GE Nuclear Energy

ESBWR Technology Program : TAPD

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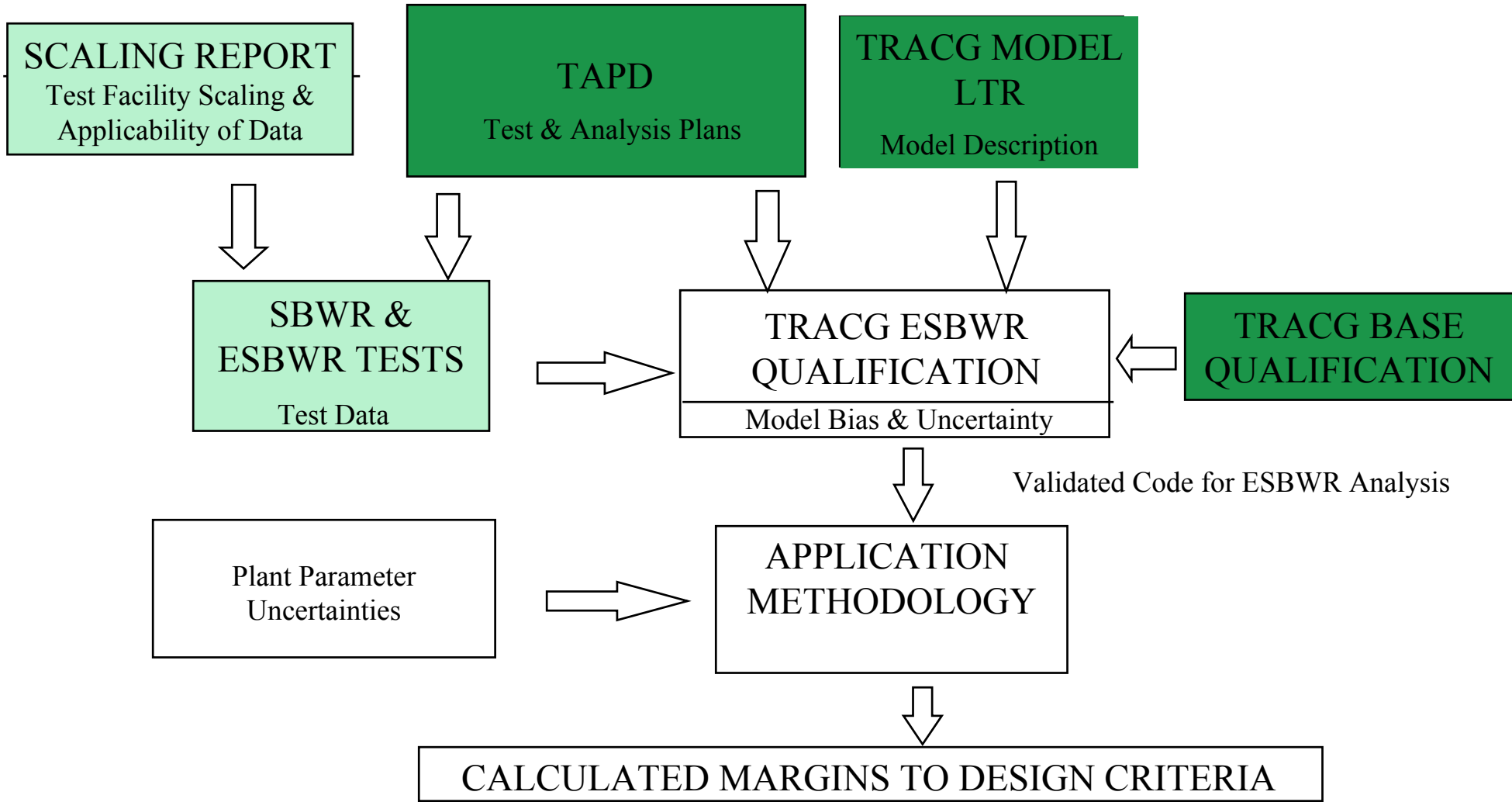
ESBWR Technology Program Basis

- ***Builds on BWR technology programs and operating experience***
  - ***BWR-related tests, plant data, TRACG and other approved design codes***
- ***Supplemented by SBWR technology programs***
  - ***SBWR-specific tests, TRACG qualification for SBWR***
- ***Further supplemented by ESBWR-specific technology programs***
  - ***ESBWR-specific tests, ESBWR performance analysis***

Comprehensive technology basis

ESBWR Technology Program Elements



Test and Analysis Program Description (TAPD)

- ***Purpose***
  - ***To provide a comprehensive, integrated plan that addresses the testing and analysis elements needed for analysis of ESBWR steady state and transient performance***
  - ***Study of calculated ESBWR transients and identification of important phenomena (PIRT)***
  - ***Systematic definition of experimental and analytical modeling needs***
  - ***Evaluation of testing and analysis plan against these needs to establish adequacy of program***
- ***Results presented here refer primarily to SBWR study***
  - ***Applicable to ESBWR***
- ***TAPD will be updated for ESBWR***

TAPD Scope

- ***Prediction of ESBWR system performance during normal operation, transients and LOCAs***
  - ***Includes: Steady state operation and plant startup; anticipated operational transients (AOOs) and ATWS; LOCA (vessel and containment); stability***
  - ***Excluded: Severe accidents are considered separately (design requirements for containment to handle hydrogen generation assuming metal-water reaction are considered). Non-thermal hydraulic issues (structural integrity, seismic response; etc.) are not covered other than as input parameters for system response evaluations.***

