GE Nuclear Energy

ESBWR Technology Program : TRACG

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NRC Staff - GE Meeting
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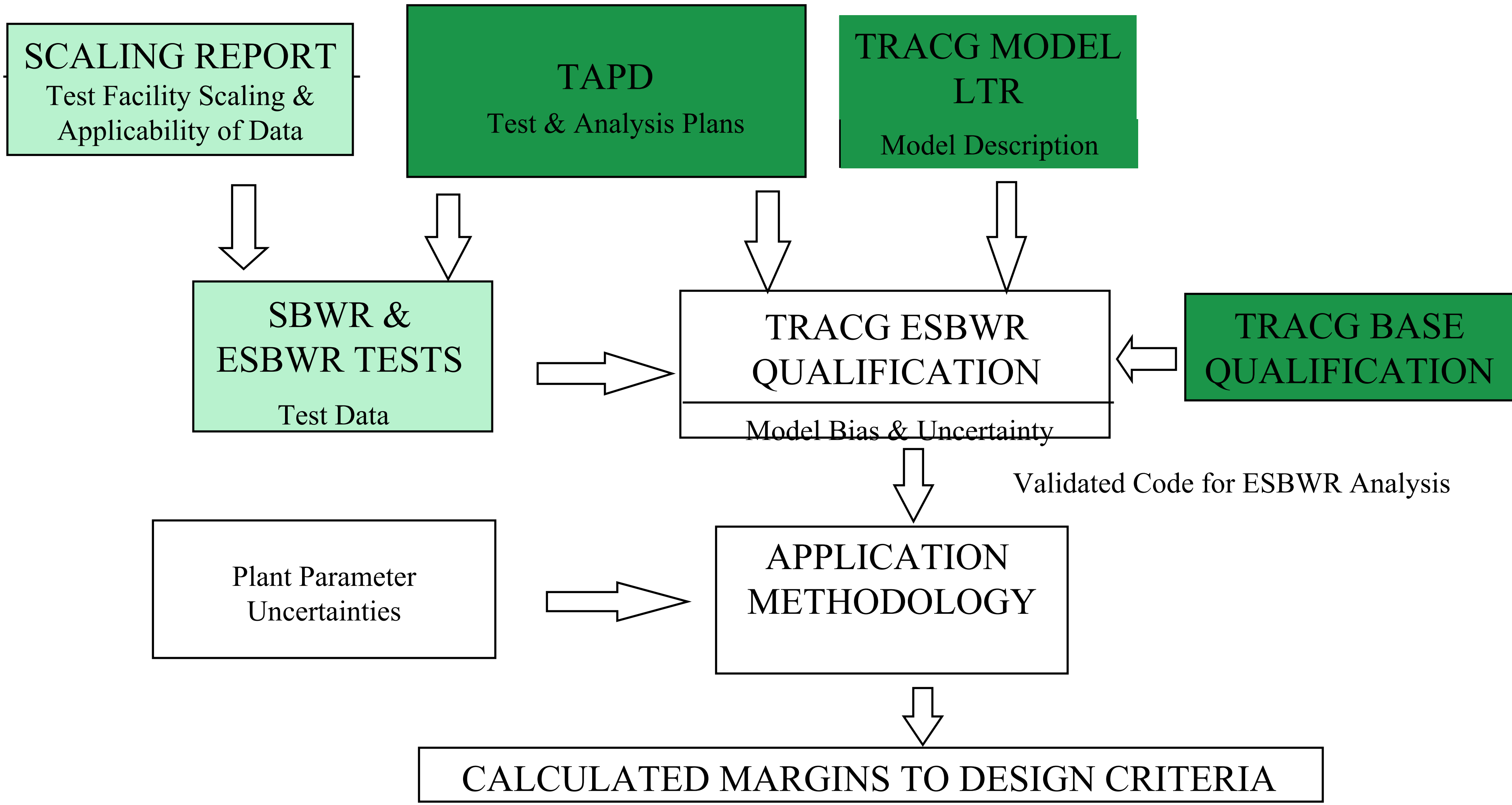
Rockville, Maryland

ESBWR Technology Program Elements



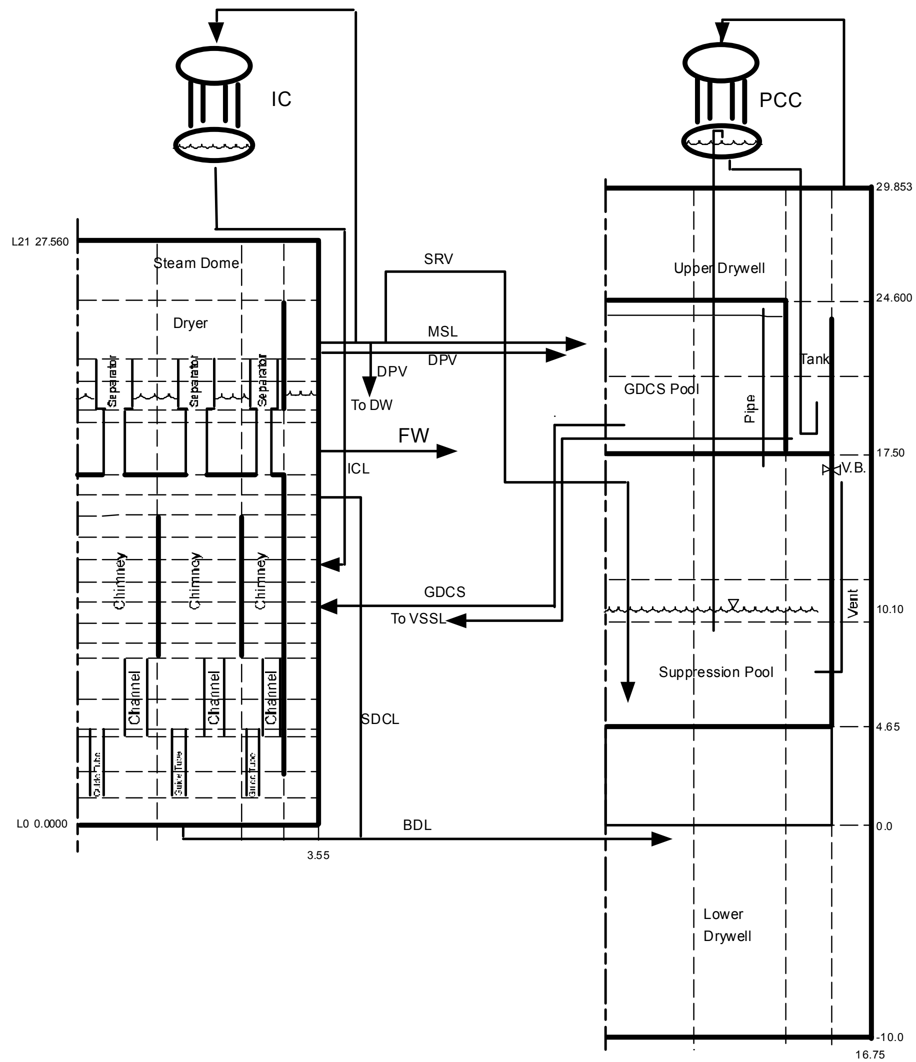
TRACG for ESBWR

- ***TRACG Models***
- ***TRACG Qualification***
- ***TRACG Application***

TRACG Model Description

- ***TRACG Model Description, NEDE-32176P, Rev. 1 submitted to NRC (Reactor Systems and Containment Branches)***
- ***Acceptability review performed by both branches***
- ***Details of models have been discussed several times with both branches***

