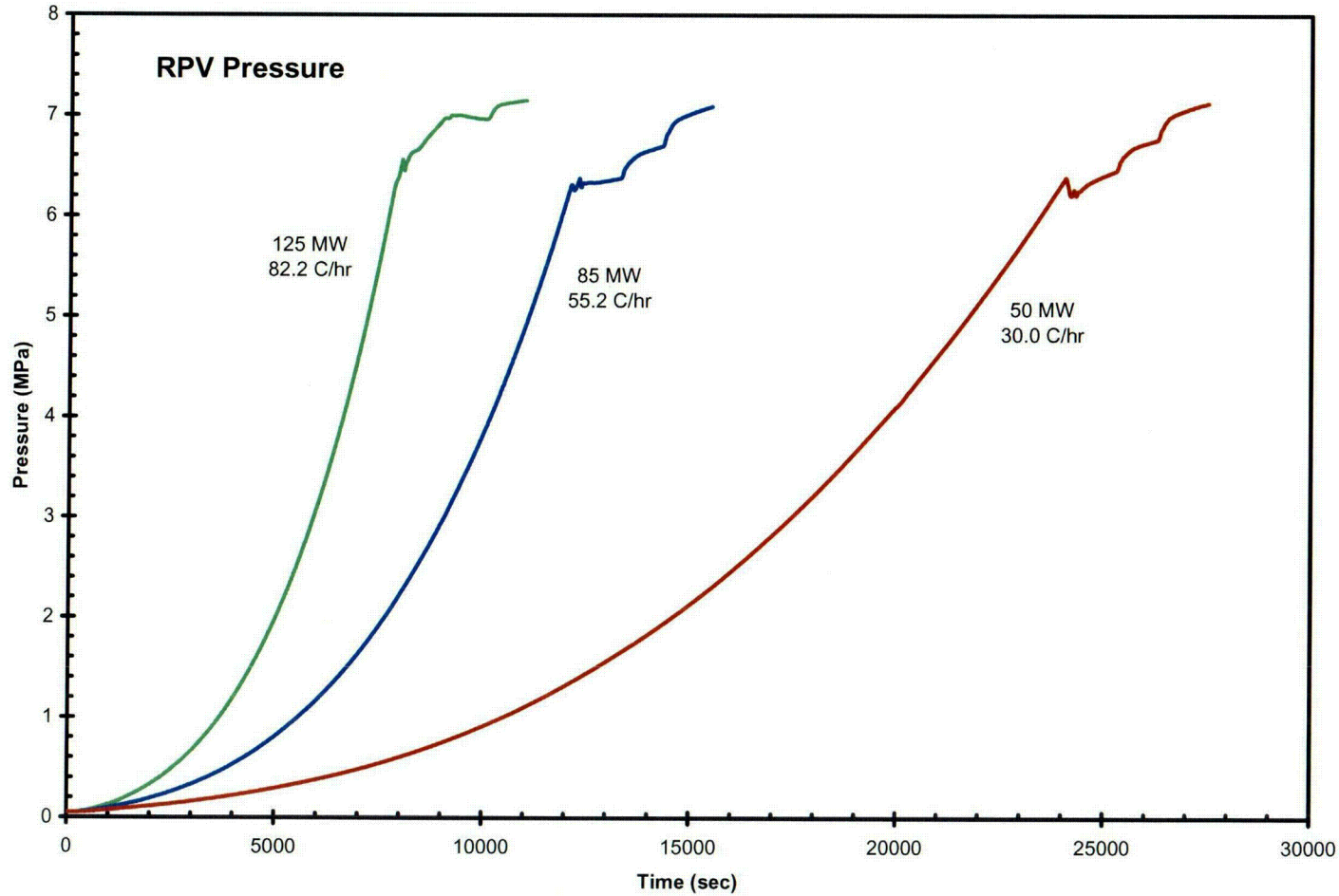
Startup.xls

TRACG Simulations of ESBWR Startup - Power



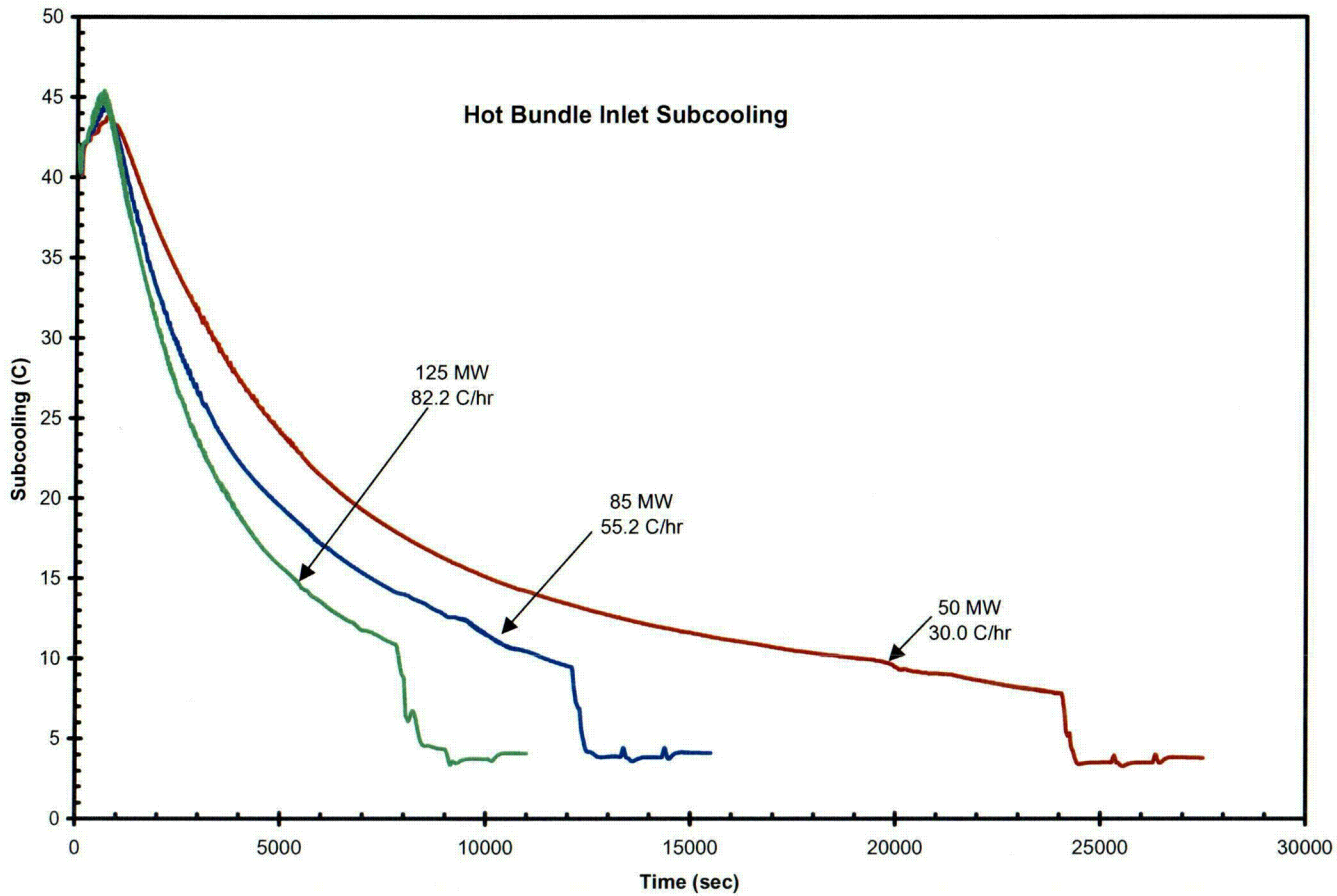
C08