ESBWR and BWR Analysis Methods

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

BWR methods familiar to NRC – TAPD provides basis for applicability to ESBWR

Strategy for Determination of Test & Analysis Needs

- ***Develop list of governing phenomena and system interactions***
  - ***Top-Down process***
  - ***Bottom-Up process***
- ***Top-Down Process***
  - ***Calculate scenarios for transients/LOCAs***
  - ***Determine key phases of transients***
  - ***List potentially important phenomena***
  - ***Expert Group ranking phenomena (PIRT)***
- ***Bottom-Up process***
  - ***List all unique ESBWR design features***
  - ***Determine associated phenomena/system interactions***
  - ***Evaluate and rank issues by importance***
  - ***Supplements PIRT ranking approach to fill any gaps by focusing on ESBWR-unique features***
- ***Consolidate highly ranked phenomena and system interactions from both approaches***

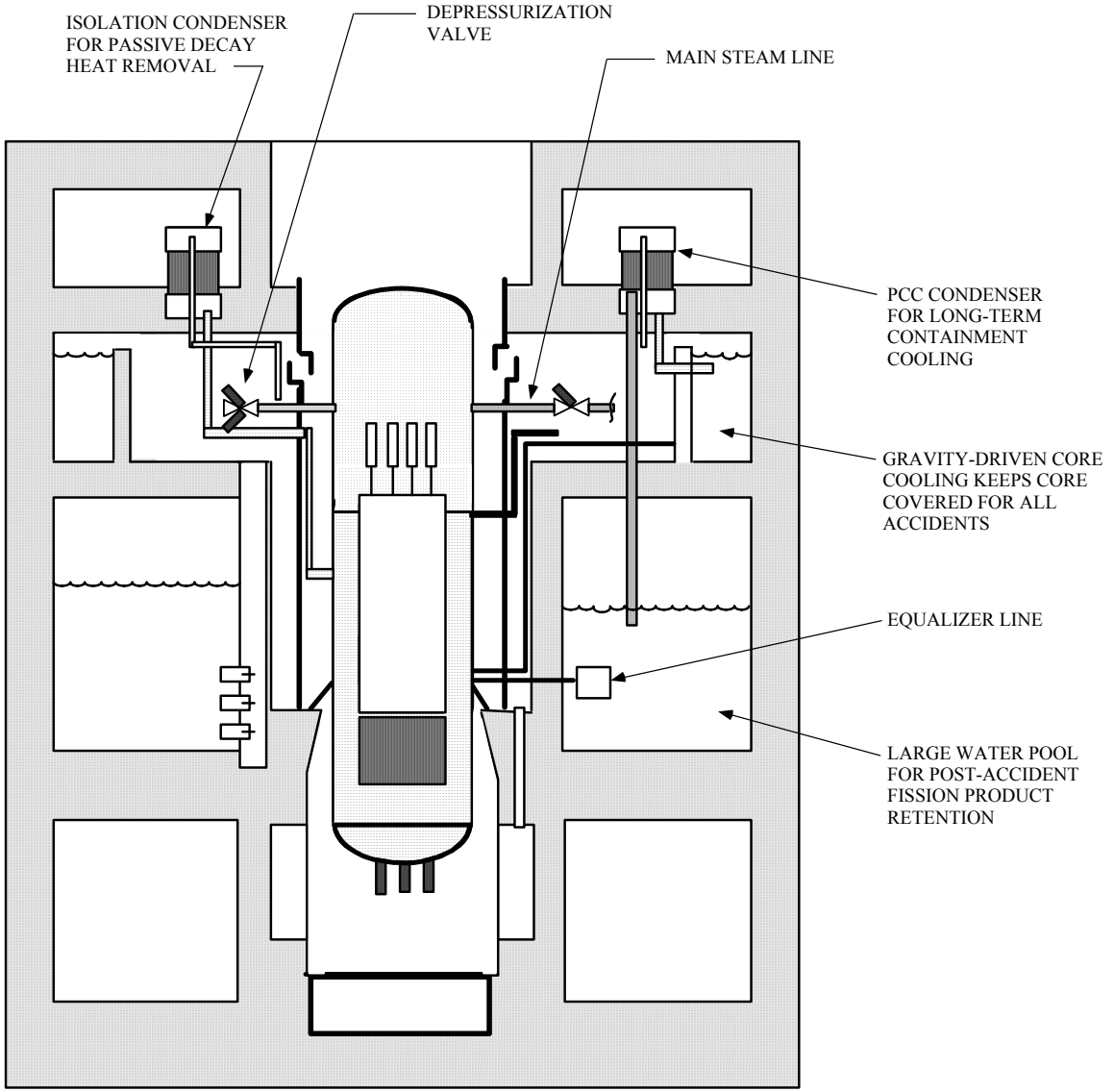
Strategy for Determination of Test & Analysis Needs (contd)

- ***Use high ranked phenomena lists to:***
  - ***Evaluate capability/applicability of analysis models (TRACG)***

