ENCLOSURE 2

MFN 15-007

Safety Limit Minimum Critical Power Ratio Methodology Presentation

Non-Proprietary Information – Class I (Public)

IMPORTANT NOTICE

Enclosure 2 is a non-proprietary version of Enclosure 1, which has the proprietary information removed. Portions that have been removed are indicated by open and closed double brackets as shown here [[ ]].

Process for Calculating Safety Limit Minimum Critical Power Ratio (SLMCPR)

Global Nuclear Fuel - Americas

February 5, 2015

Agenda

- Safety Limit Design Basis (GETAB,NEDO-10958-A)
- How the Statistical Analysis Determines %NRSBT
- Description of the uncertainties and how they are applied, description of the sampling methods, etc.
- Revised SLMCPR Methodology (NEDC-32694P-A)
- Reduced SLMCPR Uncertainties (NEDC-32601P-A)
- Cycle-specific Application Process

Agenda: 1 of 6

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10 CFR 50, Appendix A, GDC 10

Criterion 10—Reactor design. The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

NUREG-0800, 15.0, VI. Definitions

VI. DEFINITIONS

Term	Definition
anticipated operational occurrences (AOOs)	Conditions of normal operation that are expected to occur one or more times during the life of the nuclear power unit and include but are not limited to loss of power to all recirculation pumps, tripping of the turbine generator set, isolation of the main condenser, and loss of all offsite power. AOOs are also known as Condition II and III events.

GETAB Introduces Critical Power and GEXL

Section 1.2 Terminology in NEDO-10958-A, January 1977

The physical phenomenon being discussed is the *onset of transition boiling* and this phenomenon is referred to in this report as the *boiling transition.*…*

*The terminology "boiling transition" is considered to be more descriptive of the onset of transition boiling which actually occurs and is used throughout this document rather than terms such as CHF, DNB or the "boiling crisis."

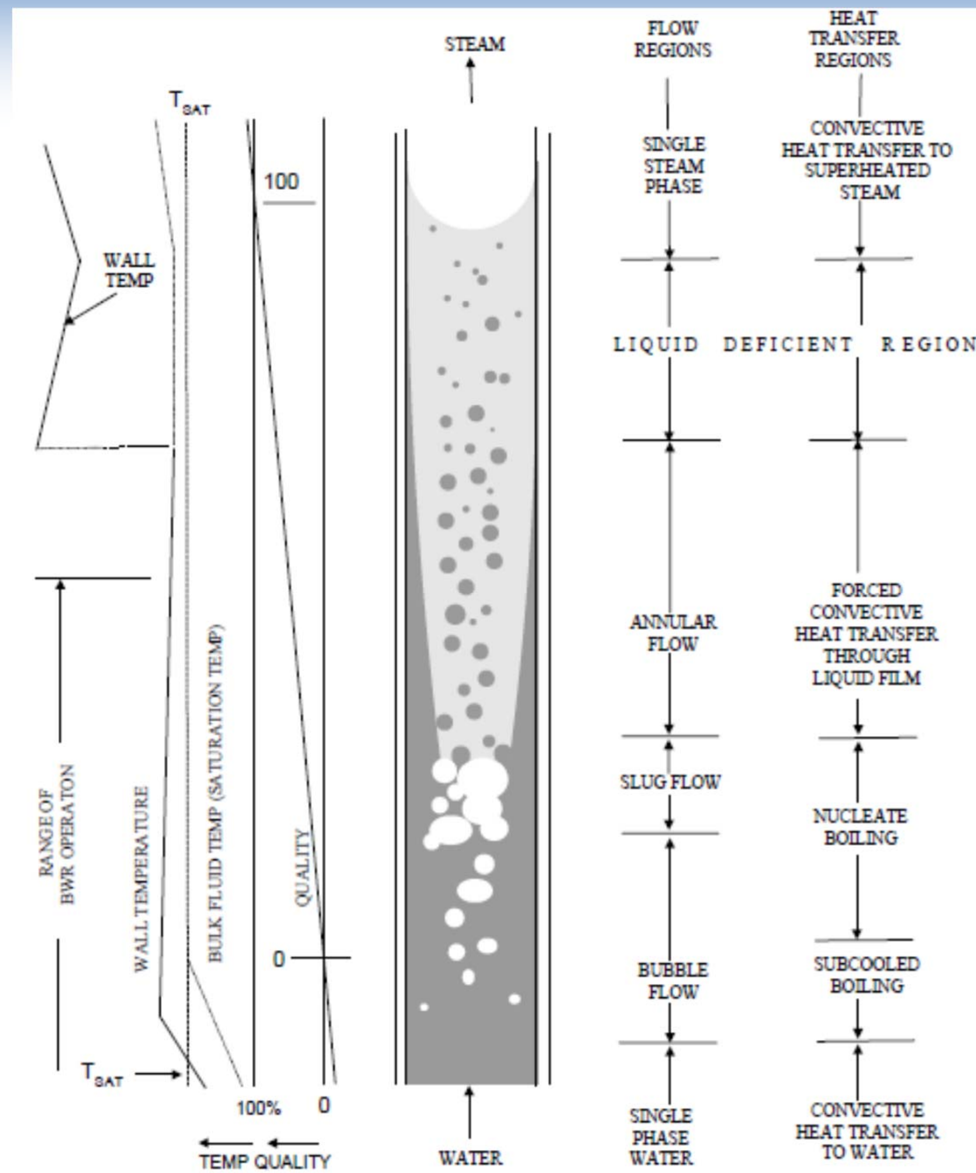
The physical phenomenon is represented by an analytical *correlation* of the data. This presentation describes the development of the General Electric Critical Quality *(Xc)* -Boiling Length Correlation- *GEXL.* GEXL is used in the design and operation of BWRs to establish appropriate thermal margins and to assess appropriate operating transient and accident conditions. That assembly power which causes some point in the assembly to experience a boiling transition is called the *critical power.* The ratio of the critical power to the bundle power at the reactor condition of interest is defined as the *critical power ratio (CPR)* and used as the new figure of merit for expressing BWR thermal margin. The net result is characterized as *GETAB,* the General Electrical Thermal Analysis Basis.