TRACG Simulations of ESBWR Startup – Steam Dome Pressure



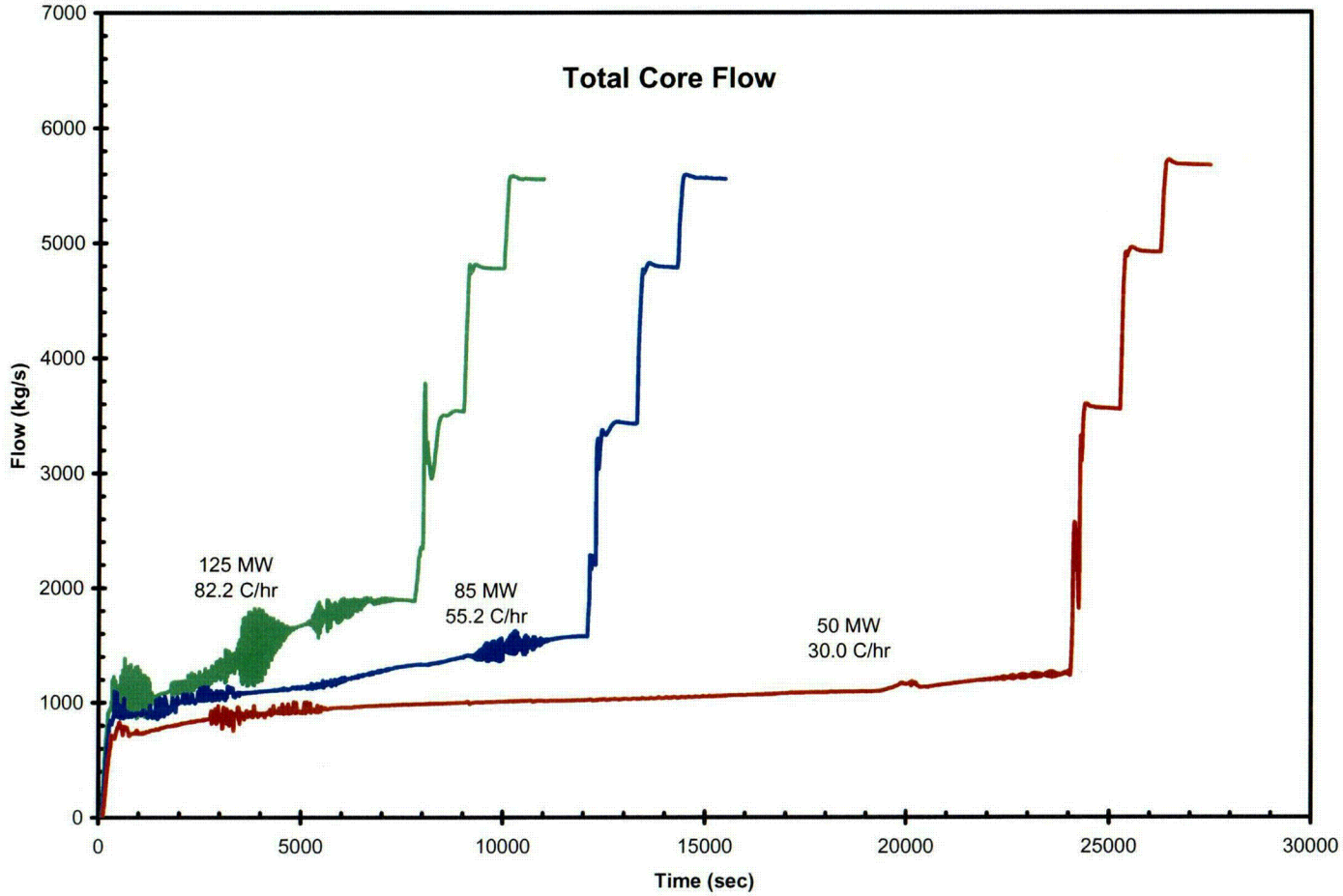
C09

TRACG Simulations of ESBWR Startup – Core Inlet Subcooling