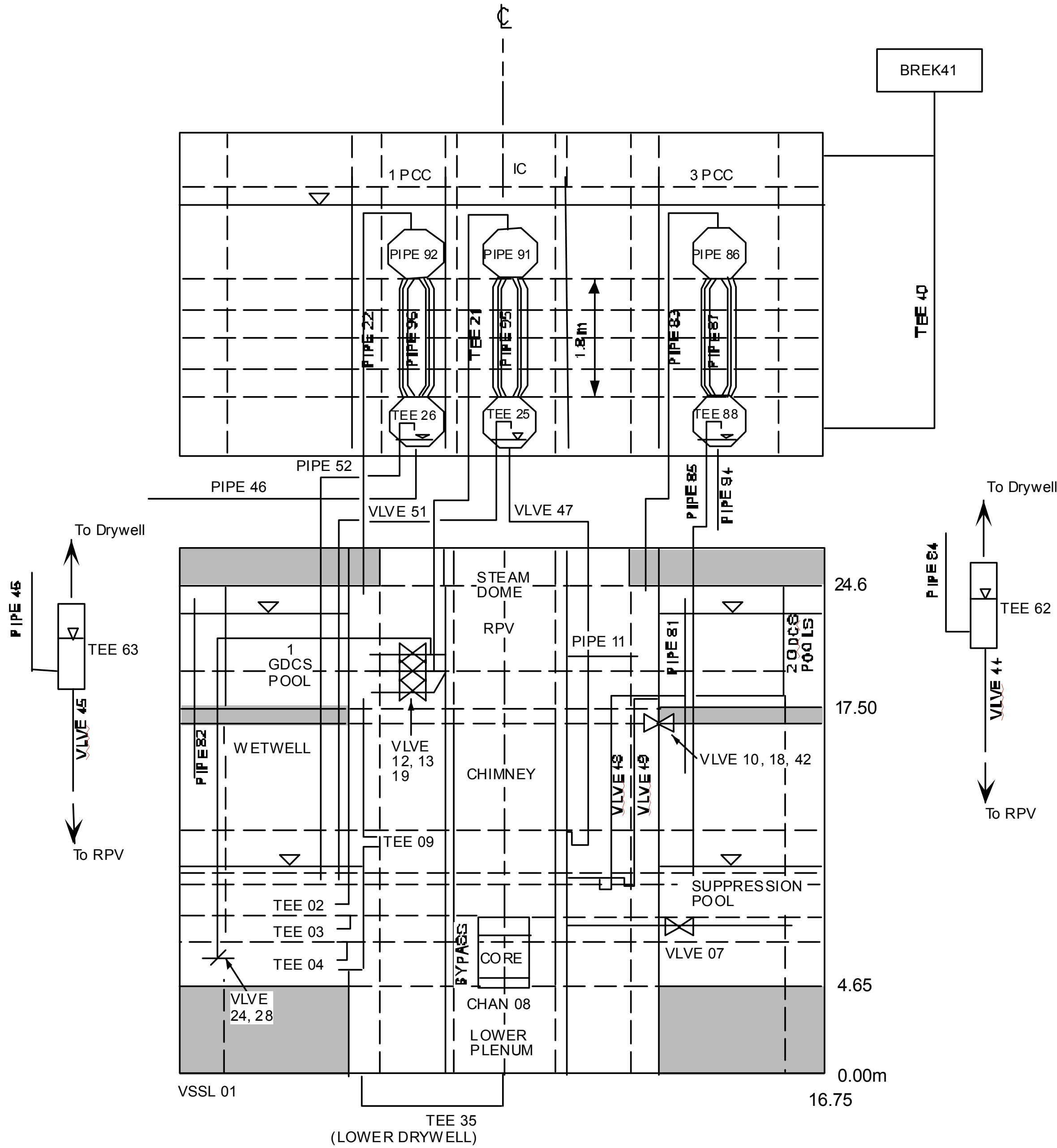
TRACG Nodalization for ECCS/ Transient Analysis



ESBWR TRACG LOCA MODEL

ESBWR1-a.CNV

TRACG Nodalization for Containment Analysis



Reactor Systems Branch Reviews

- *NRC Letter of July 5, 1996 : Staff Review of General Electric's LTR NEDE-32167P, "TRACG Model Description" Revision 1, related to Reactor Systems Area*
  - *Revised LTR is acceptable for detailed future review*
  - *5 Open issues*

    Lack of BOP model – not needed, treated as BC

    Lack of turbulent mixing model assessment – not used

    Lack of assessment of Upper plenum and Steam dryer models – Upper plenum model is not used; steam dryer model has been assessed

    Lack of boron mixing assessment – assessment performed

    One group 3D kinetics model needs assessment – assessment performed
- *Subsequently, Reactor Systems Branch has reviewed and accepted Revision 2 for operating plant transients*
  - *Rev 2 is the same as Rev 1, but without specific references to SBWR*
  - *No changes to models*

ESBWR-specific TRACG qualification remains to be reviewed

Containment Branch Review

- *Letter of July 31, 1996: Staff Review of General Electric's LTR NEDE-32167P, "TRACG Model Description" Revision 1, related to Containment Area*
  - *Several concerns identified for containment modeling*
  - *Needs extensive comparitive studies using both experimental data and other containment models*
  - *Areas identified*

    Steam/noncondensible mixing and noncondensible distribution

    Thermal stratification in suppression pool

    Applicability of flow regime map for containment volumes

    Applicability of heat transfer correlations for containment volumes
- *GE has developed conservative approaches to address calculations of gas mixing and suppression pool stratification*
- *GE has since performed extensive qualification against the SBWR and ESBWR integral tests of containment response*

TRACG can be used to perform conservative calculations for containment pressures and temperatures

TRACG Qualification

- ***TRACG has been systematically assessed against:***
  - ***Separate effects tests***
  - ***Component performance tests***
  - ***Integral system effects tests***
  - ***BWR plant data***
- ***"Generic BWR" and early SBWR qualification studies documented in base TRACG Qualification LTR NEDE-32177P Rev 1***
- ***Supplemented by "TRACG Qualification for SBWR", NEDC-32725P Vol. 1 and 2***
- ***Further supplemented by TRACG Qualification for ESBWR-specific TEPSS tests***

- ***Separate Effects Tests***

Test	Assessment Objective
FRIGG OF-64 Void Fraction Tests	Void fraction (interfacial shear)
Christensen Subcooled Boiling Void Fraction tests	Void fraction (interfacial shear and heat transfer)
Wilson and Bartolomei Bubble Rise Tests	Void fraction (interfacial shear at low flow)
EBWR Void Fraction Tests	Void fraction (interfacial shear), large Dh
PSTF Level Swell Tests	Void fraction/two-phase level (interfacial shear)
THTF Film Boiling Heat Transfer Test	Wall and interfacial heat transfer
Core Spray Heat Transfer Tests	Wall and interfacial heat transfer, radiative heat transfer
Upper tieplate counter current flow limiting (CCFL) tests	CCFL corrrelation
Marviken Critical Flow tests	Critical flow
PSTF Critical Flow Tests	Critical flow
Edwards Blowdown test	Critical flow
FRIGG Natural Circulation and Stability Tests	Pressure drop. oscillation inception and magnitude
ATLAS Pressure Drop Tests	Bundle pressure drop components
ATLAS Flow Oscillation Critical Power Tests	Boiling transition, post-dryout heat transfer and rewetting
ATLAS Pressurization Transients	ΔCPR/ICPR
SPERT Reactivity Insertion Test	Neutronic parameters and kinetics