What is Critical Power Ratio?

$$CPR = \frac{\text{critical power}}{\text{calculated power}}$$

where critical power is calculated from the GEXL correlation. CPR can be evaluated for a fuel bundle or for a single rod.

$$ECPR = \frac{\text{measured critical power}}{\text{calculated critical power}}$$



The Safety Limit MCPR SAFDL

Quote from Section 5.2 of NRC Safety Evaluation Report Approving Revision 0 NEDE-24011-P (“Generic Reload Fuel Application”, GESTAR II) transmitted May 12, 1978.

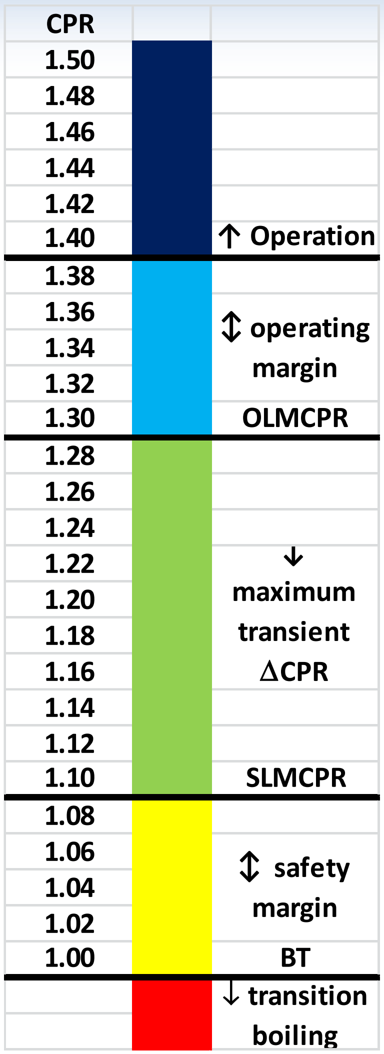
5.2 Fuel Cladding Integrity Safety Limit MCPR

General Design Criterion 10 requires that the reactor core be designed with appropriate margin, to assure that specified acceptable fuel design limits (SAFDL) are not exceeded during any condition of normal operation, including the effects of abnormal operational transients. In order to avoid fuel damage caused by overheating of the cladding, transient consequences are limited such that more than 99.9% of the fuel rods would be expected to avoid boiling transition during a transient event. This design basis has been previously accepted for initial and reload core applications in connection with the staff’s review of the General Electric Thermal Analysis Basis (GETAB) method.