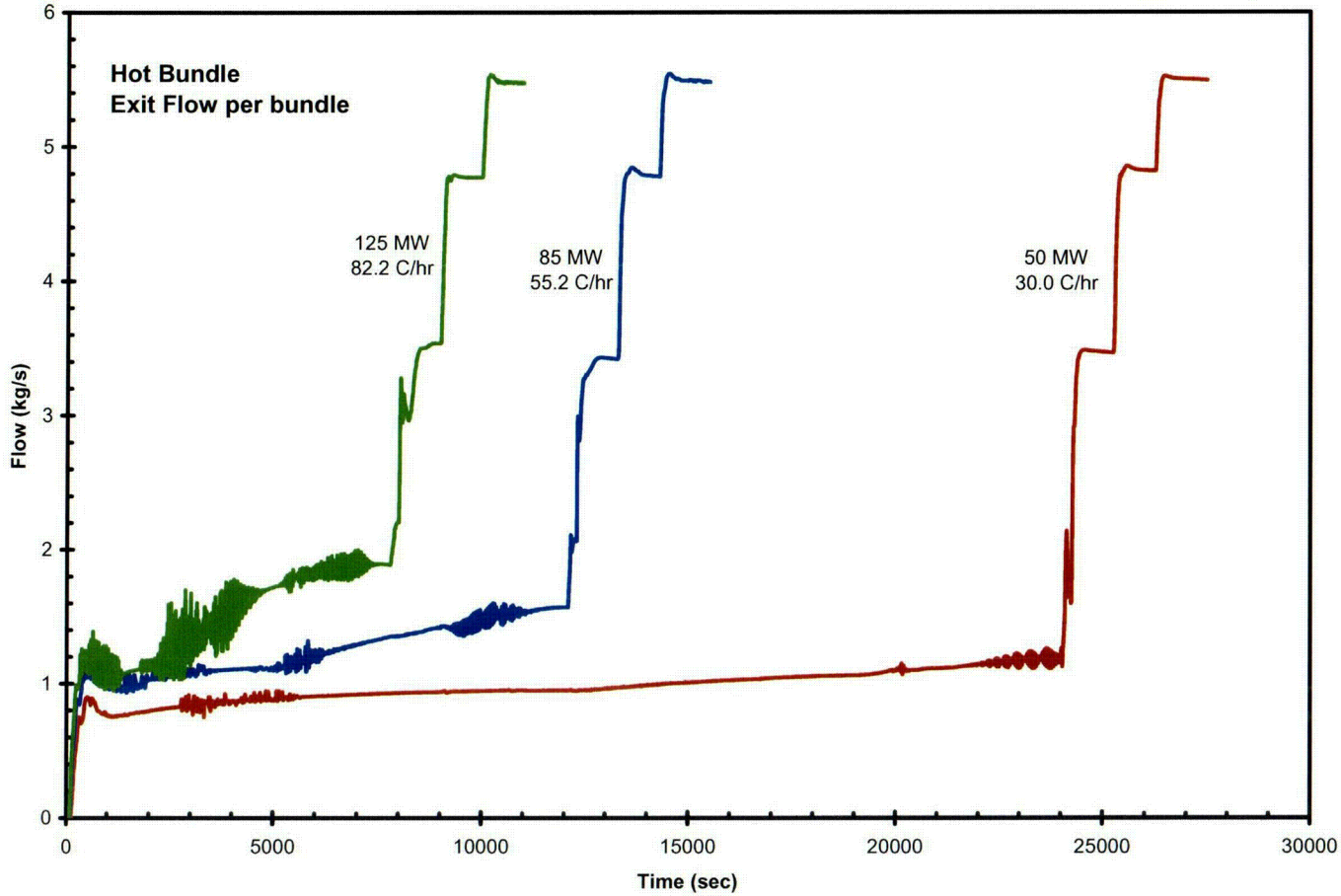
C10

TRACG Simulations of ESBWR Startup – Total Core Flow



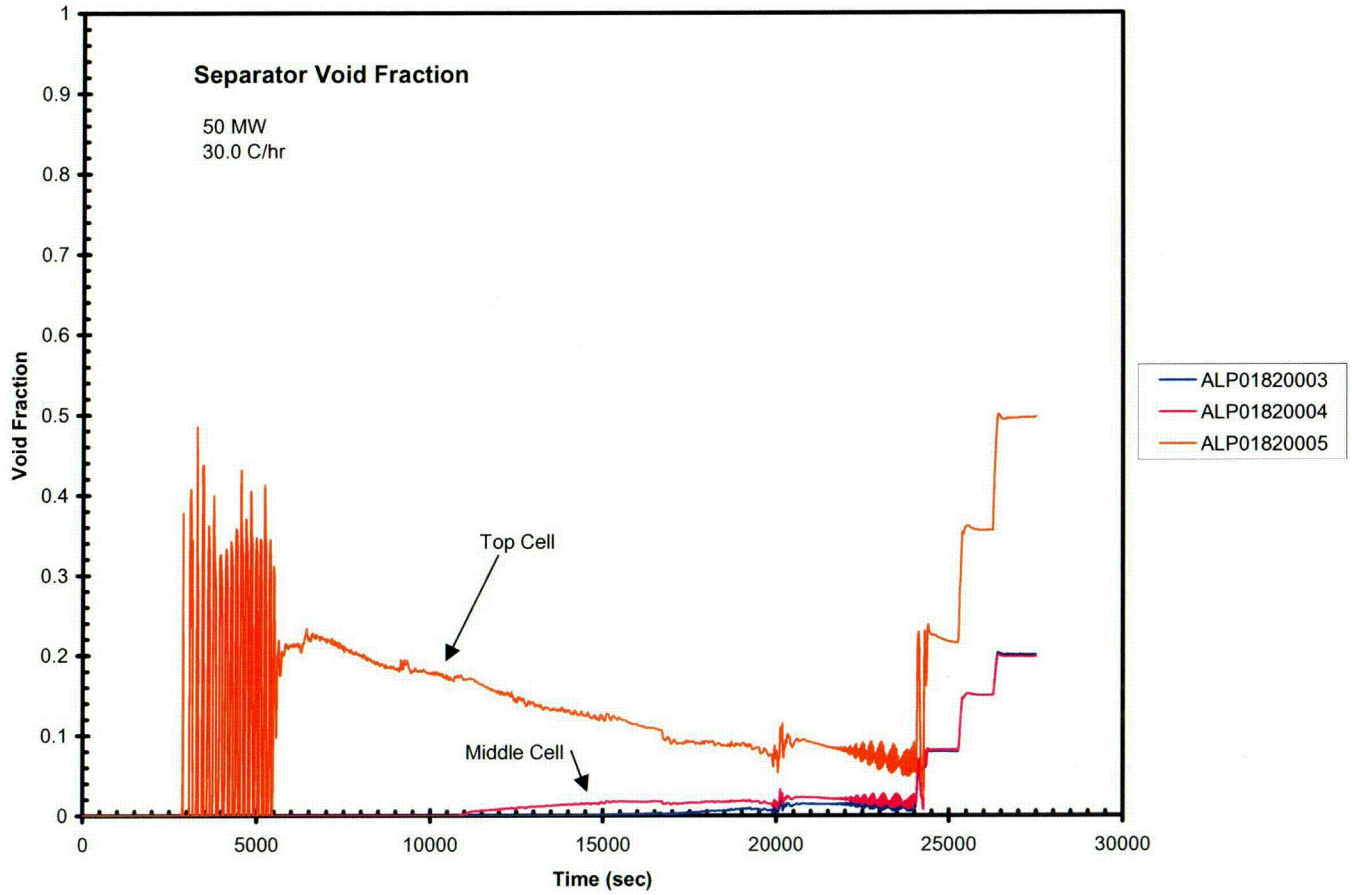