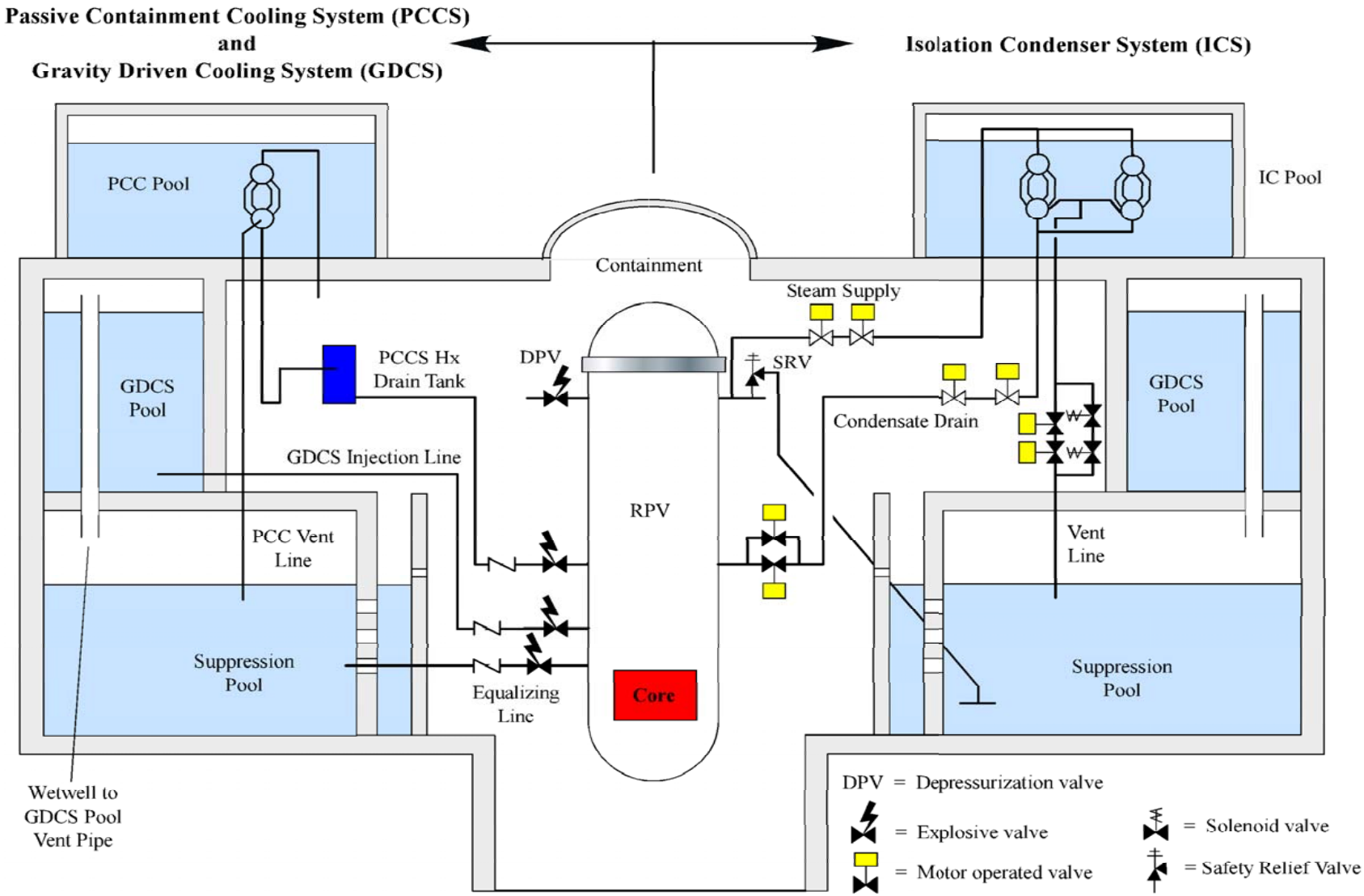
    Implement any needed models or bounding modeling procedures
  - ***Evaluate tests coverage***

    Plan for tests to fill in gaps
  - ***Evaluate uncertainties to establish appropriate design margins***

SBWR Passive Safety Systems



ESBWR Passive Systems



Applicability of TAPD to ESBWR

- ***Phenomena important for transient and accident performance are the same***
  - ***Scaling factors have changed for ESBWR size***
- ***Containment performance improved through minor configuration change***
  - ***GDCS pools are now part of wetwell volume***
  - ***Impact:***

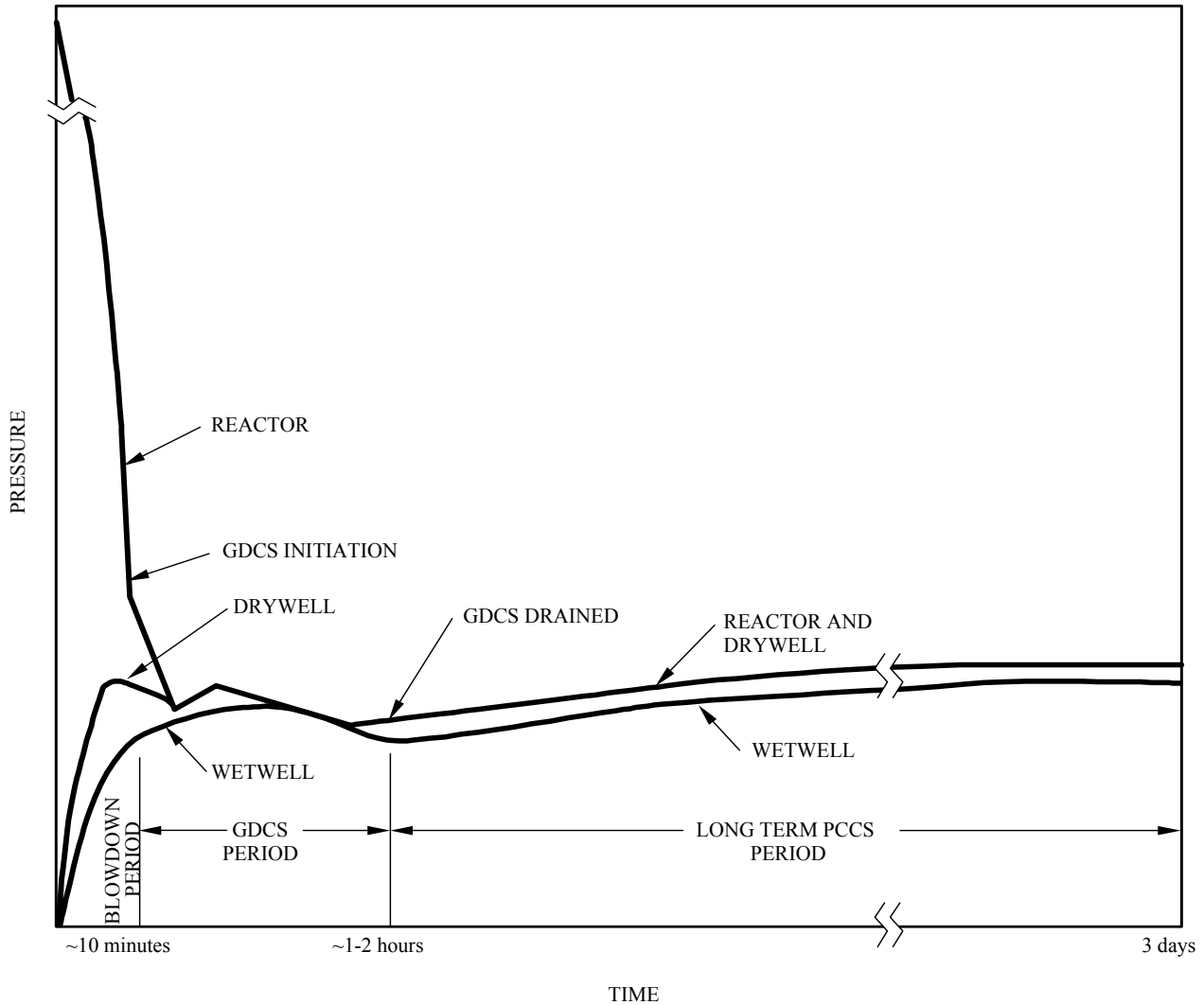
    GDCS initiated at slightly lower reactor pressure (a few seconds later)

