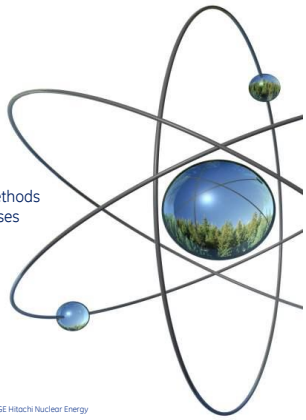
GE Hitachi Nuclear Energy



GEH Experience with Best Estimate Methods for BWR Transient and Accident Analyses

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Introduction

- Transient and accident analyses were historically done with simple and conservative methods, e.g. Appendix K LOCA methods
- GEH started the transition to more realistic methods in the seventies
  - ODYN transient analysis approved in 1981
    Realistic evaluation of transient ΔCPR plus 2-sigma uncertainty
  - SAFER LOCA methods approved in 1983
    Realistic method with limited conservatism
    Justified by best estimate calculation plus bounding 2-sigma uncertainty
- CSAU methodology (NUREG/CR-5249) and RG 1.157 were issued in 1989 and provided guidance for the application of best estimate methods plus a rigorous quantification of the uncertainties.
- GEH has developed and implemented best estimate transient and accident analyses methods based on these guide lines.

TRACG

- TRACG is the computer code for best estimate and transient analyses
  - Early development was done as a cooperative project between GE and INEL to develop models for phenomena unique to the BWR
  - Most development done by GEH in cooperation with our Japanese partners
- TRACG BWR model
  - 1D/3D two-fluid model plus non-condensable gasses and boron transport
  - Best estimate correlations for shear and heat transfer
  - Best estimate BWR component models
  - 3D kinetics based on PANAC nuclear design methods.
  - Extensive qualification – separate effects tests, component tests, integral tests and plant data.

Transient Analyses

- TRACG application for anticipated operational occurrences (AOO) transient analyses (NEDE-32906P) was submitted in January 2000
  - Follows CSAU and RG 1.157 guidelines
  - Extensive USNRC and ACRS reviews
  - NRC SE and approval issued in October 2001.
- 5-10% operating margin benefit
  - Integral best estimate methods plus a rigorous quantification of uncertainties at the 95/95 level.
  - 3D kinetics
- TRACG application for anticipated transient without scram (ATWS) overpressure transient analyses (NEDE-32906P Supp. 1) was approved in 2003

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Stability

- The BWROG reactor stability detect and suppress solution (NEDO-32465) was developed following the 1988 LaSalle instability event and approved by USNRC in 1996
  - Conservative approach with no applicability for MELLLA+
- The stability detect and suppress solution – confirmation density (DSS-CD) TRACG application (NEDE-33147P-A, Rev. 2) was approved in 2007.
- NEDE-33147P Rev. 3 with TRACG04, PANAC11 kinetics and PRIME fuel thermal mechanical model submitted to USNRC in 2011
  - Integral simulation of instability event
  - Full core simulation – Every fuel bundle in the core simulated individually
  - Rigorous application of CSAU and RG 1.157

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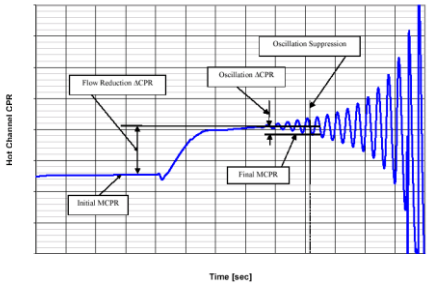
Stability – DSS-CD TRACG Application



- Significant CPR margin at time of oscillation suppression

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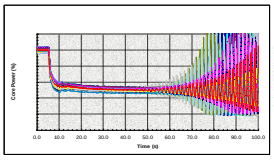
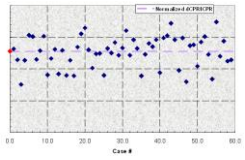
Stability – DSS-CD TRACG Application

Typical BWR Instability following a Two-Pump Trip



Core Power



ΔCPR/ICPR

- Full core simulation
- 59 random trials - 95/95 One-Sided Upper Tolerance Limit for ΔCPR/ICPR
- Rigorous quantification of uncertainty and evaluation of plant operating limit

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ESBWR Applications

- Transient and accident analyses evaluated with TRACG
  - Best estimate methods plus uncertainties
  - CSAU and RG 1.157
  - TRACG Application for ESBWR (LOCA), NEDC-33083P-A, Approved 2004
  - TRACG Application for ESBWR Stability Analysis, NEDC-33083P-A S1, Approved 2007
  - TRACG Application for ESBWR ATWS Analysis, NEDC-33083P-A S2, Approved 2010
  - TRACG Application for ESBWR Transient Analysis, NEDC-33083P-A S3, Approved 2010

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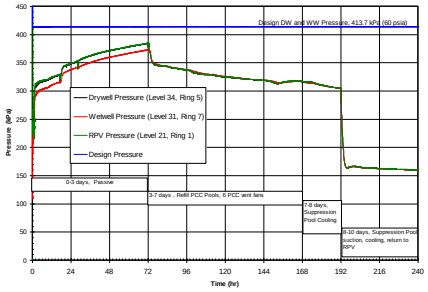
ESBWR Applications



- Main Steam Line Break - Containment Pressure

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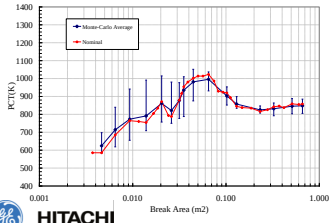
Ongoing Application Development

- LOCA application for operating BWRs
  - NEDE-33005P submitted to USNRC in 2011
- ATWS application for operating BWRs
  - ATWS with depressurization
  - ATWS instability
- TRACG LOCA example: BWR/4 suction line break spectrum



- Tolerance bands
  - 1st and 59th rank trial values
- Number of calculations
  - 981 for this example
  - 37 nominal +16 x 59 trials
- Robust code

100-150 K PCT improvement

1-1.5 kW/ft MAPLHGR benefit for LOCA limited plants

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GEH Experience with Best Estimate Methods for BWR Transient and Accident Analyses

- GEH has 10+ years experience with the application of advanced best estimate methods
  - Application to transients, stability, LOCA and ATWS
  - Application to operating plants and new plants
  - 7 Approved LTRs
- Improved characterization of events and quantification of safety margins
  - Realistic results
  - Rigorous quantification of uncertainties
  - Robust and reliable calculations
- Enabler for:
  - Expanded operating domains for operating plants
  - New plant design

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Acronyms

ACRS	Advisory Committee on Reactor Safeguards
AOO	Anticipated Operational Occurrence
ATWS	Anticipated Transient Without Scram
BWR	Boiling Water Reactor
BWROG	BWR Owners Group
CPR	Critical Power Ratio
CSAU	Code Scaling, Applicability and Uncertainty
DSS-CD	Detect and Suppress Solution – Confirmation Density
DW	Drywell
ESBWR	Economic Simplified Boiling Water Reactor
GE	General Electric
GEH	GE Hitachi
ICPR	Initial Critical Power Ratio
LOCA	Loss Of Coolant Accident
MAPLHGR	Maximum Average Planar Linear Heat generation Rate
MCPR	Minimum Critical Power Ratio
MELLLA+	Maximum Extended Load Line Limit Analysis Plus
PCC	Passive Containment Cooling
PCT	Peak Cladding Temperature
RPV	Reactor Pressure Vessel
USNRC	United States Nuclear Regulatory Commission
WW	Wetwell

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