Base Qualification Report

- ***Component Performance Tests***

Test	Assessment Objective
Jet Pump Performance Tests	M and N- ratios
Full-scale Separator Performance Tests (GE)	Carryover, carryunder and pressure drop
SSTF Upper Plenum Mixing Tests	Subcooling distribution at top of bundles
Toshiba GIRAFFE Phase I Tests	PCCS performance /condensation in presence of noncondensibles

- ***Integral System Tests***

Test	Assessment Objective
TLTA Tests	Integral system ECCS/LOCA response
FIST Tests	Integral system ECCS/LOCA response
GIST Tests	Integral system ECCS/LOCA response
SSTF Tests	Multi-channel refill/reflood response
GIRAFFE Phase II Tests	Integral system ECCS/LOCA response
Tokyo Institute of Technology Geysering Experiment	Low pressure stability response

Base Qualification Report

- ***Operating Plant Data***

Test	Assessment Objective
Peach Bottom Turbine Trip Tests	Pressure, fission power, downcomer level response
Hatch Two-Pump Trip Test	Core flow, fission power, downcomer level response
Hatch MSIV Closure Test	Pressure and downcomer level response
LaSalle Instability Event	Oscillation inception and magnitude
Leibstadt Stability Tests	Oscillation inception and magnitude
Forsmark Stability Tests	Oscillation inception and magnitude
Cofrentes Stability Event	Oscillation inception and magnitude

Assessment studies added in SBWR Qualification Report

- ***Separate Effects Tests***

Test	Assessment Objective
Toshiba Low Pressure Void Fraction Tests	Void fraction (interfacial shear) at low pressure
Ontario Hydro Void Fraction Tests	Void fraction (interfacial shear) for large Dh

- ***Component Performance Tests***

Test	Assessment Objective
PANTHERS PCC Performance	PCC heat removal (full scale)
PANTHERS IC Performance	IC heat removal (full scale)
PANDA PCCS Performance	PCC heat removal (scaled)
PSTF Mark III tests	Suppression Pool Stratification

Assessment studies added in SBWR Qualification Report

- ***Integral System Tests***

Test	Assessment Objective
GIRAFFE/Helium Tests	Long term containment response with light noncondensibles
GIRAFFE/SIT	Integral LOCA response (vessel inventory, GDCS performance)
1/6th Scale Boron Mixing Tests	Boron mixing and stratification
PSTF MARK III Containment Response	Short term containment response
4T/MARK II Containment Response	Short term containment response
PANDA Transient Tests	Long term containment response

- ***Natural Circulation and Flow Oscillation Tests***

Test	Assessment Objective
Dodewaard Steady State	Natural circulation
Dodewaard Startup	Plant startup
CRIEPI Low Pressure Oscillation Tests	Low pressure flow oscillations
PANDA Exploratory Tests	Low pressure flow oscillations

ESBWR-specific assessment

- ***PANDA TEPSS program conducted for ESBWR configuration***
- ***TRACG qualification completed for TEPSS tests (separate report)***
  - ***Long term containment response tests***
  - ***Tests with helium injection to simulate hydrogen release***
  - ***Late GDCS phase response***

- ***CRIEPI High Pressure Thermal Hydraulic Stability Tests***
  - ***Pressure range up to operating pressure***

TRACG Qualification Review Status

- *NEDE-32177 Rev. 1 reviewed primarily by Reactor Systems Branch*
  - *Responses to RAIs were provided by GE*
  - *NRC evaluated RAI responses*
- *Rev 2 (Rev 1 minus SBWR-specific assessment) reviewed and accepted for BWR AOO application*
- *TRACG Qualification for ESBWR*
  - *SBWR Qualification Report completed after NRC review terminated*

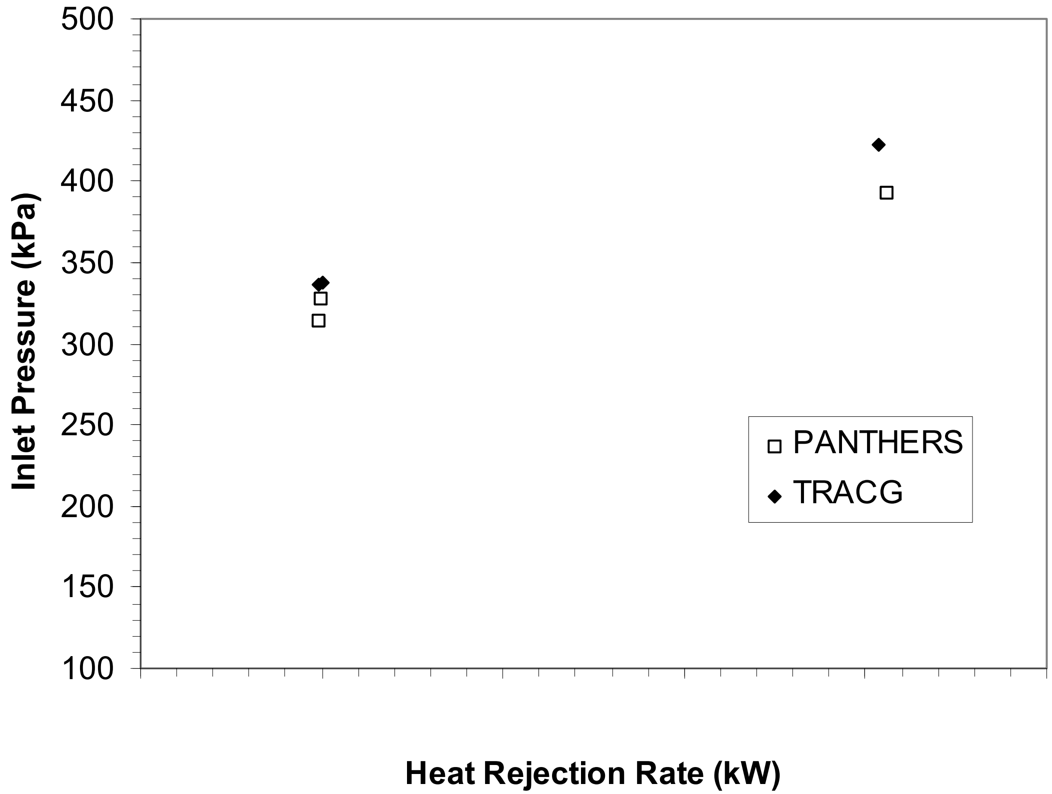
    Includes PANTHERS, PANDA , GIRAFFE-Helium and GIRAFFE-SIT tests

    Reviewed by Utility Analysis & Test Review Team
  - *TRACG Qualification of TEPSS Tests*
  - *Not submitted for NRC review*