    Volume of empty GDCS pools added to wetwell gas space reduces containment pressure
- ***Testing performed for both configurations confirm phenomena not affected***
  - ***GIST vs. GIRAFFE/SIT for ECCS/LOCA***
  - ***PANDA vs. PANDA/TEPSS for long term containment performance***

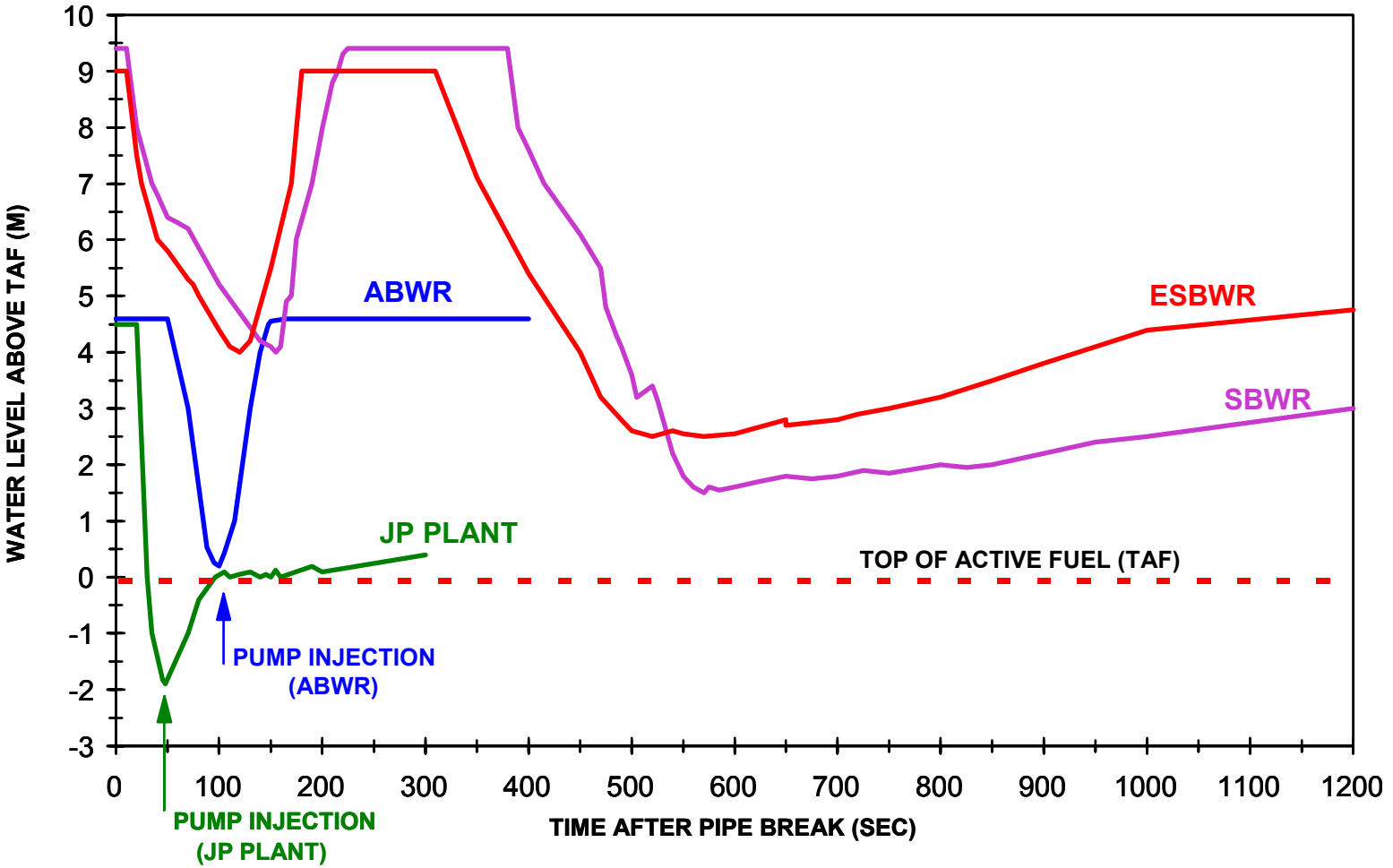
TAPD Results

- ***Lists of Highly Ranked Phenomena and System Interactions***
  - ***Consolidated from Top-Down and Bottom-Up processes***
- ***Grouped by transient type***
  - ***ECCS/LOCA***
  - ***Containment/LOCA***
  - ***AOOs***
  - ***ATWS***
  - ***Stability***
- ***Separated by phase of transient for LOCA***
  - ***Blowdown***
  - ***GDCS***
  - ***Long term PCCS***