C11

TRACG Simulations of ESBWR Startup – Hot Bundle Exit Flow



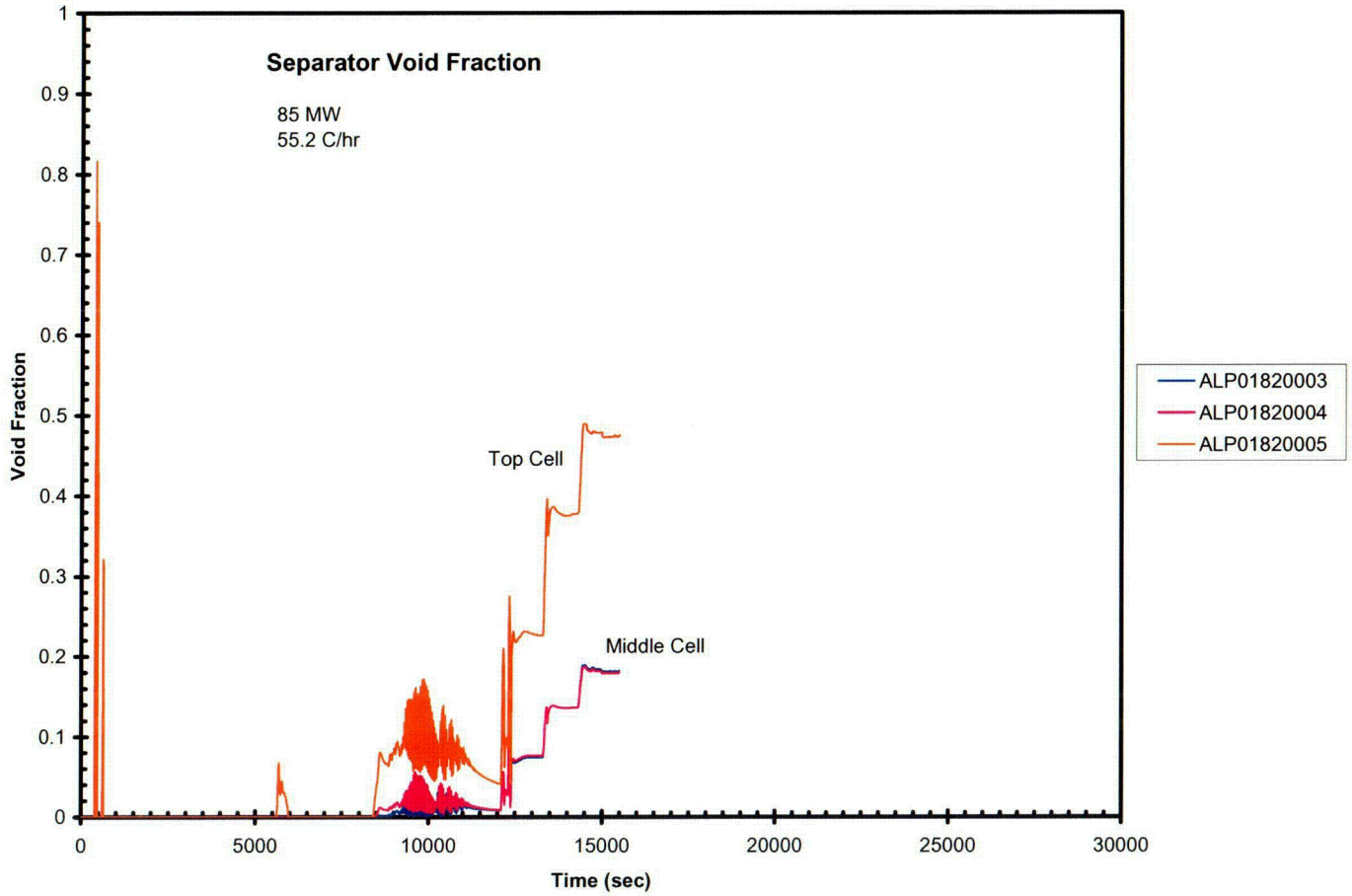
C12

TRACG Simulations of ESBWR