What is the Safety Limit MCPR?

Safety Limit Minimum Critical Power Ratio (SLMCPR) is the minimum CPR during the most limiting Anticipated Operational Occurrence (AOO) transient such that considering uncertainties in monitoring the core operating state, 99.9% of the rods in the core must be expected to avoid boiling transition (BT).

OLMCPR and SLMCPR



Operating limit MCPR (OLMCPR) is calculated as

$OLMCPR > SLMCPR + \max \Delta CPR$

so in the event of the limiting transient event giving the maximum transient ΔCPR will result in a minimum CPR > SLMCPR thus ensuring (considering calculational and monitoring uncertainties) that 99.9% of the rods in the core will be expected to avoid boiling transition (BT).

The SLMCPR value is calculated (considering uncertainties) as the lowest steady state MCPR such that the percentage **n**umber of **r**ods **s**usceptible to **b**oiling **t**ransition satisfies

$\%NRSBT \leq 0.1\%$.

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Relevant Licensing Documentation

- NEDO-10958-A, General Electric BWR Thermal Analysis Basis (GETAB): Data, Correlation and Design Application (January 1977)
- NEDC-32601P-A, Methodology and Uncertainties for Safety Limit MCPR Evaluations (August 1999)
- NEDC-32694P-A, Power Distribution Uncertainties for Safety Limit MCPR Evaluations (August 1999)
- Amendment 25 to NEDE-24011-P, GESTAR-II (MFN-003-99, March 11, 1999; TAC NOS. M97490, M99069, and M97491)

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ECPR Examples

GEXL14 for GE14 from NEDC-32851P-A, Rev. 5, April 2011

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[[GEXL17 for GNF-2 from NEDC-33292P, Rev. 3, April 2009

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MIP

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RIP

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Correlation of SLMCPR

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SL Calculated from NRC-Approved Monte Carlo Process

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Methodologies/Uncertainties

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Power Uncertainties (details given later)

- Bundle Power uncertainty
- R-factor uncertainty components

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- TIP uncertainties
    - Systematic, Random, Effective
- GEXL bias and uncertainty

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Plant and Core Uncertainties

- Total core flow
- Individual channel flow area
- Individual channel friction factor, 2-phase friction factor multiplier
- Reactor pressure
- Core inlet temperature (enthalpy)
- Feedwater flow, temperature

Generic Plant System Uncertainties

Description of Uncertainty	Input Variable	Input Values (%)
core flow rate (derived from pressure drop) [[		
individual channel flow area		
individual channel friction factor		
friction factor multiplier		
reactor pressure		
core inlet temperature		
feedwater temperature		
feedwater flowrate		]]

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GE Statistical Analysis Methodology

GESAM02P is the current Engineering Computer Program (ECP) used to calculate the SLMCPR using Monte Carlo sampling from the set of all specified uncertainties that influence rod CPRs.

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GESAM Calculation Procedure for SLMCPR Evaluations

Figure 4.1 in NEDC-32601P-A (like Figure IV-4 in GETAB)

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Stratified Sampling for Core Power & Inlet Temp.