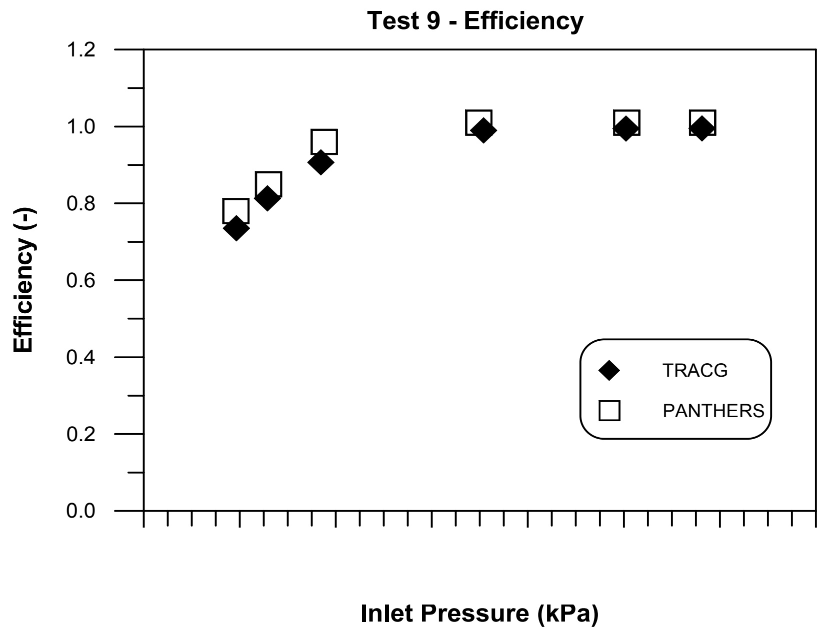
Examples of TRACG Qualification Results

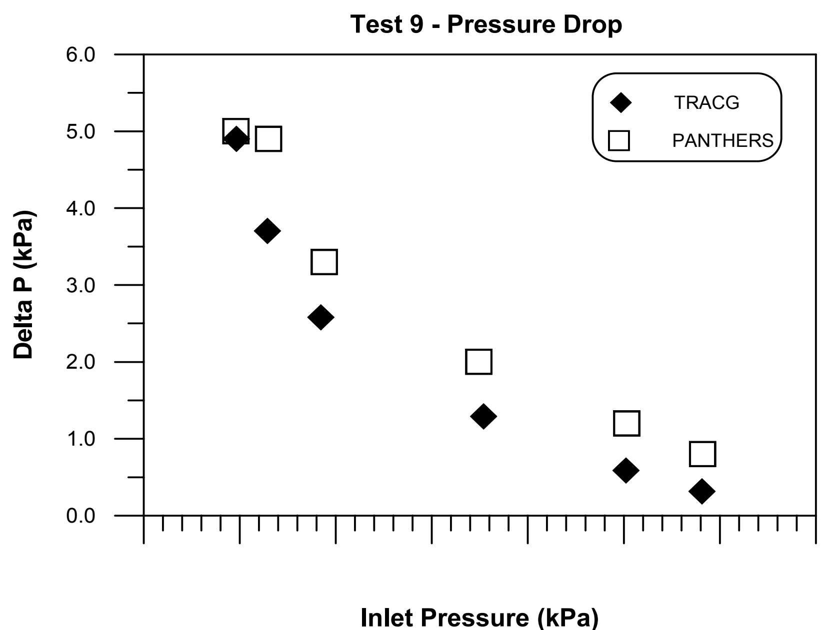
- ***PANTHERS PCC Heat Removal for Steam***
- ***PANTHERS PCC Performance with Noncondensibles***
- ***PANTHERS IC Heat Removal vs. Inlet Pressure***
- ***GIRAFFE-SIT GDCS Line Break***
- ***PANDA Test M3 – Long Term Containment Response***