Startup – Separator Voids (50 MW)



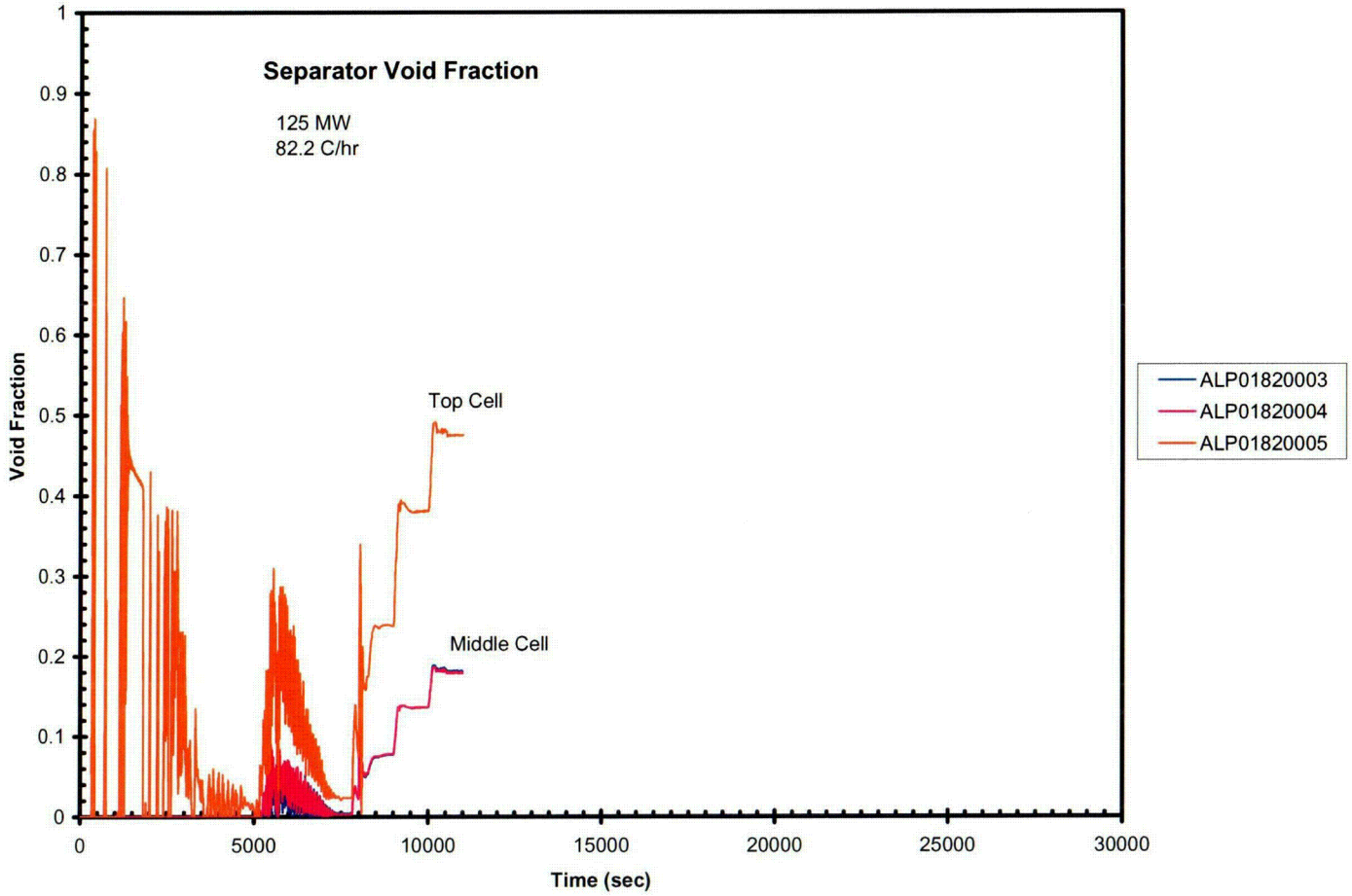
C13

TRACG Simulations of ESBWR Startup – Separator Voids (85 MW)