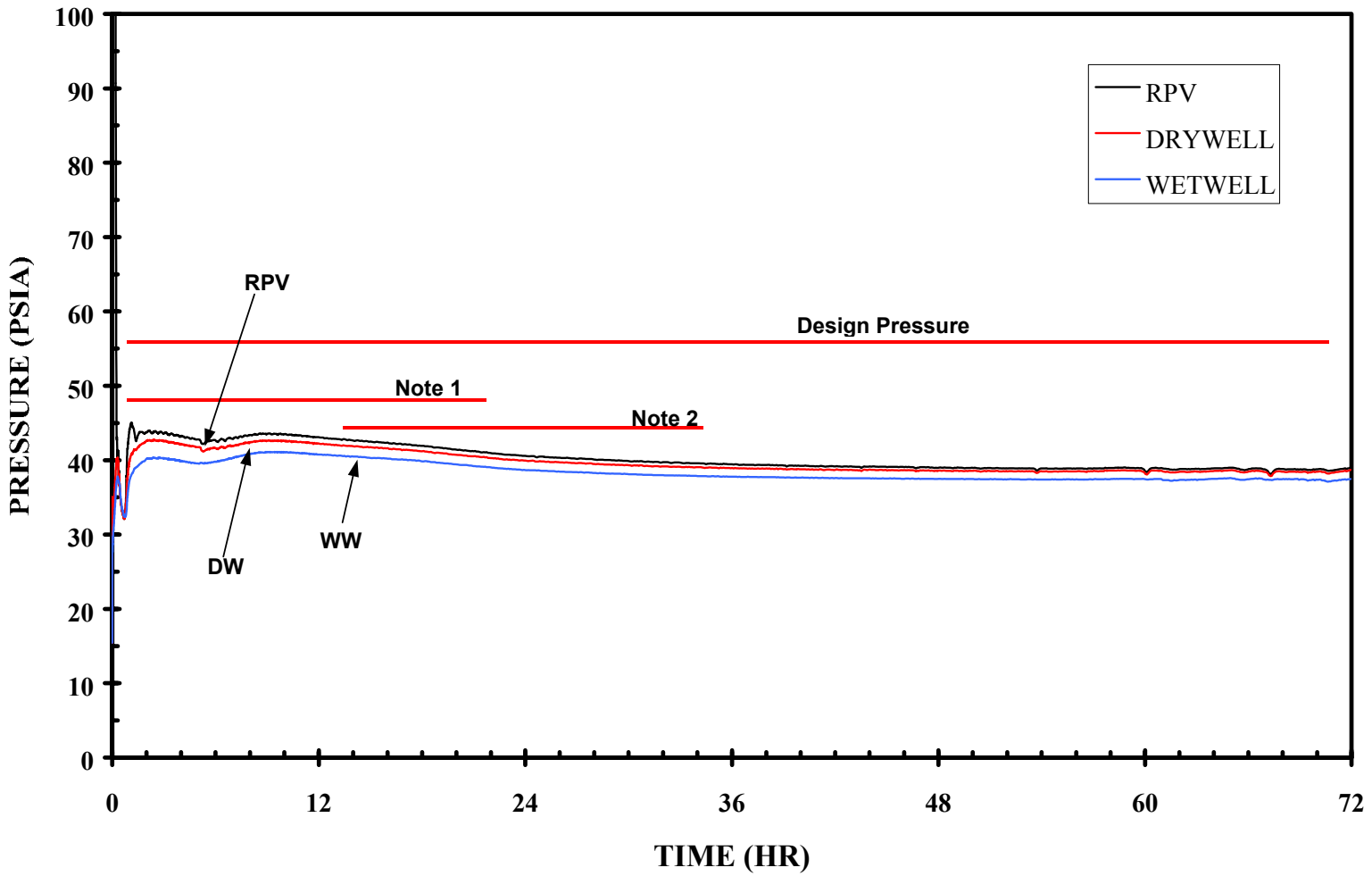
Phases of ESBWR LOCA Transient



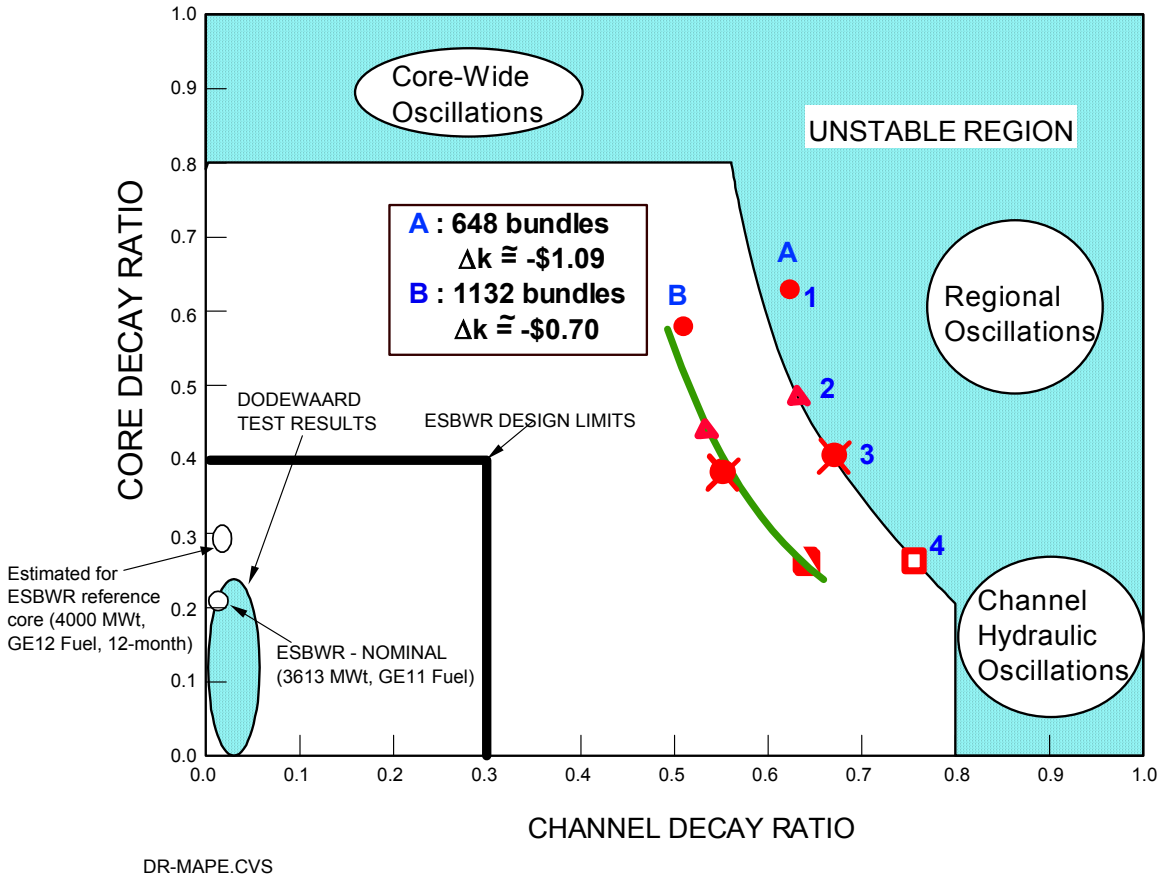
GDCS Line Break – Chimney Level



Steam Line Break – RPV and Containment Response



ESBWR Stability Design Criteria and Performance



Example of List of Highly Ranked Phenomena (ECCS/LOCA)

Governing Phenomena for SBWR LOCA						
		LOCA (Focus: PCT, Water Level in Shroud and Downcomer)				
	Break	**Small Break**		**Large Break**		
	Phase	**Bldn**	**GDCS**	**Bldn**	**GDCS**	**Source**
	Phenomena	**H = High, M = Medium, P = PIRT, B = Bottom Up**				
A	**Region: lower plenum (sub-focus: inventory)**					
A1	Flashing/redistribution			H	H	P
A2	Heat slab stored energy release		H		H	P, B
A3	Two-phase level inlet orifice uncovery time	H		H	H	P
A4	Void distribution	H	H	H	H	P
A5	Mixing/condensation/void collapse/inlet subcooling		H		H	P, B
B	**Region: bypass (sub-focus: inventory, leakage flow)**					
B1	Flashing	H	H	H	H	P
B2	Two-phase level		H		H	P
B4	CCFL at bottom of bypass	H	H	H	H	P
B5	CCFL at top of bypass	H	H	H	H	P
B6	Channel-bypass leakage flow	H	H		H	P, B
C	**Region: core/bundle (sub-focus: PCT, refill time, bundle inventory)**					
C4	Flashing	H	H	H	H	P
C5	Inlet orifice (IO) uncovery, vapor flow split	H		H	H	P
C6	CCFL/CCFL breakdown (IO)	H		H	H	P
C9	Parallel channel flow distribution	H		H		P
C10	Void distribution	H	H	H	H	P, B
C11	Channel-bypass leakage flow	H	H		H	P, B
C12	Natural circulation flow	H	H	H	H	P, B
C13	Margin to dryout/boiling transition		H	H	H	P
C24	Decay heat		H		H	P
D	**Region: guide tube (sub-focus: refill)**					
D1	Flashing/redistribution			H		P
D2	CCFL: top of guide tube			H	H	P

Example of List of Highly Ranked Phenomena (Containment/ LOCA)

Governing Phenomena for LOCA/Containment						
			LOCA/Containment (Focus: Containment Pressure)			
		Phase	Bldn	GDCS	Long Term	Source
	Phenomena	Basic Phenomena	H = High, M = Medium P = PIRT, B = Bottom Up			