PANTHERS PCC Heat Removal for Steam

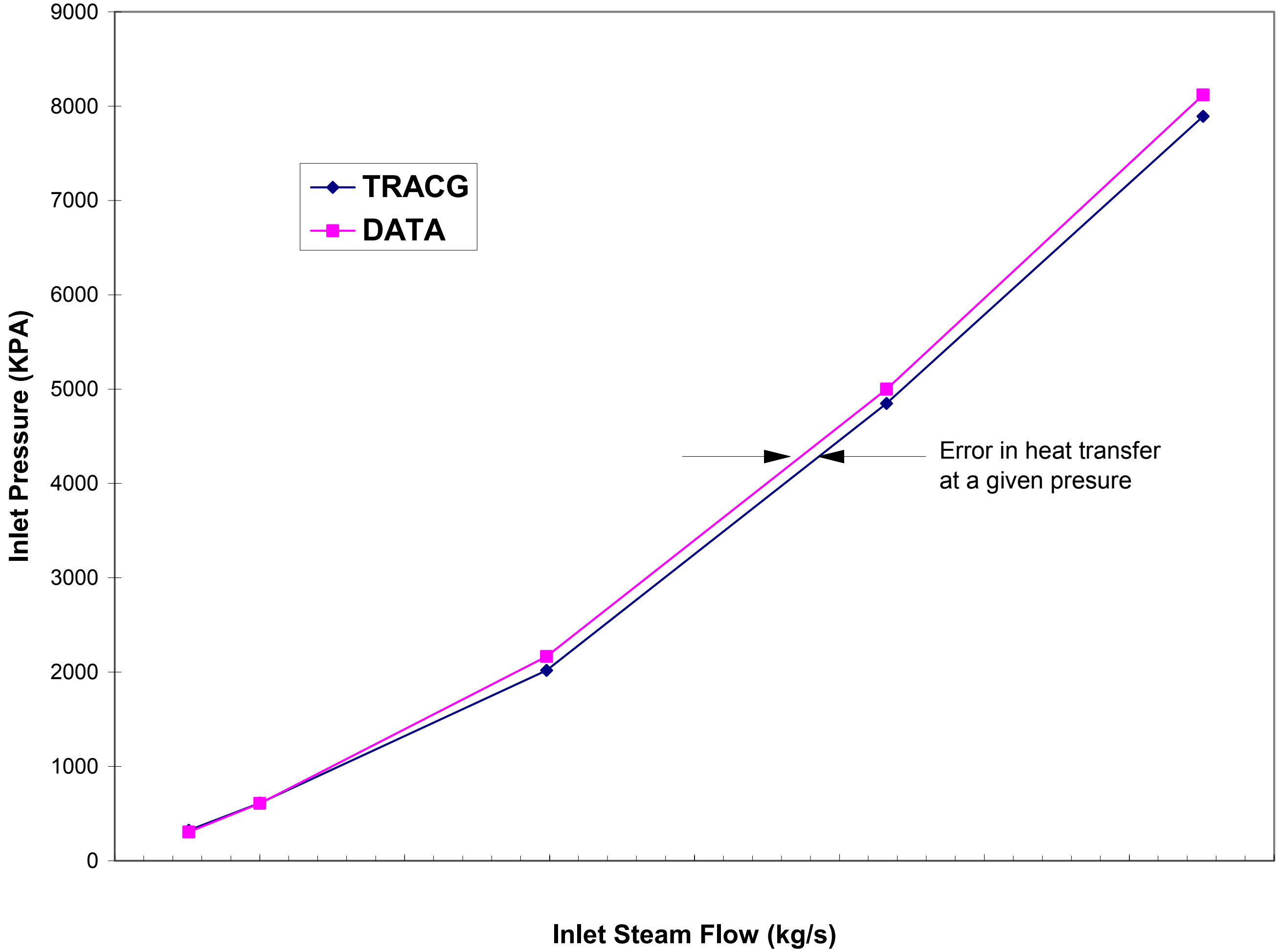


PANTHERS PCC Performance with Noncondensibles

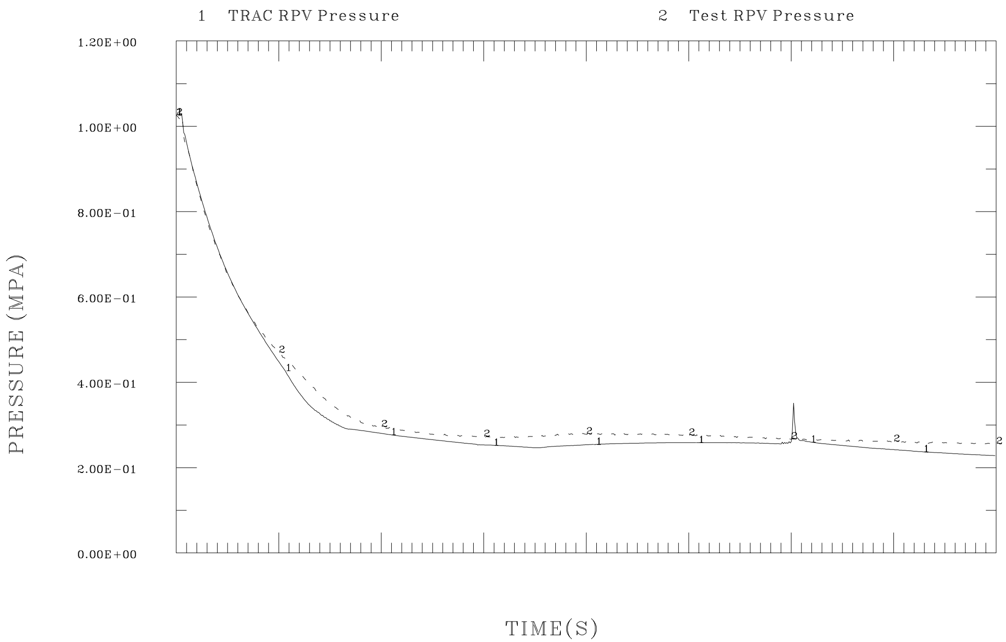




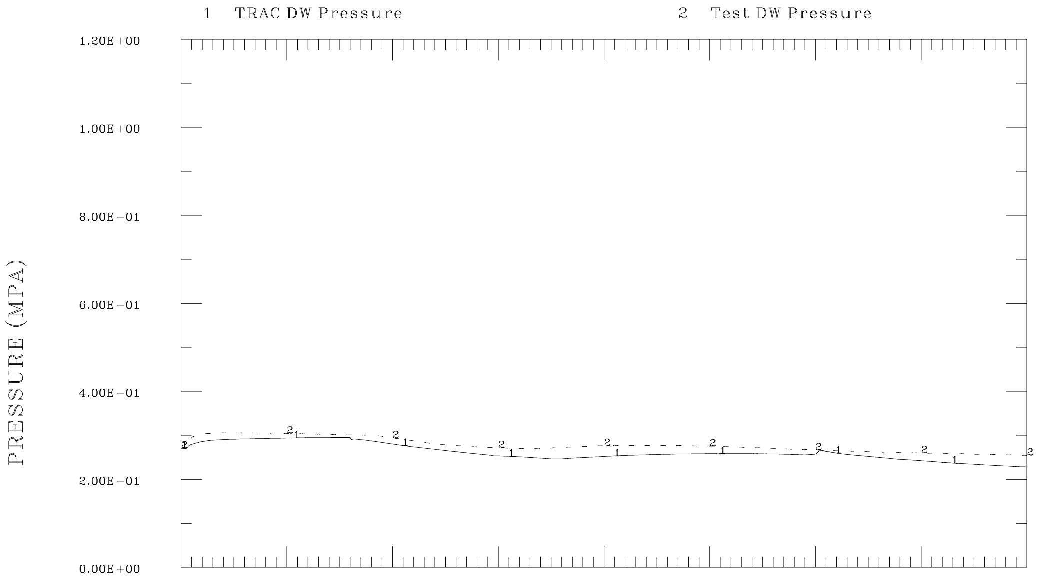
PANTHERS IC Heat Removal vs. Inlet Pressure