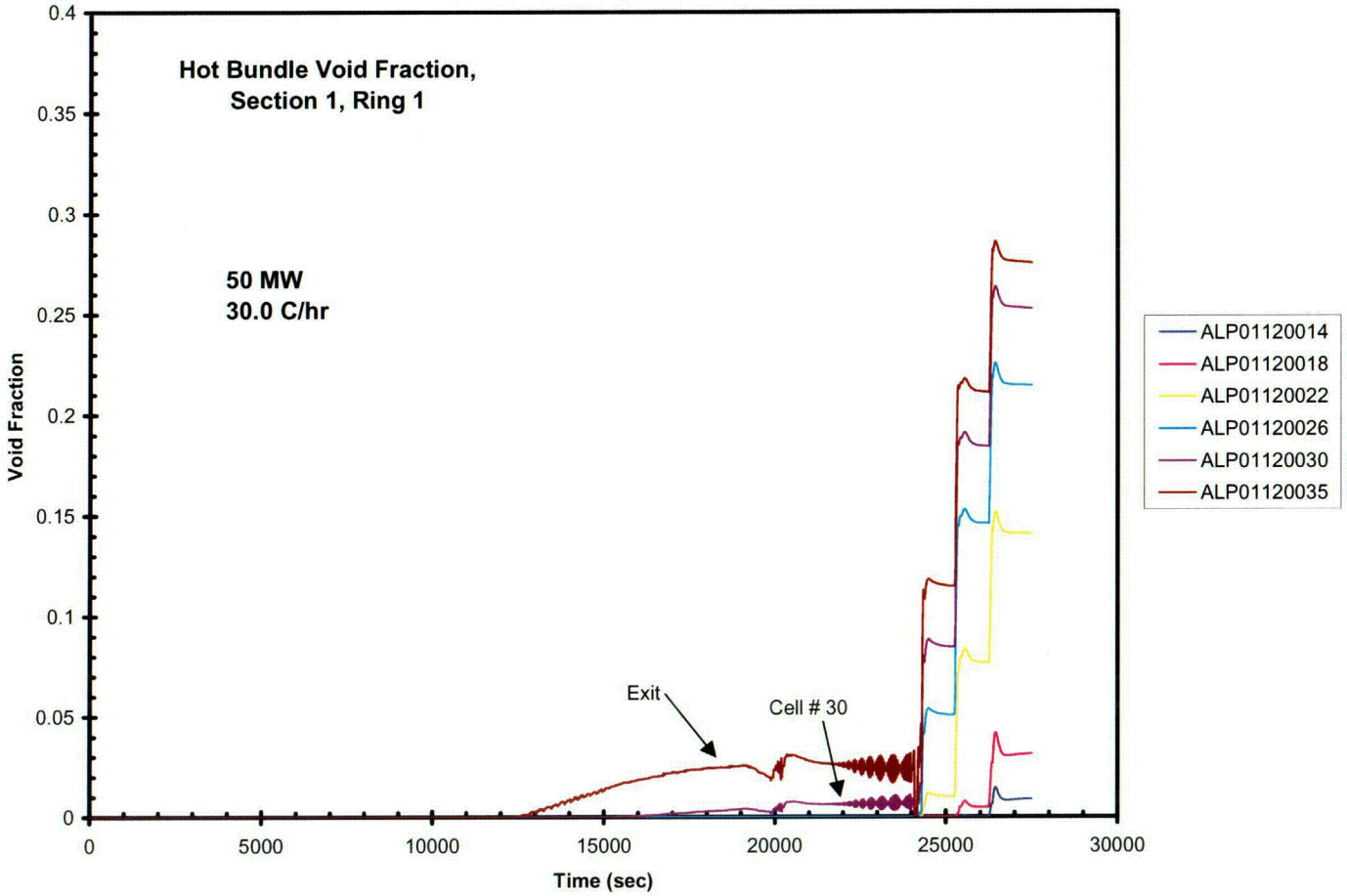
C14

TRACG Simulations of ESBWR Startup – Separator Voids (125 MW)