WW	**Region: wetwell (sub-focus: pressure, pool and gas temperature**					
WW1	Condensation/evaporation of main vent discharge	Interfacial heat transfer	H			P, B
		Degradation by N/C	H			P
WW2	Condensation/evaporation of SRV discharge	Interfacial heat transfer	H			P
WW3	Condensation/evaporation of PCC vent discharge	Interfacial heat transfer	H		H	P, B
		Degradation by N/C			H	P, B
WW4	Free surface condensation/evaporation	Interfacial heat transfer			H	P
		Degradation by N/C			H	P, B
WW5	Heat sources/sinks	Condensation	H			P
		Wall/structure conduction	H		H	P, B
WW6	3-D effects in pool	Stratification/thermal plumes	H		H	P, B
WW7	3-D effects in gas space	Interfacial shear	H			P
		Mixing, entrainment into jets	H		H	P, B
		Buoyancy/natural circulation			H	P, B
		Phase separation			H	P, B
		Mixing/component separation			H	P
WW8	Containment spray condensation	Interfacial heat transfer			H	P
		Degradation by N/C			H	P

Example of List of Highly Ranked Interactions

Governing Interactions for SBWR LOCA					
		LOCA (Focus: PCT, Water Level in Shroud and Downcomer)			
	Break	**Small Break**		**Large Break**	
	Phase	**Bldn**	**GDCS**	**Bldn**	**GDCS**
	Interaction	**PI= Potentially Important**			
XL1	Multiple IC modules and units	PI		PI	
XL2	IC/DPV/PCCS	PI		PI	
XL3	GDCS/system depressurization	PI	PI	PI	PI
XL4	RPV/DW/WW/IC/DPV/PCCS/ GDCS	PI	PI	PI	PI
XL5	GDCS/FAPCS (LPCI mode)		PI		PI

Overview of SBWR–specific Test Programs

- ***Component Tests***
  - ***PANTHERS/PCC***
    Full-scale prototype performance tests
    Steady state and transient tests with heavy (air) and light (helium) noncondensibles
  - ***PANTHERS/IC***
    One of two modules of a full scale unit
    Steady state, startup and transient tests
  - ***PANDA PCC Tests (S Series) (1/25 scale)***
    10 steady state tests
  - ***DPV Tests***
    Performance tests of prototype valve
  - ***Vacuum Breaker Tests***
    Performance tests of prototype valve