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Bundle Power Uncertainty: GETAB

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Bundle Power Uncertainty: REVISED

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Generic Power Uncertainty Values

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Cycle-Specific Design Process Map

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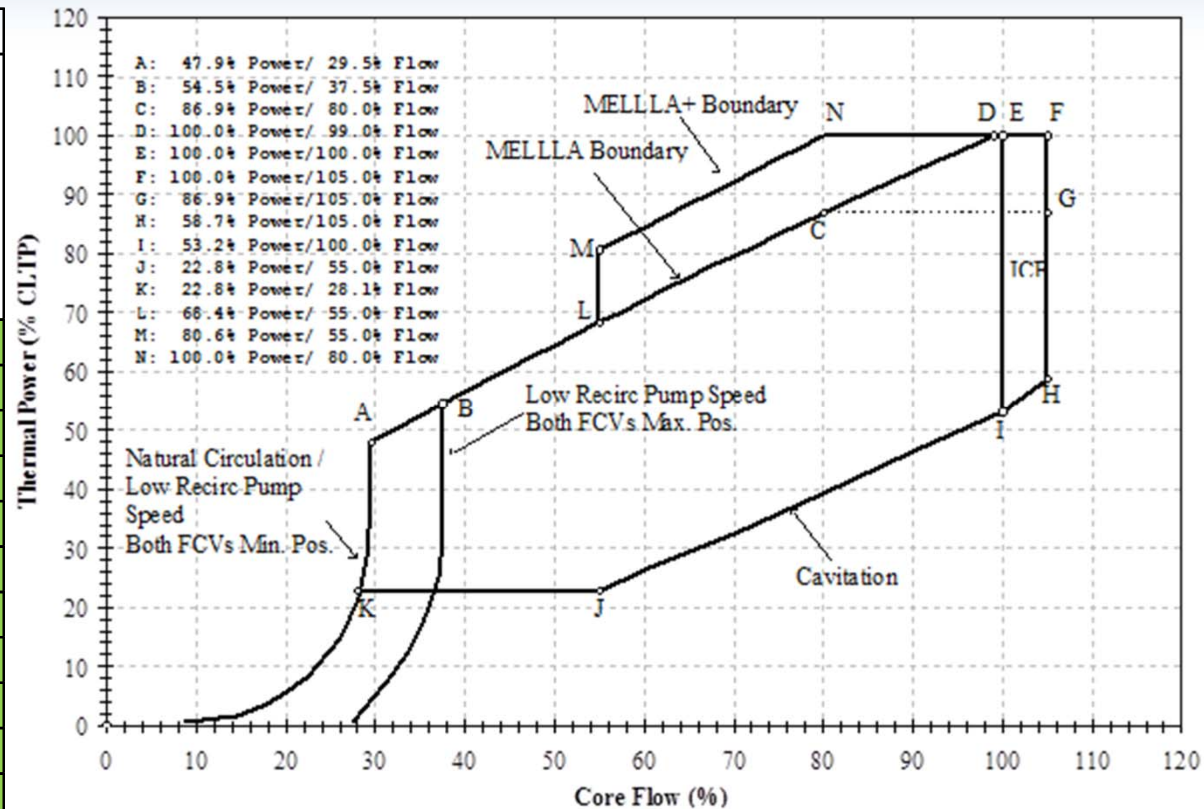
Scope for Cycle-Specific SL Calculations

			TLO SLMCPR Required		
Cycle Exposure	Core Power	Core Flow	Non-MELLLA+ Plants with Min Core Flow ≥ 99%	Non-MELLLA+ Plants with Min Core Flow < 99%	MELLLA+ Plants
B	rated	rated	E	E	E
M	rated	rated	E	E	E
E	rated	rated	E	E	E
B	rated	LCF		D	N
M	rated	LCF		D	N
E	rated	LCF		D	N
B	rated	ICF			F
M	rated	ICF			F
E	rated	ICF			F
B	off-rated	off-rated			M
M	off-rated	off-rated			M
E	off-rated	off-rated			M



Examples of Limiting Blade Patterns

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Criteria for PANAC Limiting Blade Patterns

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Example GESAM Results Summary (1 of 2)

Table 3. Monte Carlo Calculated SLMCPR vs. Estimate

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Description	Previous Cycle Minimum Core Flow Limiting Case	Previous Cycle Rated Core Flow Limiting Case	Current Cycle Minimum Core Flow Limiting Case	Current Cycle Rated Core Flow Limiting Case

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Example GESAM Results Summary (2 of 2)

Table 3. Monte Carlo Calculated SLMCPR vs. Estimate

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Description	Previous Cycle Minimum Core Flow Limiting Case	Previous Cycle Rated Core Flow Limiting Case	Current Cycle Minimum Core Flow Limiting Case	Current Cycle Rated Core Flow Limiting Case
Requested Change to the Technical Specification SLMCPR	N/A		1.09 (TLO)/ 1.12 (SLO)	

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Internal Quality Control

- SLMCPR activities are guided by a series of Design Basis (DB) Documents, Technical Design Procedures (TDP), and an Application Guide (AG).