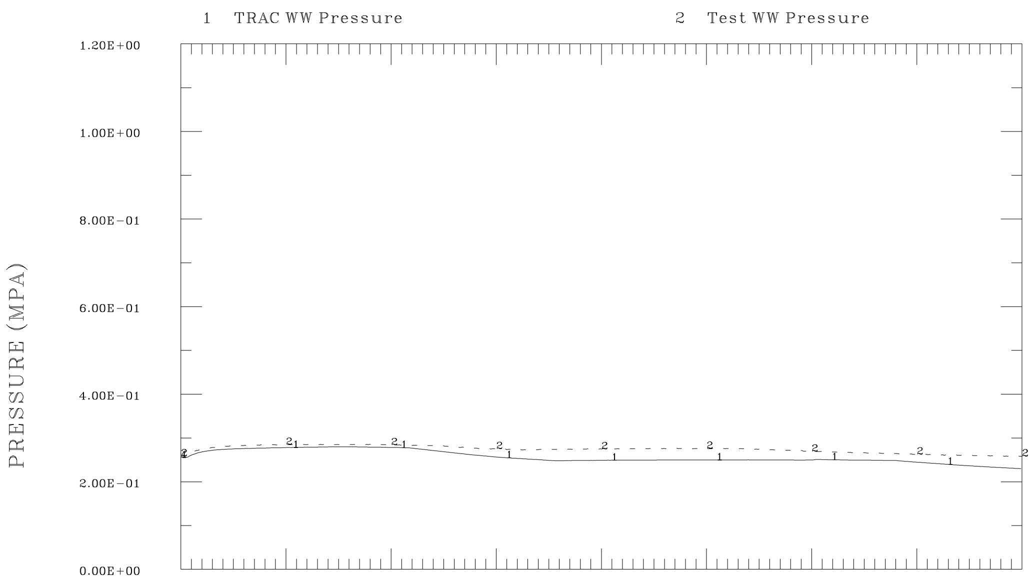


GIRAFFE-SIT GDCS Line Break – RPV Pressure

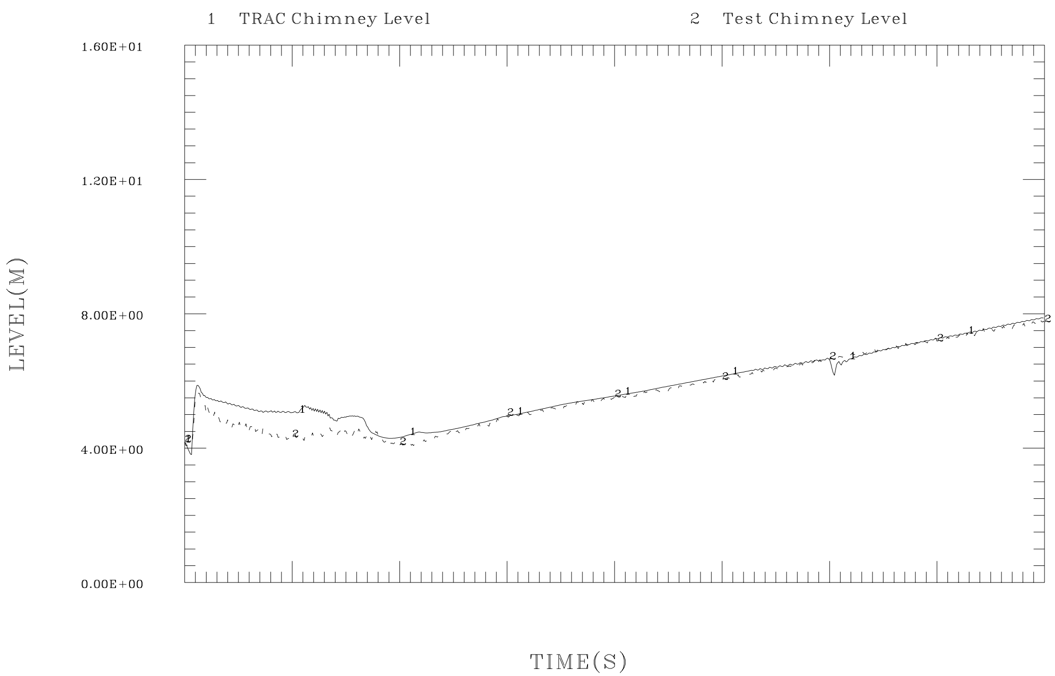


GIRAFFE-SIT GDCS Line Break – Drywell & Wetwell Pressure

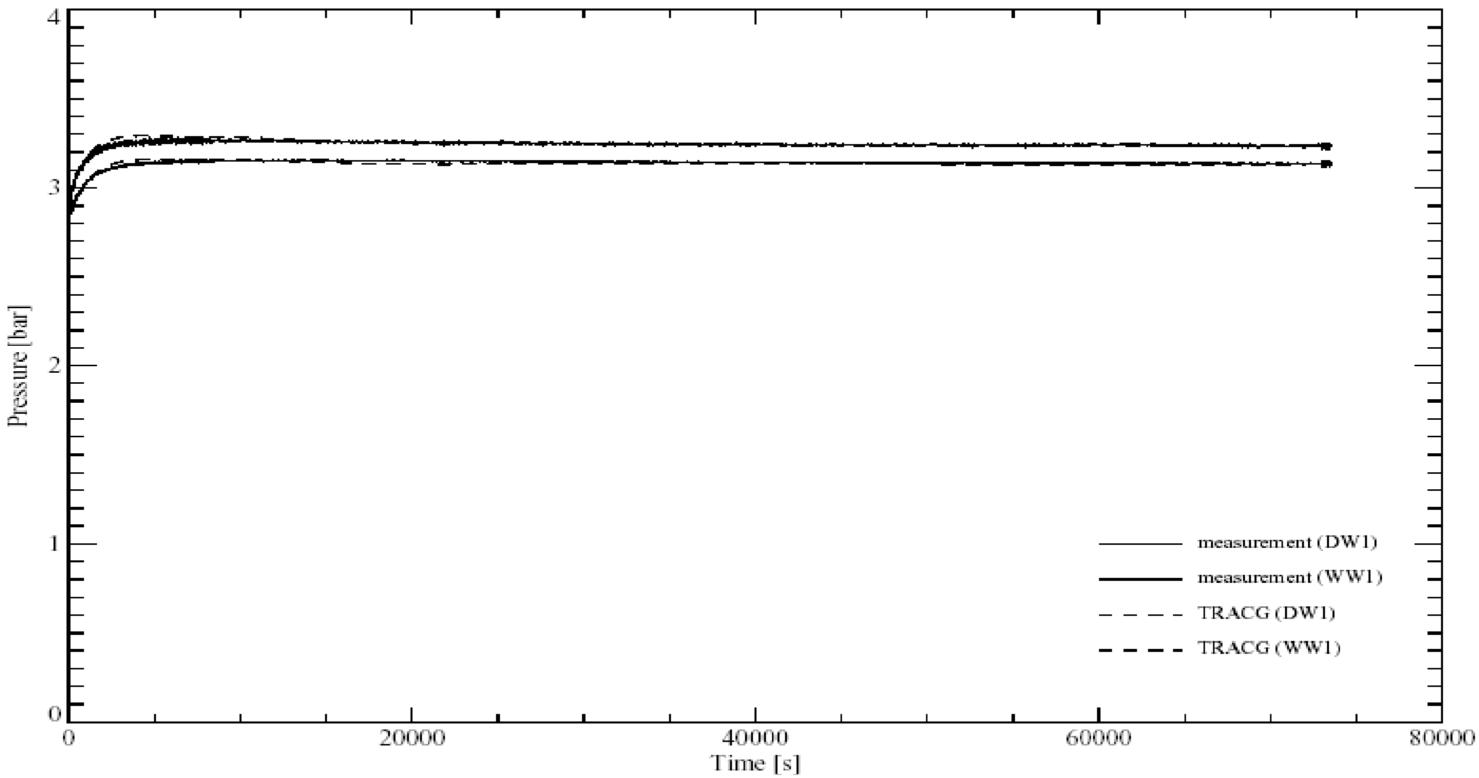




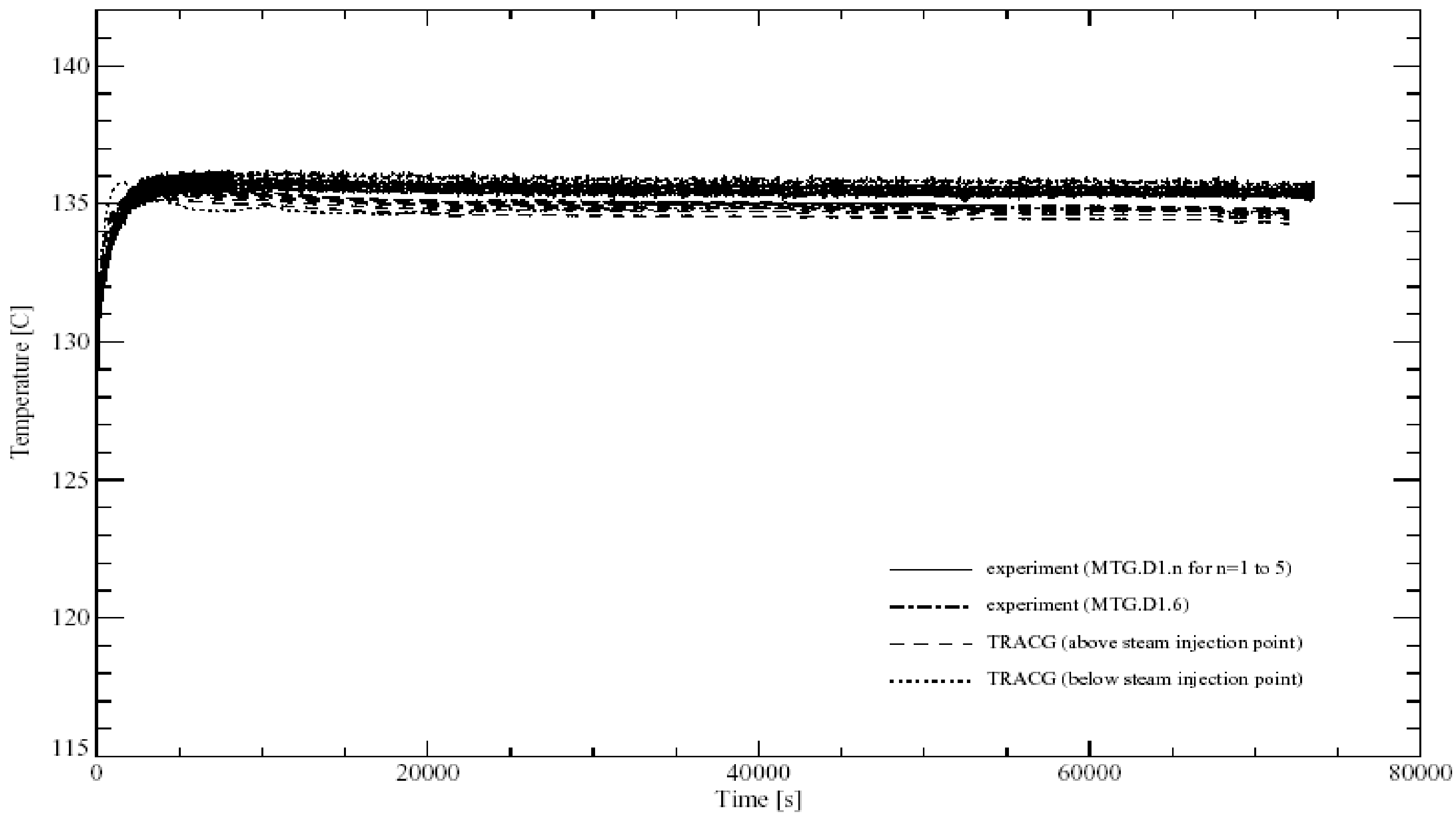
GIRAFFE-SIT GDCS Line Break – Chimney Level