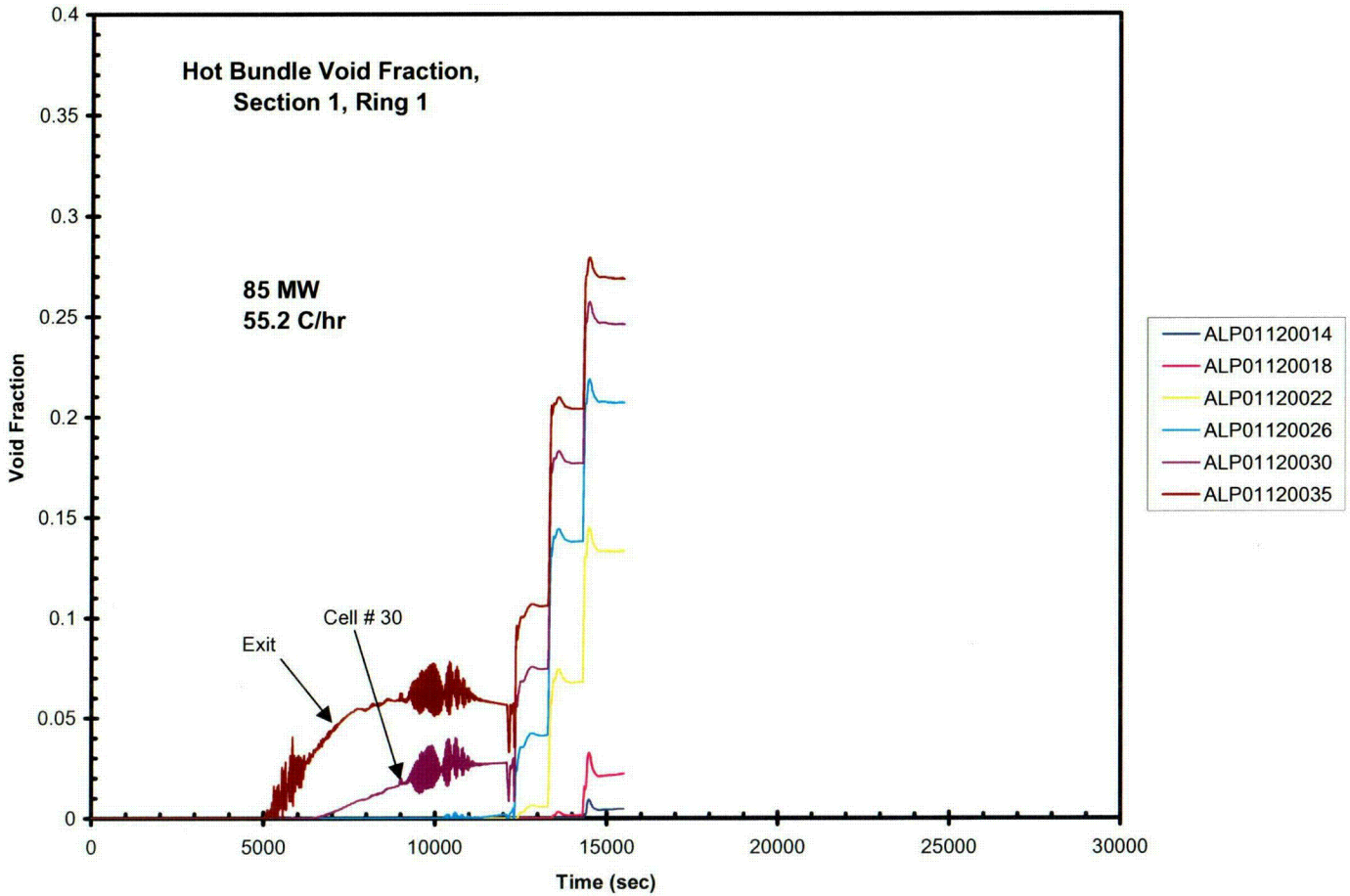
C15

TRACG Simulations of ESBWR Startup – Hot Channel Voids (50 MW)



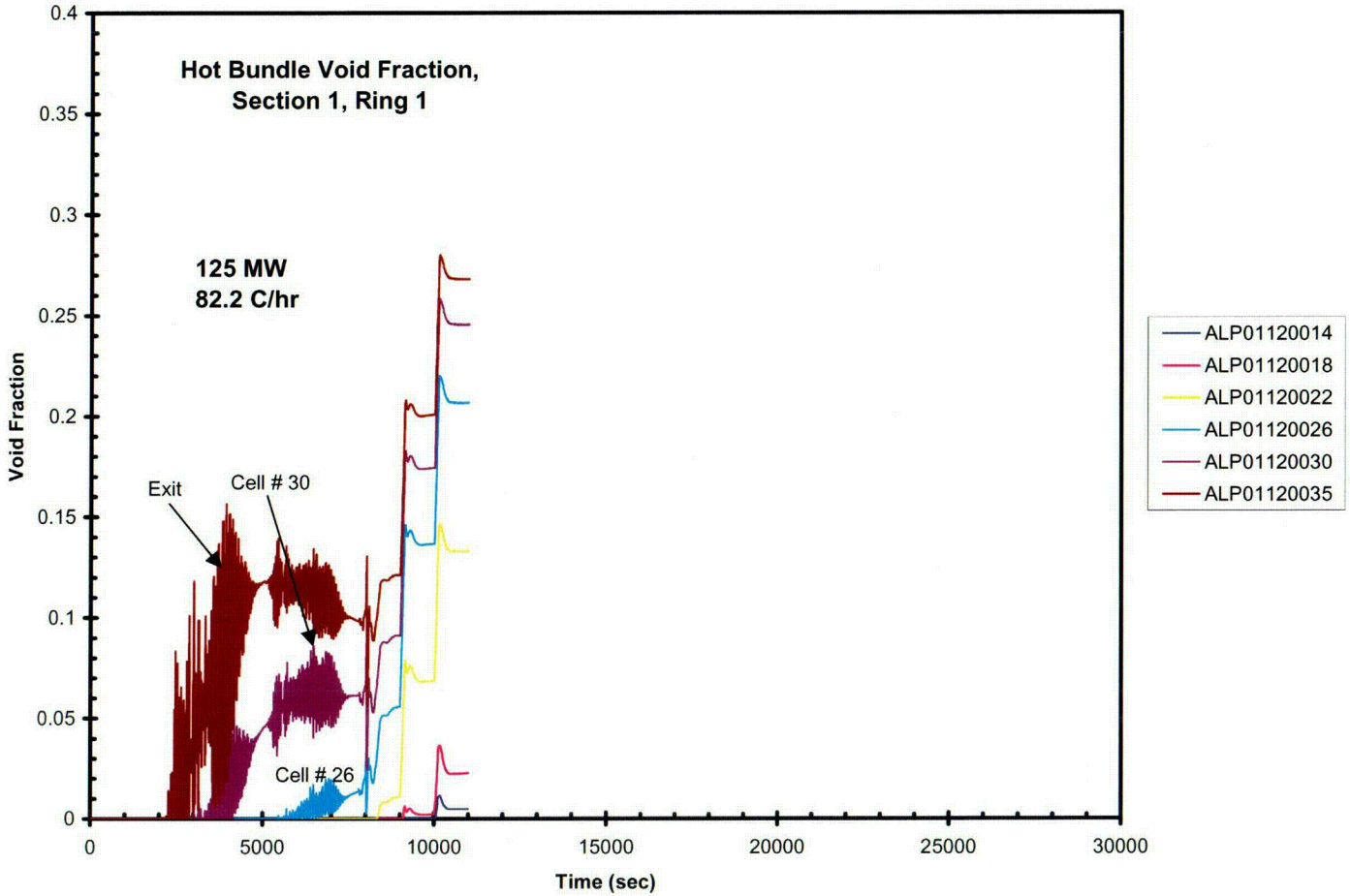
C16

TRACG Simulations of ESBWR Startup – Hot Channel Voids (85 MW)



C17

TRACG Simulations of ESBWR Startup – Hot Channel Voids (125 MW)