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- Verification process is aided by Design Verification Guide (DVG) checklist.
- Relevant quality records pertaining to SLMCPR calculations are verified, approved, stored and archived in accordance with requirements and procedures.

Questions

Answers

Discussion

Acronyms (1 of 3)

AG	**a**pplication **g**uide
ALC	**a**s-**l**oaded **c**ore
AOO	**a**nticipated **o**perational **o**ccurrence (FSAR Chapter 15 transients)
BOC	**b**eginning **o**f **c**ycle
BT	**b**oiling **t**ransition
BWR	**b**oiling **w**ater **r**eactor
BWREDB	**BWR** **e**ngineering **d**ata **b**ank
CHF	**c**ritical **h**eat **f**lux
CPR	**c**ritical **p**ower **r**atio
DB	**d**esign **b**asis
DNB	**d**eparture from **n**ucleate **b**oiling
ECO	**e**ngineering **c**hange **o**rder
ECP	**e**ngineering **c**omputer **p**rogram
ECPR	calculated critical power to **e**xperimental **c**ritical **p**ower **r**atio
EOC	**e**nd **o**f **c**ycle
EOR	**e**nded **o**f **r**ated (near EOC for rated power operation)

Acronyms (2 of 3)

FCV	**f**low **c**ontrol **v**alve (in the recirculation loop)
FRED	**f**uel **r**eload-licensing **e**ngineering **d**ata (AG-0007)
FSAR	**f**inal **s**afety **a**nalysis **r**eport
GDC	**g**eneral **d**esign **c**riteria (in 10CFR50, Appendix A)
GESAM	**GE** **s**tatistical **a**nalysis **m**ethod ECP
GETAB	**GE** **t**hermal **a**nalysis **b**asis
GEXL	**GE** quality (**X**) versus boiling length (**L**) correlation of critical power
ICF	**i**ncreased **c**ore **f**low
LCF	**l**owest (licensed) **c**ore **f**low (for a particular core power)
MCPR	**m**inimum **CPR**
MELLLA+	**m**aximum **e**xtended **l**oad **l**ine **l**imit **a**nalysis **plus** (NEDC-33006P-A, R3, June 2009)
MIP	**M**CPR **i**mportance **p**arameter
MOC	**m**iddle **o**f **c**ycle
NRSBT	**n**umber **r**ods **s**usceptible to **b**oiling **t**ransition
OLMCPR	**o**perating **l**imit **m**inimum **c**ritical **p**ower **r**atio
OPL	**o**perating **p**arameters for **l**icensing

Acronyms (3 of 3)

RCF	**r**ated **c**ore **f**low
RIP	**R**-factor **i**mportance **p**arameter
RIPBAR	**RIP *average*** (effective average RIP for all participating bundles in core)
SAFDL	**s**pecified **a**cceptable **f**uel **d**esign **l**imit
SL	**s**afety **l**imit
SLMCPR	**s**afety **l**imit **m**inimum **c**ritical **p**ower **r**atio
SLO	**s**ingle **l**oop **o**peration (or operating with less than all recirculation loops)
SRLR	**s**upplemental **r**eload **l**icensing **r**eport
TDP	**t**echnical **d**esign **p**rocedure
TIP	**t**raversing **i**n-core **p**robe
TLO	**t**wo **l**oop **o**perations (for jet pump plants or all external recirc loops)
WILMA	**w**ork **i**nstruction **l**ist for **m**ulti-cycle **a**nalysis form (AG-0044)