- ***Integral System Tests***
  - ***GIST (1/500 scale)***
    26 ECCS/LOCA integral tests with GDCS from wetwell pool
  - ***GIRAFFE Step 3 (1/400 scale)***
    Long term containment response

Overview of SBWR–specific Test Programs

- ***Integral System Tests (continued)***
  - ***GIRAFFE/Helium (1/400 scale)***

    Long term containment response with light noncondensible gas
  - ***GIRAFFE/SIT (1/400 scale)***

    ECCS/LOCA and containment integral tests with SBWR configuration (GDCS pool in drywell)
  - ***PANDA (1/25 scale)***

    Long term containment response (10 tests)

Other Applicable Test Programs

- ***CRIEPI Natural Circulation Stability Tests***
  - ***Thermal-hydraulic stability tests of natural circulation loop***
- ***Dodewaard Plant Startup***
  - ***Natural circulation plant startup***
- ***PSTF Mark III***
  - ***Containment Early Blowdown Response***
  - ***Suppression Pool Stratification***
- ***Mark II 4T***
  - ***Containment Early Blowdown Response***
- ***1/6 Scale Boron Mixing Test***
  - ***Measurements of "boron" concentration in scaled regions of a BWR***

ESBWR-specific Test Program

- ***PANDA TEPSS Program***
  - ***Integral System LOCA Test with ESBWR configuration (1/50 scale)***
  - ***Tests of Long Term Containment Response and late GDCS period***
  - ***Tests include release of lighter-than-steam gas (Helium)***
- ***CRIEPI High Pressure Stability Tests***
  - ***Thermal hydraulic stability tests with natural circulation loop***

Test Coverage of Qualification Needs

- ***Matrix of Test Data vs. Qualification Needs***
  - ***Qualification Needs grouped by Reactor Core/ Vessel and Containment***
  - ***Test Data grouped by Separate Effects, Component, Integral System Tests and BWR Operating Plant Data***
- ***Every Qualification Need covered by at least one test***

Example of Qualification Coverage by Separate Effects Tests

Table 5.1-2a Separate Effects Tests for Highly Ranked Phenomena for TRACG Qualification for SBWR - Containment (Continued)

PIRT Reference - No.	Phenomena	UCB Tube Tests	MIT Tube Tests	Edwards Blowdown	PSTF Simple Vessel	Marviken
WW9	Containment hydrodynamic loads: SRV discharge chugging/condensation oscillations					
WW10	WW response to long term heat addition: "channeling" of PCCS vent discharge to WW airspace					
GD (gravity driven cooling system) 2	GDCS mass flow					
PC (passive cont. cooling) 1	Mass flow into PCC					
PC2	Condensation on PCC primary side	X	X			
PC3	PCC secondary heat transfer					
PC5/XC5	Parallel PCC modules unit effects					
PC8	Purging of noncondensibles					
DWB (drywell/ wetwell boundary) 1	DW/WW boundary leakage: friction					
VB (vacuum breaker) 1	Vacuum breaker mass flow					
EQ (equalizing line) 1	Equalizing line mass flow: friction					
OC (outside containment) 1	Heat transfer to safety envelope: free convection					
RPV (reactor vessel) 2	RPV steam generation: GDCS mixing					
DPV (depressurization valve) 1	DPV mass flow				X	X

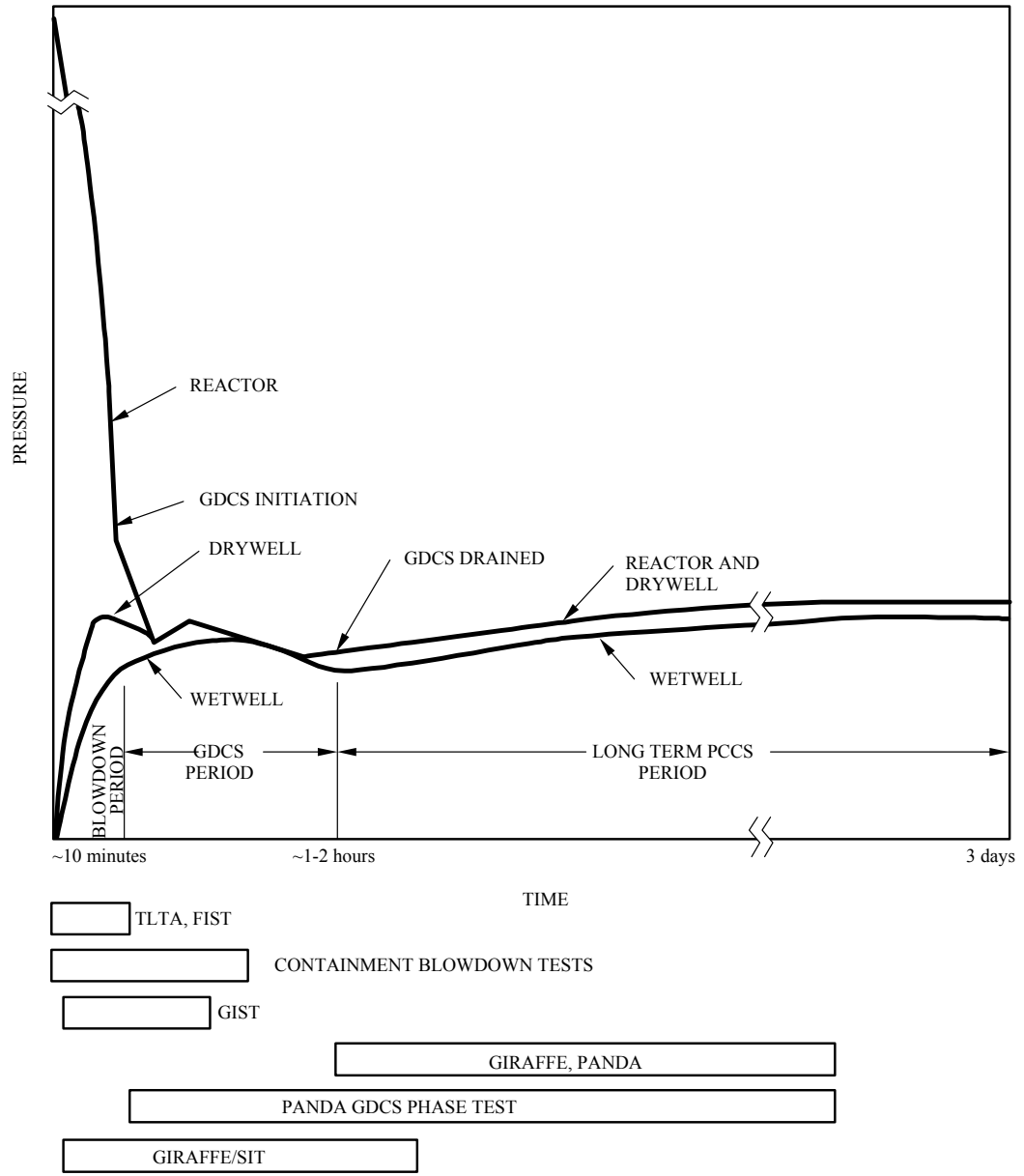
Example of Qualification Coverage by Component Tests