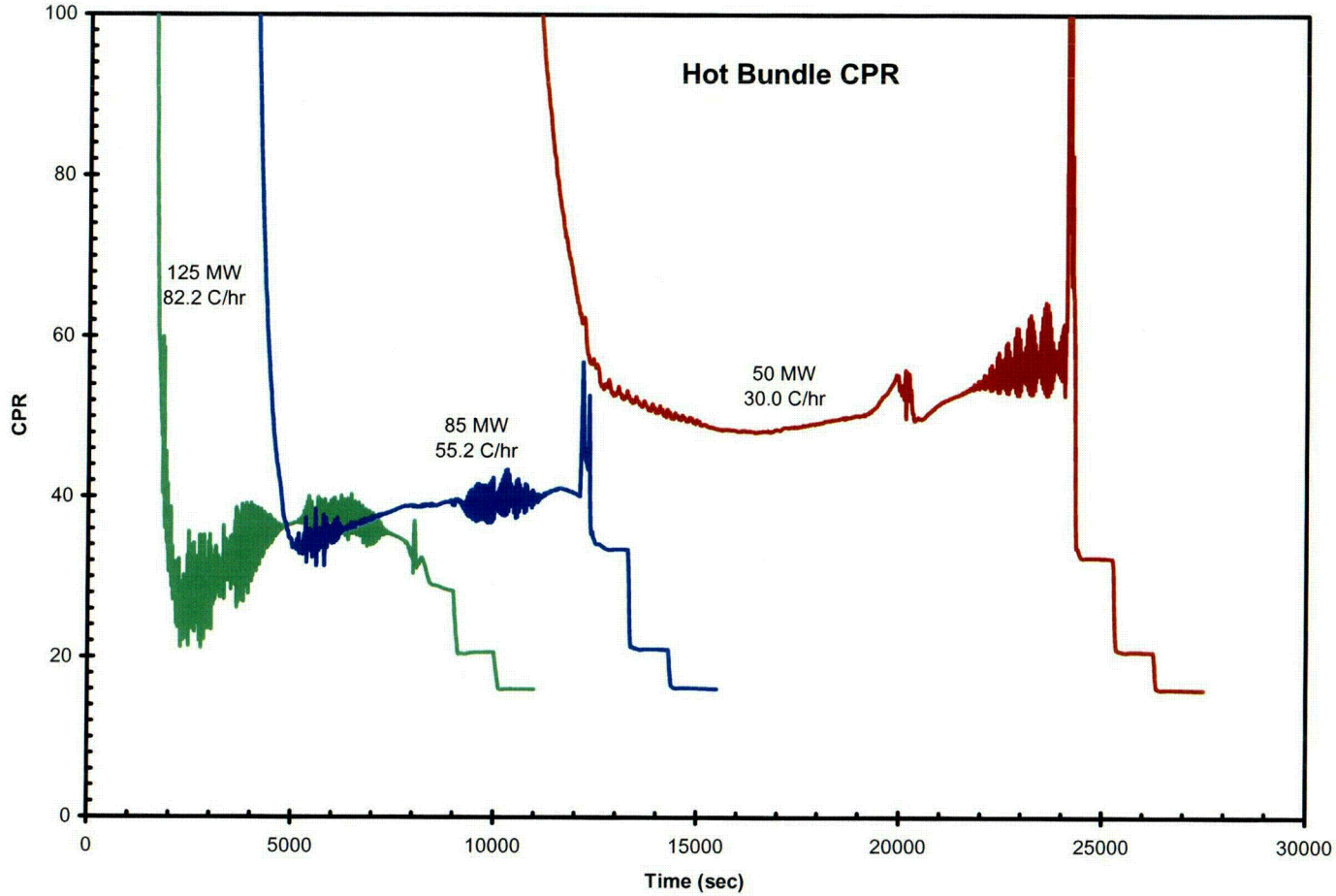


BSS
January 19, 2006

imagination at work

C18

TRACG Simulations of ESBWR Startup - CPR



C19

Plant Startup Summary

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 (125 MW) 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

Calculations with 3D kinetics confirm startup response

Startup flow oscillations pose no threat to thermal limits

ENCLOSURE 3

MFN 06-035

Affidavit

General Electric Company

AFFIDAVIT

I, George B. Stramback, state as follows:

(1) I am Manager, Regulatory Services, General Electric Company ("GE") and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in Enclosure 1 of GE letter MFN 06-035, David H. Hinds to NRC, *GE Presentation Regarding TRACG Application for ESBWR Stability - ACRS Thermal-Hydraulic Phenomena Subcommittee - January 19, 2006*, dated January 28, 2006. The proprietary information is in Enclosure 1, *Presentation Regarding TRACG Application for ESBWR Stability - ACRS Thermal-Hydraulic Phenomena Subcommittee - January 19, 2006.* The proprietary information is enclosed within double brackets and pages which contain proprietary information are identified by the marking "GE Proprietary Information." The superscript notation {3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner, GE relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.790(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by General Electric's competitors without license from General Electric constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future General Electric customer-funded development plans and programs, resulting in potential products to General Electric;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a., and (4)b, above.

(5) To address 10 CFR 2.390 (b) (4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GE, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GE, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within GE is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GE are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains the results of TRACG analytical models, methods and processes, including computer codes, which GE has developed, and applied to perform stability evaluations for the BWR. GE has developed this TRACG code for over fifteen years, at a total cost in excess of three million dollars. The reporting, evaluation and interpretations of the results, as they relate to stability evaluations for the BWR was achieved at a significant cost, in excess of one quarter million dollars, to GE.

The development of the evaluation process along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GE asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GE's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GE's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GE.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GE's competitive advantage will be lost if its competitors are able to use the results of the GE experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GE would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GE of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 28th day of January 2006

George B. Stramback
General Electric Company