PANDA Test M3 – Long Term Containment Response



PANDA Test M3 – Long Term Containment Response



Summary of TRACG Qualification

- ***Assessment accuracy (error) compiled for all comparisons***
- ***Adequacy established by comparing against:***
  - ***Experimental uncertainty***
  - ***Design margin***
  - ***Engineering judgment***
- ***Examples in following charts***

ESBWR-specific Test ProgramTRACG Accuracy for Chimney Void Fraction

Test Program	**Average Difference (bias)**		**Standard Deviation of Differences**	
Ontario Hydro Void Fraction (3.2)	Absolute	Relative	Absolute	Relative
Time average chimney void fraction	x.xx%	x.xx%	x.xx%	x.xx%
Bartolomei et al. (3.3)	Absolute	Relative	Absolute	Relative
Tests at 4.6 MPa	x.xx%	-	x.xx%	-
Wilson et al. (3.3)	Absolute	Relative	Absolute	Relative
Tests at 2.2 MPa	x.xx%	-	x.xx%	-
EBWR (3.3)	Absolute	Relative	Absolute	Relative
Chimney center (4.2 MPa) Chimney edge (4.2 MPa)	x% x%	-	x% x%	-

TRACG Accuracy for IC/PCC Heat Removal

Test Program	Average Difference (bias)		Standard Deviation of Differences	
PANTHERS IC (4.2)	Absolute	Relative	Absolute	Relative
IC heat transfer rate	x kW	x.x%	x kW	x.x%

Test Program	Average Difference (bias)		Standard Deviation of Differences	
PANTHERS PCC (4.1)	Absolute	Relative	Absolute	Relative
Condenser efficiency for steam/air inlet conditions	x.xx	x.xx%	x.xx	x.xx%
Condenser heat removal for pure-steam inlet conditions	x MW	x.xx%	x MW	x.xx%
PANDA/PCC (4.3)	Absolute	Relative	Absolute	Relative
Condenser efficiency for steam/air inlet conditions	x.xx	x.xx%	x.xx	x.xx%
Condenser heat removal for pure-steam inlet conditions	x kW	x.xx%	x kW	x.xx%

TRACG Accuracy for Long Term Containment Pressure

Test Program	Average Difference (bias)		Standard Deviation of Differences	
GIRAFFE Helium (5.2)	Absolute	Relative	Absolute	Relative
DW peak pressure	x.x kPa	x.xx%	x.x kPa	x.xx%
GIRAFFE SIT (5.3)	Absolute	Relative	Absolute	Relative
DW pressure at end of test	x.x kPa	x.xx%	x.x kPa	x.xx%
PANDA Transient (5.7)	Absolute	Relative	Absolute	Relative
DW peak pressure	x.x kPa	x.xx%	x.x kPa	x.xx%

TRACG Limitations and Treatment

- ***Phenomena requiring more modeling detail***
  - ***PCC model with a single tube representation not adequate when light noncondensibles (hydrogen) are present***
    - ***6 tube model compared better with data***
    - ***Recommended for hydrogen release scenarios***
  - ***PANDA tests showed unequal load sharing among PCCs as heat load dropped off***
    - ***However total heat removal adequately calculated by TRACG***
- ***Phenomena requiring bounding models***
  - ***Boron mixing***
  - ***Suppression pool stratification***
  - ***Stratification of steam leakage flow into Wetwell Gas Space***
  - ***Mixing of Drywell Noncondensible Gases***
  - ***Bounding approaches developed based on assessment results***

Sound design approaches developed

TRACG Application to ESBWR

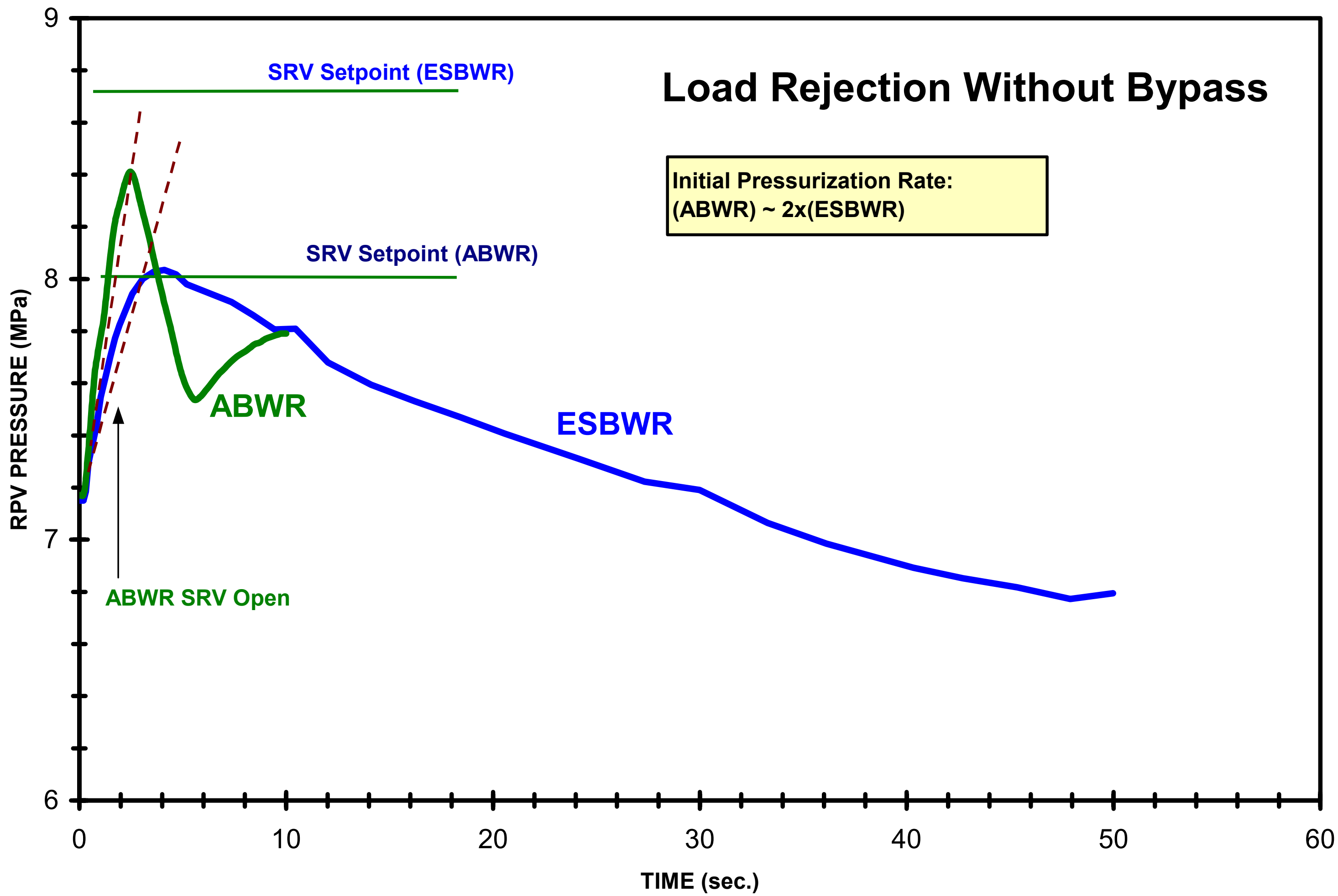
Analysis Type	Analysis Method	
	BWR	***ESBWR***
Steady state	ISCOR	ISCOR
Transients		
· Pressurization	TRACG	TRACG
· Loss of feedwater heating	PANACEA	PANACEA
ATWS	ODYN/TASC	TRACG
Stability	ODYSY/TRACG	ODYSY/TRACG
LOCA/ECCS	SAFER	TRACG
LOCA/containment		
· Pressure/temperature response	M3CPT/SUPERHEX	TRACG
· Loads	Approved Methodology	Approved Methodology