PIRT Reference No.	Phenomena	GIRAFFE Step 1	PANTHERS PCC	PANDA PCCS Compo-nent Tests	PSTF/Full Scale Stratifi-cation	Vacuum Breaker Test Facility
WW10	WW response to long term heat addition: "channeling" of PCCS vent discharge to WW airspace					
GD (gravity driven cooling system) 2	GDCS mass flow					
PC (passive cont. cooling) 1	Mass flow into PCC	X	X	X		
PC2	Condensation on PCC primary side	X	X	X		
PC3	PCC secondary heat transfer		X	X		
PC5/XC5	Parallel PCC modules unit effects		X			
PC8	Purging of noncondensibles					
DWB (drywell/wetwell boundary) 1	DW/WW boundary leakage: friction					X
VB (vacuum breaker) 1	Vacuum breaker mass flow					X
EQ (equalizing line) 1	Equalizing line mass flow: friction					
O (outside containment) 1	Heat transfer to safety envelope: free convection					
CW (containment vessel) 2	Concrete properties at high temperatures					
RPV (reactor vessel) 2	RPV steam generation: GDCS mixing					
DPV (depressurization valve) 1	DPV mass flow					

Qualification Coverage of System Interactions by Integral Tests

PIRT Reference No.	Phenomena	PSTF/ Mk III Full Scale	PSTF/ Mk II 4T	PANDA	ABWR Horizontal Vent Tests	Caorso/ Monticello, SRV Blow-down	GIRAFFE Helium Tests	GIRAFFE SIT
	System Interactions							
XC2	Potential system interaction: ICC/PCC units, GDCS, etc.			X				X
XC6	Light noncondensibles/ DW/PCCS/WW						X	
XC7	Early containment response (DW, WW, MV)	X	X					
XC8	Interaction PCC/MV			X			X	X
XC9	Manometric interaction in GDCS line between GDCS pool(s) and RPV			X				

Integral Test Coverage for ESBWR LOCA



TAPD Summary

- ***TAPD provides sound technology basis for ESBWR design certification***
  - ***Test and analysis needs systematically defined***
- ***TAPD addresses 10CFR52.47 requirements***
  - ***Performance of each safety feature of the design evaluated***
    - ***All unique features evaluated***
    - ***Important phenomena identified***
    - ***Test and analysis basis established***
  - ***Interdependent effects among safety features of the design evaluated***
    - ***Important interactions identified and studied***
    - ***Tests added to program to cover needs***
  - ***Sufficient data exist on the safety features of the design to assess analytical tools (TRACG) used for safety analysis***
    - ***Comprehensive study performed to assess TRACG modeling and qualification needs***
    - ***Test and analysis plans developed to address these needs***
    - ***Test coverage detailed in Qualification Plan***

NRC Review Status of TAPD

- ***Reference: Letter from Theodore R. Quay to James E. Quinn, Staff Evaluation of GE's TAPD, NEDC-32391 Rev. C, July 11, 1996.***
- ***"The staff concludes that, with the exception of the PAR and PIRT issues, TAPD Revision C can be accepted as a framework for the SBWR testing program and TRACG qualification process, if it is fully implemented as described."***
  - ***All tests and code qualification activities described in TAPD have been completed.***
  - ***Open items will be addressed in ESBWR revision***
- ***"However, a final approval of the adequacy of the test program for the qualification of the SBWR is not possible without completing a detailed review of the test data, scaling report, TRACG LTRs and GE's analysis thereof."***
  - ***Test data reports and scaling report were supplied to the NRC but detailed review was not performed***
  - ***Base TRACG model and qualification reports were the same reports NRC has accepted for BWR AOO applications***
  - ***Supplementary SBWR qualification report completed but not reviewed by NRC***

(Items in red expected to require greater NRC review)

Outstanding RAIs on TAPD

- ***Referenced NRC letter includes 98 RAIs***
  - ***About 70 of these are minor disagreements about the relative importance of PIRTs or inconsistencies in their relative ranking; or seek some clarification or expansion in the writeup***
  - ***Many of the remaining relate to clarification of the proposed design process and treatment of the PARs (containment issues)***
- ***There are no requirements for additional testing or code qualification***
- ***GE will address RAIs in the revision of the TAPD for ESBWR***
- ***However, it is important to take a reasoned approach to issue resolution***
  - ***The PIRTs are only a means to an end***
  - ***Mutually acceptable test and analysis program has been defined***