TRACG is the primary analysis code for ESBWR

TRACG Application for AOOs

- ***TRACG is applied to all AOOs in SSAR Chapter 15 and ASME vessel overpressure protection events in Chapter 5, <u>except for</u>:***
  - ***Control Rod Withdrawal Error (analyzed with PANACEA)***
  - ***Control Rod Drop Accident (incredible event for FMCRDs)***
  - ***Stability (in conjunction with ODYSY frequency domain code)***
  - ***Radiological release events (Fuel handling accident)***
- ***Pressurization events are limiting for CPR***
- ***Four events need to be considered:***
  - ***Single control valve closure: slow pressurization event terminated by high simulated thermal power***
  - ***Feedwater controller failure: turbine trip on high water level***
  - ***Loss of AC Power (bypass valves available): fast pressurization event***
  - ***Load rejection with bypass failure to open: fast pressurization event***
- ***TRACG application methodology approved for BWR AOOs will be extended to ESBWR analysis***
  - ***Transients and limiting events are milder than for operating plants***

Reactor Pressure Response to Isolation Events



ESBWR has slower pressurization - no relief valves open

TRACG Application for ECCS/LOCA

- ***No new phenomena are introduced in ESBWR ECCS/LOCA***
  - ***Operating BWRs have ADS to depressurize system and allow LPCI to inject***
- ***Tests and analysis show that core does not uncover for any break***
  - ***Minimum two-phase level in chimney above core is greater than 2 m for limiting break (GDCS/BD line break)***
- ***GE intends to follow Reg Guide 1.157***
  - ***Uncertainties in high ranked model parameters and plant parameters will be quantified***
- ***However, statistical analysis of PCT is not meaningful***
  - ***No core heatup***
- ***Propose performing best estimate and bounding calculations of mixture level with key uncertainties set to bounding values (say, 2 σ)***
- ***Approach consistent with level of ECCS margin built into design***
  - ***Uncertainty in calculation bounded as per Reg Guide intent***

TRACG Application for Containment

- ***GE is not proposing a best estimate analysis of containment response with TRACG***
- ***Assessment studies demonstrate that effects of pool stratification and noncondensible distribution can be modeled conservatively***
- ***ESBWR containment response to LOCA is mild and has ample margin to design limits***
- ***Propose a conservative application approach***
  - ***Key parameters that affect containment response will be identified***

    Model parameters (pool stratification, wetwell gas space stratification, drywell stratification and hideout, PCC heat transfer coefficients, decay heat, critical flow, etc.)

    Initial conditions (drywell and wetwell pressures and temperatures, drywell relative humidity, PCC pool initial temperature, suppression pool initial temperature, etc)

    Analysis assumptions (leakage from drywell to wetwell gas space,, etc)
  - ***Key parameters will be treated conservatively***
  - ***Bounding calculations will be performed to demonstrate margins to design limits***

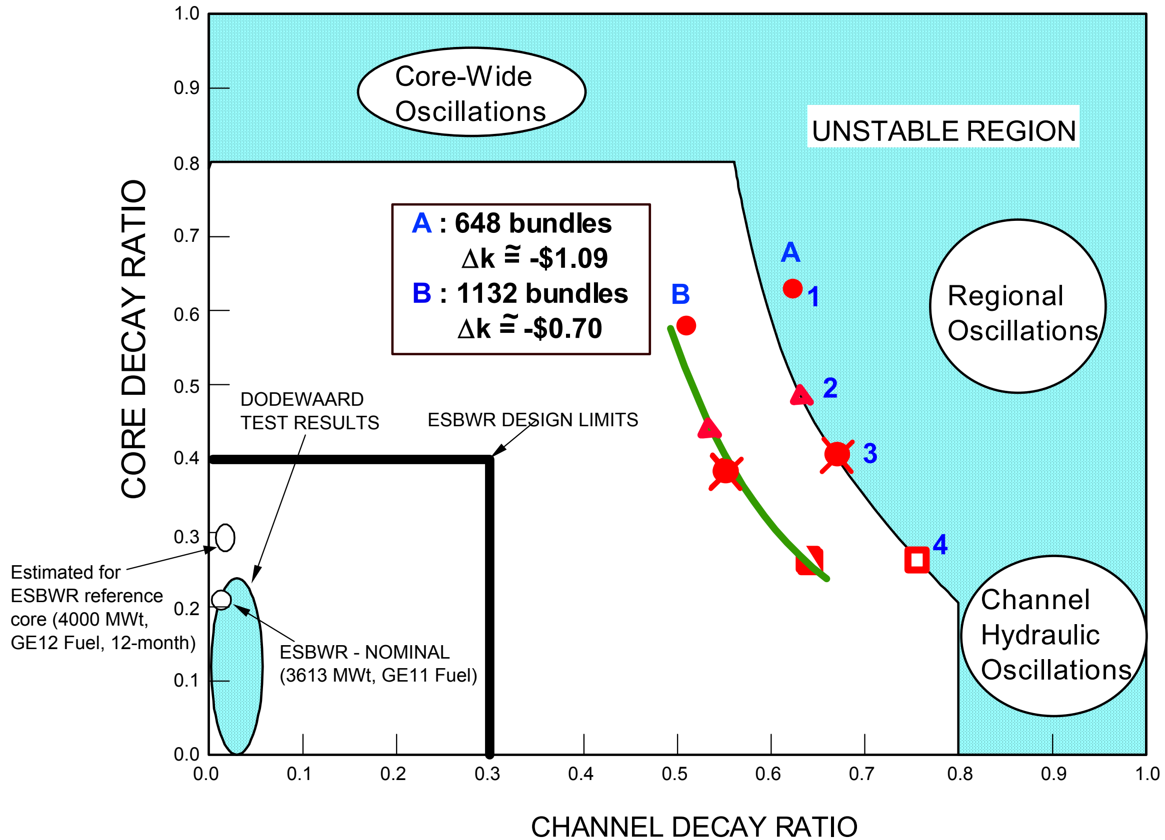
TRACG Application for ATWS

- ***Because of low event probability, detailed statistical quantification of uncertainty not required***
- ***Accepted approach utilizes a realistic calculation with some conservatism to cover uncertainties***
- ***TRACG calculations will include a bounding approach to boron mixing***
  - ***Established from assessment studies***

TRACG Application for Stability Analysis

- ***ODYSY (frequency domain code) is used for decay ratio calculations at operating conditions***
  - ***Previous frequency domain calculations have demonstrated large stability margins***
  - ***Margins corroborated by ORNL calculations***
  - ***Decay ratios also calculated for harmonic modes (regional stability)***
- ***ESBWR will also implement hardware solutions (e.g. Confirmation Density Algorithm) approved for operating plants***
- ***TRACG is used to establish startup procedures to avoid possibility of low pressure flow oscillations***
  - ***Qualified against available low pressure data***

ESBWR Stability Design Margins



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Summary

- ***TRACG Model Description***
  - ***Unchanged from previous version reviewed by NRC and accepted for AOOs for operating plants***
- ***TRACG Qualification***
  - ***Rev. 2 has been reviewed and accepted by NRC for AOOs for operating plants***
  - ***Significant amount of additional qualification performed, particularly for long term containment response***
  - ***Accuracy of models quantified for prediction of key parameters***
  - ***Model limitations identified and bounding approaches developed to treat these limitations***
- ***TRACG Application***
  - ***AOOs – extend operating plant approach to ESBWR***
  - ***ECCS/LOCA – account for uncertainties in manner commensurate with margin***
  - ***Containment/LOCA – bounding models and input parameters***